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Final report

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Contents

1 Acknowledgments

The research was conducted with the financial support from the Australian Centre for International Agricultural Research (ACIAR) through the project titled "Improving sustainable productivity in farming systems and enhanced livelihoods through adoption of evergreen agriculture in eastern Africa" shortened as 'Trees for Food Security Project'.- T4FS

The government support exhibited in good political environment and enabling policies related to tree planting particularly in Rwanda, Ethiopia and Uganda is greatly acknowledged.

We appreciate the tremendous support and commitment from the senior leadership at the World Agroforestry Centre (ICRAF) the lead institution in this project. The strong support from the country partners, (Rwanda Agricultural Board (RAB), Ethiopian Institute of Agricultural Research (EIAR) and now EEFRI, Institut des Sciences Agronomiques du Burundi (ISABU), and National Forestry Resources Research Institute (NAFORRI); Australian partner Commonwealth Scientific and Industrial Research Organization (CSIRO), international organization namely International Maize and Wheat Improvement Center (CIMMYT) and International Livestock Research Institute (ILRI) and development partners mainly World vision in project implementation was commendable. For instance there is strong collaboration between ICRAF CSIRO and PhD students, in the development of the new APSIM Agroforestry Systems model. This model is also available for use by CIMMYT using the on farm trials data. The project also benefited from attaching students from University of Rwanda, Makerere, Addis Ababa, Jomo Kenyatta University of Agriculture and Technology (JKUAT), University of Nairobi, and Bangor Universities who were instrumental in sound data collection. There was also strong collaboration between CIMMYT and Wageningen University through exchange programmes for PhD students.

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The approval of the second phase of this project provided the project team a great opportunity to maximize and consolidate the gains made in the first phase of the project. This will ensure sustainability and enable the beneficiaries and researchers time to realize the full benefits at scale of the knowledge, technologies and facilities provided for funding from ACIAR of which we are very grateful.

2 Executive summary

The project, "Improving Sustainable Productivity in Farming Systems and Enhanced Livelihoods through Adoption of Evergreen Agriculture in Eastern Africa, (FSC/2012/014)", also known as the 'Trees for Food Security' (T4FS), commenced in June 2012 and was completed in November 2016. The aim was to enhance food security for resource-poor rural people in Eastern Africa through research that underpins national programmes to scale up the use of trees within farming systems in Ethiopia and Rwanda and then scale out successes to relevant agro-ecological zones in Uganda and Burundi. Project partners were ICRAF (lead institution), EIAR, RAB, NAFORRI ISABU CIMMYT, CSIRO and WV and ILRI.

Key achievements of the project include but not limited to:

1. Establishment of six Rural Resource Centers (RRCs) and nurseries - 2 each in Rwanda and Ethiopia and 1 each in Uganda and Burundi. The RRCs provided training, and supply of improved tree germplasm and business opportunities for farmer groups and unemployed youth. This experience demonstrated the effectiveness of RRCs in empowering local communities, enhancing knowledge about locally appropriate agroforestry systems and facilitating adoption and scaling up of agroforestry.

2. Improved understanding of the contexts and patterns of tree adoption on farm (Iiyama et al., 2016). This was critical in informing the design of agroforestry interventions thus enhancing their success, adaptability, acceptance and sustainability. The development of Potential Natural Vegetation Map of Eastern Africa integrating Burundi (not originally there) was an important milestone (van Breugel et al 2015).

3. Improved understanding of tree crop interactions in different species and contexts through establishment of four long-term tree diversity trials and controlled on farm experiments. Wheat yield increases was reported under *Faidherbia albida* (mean of 3.3t ha^{-1} under compared to 2.6 tha^{-1} away) in Modjo Ethiopia (Sida et al. 2017, Assefa et al. 2016) translating to an additional 2.6 t per household with mean land size of 3.7 ha (Muthuri et al. 2017). This was attributed to microclimate effect, reverse phenology, available moisture and enhanced nutrients under the trees. The importance of tree management (shoot pruning) in reducing competition for water and enhancing maize productivity while providing firewood was demonstrated in *Grevillea robusta* maize systems in Bugesera Rwanda (Ngoga et al 2016). As a result of these benefits many farmers in this area are now pruning these trees to manage competition.

4. Enhanced tree crop modelling capability through development of APSIM crop modelling framework's (APSIM X AF) (Luedeling et al., 2016). This allows reliable predictions of tree and crop yields essential for informing policy decisions relating to food security. At present model evaluation has been done using *Grevillea robusta* (Masikati et al 2017)*, Gliricidia sepium* (Smethurst et al., 2017) and *Faidherbia albida* interacting with wheat and maize *(Dila et al 2017)*.

5. Capacity development and strengthening through farmer training and support in MSc and PhD training. Twenty seven students 10 PhDs and 17 MSc have benefited from the project.

6. Improved extension systems, diversified agroforestry technologies, increased farm productivity and hence food security. For example the successful uptake of the best fit agroforestry technologies through the 1600 participatory trials (Ethiopia 650, Rwanda 700 and Uganda 250) demonstrated the importance of the participatory approach in scaling up trees on farm as well as increasing food security and livelihoods. For instance, the use of green manure from trees and shrubs in participatory trials in Gishwati, Rwanda resulted in increased maize, potato and bean yields translating to an additional income of 1,620 USD/year which is significant, given the per capita income of USD 1343 in USD (Musana et al 2016, Muthuri et al. 2017). The project reached 30,507 beneficiaries through participatory trials, RRCs, trainings and other country specific strategies (Muthuri et al. 2016b).

Table 1. Total number of beneficiaries directly reached by the project

Country	**Postgraduate students PhD**		**MSC**		**Trainings**		**Other project activities**		
	M	**F**	**M**	**F**	**M**	**F**	**M**	**Female**	**Total**
Rwanda	3	1	3	1	512	488	8033	2677	**11718**
Ethiopia	3	1	3	3	1832	457	8037	2009	**12345**
Uganda	1	1	3	2	406	188	2025	763	**3389**
Burundi	**-**	-	1	1	130	36	2367	520	**3055**
Total	**7**	**3**	**10**	**7**	**1287**	**457**	**22116**	**6621**	**30507**

More information on this project is available at the project webpage [http://www.worldagroforestry.org/project/trees-food-security-improving-sustainable-productivity-farming-systems-and-enhanced.](http://www.worldagroforestry.org/project/trees-food-security-improving-sustainable-productivity-farming-systems-and-enhanced)

Building on the successes of this project, ACIAR approved a second phase of the project (Au$5M) to operate in Ethiopia, Rwanda and Uganda from January 2017 to January 2021.

3 Background

Nearly 400 million people live in the eastern and southern Africa (ESA) region, with more than half living in extreme poverty. Seventy five percent of the population resides in rural areas characterized by poor infrastructure, poor market access, environmental degradation (including mud slides, soil erosion and massive deforestation), fragile ecosystems and vulnerability to climatic variability and change. Declining agricultural production in the face of increasing population pressure in the region points to a major crisis including increasing hunger and poverty levels, unless innovative approaches to the management of agricultural lands are adopted. The eastern Africa region has four out of the nine hunger and poverty hotspots in Africa spread over Ethiopia, Kenya, Uganda, Tanzania, Rwanda and Burundi (Inter-Academy Council, 2004). In this region, smallholder agricultural production constitutes the basis of livelihoods and income for more than 70% of the people. However, they are faced with formidable challenges as most have remained poor and food insecure due to a myriad factors that include poor agricultural methods and declining crop and livestock yields.

Between 2011 and 2016 Australia provided funding for food security research and development through the Australian International Food Security Research Centre (within ACIAR) to assist developing countries, maximise the benefits and opportunities of agricultural productivity to achieve food and nutritional security. This project was funded under that initiative because of evidence from southern Africa that the adoption of evergreen agriculture, whereby the incorporation of trees such as *Faidherbia albida*, had the potential to increase cereal crop yields and help address food insecurity for smallholders, while building soil health and enhancing environmental sustainability.

National food security programs in eastern Africa have mostly focussed on economies of scale, targeting commercially-oriented farmers in breadbaskets, while the majority of resource-poor smallholders remain trapped in poverty. Consequently, the majority of small farm households experience an annual 'hunger period' due to their inability to produce adequate food stocks to last through the year. Most observers believe that the fundamental problem is that Africa's soils are degrading rapidly, and their nutrient supplies are not being replenished. Commercial fertilizer use is minimal in the aggregate; only 1 in 5 farmers in Africa are applying inorganic fertilisers. Most technical solutions to improve productivity involve the use of purchased inputs (Keating et al., 2010), but the poorest farmers have very limited ability to procure these inputs, or to bear the financial risks of using them in the face of frequent droughts. For these farmers, a major increase in both crop and livestock production is a prerequisite to achieve food self-sufficiency (Salami et al. 2010). Therefore, interventions targeting the smallholder sector have a high potential for positive impacts on food security, poverty reduction, environmental management and resilience to climate change, but these interventions must be compatible with the livelihood realities of the majority of farm families.

The conundrum of poor performance of the agricultural sector calls for innovative approaches, including enhanced tree cover in cropland to intensify production of annual crops. Integrating tree-crop-livestock in the agriculture production systems as was proposed in this project can decrease the competition between crop and livestock systems. It is observed that trees on farms are a widespread feature of landscapes across a large part of East Africa with an important role in enhancing the resilience of smallholder livelihoods through the provision of ecosystem services (Iiyama et al. 2016). Depending upon which species are used, their arrangement and how they are managed, trees incorporated into crop fields and agricultural landscapes may contribute to:

i. Increased nutrient availability to crops through nitrogen fixation and enhanced nutrient cycling (Barnes and Fagg, 2003) coupled with maintenance of soil organic matter and structure (Akinnifesi et al. 2007)
ii. Improved water infiltration (Sanou et al., 2010), resulting in increased water use efficiency by reducing the unproductive components of the water balance (i.e. run-

off, bare soil evaporation and drainage (Ong et al., 2002, Muthuri et al 2004) and reducing wind speed, raising humidity and reducing leaf temperature of crops (Brenner, 1996). There are key design issues for agroforestry interventions required to strike a balance between how much water trees use through transpiration and add to the system via infiltration and recycling from deeper soil layers or the water table (Roupsard et al., 1999; Favreau et al. 2009). Care is required to manage competition and understand long term impacts on the water table,

iii. Greater abundance and activity of beneficial soil organisms (Barrios et al., 2011)
iv. Yields of fruit, fodder, fuel, fibre and timber from trees that may increase income directly through sales or intensify the system (Garrity et al. 2010),
v. Enhanced carbon storage both above- and below-ground (Makumba et al. 2007; Kuyah et al. 2016) associated with production resilience in the face of climate variability (Neufeldt et al. 2009).

There is considerable evidence that enhanced tree cover on farms has increased cereal crop yields in sub-Saharan Africa, through improved soil and water productivity from field to landscape scales. This leads to enhanced food insecurity for smallholders, while building soil health and enhancing environmental sustainability. For example Malawi has been implementing a National Agroforestry Food Security Programme for the past five years, in which a portfolio of fertilizer, fodder, fruit, timber and fuelwood trees was extended to approximately 200,000 farmers during that period (Sileshi et al., 2008). A meta-analysis of impacts of fertilizer shrubs on crop yields across sub-Saharan Africa showed a large mean effect (roughly doubling yield) but high variability (Sileshi et al., 2008), some of which could be associated with tree species, soil type and climate (Sileshi et al., 2010).

One of the fertiliser tree widely grown in the semi-arid areas of Ethiopia is *Faidherbia albida* and has been reported to increase productivity of the crops under its canopy. Numerous published studies have shown increase in the yields of maize, sorghum, and millet with *F. albida* trees incorporated in crop fields (Barnes and Fagg, 2003). The most comprehensive on farm trials comparing the yields of crops under and outside the canopy of *F. albida* trees that we are aware of have been reported by Shitumbanuma (2012). These trials were conducted over four years / agricultural seasons (2010/2011, 2009/2010, 2008/2009 and 2008/2007) on 40 farmers' fields using high-yielding varieties (hybrids in the case of maize), cotton, groundnuts and soybeans grown in rotation under and outside mature *F. albida* and using good agronomic practices, but without inorganic fertilizer application. Four plots (each containing one of the four crops) were demarcated under the canopy of a mature tree while another four were demarcated in a rectangular block on the leeward side of the tree. Ten trial sites were established in each region, Central, Eastern, Western and Southern regions of Zambia and replicated within and across sites. The average maize yields (over the four years) under *F. albida* canopy was more than double 5040 kg ha^{-1}) compared to that outside the tree canopy (2420 kg ha^{-1}) (Shitumbanuma, 2010). Higher but insignificant yields of were reported in soybeans and cotton outside the canopy. The results suggest that under Zambian conditions, maize production strongly and consistently benefits from the presence of *F. albida* trees.

In Ethiopia, a countrywide farmer survey indicated that farmers' perceptions were that *F. albida* had increased the grain yield of cereal crops from around 1 t/ha to 2.5 t/ha through enhancement of soil fertility and soil moisture retention (Hadgu et. al., 2011). Soil nutrient content and crop yields under *F. albida* canopies, compared with controls in the open were reviewed for the Sahel (Boffa, 1999). He reported increases in nitrogen content ranging from 15 to 156 percent, but significant increases were also found in carbon, phosphorus, exchangeable potassium, calcium, and magnesium. Increases in millet yields ranged from 49 to 153 percent while increases of 36 to 169 percent in sorghum yield were reported. In absolute terms, this means in most cases an additional cereal yield of 400 to 500 kg/ha or more. However, some care is required in generalising from these data because of confirmation bias and uncertainty associated with how much yield and soil improvements from observational studies represent additionality from trees, as opposed to concentration effects under tree crowns (Bayala et al., 2011). The low investment costs to establish fertilizer trees, and the high internal rates of return are advantages emphasized by numerous authors (e.g. Ajayi et al, 2010).

The integration of trees on farm ensures not only food and nutritional security but also income and energy security from the several tree products including fruits, fodder, fuelwood, timber and medicinal herbs providing smallholders with diversified income sources especially when they are well linked to markets. Its role has been highlighted as a key element in creating a science-based climate smart agriculture in Africa targeted to the needs and realities of resource-poor smallholders (World Bank, 2011). Thus, there is strong justification to expand the scaling-up of trees on farm in the East African countries through research 'in' rather than 'for' development (Coe et al. 2014), and to deepen the research base to validate its utility across a wider domain of agroecologies.

However in order to reap these benefits, there is still a great need not only to increase the density of trees but also the diversity to meet the growing demand of their products (fuel, fruit, timber, fodder and fertiliser) and services. Currently the diversity of trees in farmers' fields is still low and besides matching the right species for the right niche and management is also an area that required urgent attention in the study sites. There were also threats to taking trees to scale which included massive deforestation due to demand for tree products, drought, that inhibit tree survival, inadequate sources, supply and distribution of quality germplasm and unfavourable free grazing policy of livestock management that threatens tree survival particularly in Ethiopia.

A structured literature review about provision ecosystem services (ES) by trees on farms and in agricultural landscapes in SSA concluded that although the effects of trees were mainly positive, a decline in crop production was noted as a key trade-off against the provisions of ESs, such as modification of microclimate (Kuyah et al. 2016). This highlighted the need to manage trade-offs among impacts of trees on ES provision to reduce competition and increase complementarity between trees and crops. On the other hand, the potential negative consequences associated with deep rooted trees depleting groundwater reserves and hence lowering the water table are site specific, related to limited soil depth above impenetrable bedrock, perched water tables or persistent anaerobiosis at depth (Ong et al., 2006). It is possible to achieve a satisfactory balance between recharge and exploitation of groundwater by selecting agroforestry tree species and pruning management, to exploit differing leafing phenologies and rooting depths of trees and crops (Ong et al ., 2006; Muthuri et al. 2009). Quantification of water use by different tree species in the range of contexts they are to be deployed, coupled with modelling to extend these results across agroecologies was an important element of the current project. Effort to select trees for the right place and people and having them managed the right way was therefore critical for this project. The importance of a diversity of tree species to meet variable site conditions and farmer needs is an increasingly general finding across Africa (Nyaga et al. 2015).

The project therefore undertook research to underpin national scaling up programmes for enhancing tree cover on farms by adopting an iterative co-learning paradigm within which the following key research questions were addressed:

- What mix of trees, crops and management practices will work for which sites and farmer circumstances across the target agroecologies?
- What are the impacts and trade-offs of integrating trees, crops and livestock in target farming systems? What policy, socio-economic and institutional arrangements are required to enable the adoption of farm trees?
- What are the most effective extension methods, including seed and seedling supply systems, for promoting adoption of farm trees in the target agroecologies?
- How can the impact and trade-offs associated with adding trees to crop fields be quantified for different farming systems?

The research strategy was such that the project worked in four countries. The initial emphasis in year one was on scaling up within Ethiopia and Rwanda because there were ongoing government commitments that the project would underpin. There are areas within Burundi and Uganda that are appropriate for scaling out successes from Rwanda and so the focus in these two countries, beginning year three was to map the areas where the Rwandan experience is relevant, establish pilots and stimulate similar commitment to scaling up as already secured in Ethiopia and Rwanda.

4 Objectives

The aim of this project was to enhance food security for resource-poor rural people in Eastern Africa through research that underpins national programmes to scale up the use of trees within farming systems in Ethiopia and Rwanda and then scale out successes to relevant agro-ecological zones in Uganda and Burundi.

The specific objectives of the project were:

1. To characterise target farming landscapes and systems, and develop tools for matching species and management options to sites and circumstances.
2. To generalize predictions of impacts of tree species and management on crop productivity, water resources and nutrients at field, farm and landscape scales to inform scaling up to improve food security and reduce climate risk.
3. To develop effective methods and enabling environments for scaling up and out the adoption of trees on farms.
4. To develop databases and tools for monitoring and evaluation of the impact of scaling up and out the adoption of trees on farms, and
5. To enhance capacity and connectivity of national partner institutions (including farmer groups) in developing and promoting locally appropriate options for adoption of farm trees.

5 Methodology

Project sites

The project aimed to produce results that are scalable across the two agro ecologies – semi arid and sub humid–across the four participating countries. In Ethiopia the research was conducted in four woredas in East Shewa Zone that falls within the semi-arid agroecology, and four woredas in East Wollega and West Shewa Zones that are in the sub-humid agroecology (Fig. 1a). The semi-arid sites mostly fall in the lowlands of the Central Rift Valley with an altitude less than 1500 m, then rise up to 2300 m at the mountain fringes of the Rift. In Rwanda, the project was conducted in Bugesera District of Eastern Province chosen to represent the semi-arid agroecology, while two districts of the Western Province surrounding the Gishwati Forest were chosen to represent the sub-humid agroecology of Congo-Nile Crest (Figures 1b). More information can be accessed from Iiyama et al 2016 and 2014).

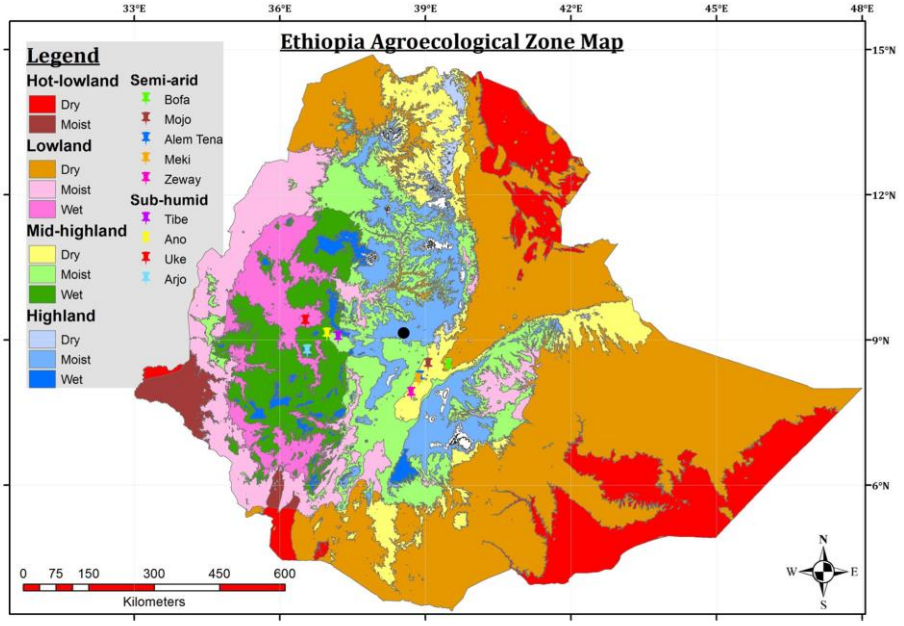


Figure 1a. Agroecological map of Ethiopia with locations of selected sites

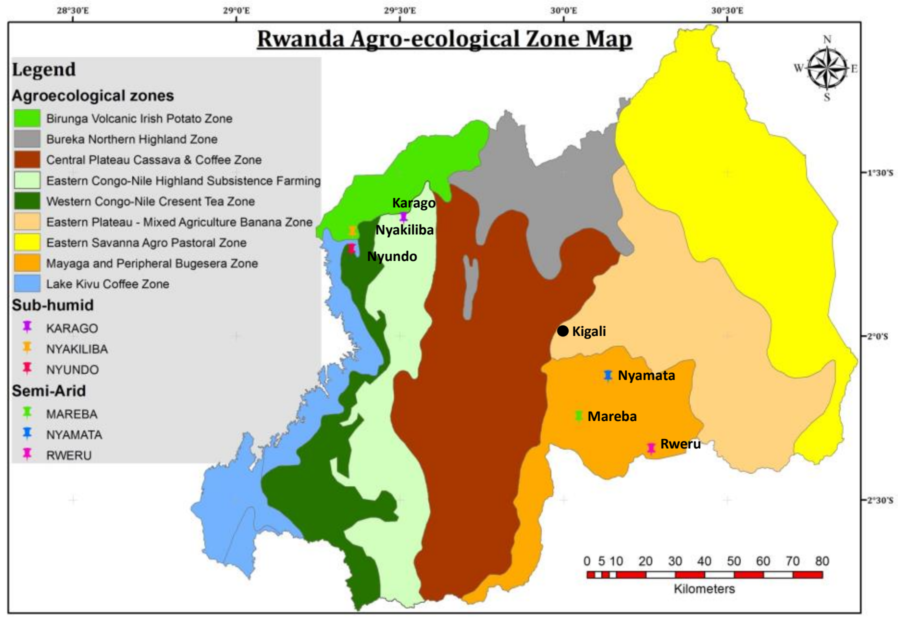


Figure 1b. Agroecological map of Rwanda with locations of selected sites

Project activities in Uganda were implemented in the Mt. Elgon Region, specifically Manafwa district in eastern Uganda. The region is characterized by low tree cover resulting from massive deforestation, limited access to quality tree planting materials and inadequate fodder for animals. The research was undertaken in Butta and Namabya sub counties of Manafwa district. In Burundi the project is implemented in Muruta commune, Kayanza province which is located in the northern part of Burundi. Sites in Muruta commune include Rwegura, Yanza and Ruvumu collines.

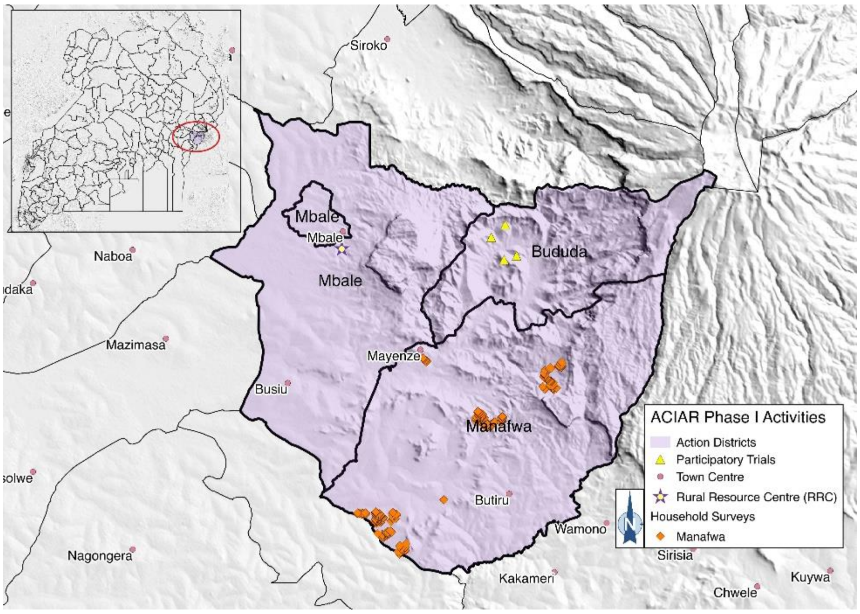


Figure 1c. The map of Uganda with locations of selected sites

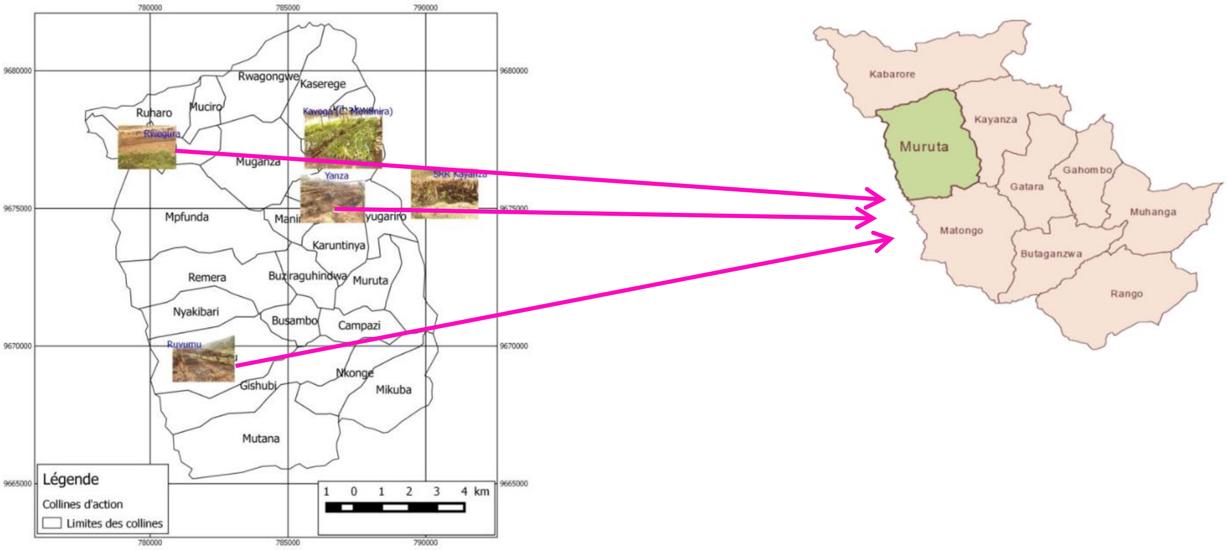


Figure 1d. The map of Burundi with locations of selected sites

Objective 1: To characterise target farming landscapes and systems and develop tools for matching species and management options to sites and circumstances:

1.1 Establish socio-economic and biophysical baselines and understand barriers to adoption of farm trees.

Household and community surveys were conducted to establish food security, health and nutrition, and income baselines, as well as to probe barriers to adoption of agroforestry. A total of 687 households were interviewed across the two agroecologies in Ethiopia and 644 in Rwanda. The data is available on Dataverse: https://dataverse.harvard.edu/dataverse/T4FS. The household survey data from both semi-arid and sub-humid agroecosystems was used to characterize tree cover on farms by deriving proxy variables reflecting adoption intensities as well as multi-dimensionality of utilities using a multi-variate analytical method.

Baseline soil health was assessed at four sites – Alem Tena and Ano in Ethiopia and Gishwati and Bugesera in Rwanda -using the Land Degradation Surveillance Framework (LDSF) and interpolation. LDSF is a hierarchical stratified random sampling approach which involves sentinel sites of 10 km × 10 km in size. Each sentinel site was stratified into 16 clusters of 1-km radius circle. Each cluster was further stratified into 10 sampling plots of 1000 m2. Within each sampling plot, there were 4 subplots of 100 m^2 each. Data on vegetation cover, structure, floristic composition, and specific tree attributes as well as land use, topography, visible signs of soil erosion and soil physical characteristics were compiled at plot level. Soil samples were collected from the top (0-20 cm) and sub (20-50) samples from all the 160 plots each sentinel site using a 7.6 cm diameter auger. 2.3. Soils samples were analysed for chemical (carbon and nitrogen) and physical properties (texture) at the soil-plant spectral lab of the World Agroforestry Centre.

Rapid market appraisal (RMA) tools were used to assess markets for tree products. RMA was used because it constitutes a quick, flexible and effective way of collecting, processing and analysing information about markets and market channels. RMA uses multiple methods of data collection, including informal field visits and observations, interviews of multiple stakeholders, and quantitative data collection, and therefore, data can be triangulated and cross checked for consistency. A qualitative research method involving focus group discussions (FGD) and key informant surveys was used for collecting the data.

Local knowledge was collected using AKT5 (see Appendix 1), a well-established knowledge-based systems methodology. The aim of the toolkit is to elicit local ecological knowledge in a rigorous and systematic way in order for it to be robust enough to be useful for informing projects. The tool enables explicit representation of local knowledge from a range of sources through the use of a knowledge based systems approach. This is a methodology for formally representing qualitative knowledge on a computer. It is based on the premise that most knowledge can be broken down into short statements and associated taxonomies of the terms that are used in them. These can then be represented on a computer as a knowledge base using a formal grammar and a series of hierarchies of terms. Connections amongst statements can be explored by viewing sets of related statements as causal diagrams. The use of formal knowledge representation procedures offers researchers the ability to evaluate and utilise the often complex, qualitative information relevant stakeholders have on agro-ecological practices and the knowledge underlying these practices. (Appendix 1).

1.2 Match species and management options to sites and circumstances.

Overlays of potential natural vegetation and vegetation dynamics (from back processed satellite imagery), demographics and socio-economic parameters were used to stratify landscapes and pinpoint vulnerable hotspots A natural vegetation map for Burundi was generated as part of the project (Appendix 2) and was fully integrated into the vegetationmap4africa – a web-based species selection and distribution tool.

The map shows the similarity between Rwanda and Burundi in distribution of potential natural vegetation types or agro-ecological zones. Hence the selection of optimal mixes of trees on farm to enhance food security in Rwanda can be applicable to guiding scaling up and out for Burundi, which was one of the main objectives of the project.

1.3 Target and prioritize sites and farmer circumstances

A framework for landscape level policy dialogues was developed and implemented with partners in Ethiopia and Rwanda. In Ethiopia, Woreda and national level policy dialogues were undertaken involving partners from subhumid and semi-arid regions. Seven core policy issues were prioritised at the Woreda level. A framework for Rwanda was also developed and policy dialogues at both district and national levels undertaken (Appendix 3).

Objective 2: To generalize predictions of impacts of tree species and management on crop productivity, water resources and nutrients at field, farm and landscape scales to inform scaling up to improve food security and reduce climate risk

This objective combined top down and bottom up data collection and modelling to assess, on one hand, the performance of options across an extensive participatory trial network represented by the national scaling programmes and, on the other hand, longer term impacts from controlled experiments, observation and modelling at field and farm scales. It benefited from data generated by other activities at ICRAF, such as extensive survey work in Malawi and Kenya. Data from these projects complemented new information that was collected in this project.

2.1 Extensive participatory and quantitative assessment of the performance of tree species and management options used in scaling up.

The performance of species and management options used in the national scaling up programmes in Ethiopia and Rwanda was assessed through extensive survey of farmer opinion, observation of farmer adoption and adaptation and field measurement of tree survival and growth, crop yield and soil conditions. This involved basic data collection across the participatory trials.

The participatory trials component started with a pparticipatory design workshops which were held in Ethiopia, Rwanda and Uganda (Barrios & Coe 2013b, 2013a, 2014). Participants from Burundi were involved in the Rwanda workshop. In Rwanda, the trials consisted of two experiments i) biomass incorporation in both Bugesera and Gishwati and alternative sources of stakes for climbing beans in Bahimba sector, Rubavu district (Musana et al., 2016; Mukuralinda et al 2016). In Ethiopia the trials were on evaluating different tree species performance in different planting niches, some assisted with soil moisture retention structures (SMRS) and manuring and composting (Derero et al., 2016). In Uganda trials were established to address challenges specific to communities along landscape categories. While the lowland areas were concerned with river bank stabilization using trees, the midland is involved with tree species diversity and the upland areas are looking at measures to control soil erosion using appropriate tree hedgerows, and grass bands (Bunyinza et al 2016).

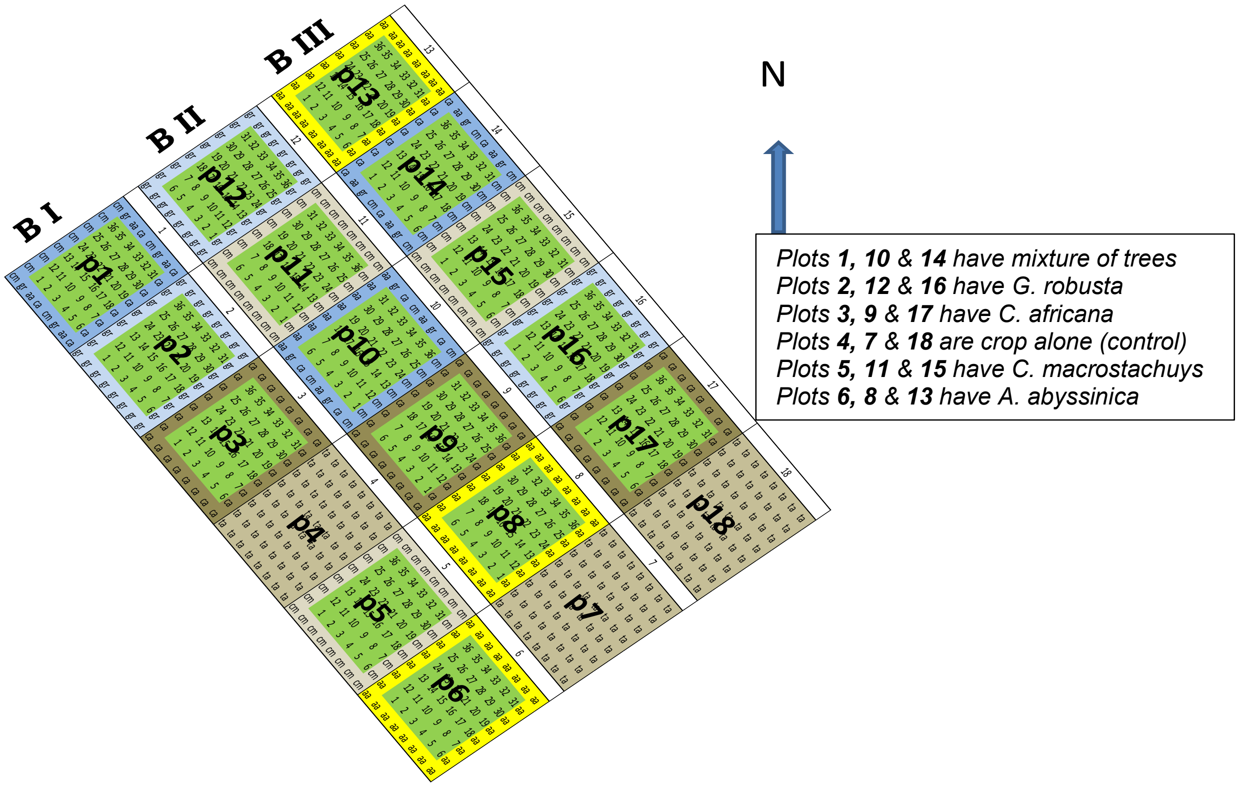
2.2 Conduct controlled experiments and develop simulation models of tree and crop yield across biophysical gradients

While the extensive but shallow survey in 2.1 provides spatially explicit information on past performance of options already in the scaling up programme across the range of circumstances surveyed, more controlled experimentation coupled with simulation modelling is required for extrapolation to other sites and to embrace a wider range of possible options and their impacts over longer time scales. A tightly coupled experiment and modelling programme was conducted in Ethiopia and Rwanda, involving measurements by partner scientists of respective national partners. The priorities for measurements were be derived from an initial modelling workshop, where gaps are defined in relation to the present limits, to accurately model impacts of trees on crop yields and associated nutrient and water fluxes for the target agroecologies. This included roughly equal effort devoted to observations on newly established trials, where trees are integrated into crop fields and, measurements on older existing trees in fields and farming landscapes. This exercise also made use of past experimental work by ICRAF and others, which was reviewed and whose results were incorporated into the proposed modelling activities (Luedeling *et al.,* 2016).

2.2 .1). The long term Agroforestry Trials

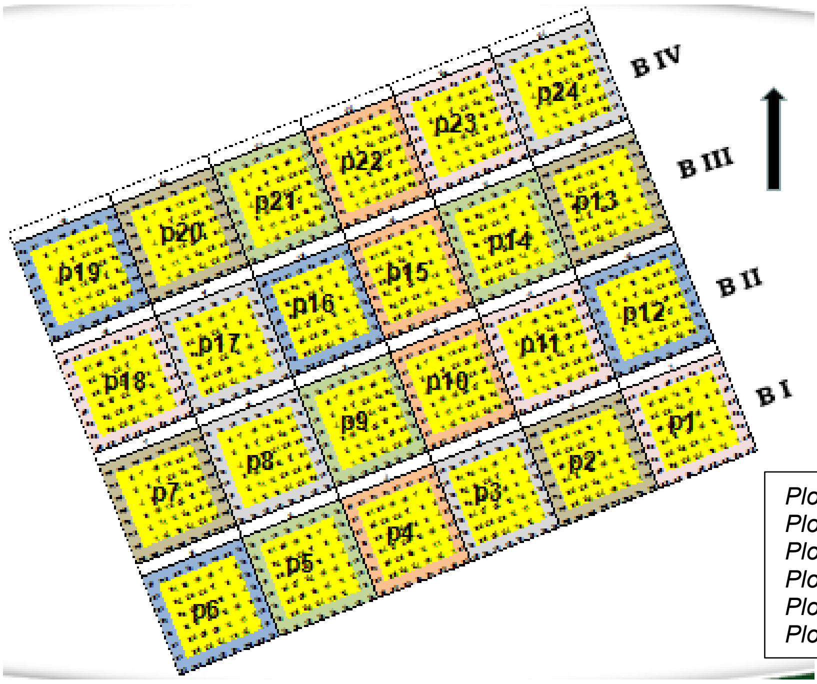
The need to parameterise models for a wider range of tree species in terms of nutrient and water uptake and to understand how trees respond to management actions such as shoot pruning in terms of where from the soil profile they take-up nutrients and water was also taken into account. The treatments in controlled trials (long term trials) were set up to reflect what more we need to know about the best-bet options selected in each country and observations in mature trees to model long term impacts on soil health, competition and water resources. Four long term trials were established in semi-arid (Melkassa and Bugesera) and humid sites (Bako and Tamira) of Ethiopia and Rwanda respectively.

In Ethiopia, one long term trial was established at Bako Agricultural Research Center starting May 2013 (Figure 2a). This is situated in the western part of Ethiopia, 242 km away from Addis Ababa at latitude of 9^{0}11’N and longitude 37^{0} 04’ E and at an altitude of 1658 m.a.s.l. The Melkassa long term trial site is located at Bishola near Melkassa Agricultural Research Center 115 km south east of Addis Ababa at the geographical location of 8^{0}24’N & 39^{0}21’E at an altitude of 1550 m.a.s.l. The experimental layout and treatments are presented in the figures below (2a &b) and more details of these trials can be accessed from (Derero et al 2016b),



Plots ***1, 10*** *&* ***14*** *have mixture of trees*
Plots ***2, 12*** *&* ***16*** *have G. robusta*
Plots ***3, 9*** *&* ***17*** *have C. africana*
Plots ***4, 7*** *&* ***18*** *are crop alone (control)*
Plots ***5, 11*** *&* ***15*** *have C. macrostachuys*
Plots ***6, 8*** *&* ***13*** *have A. abyssinica*

Figure 2a: Field layout of Bako long term trial



*Plots **1,11,18** and **23** have C. africana .*
*Plots **2,7,13** and **20** have M. stenopetala.*
*Plots **3,8,17** & **24** are crop alone (control)*
*Plots **4,10,15** and **22** have A. tortilis.*
*Plots **5,9,14** and **21** have F. albida.*
*Plots **6,12,16** and **19** have mixture of trees.*

Figure 2b Field layout of Melkassa long term trial

In Rwanda two long term trial were established in Bugesera and Gishwati. In Gishwati, the trial is located in Tamira RAB station, located in Rubavu district in Western Province. The geographic coordinate are latitude range of 1°33'59.2S" and 1°33'55.7S"; and longitude range of 29°23'37.7E" and 29°23'41.6E". The altitude is 2483m. The annual rainfall is 1187 mm and the average temperature is 13.2°C. The treatments tested included *Alnus acuminata* and *Croton megalocarpus* planted alone, their combination and maize (Zea mays) planted alone in a Randomized Complete Block Design (RCBD), (Musana et al. 2016). In Bugesera, the trial was set up at the RAB Karama research and extension center. The experiment has seven treatments of tree species which are *F. albida, G. robusta, M. lutea,* three combinations of each of the three species and crop alone treatment replicated three times. The experimental design is Randomized Complete Block Design (RCBD) with three replications. The designs are outlined below figs 3a&b More details on the Karama and Tamira trials are contained in Ngoga et al., 2016 and Musana).

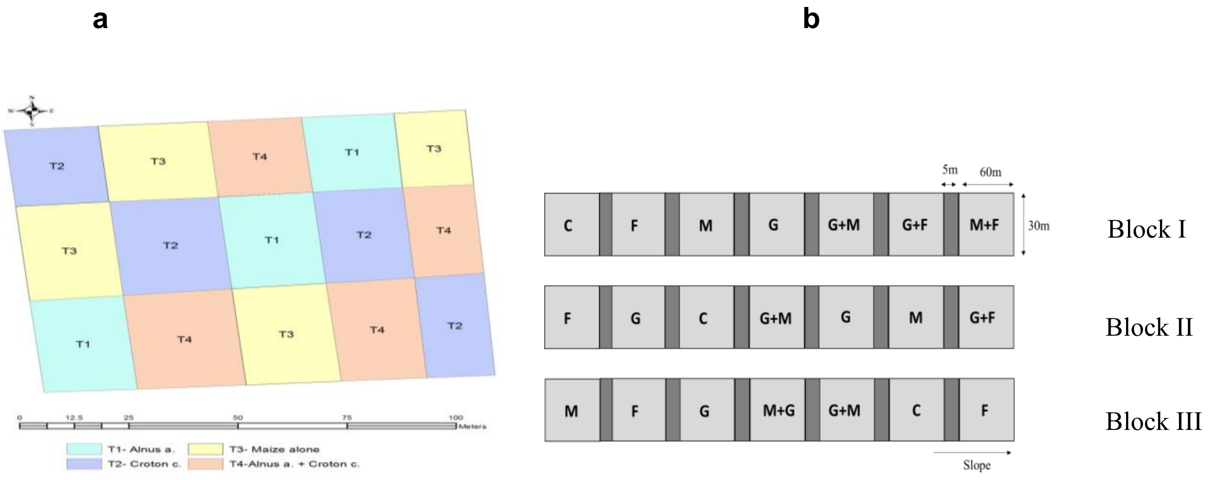


Figure 3: Experimental design of the long term trial in Tamira (a) and Karama (b) Rwanda

2.2.2) Biophysical on-farm experiments

This component involved measurements on older existing trees in farmers' fields, Tree water use was measured directly using portable sap flow gauges (Assefa et al; Ngoga et al 2016 and Buyinza et al 2016). Standard methods (were used to measure soil moisture (profile probes) and electronic dendrometers (Assefa et al., 2016) were installed to understand how trees respond to water availability management actions such as shoot pruning Since different genotypes may respond differently to such modifications. CIMMYT scientists' tested different genotype by environment by management (G×E×M) interactions in mature agroforestry systems, with varieties having different phenologies (Baudron et al 2016), different morphologies and different resistance to heat stress. G×E×M interactions with respect to heat stress and water use efficiency was also be monitored in the agroforestry system. Under this activity within-field crop and soil parameters: (1) soil water, air temperature, relative humidity, and rainfall using wireless sensor network, (2) crop canopy temperature (proxy of crop water stress) using hand-held infra-red thermometers, and (3) canopy nitrogen using hand-held NDVI sensors were monitored.

2.2.3). Modelling

Currently, tree-crop interaction models such as WaNuLCAS, developed at ICRAF, with disaggregated soil layers and horizontal zones, capture tree productivity and relative changes in crop yield well, but do not provide accurate predictions of absolute crop yield. Major crop models such as the APSIM family, provide accurate predictions of crop yield across a wide range of climatic and edaphic conditions but are constrained in their ability to represent tree-crop interactions involving light, water and nutrients. This project addressed the need for accurate prediction of impacts of trees on crop yield by developing an agroforestry module in APSIM Next Generation model (Smerthurst et al, 2016). Modelling has the potential to quantitatively synthesis knowledge of tree-crop interactions, enable predictions of food and wood outcomes in specific contexts where observations are not available, and identify knowledge gaps that need addressing by further research.

CSIRO led the modelling component of the project. Key experimentalists and modellers worked together during the first half of this project to define specific modelling needs (Luedeling et al. 2016). On-farm and on-station research by PhD students and others in the project contributed context that underpinned model development, validation and application. Working on the APSIM modelling framework the team developed the APSIM Agroforestry Model within a new version of the APSIM framework, i.e. APSIM Next Generation. Most data for model development relied on literature and datasets from earlier ICRAF research in Africa, and on literature from Australia. The model has capabilities to simulate tree-crop interactions including the competition for light, water and nitrogen. The model calculates interactions between trees and neighbouring crop or pasture zones using information about the tree structure (such as height and canopy dimensions) to calculate microclimate impacts on zones of crops. Below-ground interactions between trees and crops or pastures are calculated by the APSIM SoilArbitrator model while N uptake is calculated using the equations of De Willigen et al. (1994) as formulated in WANULCAS through an innovative partnership involving CSIRO, ICRAF, CIMMYT and national partners in Ethiopia and Rwanda. The developed model can be used to simulate performance of selected options across a series of climate change scenarios in selected ecoregions using batch processing methods for APSIM already established at ICRAF.

2.2.4). Training on simple rain water harvesting technologies done simple rainwater harvesting/water conservation technologies implemented in Melkassa

At the end of July 2015, the ICRAF water management unit with support from Ethiopia team conducted a rapid assessment of potential water harvesting interventions to support the agroforestry activities in Ziway, Ethiopia (Maimbo 2016). The recommendations of this mission guided the training and demonstration activities that followed later during 2016. Activities included remote sensing and GIS, interviews with key informants, focussed group discussion and hands on training during establishment of demonstrations.

2.3 Understand and model farmer decisions about adoption, adaptation and management of agroforestry practices and their impact on crop productivity and livelihoods

The local knowledge methodology employed to explore the potential for utilising farmers' knowledge to inform management of ecosystem services across scales in Gishwati. This was taken a notch higher through extrapolating the in depth knowledge elicited during the first three stages of the AKT5 tool (scoping, definition, and compilation) to include the generalization stage in order to help understand their decision-making process with regard to the adoption of agroforestry practices. This stage involved formulation of context-relevant questions, which were administered to 150 farmers, sampled from 3 strata along the land degradation gradient.

Objective 3: To develop effective methods and enabling environments for scaling up and out adoption of trees on farms

3.1 Develop efficient tree germplasm supply systems

Key stakeholders in the tree seed and seedling subsector were interviewed in each country and workshops conducted in Ethiopia and Rwanda to develop recommendations for improving the subsector and enabling efficient delivery of high quality tree planting material (Derero et al 2016; Mukularinda et al 2016). Rural Resource Centres (RRCs), were established in Ethiopia, Rwanda and Uganda (Mekuria et al 2016; Mukuralinda et al 2016b; Okia et al. 2016b) as well as in Burundi towards the end of the project. RRCs are hubs for production and distribution of high quality tree planting materials, development and dissemination of techniques and knowledge, and for training. Motherblocks and breeding seed orchards have also been established at each RRC for providing and maintaining high quality propagation materials. Work on appropriate business models for private engagement in RRCs is ongoing. Propagation protocols of target species have been produced to address knowledge gaps on propagation (Mukuralinda et al 2016c; Mukuralinda et al 2016d). Seeds of different provenances have been collected, raised at the RRCs and distributed to farmers for participatory evaluation. For some priority fruit species, material of improved varieties have been procured and propagated in RRCs.

3.2 Identify, test and promote effective extension methods for reaching farmers in different contexts

A rapid rural appraisal (RRA) was undertaken to identify existing extension systems, their strengths and weaknesses in the respective countries (Derero et al 2016; Mukularinda et al 2016; Nkurunziza 2016; Buyinza et al 2016). Data and experience from World Vision's experience in farmer adoption was captured in the characterisation phase. Different scaling up approaches were identified such as Champion farmers, the SCALE approach, whole village models, rural resource centres, farmer field schools, demonstration plots and Umuganda in Rwanda that are being used in different contexts to scale up agroforestry practices. Socio-economic surveys were undertaken to elicit farmer's perceptions of the technologies, track the spread of technologies and get views of impact, challenges encountered and opportunities for improvement (Derero et al 2016; Mukularinda et al 2016)

3.3 Engage stakeholders to create appropriate enabling environments for adoption of farm trees for food security

Barriers to adoption identified in the initial characterisation were addressed through national dialogue meetings, round table discussions with policy makers and key government officials to address key policy issues affecting adoption (Otiende et al 2014; Muller et al 2014) Empowering farmers to take collective action was undertaken as part of the national capacity strengthening, the training of trainers to impart business skills and collective actions to control livestock grazing.

3.4 Value chain analysis and development

Inadequate access to markets by smallholder farmers is one of the factors that are likely to impede adoption of agroforestry interventions. Therefore, analysis of the value chain for agroforestry products using participatory market system development approach was instrumental in identifying bottlenecks and opportunities in the agroforestry products' value chain that required interventions to enhance adoption (Mukularinda et al, 2016; Wilson 2015; Gyau & Muthuri 2016).

Objective 4: To develop databases and tools for monitoring and evaluation of the impact of scaling up and out adoption of trees on farms

During proposal development and prior to project inception, some project benchmarks were established. These include an initial stakeholder analysis and partnership buy-in. The project inception process involved the development of partners' goals and capacities matrix for each country. A participatory M&E plan was developed where each country was able to detail an action-research process that collated data from the characterization and targeting component, the participatory trials and modelling components and the innovation and scaling up methods component.

The projects baseline and follow up survey (mid line) and end line datasets were very useful in mapping out the impact pathways. The final external review provided a good opportunity to link the various M&E milestones and thereby providing the estimates of the impact of project interventions on food security. Throughout the project period tools have been developed to allow for attribution of the changes in food security to the intervention including the use of randomized control trials (RCT). There was a deliberate effort to make the datasets comparable across the countries, and the tools developed were used to monitor processes and progress, with a view to mapping outcomes and estimating the impact. The tools encompassed indicators that measure behavioural (technological, institutional and policy changes) and people-level impacts (food security). Proxy indicators for food security to be monitored in both the control and treated groups included dietary diversity and food consumption score.

In addition, the M&E tools were designed to capture exogenous factors such as changes in the control and treated sites that were due to other projects being undertaken in the study sites. To the extent that the interventions are hypothesized to impact food security through adoption of agroforestry technologies, an attempt was made to assess the impact of adoption of the technologies on food security using appropriate econometric techniques. The econometric method used depended on whether the two groups (control and treated) complied with the assignments or not. During sampling of the sites and experimental design, care was taken to ensure that there was sufficient power to allow for attribution of the impacts. Other pathways through which adoption of the proposed agroforestry technologies could impact food security such as improved food productivity and market access was explored and formed part of the end of project report. This informed co-learning and knowledge based capacity strengthening.

Objective 5: To enhance capacity and connectivity of national partner institutions in developing and promoting locally appropriate options for adoption of farm trees

5.1 Strengthening the capacity of research institutions

Capacity needs of national partner institutions were assessed and documented in each country and then scientific capacity on the use and development of decision support tools and measurement and modelling approaches organised through appointing key doctoral study fellows in Ethiopia and Rwanda to conduct measurements using portable equipment to measure productivity and water and nutrient fluxes. Training in the relevant methods was provided. To ensure continuity, materials collating experiences, lessons learnt and best practices in research were produced and disseminated.

5.2 Strengthening capacity of farmer advisory services

Capacity needs of farmers and extension workers were assessed and documented in association with the rapid appraisal on extension methods mounted in collaboration with World Vision. A training of the trainers' network was established to work with the communities of practice set up to provide a sustainable platform for structured learning about the effectiveness of different approaches. The Rural Resource Centres were established in Ethiopia, Rwanda and Uganda to provide hubs for training and demonstration of agroforestry technologies.

5.3 Conduct governance dialogue / advisory to government

Government policies in agroforestry and institutional arrangements were assessed through policy dialogues and guidelines developed for reform needed to address constraints to adoption of farm trees. The policy dialogues were conducted to explore key policy areas relevant to scaling up of tress on farm. The dialogues involved the identification of key aspects at the district level and brokerage of the priority areas at the national level from a multi-stakeholder perspective. The process explored the household benefits of having trees on farm and the scalability of these benefits to a landscape scale. Several constraining policy factors that may inhibit the flow of benefits from the district / Woreda level to the national level were identified and documented. Work plans that highlighted policy recommendations around the key issues were developed.

5.4 Strengthen capacity on agroforestry in educational institutions

Memoranda of understanding were established to enable effective collaboration between ICRAF and national training institutions. Training on new developments in agroforestry especially modelling and use of modern methods were conducted for project staff registered for MSc and PhD in the national universities.

6 Achievements against activities and outputs/milestones

Objective 1: To characterize target farming landscapes and systems and develop tools for matching species and management options to sites and circumstances

No	Activity	Outputs/Milestones	Completion date	Comment / supporting documents
1.1	Establish socio-economic and biophysical baselines and understand barriers to adoption of farm trees	1.1.1 Regional land health baselines	E & R Yr1 M6 U&B Yr 3, M 6	Soil samples collected from two project sites for Ethiopia and Rwanda, and data analysis completed, including shrub/tree densities, wood composition analyses. Soil analyses from Ethiopia showed higher soil carbon and nitrogen levels in Ano than Alem Tena site thereby calling for soil management interventions. Both sites were found to have low woody cover. Overall shrub density was higher in Alem Tena site while tree density was higher in Ano site. A similar trend was observed in Rwanda with the Bugesera site having lower carbon compared to Gishwati. Baseline soil reports are contained in Ayenkulu et al 2014 a&b. The data is already downloaded in dataverse at https://dataverse.harvard.edu/dataverse/T4F
		1.1.2 a) Assessment of density and diversity of extant tree cover on farms, and seed/seedling delivery systems.	E&R Yr – 1, M– 6; U&B Yr 3, M6	All the tree inventories were completed in Ethiopia and Rwanda through masters' students (2 in Ethiopia, 1 in Rwanda). In Ethiopia, results showed a higher diversity of tree species in home gardens crop fields and grazing land (Endale, 2014). In East Shewa Maximum richness and abundance were recorded in homesteads followed by boundary plantings and on farms (Dawit, 2014). In Rwanda 60 on-farm tree species were identified from 193 plots selected in 20 villages. The most representative tree botanical families were Fabaceae (19.3%), Euphorbiaceae (10.5%) and Moraceae (7.0%). In Bugesera, 53 tree species were identified (Mukularinda et al, 2016a). In Burundi the diversity of tree species was found to be limited due to inadequate access to tree germplasm. Exotic tree species were predominant in the nurseries (Deo, 2015). Similarly exotic tree species were found to be predominant in Uganda (Buyinza et al 2016). In both countries tree seeds were mainly sourced from national seed centers and private seed dealers,

		1.1.2 b) Assessment of F. albida recruitment in Mojo (including the development of allometric relation to predict the age of tree	E Y3 M 8 to the end of the project	Recruitment failure causes declining *F. albida* tree density experiment- Results F albida seedlings are mostly affected by drought and grazing, population age-size class distribution of *F. albida* is uncharacteristic of a thriving population, suggesting failure in population recruitment Allometric relations to determine age of trees (F. Albida) were developed. The core-microtome was used to estimate age of trees, which in turn was used to formulate regression equations relating allometric parameters to respective trees ages. The results showed that the limited seed source is the main constraint for the sustainability of F. albida population in the long run, although short-term management practices could slow the rate of population decline (Sida et al. 2017).
		1.1.3 Databases and reports on food security, health and nutrition, and household income	E&R Yr – 1, M – 12; U&B Yr 3, M 12	Socioeconomic data collected from Ethiopia in Y 1 (Oct-Nov 2012) and Rwanda (Jan-Feb 2013) were archived into the database, and uploaded to Dataverse by late 2013. https://dataverse.harvard.edu/dataverse/T4FS A baseline survey report for Ethiopia detailing food security, health and nutrition as well as household income was developed (Iiyama et al, 2014a). Using the food security ratio indicators results showed that more people in the sub humid zone were food insecure than in the semiarid zone. In terms of assets, on farm and off farm income scores, the semiarid zone households scored higher than those of the sub humid zones. In Rwanda more households in the sub humid were food insecure than the semiarid zone. The Rwandan sites are relatively more humid, and agro-ecologically favorable compared to Ethiopian sites. Yet, the estimated higher proportion of food insecure households may be partly due to the extreme land scarcity, and associated extremely small and fragmented landholdings and soil degradation in Rwanda to support livelihoods, especially in highly densely populated sub-humid zone (Iiyama et al, 2014b). The baseline scoping for Uganda and market survey was completed by May-June 2014 See thesis by Wilson, (2015), while the local knowledge study in Burundi was completed in April 2014 (Njenga et al 2015).

		1.1.4 Reports on opportunities for, and barriers to, adoption of farm trees for food security. Recommendations over scaling-up for the different climates, soil types, species used and farming systems	E&R Yr – 1, M – 12; U&B Yr 3, M 6	The analysis of socio-economic data in Ethiopia and Rwanda highlighted the contrasting patterns of multi-dimensional utilities and management intensity of trees on farms. This could be attributed to different agroecologies driving land use and historical conditions which provide different incentives for farmers to either actively plant trees or manage naturally regenerated trees extensively. The findings of the studies confirm the critical importance of understanding local knowledge on multidimensional utilities to make fine-scale recommendations of optimal mixes of species and management options rather than a wide-scale recommendation of a few iconic agroforestry practices. Journal article by Iiyama et al (2016). The market/extension systems survey in Ethiopia and Rwanda were also completed and reports/posters are available on the project website, details have been summarized in: Derero et al 2016; Mukularinda et al 2016) http://www.worldagroforestry.org/project/trees-food-security-improvingsustainable- productivity-farming-systems-and-enhanced .and for Ethiopia the agroforestry systems journal article (Iiyama et al., 2016)
1.2	Match species and management options to sites and circumstances	1.2.1 Spatially explicit guidelines on initial best-bet tree species and management options	E & R Yr1 M6 B & U Yr 3 M 6.	Two local knowledge trainings were undertaken in Ethiopia (Lamond, et al., 2013) and Uganda (Lamond & Kuria, 2014). Local knowledge studies in Ethiopia (East Shewa and East Wollega) showed a declining tree cover loss mainly triggered by land use change resulting from the introduction of land redistribution through government policy that began in 1974. Majority of farmers here retained trees around their homesteads (live and dead fence) to protect homesteads from livestock; while more trees are retained in the crop fields to provide shade for livestock and retain moisture for crops. A similar study in East Wollega on showed that tree cover change was greatly affected by changes in policy and legislation and land tenure that took place during the Derg regime between 1974 and 1991. Farmers were mostly interested in planting trees for income, fruits, soil fertility improvement, coffee shade, timber and fodder. Major factors limiting adoption of trees on farm were free grazing, land shortage, lack of suitable germplasm, farm mechanization, drought, labour shortage, and limited knowledge on ecological utilities of trees, tree crop interaction and tree management. (Asantewaa, 2013; Ayda, 2013; Schmidt, 2013).

1.2	Match species and management options to sites and circumstances	1.2.1 Spatially explicit guidelines on initial best-bet tree species and management options		A study on local knowledge in Gishwati, Rwanda (Mukularinda et al, 2016a) showed that the main drivers of tree cover change loss was deforestation and forest encroachment after the 1994/1995 Rwandan genocide. The study revealed low on farm tree diversity and inadequate supply of germplasm for suitable tree species. Priority issues that trees could help ameliorate were: fruits for consumption and income, soil fertility improvement, climbing bean support poles, soil erosion control, fodder and firewood. In Bugesera, Rwanda the study showed that the niches with the widest range of species were fields, field boundaries and lakeshores but the diversity on crop fields was found to be low and mainly confined to propagated exotics. Farmer preference for trees was fruit and timber trees. Challenges in Rwanda included lack of training on the management of leguminous trees, the top-down seed and seedling sourcing system constraint drought and insect attacks, limited land, inadequate and suitable tree planting materials, and limited knowledge of tree utilities, tree crop interactions and ecological suitability of tree species (Mukularinda et al 2016a). A local knowledge study in Manafwa District, Eastern Uganda that explored the knowledge of local people on tree management and tree-crop-livestock interactions and the link between farmers" knowledge and their decision-making on tree species on their land. Findings showed that farmers had extensive knowledge of native species and their functions as opposed to exotic species. Farmers also expressed limited knowledge of pest and disease and had low knowledge level on how to propagate and raise native tree species, including grafting of both native and exotic tree species. (Tam Le Thi, 2015). In Burundi (Muruta commune, Kayanza Province) farmers traced changes in land use and tree cover over 5 decades, mainly attributed to government policy, population increase and the effects of the 1993-2005 civil war which led to deforestation resulting from increased demand for fuel and charcoal and the lack of stringent implementation of laws against deforestation. Timber, firewood and stakes for climbing beans were the most common roles that trees played in these agricultural landscapes. Tree planting was limited by small land sizes, lack of proper nursery management and skills on tree propagation and theft of tree propagative germplasm, (Njenga et al. 2015). A synthesis article paper is in the pipeline consolidating all local knowledge of farmers in both Rwanda and Ethiopia focusing on the challenges and opportunities to adoption of agroforestry interventions, assessing drivers of land

				use and tree cover change, and exploring role of trees and appropriate management options to achieving food security and improved nutrition, improved livelihoods, and environmental sustainability. The Burundi vegetation map has been fully integrated into the VECEA map and its species selection and distribution tools made available from www.vegetationmap4africa.org Spatially Explicit Analysis for Improved Targeting of Interventions was made, including identification of erosion hotspot mapping across action sites. (Winowieck and Vågen, 2016). Key highlight of the study was the high scores for trees for fuel, fruit and timber in the semiarid areas of Rwanda and Ethiopia.
		1.2.2. Potential tree species map developed for Burundi	B Yr 2 M12	The Burundi vegetation map has been fully integrated into the vegetationmap4africa and its species selection and distribution tools made available from URL www.vegetationmap4africa.org (web-based maps are available from: http://www.vegetationmap4africa.org/Vegetation_map/Webmaps.html).

		1.2.3. Preliminary decision support tools for matching species and management options to sites and circumstances. 1. 2.4 Refined decision support tools	All Yr 2 M12 – Yr3 M3 E & R Yr4 M6, B & U Yr4 M2	Two tools "Interactive suitable tree species selection and management tool for Ethiopia and Rwanda" is now complete. The tools can be accessed through this link: http://www.worldagroforestry.org/suitable-tree/dashboard. The tools are a composite of different studies and surveys namely: tree diversity studies, local knowledge studies, baseline studies, seed and seedling system surveys and Land Degradation Surveillance Framework done by working with different stakeholders such as researchers, farmers, extension workers and local partner organizations The tools aim at matching 'the right tree for the right place' and promoting tree diversity on farm and in landscapes, including useful exotic tree species that the existing vegetation maps do not capture. The tool currently consists of 209 (147 native and 62 exotic) tree species in Ethiopia and 115 (54 native and 61 exotic) tree species in Rwanda, disaggregated according to agro-ecological zone suitability (Kuria et al, 2016a & b). Since Rwanda, Uganda and Burundi share most of the common tree species due to similar agro-ecological conditions, the Rwanda tool is already applicable to Uganda and Burundi sites. However, additional country sites - unique tree species will be included through updating tree species encountered in these countries to the Rwanda tool while those only unique to Rwanda sites will be removed.
	1.3 Target and prioritize sites and farmer circumstances	1.3.1 Reports of national dialogues about prioritisation criteria	E & R Yr 1 M 6; B & U Yr 2 M 6	A framework for landscape level policy dialogues was developed and implemented with partners in Ethiopia and Rwanda by Y2 M12. In Ethiopia, a Woreda and national level policy dialogues were undertaken involving partners from sub-humid and semi-arid regions. Seven core policy issues were prioritised at the Woreda level (the Workshop output and the Policy dialogue framework attached). A framework for Rwanda was also developed and policy dialogues at both district and national levels undertaken by June 2014. Reports on the policy dialogues in Rwanda Muller et al (2014) and Ethiopia Otiende et al (2014) were completed in July 2014.

		1.3.2 Frameworks for prioritising landscapes and farming systems for agroforestry interventions	E & R Yr 1 Mo 9; B & U Yr 3 Mo 9	This is based on a series of outputs from 1.2 and 1.3.1 above and participatory trials under work package 2.

Objective 2: To generalise predictions of impacts of trees species and management at field, farm and landscape scales, on crop productivity, water and nutrients to inform scaling up to improve food security and reduce climate risk.

No	Activity	Outputs / milestones	Completion date	Comments
2.1	Extensive participatory and quantitative assessment of the performance of tree species and management options used in scaling up.	2.1.1 Protocols for trials of sufficient range of options across sufficient range of conditions developed.	E & R Yr1 M12	Participatory design workshops were held in Ethiopia, Rwanda and Uganda (Barrios & Coe 2013b, 2013a, 2014). Participants from Burundi were involved in the Rwanda workshop. Of the people reached by the project, currently there are more than 3649, 2557, 802 involved in participatory trials and associated tree planting activities in Ethiopia, Rwanda and Uganda respectively with 2300 farmers having received various tree seedlings in Burundi. The numbers in Bugesera, Rwanda and Tigray, Ethiopia have been achieved through partnership between ICRAF, RAB and WVR in Rwanda and ICRAF, FRC and WVE in Ethiopia. Different participatory trials have been set up in each country based on the context. In Rwanda, the trials consist of two experiments i) biomass incorporation in both Bugesera and Gishwati and ii) Alternative sources of stakes for climbing beans in Bahimba sector, Rubavu district. For biomass incorporation experiments, results in Gishwati showed that treatments of a combination of *A. acuminata* green manure and mineral fertilizers (DAP+urea), green manure alone and mineral fertilizers alone treatments increased climbing beans yields by 115% and 54% and 48% respectively compared to the farmer practices. Equally the combination of organic and inorganic fertilizers increased potatoes production by 96.6% after 3 seasons compared to farmer practice. (Mukularinda et al 2016).

		2.1.1 Protocols for trials of sufficient range of options across sufficient range of conditions developed.		In Bugesera the participatory trials were in in two sites, Juru and Rweru. In Rweru, that combination of green manure from *Calliandra calothyrsus*, *Gliricidia sepium*, *Leucena diversiflia*, *Vernonia amygdalina* and mineral fertilizers resulted in maize grain yield of between 5.9 to 6.9 t ha^{-1} (the highest being from *G. sepium* mineral fertilizer combination) compared to the farmer practices (Farmyard manure) range of 3.1 to 3..9 t ha^{-1} . The same trend was observed in Juru but the yields were lower 2.9 to 3.9 t ha$^{-1.}$ For stakes for climbing beans findings indicate that Acacia *angustissima* grew faster (4.2 m) than *Alnus acuminata* (3.2 m), Vernonia *amygdalina* (1.8 m) and *Alnus* nepalensis (1.5 m) 12 months of after planting. Acacia is also preferred by farmers as stakes for beans because its longer and stronger (its resistance to beans weight and wind) with only 1.4% of stakes from A. *angustissima* being broken after use in one season compared 56.2% of stakes from *Pennisetum purpureum* (Mukularinda et al 2016). In Ethiopia the trials are on evaluating different tree species performance in different planting niches, some assisted with soil moisture retention structures (SMRS) and manuring and composting. Findings demonstrate that survival and growth significantly varied among species, agroecologies, niches and SMRS. The project has now demonstrated that trees on homesteads, boundaries, soil bunds and crop lands can be increased amidst the challenges from open grazing system and moisture stress (Derero et al 2016a). In Uganda trials were established to address challenges specific to communities along landscape categories. While the lowland areas are concerned with river bank stabilization using trees, the midland is involved with tree species diversity and the upland areas are looking at measures to control soil erosion using appropriate tree hedgerows, and grass bands. The response variables being measured from these trials include seedling survival (e.g. 60% for Calliandra, 52% for Eucalyptus) collar diameter, seedling height and number of branches (Buyinza et al., 2016).

		2.1.2 Sampling, survey and measurement schedules developed.		Data collection schedules have been developed for the participatory trials in all the countries. Participatory Trials Evaluation and Planning Workshops in June 2014. CIMMYT developed and circulated protocols for medium term trials related to tree-crop interactions and G×E×M (with emphasis on N, P, and germplasm). These protocols are available (data see CIMMYT report attached). Sap flow and dendrometers were installed on six *Faidherbia albida* trees at Mojo (Ethiopia) on two farmers' fields to monitor water uptake and increment. A similar set up was installed in Bugesera, Rwanda both close to CIMMYT on farm experiments in April 2014 (Year 2 month 10). Protocols for data collection in the long term trials prepared and are contained in the reports (Derero et al, 2016, Musana et al 2016 and Ngoga et al 2016). Data on two long term trials is collected on survival, collar diameter and height of seedlings; further data on crop yield (teff) is collected in the Bako long term trials.
		2.1.3 An interim report from the surveys at Yr. 2 Month 8.	E & R Yr. 2 M8-end	Protocols for tracking the participatory trials have been developed and collection of socio-economic data and biophysical data in both Rwanda and Ethiopia (Kiptot et al. 2015). This was aimed at determining the effectiveness of these technologies and understand farmers' perceptions to scaling up options.
2.2	Conduct controlled experiments and develop simulation models of tree and crop yield across biophysical gradients	2.2.1 Synthesis report of critical review and expert workshop to identify gaps in being able to model tree and crop yields in integrated systems for East African farmer conditions. Report on details of surveys and experiments to be conducted in the project.	Yr 1 M 4	In addition to the modelling workshop report (last reporting period), a report on modeling needs was completed ("Tree-Crop Modeling Strategy for the ICRAF-ACIAR Project Trees-for-Food-Security, East Africa"; October 2013; attached). A joint publication between ICRAF and CSIRO on the challenge of projecting future performance of agroforestry systems has been published: Luedeling, E., Kindt, R., Huth, N. I., & Koenig, K. (2014). Agroforestry systems in a changing climate—challenges in projecting future performance. Current Opinion in Environmental Sustainability, 6, 1-7. A manuscript by Luedeling, et al., (2016). Field-scale modeling of tree–crop interactions: Challenges and development needs Agricultural Systems 142: 51-69. Can be accessed online

		2.2.2 Papers and databases from controlled experiments and observations designed and conducted to measure impacts of trees on crop yield, water resources, soil health and N and P balances in tree crop systems.	E & R Yr2 M12- end of Project	Four (4) long term trials two in each country were established in Rwanda and Ethiopia and data collection, analysis and report writing have been undertaken (Mukuralinda et al 2016, Derero et al 2016, In Ethiopia at Bako, the mean height of *Cordia africana* and *Grevillea robusta* has reached over 140 cm as of July 2016, but *Acacia abyssinica* and *Croton macrostachyus* are only above 100 and 80 cm, respectively, and the latter was one year younger and a further replacement undertaken in July 2016. At Melkassa, the mean height of *Acacia tortilis* has reached over 2.5 meter as of July 2016, For the remaining the height is about 1.3 m for *Cordia africana*, 0.5 m for *Moringa stenopetala* and below 0.5 m for *Faidherbia albida*. .
			Uganda Yr. 3 M 11 to end of project	In Rwanda Bugesera, the tree species tested are *Grevillea robusta*, *Faidherbia albida*, *Markhamia lutea* planted alone, their combination and maize planted alone in Bugesera. The results showed that the growth of height of *G. robusta* was heighest (2.9-3.5 m) followed by *F. albida* (2-3.2 m) and *M. lutea had the lowest* (1.5-2 m). During the dry season stagnation in growth Mukularinda et al. (2016). At the humid Tamara station, the height of two year old A*lnus acuminata* ranged from (4.9-5.9 m) while *C. megalocarpus height ranged from* (1.2-1.5m). Trees planted alone grow faster than when they are combined. On the other hand, *C. megalocarpus* intercropped with maize showed higher maize grain yields (4.5 t ha^{-1}) compared to the yields under *A. acuminata* (2.8 t ha^{-1}) (Musana et al., 2016).

2.2	Conduct controlled experiments and develop simulation models of tree and crop yield across biophysical gradients	2.2.2 Experiment set up on impact of trees on water resources and crop performance in Uganda G×E×M interactions with respect to heat stress and water use efficiency	E & R Yr2 M12- end of Project Rwanda Yr. 3 M 8 to end of project	Data on tree crop water interactions experiments from controlled on-farm experiments in Ethiopia and Rwanda with pruning treatments for *F. albida* and *G.robusta* respectively have been done. The results showed that pruned *G. robusta* consumed less water than unpruned. The daily sap flows volume range from 7-34 l day^{-1} and 70 – 88 l day^{-1} for pruned and unpruned respectively. In addition, average maize grain yields under the pruned trees were higher compared to that under the unpruned trees Ngoga et al (2016). Findings on *F. albida* wheat interactions are reported in (Assefa et al. 2016), while for *F. albida* teff interactions in krampien 2015 MSc thesis). The results show increased wheat yields under *F. albida* and no effect on Teff which indicate complementarity with wheat. Pruning reduces water uptake in *F. albida* but wheat yields are reduced under pruned compared to unpruned. This means that farmers should not pollard their Faidherbia trees when grown with wheat if they are to realize increased yield benefits. Impact of varying degrees of shading on maize productivity in Melkassa was also undertaken and results reported in Derero et al, 2016. Sap flow training and installation was carried out in Uganda in October 2015 after funds for this component were availed after the project mid-term review. Measurements are ongoing (*Cordia africana* and *Albizia coriaria*) and preliminary findings are presented in the Uganda report (Njoroge and Muthuri, 2015). A number of on-farm trials were established in Rwanda and Ethiopia to answer farmer key questions: (1) What happens near trees? (2) What to plant near trees? (3) What management is needed near trees? Questions were answered from different experiments across the study sites (CIMMYT, report) 1. *F. albida* trees buffer wheat against climate change in the Rift Valley of Ethiopia- Results; effects of trees were localized with highest positive impacts close to the tree trunk. Study showed no water or nutrient competition, tree presence enhanced water and nutrient availability. Further studies need to be done on tree densities. 2. Effect of *A. acuminata* and *M. lutea* on maize microclimate water and nutrient available to maize, and maize yield in Northern Rwanda- Results- Generally tree canopy reduced incident solar radiation and day temperatures, increased soil nutrients at varying degrees. A. acuminate was less competitive with crops than M. lutea, (Baudron et al 2016)

		Assessment of the productivity and sustainability in a coffee-Tephrosia system in Rwanda		3. Tillage options and maize varieties that minimize tree-crop competition: Results: Hybrid maize performed better than open pollinated varieties (OPV) under agroforestry management, however the increase in yields are minimal to justify use of hybrids considering their high price. No till in agroforestry will not be a viable option alternative to conventional tillage since it seemed to increase tree-crop competition. 4. Adapting fertilization to minimize tree-crop competition in agroforestry systems-Results were inconclusive hence there is need for further studies to identify fertilization rates that minimize tree-crop competition for *G. robusta*-maize and *A. tortilis*-maize systems, and also to identify the rates and timing of application that optimize *F. albida*-wheat facilitation (Baudron et al 2016). 5. In what circumstances is growing in-situ mulch for coffee attractive?- Results. The coffee-*T. vogelii* intercropping system presents high potential of increasing coffee yields on a wide range of soils and landscape positions, with more benefits on nutrient depleted farms of low resource endowed smallholder farmers.
		2.2.3 Report and database of predictions of crop yields in present and future tree-crop scenarios and parameterised, combined tree-crop simulation models (APSIM and WaNuLCAS) used to calculate them	E & R Yr. 2 M 6 up to Yr4 M6 Ongoing	CSIRO/ ICRAF APSIM agroforestry workshop, Toowoomba, Australia, developed the APSIM Agroforestry Systems Model. Model has been validated using data sets from Australia, Kenya and Malawi. Predictions were adequately simulated. Project specific simulations commenced in 2015 and good progress made. A manuscript by Luedeling, et al., (2016). Field-scale modeling of tree–crop interactions: Challenges and development needs Agricultural Systems 142: 51-69. Can be accessed online and project website. Trainings on the use of the APSIM model have been undertaken and more on the training on application of Agroforestry model continues in 2016. (Smethurst et al, 2016a, CSIRO report).A number of students in Rwanda an Ethiopia have used the model in complementing their field experiments; tree-maize in Rwanda and tree-wheat systems in Ethiopia. Two manuscripts have been prepared to evaluate predictive capacity of the developed APSIM Agroforestry model its predictive capacity using data sets from Malawi, Kenya and Warra (Smethurst et al, 2017 and Masikati et al 2017-Under review)

		2.2.4 Outreach material on ecological processes and Simple EXCEL-based decision-support tools will be developed from outputs obtained from simulation models (e.g. APSIM) under different scenarios of production.	E & R Yr3 M12 To End	A two pager modelling document for announcing the APSIM Agroforestry Systems Model was produced (Smerthurst et al 2016b) and is available on project website. Excel based decision support tools for Rwanda and Ethiopia have already been prepared and few partnering country researchers preliminary training on its use done. Training and use by more country researcher, extension workers and farmers should be carried out in 2017.
		2.2.5 Training on simple rain water harvesting technologies done Simple rainwater harvesting/water conservation technologies implemented in Melkassa	Year 3 M12 to end	At the end of July 2015, the ICRAF water management unit with support from Ethiopia team conducted a rapid assessment of potential water harvesting interventions to support the agroforestry activities in Ziway, Ethiopia. (Maimbo, 2015). The recommendations of this mission guided the training and demonstration activities that followed later during 2016. Ground water prospecting, and construction of two wells and upgrading two existing ones was carried out in April 2016. Muriithi et al 2016. ICRAF commissioned training on groundwater prospecting for well technicians whereas artisans/masons and project staff were trained on construction of walls (reinforcement) and headworks. Although solar pumping is highly recommended, training was done on the use of hand pumps. In order to upgrade the water supply at the RRC, ICRAF prepared a design and layout for an improved water system. In addition, ICRAF introduced a sprinkler irrigation system for Melkassa farm.

2.3	Understand and model farmer decisions about adoption, adaptation and management of agroforestry practices and their impact on livelihoods	2.3.1 Database of collated information from characterisation and participatory feedback surveys, including system integration effects, of how agroforestry practices affect livelihood systems	E & R Yr1 M12	A database has been prepared based on results from the baseline surveys. The database contains all data from the socio-economic baseline, soil survey and local knowledge collection and is continually updated as more data is gathered. The data is accessible at http://thedata.harvard.edu/dvn/dv/icraf Two "Interactive suitable tree species selection and management tools developed for Ethiopia and Rwanda". The tools aim at matching 'the right tree for the right place' and promoting tree diversity on farm and in landscapes, including useful exotic tree and hence livelihoods. The tool currently consists of 209 (147 native and 62 exotic) tree species in Ethiopia and 115 (54 native and 61 exotic) tree species in Rwanda, disaggregated according to agro-ecological zone suitability (Kuria et al, 2016a & b). Local knowledge findings on farmers perceptions, motivations in management and adoption of various agroforestry technologies based on context have been documented in Ethiopia sites (Asentewa 2013; Kuria et al., 2014). A PhD local knowledge study was conducted in Gishwati in 2015 to explore the potential for utilising farmers' knowledge to inform management of ecosystem services across scales. The study was conducted on a sample of 150 farmers selected along the land degradation gradient (Details are provided on the PhD local knowledge research progress report - Kuria et al., 2016c).
		2.3.1 Preliminary report on farmer surveys and experiences from stakeholders	E & R Yr1 M12 U&B Y2 M12)	Reports from farmer survey which includes socio economic surveys, participatory trials, market, extension, and local knowledge surveys are contained in socioeconomic surveys reports, local knowledge student's thesis, reported in objective 1 and 2.1 above. A report on farmer's experiences and feedback from the participatory trials in Ethiopia is also contained in Derero et al 2016b). See also report on Winowieck & Vågen 2016 on Spatially Explicit Analysis for Improved Targeting of Interventions. Experiences from stakeholders are contained in farmers stories and blogs (see project websites) and ACIAR T4FS 2016 annual report All these reports are available at http://www.worldagroforestry.org/project/trees-food-security-improving-sustainable-productivity-farming-systems-and-enhanced

Objective 3: To develop effective methods and enabling environments for scaling up and out adoption of trees on farms

No.	Activity	Outputs / milestones	Completion date	Outputs/ Milestones
3.1	Develop efficient tree germplasm supply systems	3.1.1 National seed and seedling subsectors analysed from characterisation data and stakeholder workshops (see 1.1.2 above) and reports produced.	E&R Yr1 M1	Key informant surveys on seed and seedling systems in Ethiopia (Derero et al 2016),and Rwanda (Mukularinda et al 2016), and an assessment of 40 different nurseries located in four sub-humid and four semiarid sites and interview of 169 respondents in Ethiopia was conducted by an MSc student from Hawassa University (Kassim, 2014). An MSc thesis on tree diversity studies by Dawit, (2014) was produced. Two journal articles from the seedlings and tree diversity studies have been published by Dedefo et al. 2016 and Endale et al. 2016 National Stakeholder workshops on seed/seedling systems in Rwanda and Ethiopia were held in July 2014. (Derero et al, 2016; Mukularinda et al, 2016). In Burundi nursery surveys and seed and seedling system surveys were concluded and the Masters student has completed his thesis and project report Havyarimana, Deo (2015). In Uganda a key informant survey on extension systems and seed and seedling systems was done in 2015 and reported in Buyinza et al 2016.
		3.1.2 Establishment of RRCs	E & R Yr 2 M 5 B & U Yr 3 M 9	Construction of 2 RRCs was completed in Rwanda in 2014 at Karama and Karago. In Ethiopia, establishment of an RRC at Ziway was completed in 2014 and was officially opened in March 2015 while the one in Bako Tibe is operational as of October 2016. In Uganda, the central tree nursery in Mbale was upgraded to an RRC in 2015. It hosts a nursery, demonstration plots and a training unit. Three RRC fact sheets for Rwanda (Mukuralinda et al 2016b), Ethiopia (Mekuria et al, 2016) and Uganda (Okia et al, 2016b) contain details of each RRC.

		3.1.3 Designs and business models for alternative seed/seedling supply systems for use in national scaling programs including rural resource centres, satellite nurseries, genebanks and motherblocks prepared and implemented	E & R Yr4 M6	2 RRCs (Ziway RRC complete and Bako one is operational as of October 2016 and several satellite nurseries have been established in Ethiopia while in Rwanda, 2 RRCs and 3 satellite nurseries have been established for the supply of planting materials. RRC farmers have started seedling production and are selling seedlings of high value trees to other farmers. A mother block has also been established at Ziway where farmers buy high quality germplasm Development of different business models is on-going and will continue in phase 2.One of the business models developed in phase 1 is where a farmer group registered as a cooperative runs an RRC where they provide labour for raising seedlings, train other farmers and sell quality planting material (scions, rootstocks and seedlings) at a fee to other farmers (Batu RRC, Mekuria et al 2016). These activities have provided the group members income. They also have demonstration plots where other farmers come to learn about improved practices.
		3.1.4 Protocols for participatory provenance and propagation trials for target species produced; trials established and journal papers produced later	E & R Yr 2 M 1 B & U Yr 3 M3	Propagation protocols for *Alnus acuminata* and Tamarillo (*Cyphomandra betacea*) have been produced in Rwanda Mukuralinda et al 2016 c & d. In Ethiopia, currently there are 446 farmers participating in various trials while 1511 farmers have benefitted from the project seed/seedling supply with over 230,000 seedlings distributed to farmers. In Rwanda 158 farmers are involved in the trials. An additional 606 farmers have received 800,000 seedlings from the project through RAB, ICRAF and WV in the two areas, Gishwati and Bugesera. Over 50,000 priority tree germplasm for establishment of on-farm participatory trials have been raised at the Mbale RRC in Uganda and distributed to farmers. A summary of key project highlights for Ethiopia, Rwanda, Uganda and Burundi (including trial established and seedlings produced) are reported in Derero et al 2016a, Mukuralinda et al., 2016, Nkurunziza et al 2016, Okia et al., 2016 a respectively. An overall summary magazine of project achievements as at April 2016 is also available online (Muthuri et al., 2016b).

		3.1.5. Report on developing efficient germplasm support systems for partner government	B & U Yr4 M6	Tree nurseries have been established in four sites of Kayanza Province, Burundi. Individual tree nurseries have also been established one RRC is under construction.
3.2	Identify, test and promote effective extension methods for reaching farmers in different contexts	3.2.1 Report on different extension methods and their suitability for different contexts, materials and messages in the evergreen agriculture domain.	E & R Yr1 M6 U & B Yr3 M 6	The surveys on extension methods were completed in Rwanda and Ethiopia in 2013. The reports have identified extensions models which ACIAR project is building on in scaling up evergreen agriculture activities e.g. the use of champion farmers, demonstration plots and Umuganda (community work) in Rwanda (Derero et al, 2016; Mukularinda et al, 2016). Key informant surveys on extension systems in Burundi and Uganda were undertaken in March/April 2015. Reports are available on the ICRAF web page. Buyinza et al. 2016 and Nkurunziza et al 2016.
		3.2.2 Different extension methods tested and compared	E & R Yr2 M12 U & B Yr 3 M12	Different extension methods such as the use of champion farmers, RRCs, demonstration plots sensitization meetings, are being used in different countries. The methods are complementary. (Mekuria et al. 2016, Okia et al. 2016b, Mukuralinda et al 2016e; Nkurunziza et al 2016). A manuscript is under preparation on the different extension methods, their strengths and weaknesses. It will be ready for submission to a journal by the end of May 2017 (Kiptot et al).

		3.2.3 Community of practice with network of users applying and evaluating approaches to scaling up established and a communication strategy developed	E & R Yr 3 M1 U & B Yr 4	In Ethiopia, ICRAF in partnership with WVE, FRC, CIMMYT and the woreda administrations has used various strategies/approaches viz. participatory trials, germplasm supply, Rural Resource Centers (RRC), nurseries and demonstration plots, on farm experimentation, training and capacity building, and sensitization meetings. More than 6,000 community members have been reached through the community of practice established. In Uganda, Mbale RRC has firmed up collaboration with seven local and national institutions to increase production of planting materials, enhance training actions and support wider coverage of TFSP activities within and outside the project sites. In Rwanda, the trainings are conducted in collaboration with farmer cooperatives, local extension services from government departments such as Rwanda Natural Resources Authority, (RNRA), Rwanda Environment Management Authorities (REMA) and Non-governmental organizations such as World Vision Rwanda
3.3	Engage stakeholders to create appropriate enabling environments for adoption of farm trees for food security	3.3.1 Dialogue with policy makers to remove barriers to and encourage adoption of farm trees for food security	E & R Yr. 2 M 4 U & B Yr3 Yr4	Policy dialogues were conducted at district and national levels in Rwanda and Ethiopia in 2014 to identify policy related challenges that inhibit the adoption of trees on farm. Refer to Otiende, et al (2014) and Muller et al. (2014).

		3.3.2 Trainers of farmers trained to impart training in negotiation skills and in identifying market opportunities; Training manuals and training event reports produced	E & R Yr2-Yr 4 U & B Yr 3-Yr 4 E & R Yr 2-Yr 5 U & B Yr 3-Yr 6	Within the RRCs like in Ziway, Ethiopia basic training on market, value addition and entrepreneurship skills has been ongoing and certificate awarded to participants, These trainings were extended to Bako by November 2016 (Derero et al 2016c). Work in progress. Simple manuals are under preparation and more advanced ones will be undertaken in phase 2 of the project. Community tree nursery operators in Uganda were trained on establishing and managing tree nurseries for business using the training manual by (Buyinza and Opolot 2016) and the proceedings of this training are contained in a report by Buyinza (2016). In Ethiopia, entrepreneurship training that was done at the RRC in 31st March 2015 and details of the training manual are contained in (Eshetu, 2016).
		3.3.3. Process documentation for strengthened rural institutions for enhanced collective action to, where appropriate, control livestock grazing and develop quality tree germplasm supply systems	E & R Yr2-Yr4 U & B Yr3-Yr4	This is work in progress and it will continue in the second phase of the project under objective 3
		3.3.4 Report on lessons learnt from rural institutions	All Yr4-M6	Work in progress and will continue in the second phase of the project under objective 3.whereby principles for effective cross-scale linkages and the support structures required in response to the increased complexity of managing tree crops at the landscape level will be identified with a view to defining appropriate implementation mechanisms that link different institutions at different levels.

		3.3.5 Guidelines on the appropriate balance of community and private sector engagement in different contexts that is required along the tree-crop intensification value chain for farmers to gain market access prepared	E & R Yr2-Yr4 U &B Y3-Yr4	Value chain study conducted in Rwanda on prioritization and Rapid Market Appraisal for tree products in Rwanda (Mukularinda et al, 2016. In Ethiopia the study was carried out and a paper by Gyau & Muthuri (2016). On The socio - economic potential of under of utilized species to small holder farmers: The case of Khat (Catha edulis) in Ethiopia is published in African Journal of Business Management Volume; In Uganda an MSc study on 'agroforestry tree products, markets and decision making- A grounded theory study of smallholders' experience of market participation in Manafwa District, was completed in January 2015. Master's thesis by Wilson, (2015) is available on the project webpage. Despite the political turmoil in Burundi, marketing study was conducted and completed and an MSc student registered at JKUAT. Please see thesis (Abingoye 2016).
		3.3.6 Report on outcomes from enhancement of value chain to ensure sustained market access for the agroforestry products	E & R Y4-M4 U & B Y4-M8	Work in progress. Will be followed up in the second phase of the project under objective 4 whereby different financing options for tree products, identifying the various organizational and institutional arrangements which support tree based enterprise development that will increase stakeholders especially smallholder farmers, traders and processors participation in tree product value chains.
3.4	Prepare project communication strategy	3.4.1 Prepare project communication strategy	Y1 M9	Project communication strategy (Muthuri et al. 2013)
		3.4.2. Development of Communication materials for all the outputs	E & R Yr1 M12 U & B Yr3 M 8	Different communication materials in the four countries have been prepared and some translated in French and Kirundi. Brochures, posters, fact sheets, journal articles are available on the web. Sign posts have been placed in areas of operation to create visibility of the project

Objective 4: To develop databases and tools for monitoring and evaluation of the impact of scaling up and out the adoption of trees on farms.

No	Activity	Outputs/ milestones	Completion date	Outputs/ Milestones
4.1	Engage partners to undertake preliminary planning of the project using appropriate tools and methodologies	4.1.1 Workshop held and proceedings produced indicating partner goals and capacities matrix Development of key M & E research questions	E & R – Yr1 M12 Completed	Feedback and inputs were solicited from the project partners and stakeholders during the inception workshops, (Mukuralinda et al. 2012 and Derero et al. 2012) especially towards the baseline collection activity in the respective countries. All the work packages were consulted in the development of indicators and M&E plan. The partners were appraised on the progress in May 2013, and feedback was solicited. Completed by E & R – Yr1 M12
	4.2 Develop a robust M&E strategy	4.2.1 Performance indicators and participatory measurements protocols developed	E & R – Yr1 M4 U & B – Yr3 M6 Completed	Performance protocols for Rwanda and Ethiopia completed. Development of the protocols for integrating indicators of scaling up in the Uganda and Burundi Baselines. The project Scaling up Strategy is documented in Muthuri et al. (2016b).
		4.2.2 M&E plan developed	E & R – Yr1 M4	An updated M&E draft has been produced incorporating Uganda baseline data and available data from Burundi with that of information from Ethiopia and Rwanda. Linking data collection and aggregation (Mohan et al, 2015).

	4.3 Conduct regular performance data collection and periodic evaluations	4.3.1 Evaluation reports developed on: 1] Social returns and cost benefits of investment by smallholder farmers ; 2]Tree species selection and RRC; 3]Capacity through project activities; 4] Effectiveness of scaling up and scaling out activities	E & R – Yr1 - Yr4;	Key evaluation questions developed around project activities and included as part of the M&E strategy. The 4 questions are a part of the M&E strategy document, and pertain to the 4 listed under the description of the indicator
		4.3.2 Project M&E report developed and proceedings of workshops recorded	E&R Yr 4	Two (2) meetings were held in Ethiopia and Rwanda on M&E, and recommendations from the meetings were incorporated into the M&E strategy. The proceedings of the meetings were duly recorded. Mohan et al., 2014. An inventory of tools and methodologies modified or created for use in the project was compiled for the respective countries, and data hosting procedures were discussed for implementation in Yr4 for both countries and this will be followed up in phase 2.
		4.3.3 Final Impact assessment report containing estimates of the impact of the interventions on food security produced	Yr 4	Assessment questions developed as part of M&E strategy, and the information generated will be used to scale-out the project activities to other countries that are not part of the project and influence policy decisions in the target countries. The AIFSRC M&E plan outlines the M&E of Development Outcomes with key indicators and impacts of the project on food security among other indicators are well explained (Muthuri et al. 2017).

Objective 5: To enhance capacity and connectivity of national partner institutions in developing and promoting locally appropriate options for adoption of farm trees

No.	Activity	Outputs/ milestones	Completion date	Outputs/Milestone
5.1	Strengthening the capacity of research institutions	5.1.1 Capacity needs of national partner institutions assessed and documented	E & R Yr 1 M4	The lead institutions of the project all the four countries are research institutions. Capacity of these institutions were identified during the, baselines design workshops, characterization, participatory design workshops, modelling design, workshops, associated trainings and M&E plan development. Details of proceedings and output the proceedings/ reports are covered under objective1, 2 & 3
		5.1.2 Proceedings of training on decision support tools, materials, methods and approaches produced	E & R Yr 2 M12 U & B Yr 3 M4	Training on local knowledge, enumerators on data collections for all baseline components, participatory design workshops, physiological instrumentation like sap flow and dendrometer, were done and reports are available on the website. Local knowledge: Lamond et al 2013; Lamond & Kuria 2014. Sap flow trainings Njoroge and Muthuri 2015. Two tools "Interactive suitable tree species selection and management tool for Ethiopia and Rwanda" were now completed. The tool can be accessed through this link: http://www.worldagroforestry.org/suitable-tree/dashboard (Kuria et al, 2016a & b).Training on their use by few partner researchers has been done in Rwanda and Ethiopia. Training for more researchers, extension officers and farmers will be carried out in 2017 and extended to Uganda.
		5.1.3 Materials on experiences, lessons learnt and best practices produced and disseminated	E & R Yr2 M12 U & B Yr 3 M4	Project summary magazines for the four countries were produced and disseminated. These give an overview of the lessons learnt and best practices for each country (Derero et al. 2016a, Mukuralinda et al 2016e, Okia et al 2016a and Nkurunziza et al, 2016). A project overview factsheet that summarizes the project overview across the countries is also available (Muthuri et al 2016a).

5.2	Strengthening capacity of farmer advisory services	5.2.1 Capacity needs of farmers and extension workers assessed and documented	E & R Yr1 M3	Capacity strengthening was embedded in all the other work package activities. Capacity needs assessment of governmental agricultural planning and coordinating structures, governmental extension agencies, as well as NGOs and CBOs engaged in agricultural extension was carried out in August 2013 in Musanze, Rwanda involving participants from Rwanda, Burundi, Uganda and Ethiopia with technical support from ICRAF capacity development unit.
		5.2.2 Farmer network established where experience and lessons learnt are shared		Training and demonstration activities have been conducted in the RRCs and some training materials are available in the centres. This is an ongoing activity. Farmer groups are working closely with extension workers. Also there has been exchange visit for example between Ziway and Bako. Some few materials like on grafting are available and training reports produced. Training on nursery operations and management were also carried out in Mbale RRC (Buyinza et al 2016) and a manual on the same is attached (Buyinza, 2016b) RRC fact sheets (Mekuria et al 2016; Mukuralinda et al 2016b. and Okia et al 2016b) have been produced. A training manual on erosion control was also developed in Burundi. (Nkurunziza, 2015)
5.3	Conduct governance dialogue with government / policy institutions	5.3.1 Government policies in agroforestry and institutional arrangements assessed and guidelines developed	E & R Yr1 M4	A Systematic government dialogue to assess policies and institutional arrangements was completed for Ethiopia and Rwanda. The final report of the consultancy in Ethiopia (Birhane, 2014).

		5.3.2. Proceedings of regional and country policy workshops on research findings processed	E & R Yr 3 M6 U & B Yr3 & 4	Country workshops were held in Rwanda (Muller et al 2014) and Ethiopia (Otiende et al. 2014) and a policy brief produced for each country (ref to the website). A policy brief for Ethiopia titled 'Harnessing Agroforestry in Ethiopia to boost crop productivity and strengthen food security' by Hassan, et al (2015a) was produced. A similar one for Rwanda was also produced the same year Hassan, et al (2015b) However, regional workshops component would not be achieved in this phase due to limited budget. This component will be part of the second phase of the project.
5.4	Strengthen capacity on agroforestry in educational institutions	5.4.1 MOUs and effective collaboration established between ICRAF and national training institutions.	E & R Yr1 & 3	Key partner institutions in Rwanda Ethiopia, Uganda and Burundi are universities and the lead institutions. MOUs have been developed with EIAR, EEFRI RAB, ISABU and NAFORRI, NARO and Addis Ababa University. MOUs are a perquisite for subcontracts. Collaboration between these institutions and ICRAF continue to be strengthened in this project through involvement of their staff in all the workshops/ trainings, design of trials, modelling and data collection.
		5.4.2 Six partner scientists engaged. and 7 journal papers published	E & R Yr 2 - Yr 4	Students belonging to these institutions have been registered for masters and PhD (17 MSc students and 8 PhD students) with support from the project (an additional PhD Student Joel has already been awarded an Alwright scholarship commencing in 2017). Capacity covering aspects in objectives 1, 2 & 3 has therefore been strengthened and training needs identified. The following papers have been published (or in process) in journals so far: de Dieu Habiyaremye, et al (2015); Iiyama et al (2016). Luedeling et al (2016). Dedefo et al. (2016) and Endale et al. 2016, Gyau, & Muthuri (2016) Fredrick et al, 2015 and Fredrick et al, 2016. Some are under review while a significant number are under preparation to be submitted in 2017.

		5.4.3 Short courses conducted and modules on tree crop intensification developed	E & R Yr2 M4- Yr4 M4	Training on key components within various WPs have taken place like modelling, sap flow, design of participatory trials and local knowledge. However, no modules have been developed as this would require more structured and greater involvement by University leadership and this will be accomplished in the next phase of the project through ANAFE.
		5.4.4 Agricultural and forestry curricula reviewed in participating universities	E&R Yr 3 M10 E & R Yr 4 M 8	This component cannot be achieved in the current project and will require to be led by a body linking with the Universities in the region. This component will be led by ANAFE in the second phase of the project.

7 Key results and discussion

The project's research was organised in four scientific work packages that were tied together by a major effort to strengthen national capacities. The work packages include:

1. Characterisation and targeting;
2. Measurement and modelling of impacts of trees on crop yields, farming systems and livelihoods;
3. Innovations in scaling up methods and enabling environment
4. Monitoring and evaluation.
5. Capacity strengthening.

A summary of activities for each work package is outlined below:

1.1 Establish socio-economic and biophysical baselines and understand barriers to adoption of farm trees.

Household baseline survey results

A total 340 households in four semiarid sites and 347 households in four sub-humid sites in Ethiopia and 320 households in three semiarid sites and 324 households in three sub-humid sites in Rwanda were interviewed to understand patterns of tree adoption on farms. The study highlighted the multi-dimensional utilities and management intensity of trees on farms that include farmers managed natural regeneration (FMNR) and high value agroforestry (HVAF). The results revealed that farmers integrate many native and exotic tree species on their farms to meet their variable farm conditions, needs and asset profiles in contrast to most tree promotion efforts that focus on a few, usually exotic, tree species. It was recommended that future agroforestry promotion should embrace a diversity of tree species appropriate to matching the fine scale variation in ecological conditions and farmer circumstances encountered in the field. Findings of the study in Ethiopia are contained in a journal paper (Iiyama et al, 2016). Findings in Rwanda highlighted patterns of trees on farms that include farmer managed natural regeneration of timber, fruit, and fuel species and planting of species for environmental services. These are indeed quite contrasting patterns to those of Ethiopia, i.e., FMNR of environmental service species and active planting of fruits, timber etc. This could be attributed to Rwanda's susceptibility to soil erosion which provide strong incentives for farmers to actively plant trees with environmental services (Mukularinda et al, 2016a).

Biophysical baselines

This component included multi-disciplinary baseline surveys which yielded rich database to allow the analysis of barriers of adoption of farm trees in the targeted agroecologies. Relevant information on land health to assist planning and targeting site-specific management interventions was generated using the Land Degradation Surveillance Framework (LDSF) to characterize two sentinel sites (each 10 km × 10 km) in semi- arid (Bugesera) and sub-humid (Gishwati) agroecologies in Rwanda and semi-arid (Alemtena) and sub humid (Anno) regions of Ethiopia.

Soil properties

In Ethiopia results showed that Ano (sub humid) has significantly higher soil carbon content than Alem Tena site (semiarid) (Fig. 4a). Soil carbon content significantly decreases with increasing depth in both sites (Fig. 4b).

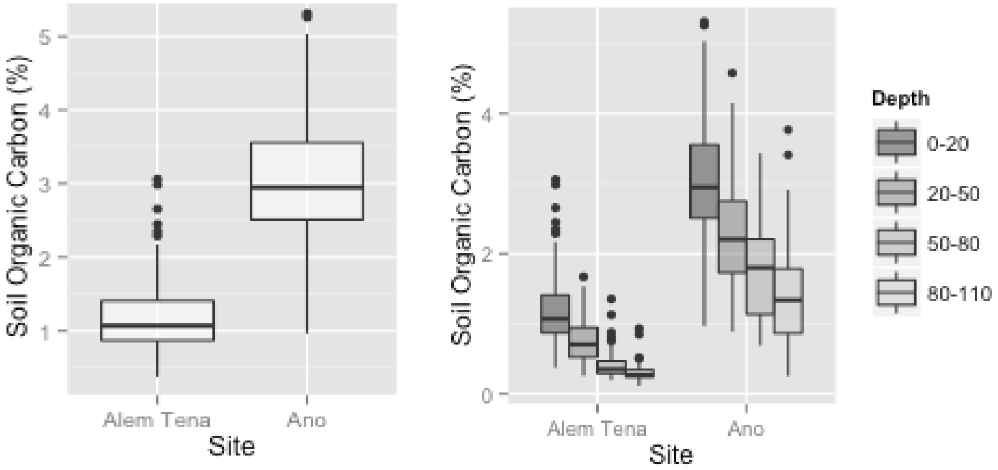


Figure 4: (a-left) Ano site has higher soil organic carbon in the top (0-20 cm) than Alem Tena site, (b-right) Soil carbon decreases with increasing soil depth in both sites.

There was no significant difference in soil carbon and nitrogen contents between cultivated and semi-natural lands in both sentinel sites. Soils in Ano site are richer in clay than Alem Tena site but no difference in clay content between cultivated and semi-natural lands was found in both sites. The higher soil carbon and nitrogen contents compared to Alem Tena could be attributed to the higher clay content in Ano site than Alem Tena site.

Generally soils at Alem Tena site have lower soil carbon and nitrogen contents and infiltration rates and require appropriate interventions like crop residue incorporation, increasing tree cover to build soil physical, chemical and biological properties to sustain agricultural productivity and environmental sustainability.

In Rwanda, soils in Gishwati site had significantly higher carbon content than Bugesera site. Soil organic carbon increases with increasing longitude at Bugesera and increasing latitude for the Gishwati site which follows the trend in increasing soil moisture in the two sites (Figure 5). Infiltration capacity was higher in Bugesera (202 mm hr-1 (95% CI = 189 – 216 mm hr-1)) than Gishwati (77 mm hr-1 (95% CI = 73 – 82)). Similar trend was observed in Ethiopia with the organic carbon being higher in the wet than the drier site (Fig. 5b)

A) B)

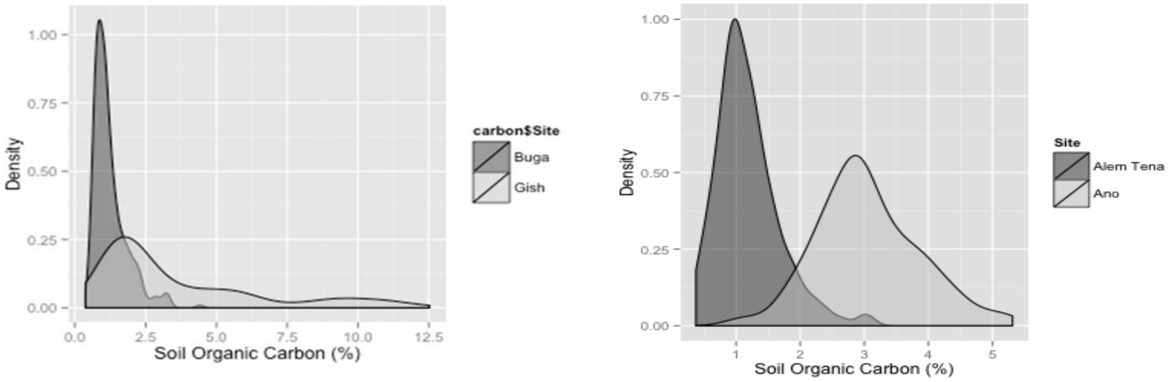


Figure 5: The spatial distribution of soil carbon in a) Rwanda sentinel sites and b) Ethiopia sites

Tree diversity studies

In Ethiopia the study showed a higher tree diversity in the sub humid site- in Ano (46) than in the semiarid site-Alem Tena (28). Acacia tortillis and Croton macrostachyus have the highest relative density in Alem Tena and Ano sites respectively. Most of the species at Alem Tena are naturally grown while Ano site had some planted trees (e.g. Eucalyptus camaldulensis).The dominant species at Alem Tena are nitrogen fixing trees that can be used as fertilizer trees to improve soil health. The species accumulation curve (Fig. 6) shows that Ano site has more accumulation rate of new species over the sampled area than Alem Tena site.

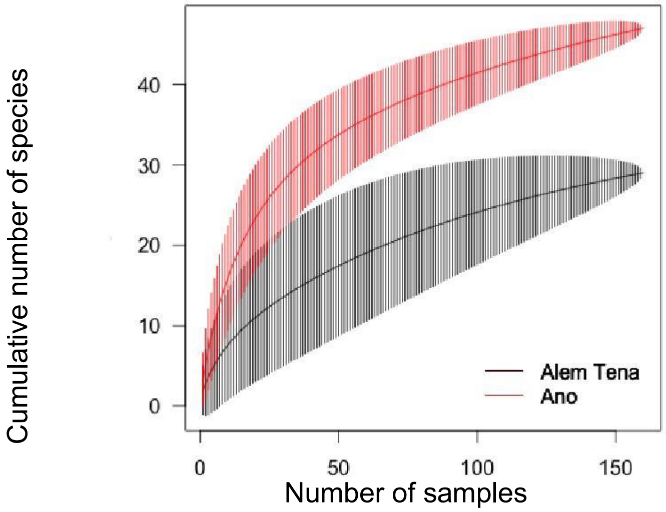


Figure 6. Species-accumulation curve for Alem Tena and Ano sites in Ethiopia

Unlike Ethiopia, a greater tree diversity was observed in the semiarid area (Bugesera) where 53 tree species were identified while 20 tree species were identified in the sub humid area (Gishwati). In Bugesera, *Euporbia tirucalli* was the most abundant (26.6%) followed by *Grevillea robusta* (15.6%) and *Eucalyptus* sp. (14.3%) (Figure 7a). In Gishwati site, the most abundant species were *Eucalyptus maidenii* (71.5%), *Yushania alpina* (9.90%), *Erythrina_abyssinica* (7.2%) and *Alnus acuminata (*5.25%) (Figure 7b).

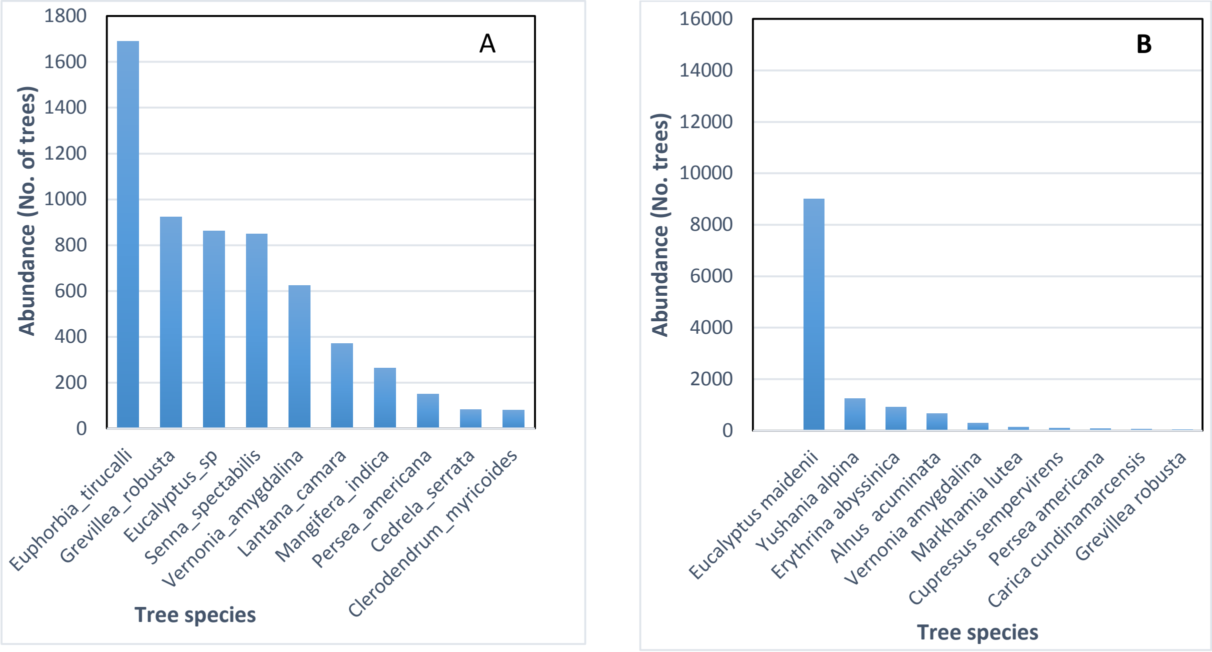


Figure 7: Top ten abundant tree species on farm in Bugesera (7a) and Gishwati (7b).

Seeds and seedlings system

A survey comprising agricultural officers, nursery workers and farmers was done in the four countries to understand the state of seeds and seedlings system and provide recommendations for scaling up best germplasm supply methods. In Ethiopia, assessment of 40 different nurseries located in four sub-humid and four semiarid sites was done (Derero et al 2016) and an interview of 169 respondents was conducted by an MSc student (Kassim, 2014). Results highlighted that high costs, insufficient government and NGO nurseries as well as lack of seed dealers are the major hindrances to farmers' tree germplasm access. The studies suggested the need to develop the germplasm management capacity of nursery operators and seed dealers in order to improve both genetic and physiological quality of seed used in seedling production.

In Rwanda results revealed that seed and seedling system in Rwanda has a top-down approach and is largely controlled by the government. Seeds are distributed by Rwanda Agricultural Board (RAB) and seedlings raised mostly through cooperatives. Most farmers lacked access to improved/ quality germplasm. The study recommended proper training and awareness creation on establishing private nurseries as well as nursery management practices (Kuria et al, 2014).

Findings in Uganda revealed that the main sources of seeds are the national seed centre, individual farms, natural forests and plantations. There are very few existing seed orchards and mother blocks thus a major setback for Uganda's seed sector. This compromises quality of seedlings established in the nurseries because nursery operators' source of planting material is greatly influenced by ease of access. Most nursery operators use any planting material easily accessible to them irrespective of quality. Only 34% of the respondents consider good quality sources while selecting planting materials. The study recommended decentralization of seed supply through establishment of more seed centres closer to the communities and supporting local communities to establish genetically diverse and quality germplasm (Buyinza et al, 2016).

In Burundi the major constraints facing organizations and nursery operators dealing with seeds and seedlings were lack of capital, nursery equipment, extension services, technical knowledge and information on nursery management and low survival of seedlings in farms, pests and diseases, high cost of labour and water scarcity (Deo, 2015). The study recommended involvement of private sector and NGOs in establishment of tree nurseries, provision of quality germplasm and capacity development on nursery management practices

Extension system

Extension methods used in Ethiopia include: model farmers demonstrations at farmer training centers and on individual farms, individual farm visits, field days and mass media (Derero et al 2016). In Rwanda methods such as lead farmers/farmer promoters, farmer field schools, demonstrations on individual farms, individual farm visits, field days and mass media and community mobilization campaigns (Mukularinda et al 2016). Methods used in Uganda include trainings, demonstration plots, model farmers, radio outreach and follow-up visits (Buyinza et al, 2016) while in Burundi extension information is disseminated through trainings, model farmers, demonstration plots and exchange visits (Kinuthia et al, 2015c). Building on the existing country-specific methods, the project establishes RRCs in the four countries to scale up agroforestry technologies. The RRCs have been effective conduits for transfer of knowledge and skills of improved technologies such as grafting. Not only have the RRCs been beneficial in disseminating skills on agroforestry related technologies but also other skills such as financial management, entrepreneurship, credit facilities among others.

Rapid market appraisal

In Rwanda, the key actors involved in the value chain are the input suppliers (which include neighbors, shops and NGOs and national nurseries), producers, middlemen and traders. No business services exist in terms of extension, credit, market information for tree products. Most products are bought by middlemen and sold in these markets. The main form of governance of the chain is spot market although there are few relationships. Demand for tree products preferred by farmers generally exceeds supply indicating availability of markets. No processing of the fruit takes place at the local level. There are no group activities in terms of production and marketing. From the study a potential opportunity for developing tree value chains was noted. The study recommended capacity building on value chain development to the communities and establishment of cooperatives to market products (to take advantage of the gross margins) as opposed to trading through the middlemen (Mukularinda et al, 2016).

In Uganda farmers sell their products through sell directly to consumers or to local middlemen who in turn sell the produce to other middlemen, shop keepers, or Bugisu Cooperative Union (BCU). Other farmers sell directly to the BCU. Market constraints such as price fluctuation discourage some farmers from engaging in value chain upgrading of their tree products, despite the potential financial rewards. The RMA study in Uganda recommended empowering farmers through groups or cooperatives to engage in value chain development as well as marketing their products directly to consumers (Okia et al, 2016a).

Timber production was most common agroforestry practice in Burundi and therefore high potential for timber value chain. Eucalyptus spp. and *Grevillea robusta* were preferred by majority of the community members. Key challenges identified include lack of quality planting materials, low demand and high taxes; small land size, government standards and regulations which was seen as unfriendly and cumbersome. The study recommended creation of befitting policies for timber production and increased tree planting activities in different niches (Nkurunziza et al, 2016).

In Ethiopia, East Shewa region, Eucalyptus, Papaya Coffee and Gesho are the most preferred species because of high demand and high market potential. There's also a lot of support for

Papaya growing from government and local NGOs in the form of supply of seed and seedling as well as extension information from local NGOs and agricultural office in the area. In west Shewa, the most preferred tree species are Khat, Coffee, mango and Eucalyptus. Khat is reported to have experienced rise in quantity marketed as a result of the increasing price and ready market (Gyau & Muthuri, 2016). There are mixed results for Mango. Whereas farmers in Ukee have experienced increase in quantity they are able to sell, farmers in Bako reported the number of trees is increasing but productivity per tree in decreasing due to diseases and termite attack. In all the areas there is no special credit facilities which is targeted towards fruit products in particular although farmers highly demand for the service. However, there are other micro finance institutions which provide general credit facilities to farmers. In most of the areas the main micro finance institution is the Oromia Credit and Savings which is often very far away from villages. The study recommended enhancing effective market information systems which will enable producers to make the right marketing decision especially on when to harvest tree products such as fruits that have a short shelf life.

1.2 Match species and management options to sites and circumstances.

Local knowledge

In East Shewa, Ethiopia, farmers were able to trace land use and tree cover change across four decades through three political regimes. Farmers identified government policies, specifically the villagilization policy and land redistribution policy which was implemented in 1967 EC (1975) and 1978EC (1986) in Jawee Bofoo and Ejersa Jorro respectively as the major drivers of land use change in the areas. Loss of tree cover from the cropland was caused by the conversion of forest areas to cultivation lands. Majority of farmers in East Shewa retained trees around their homesteads (live and dead fence) to protect homesteads from livestock; while more trees are retained in the crop fields to provide shade for livestock and retain moisture for crops. Farmers were mostly interested in planting trees for fuel, charcoal, fodder, live and dead fence and farm implements and household tools. Major constraints to adoption of agroforestry technologies heavy browsing of seedlings by free-grazing livestock, limited land, land degradation, lack of quality germplasm, limited knowledge on both tree-crop interactions as well as the ecological suitability of trees (Asantewaa, 2013; Schmidt, 2013, Kuria et al., 2014).

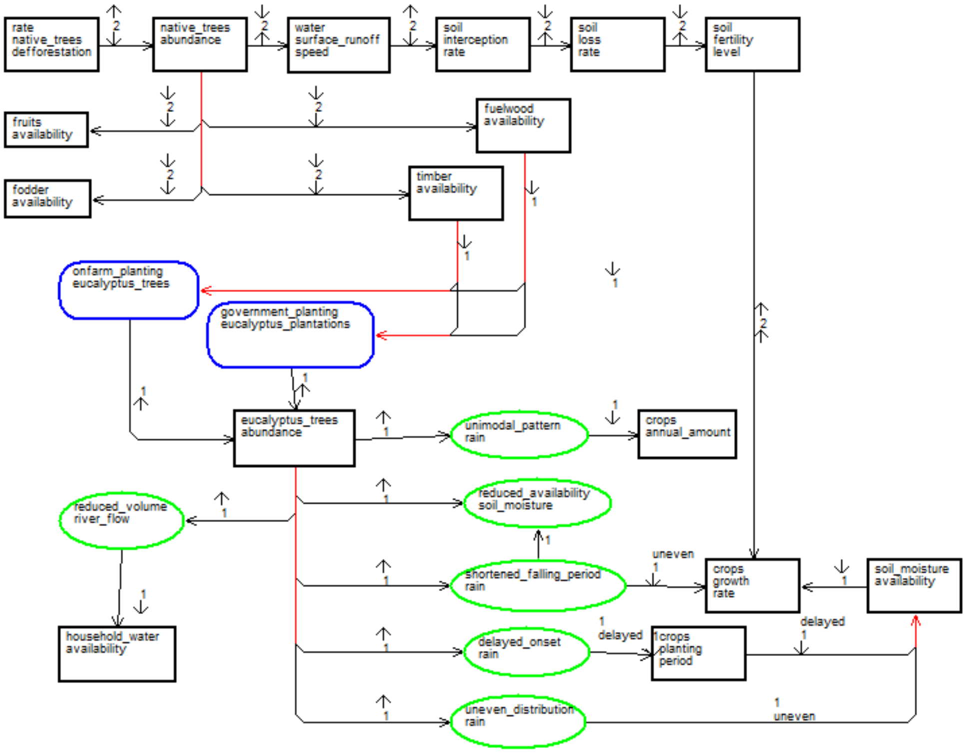


Figure 8: AKT5 Causal diagram showing the impacts of land-use and tree cover changes in the Sub-humid East Wollega area, Ethiopia (Source: Kuria, 2014)

A similar study in East Wollega (Fig. 8) on showed that tree cover change was greatly affected by changes in policy and legislation and land tenure that took place during the Derg regime between 1974 and 1991 (1967 to 1983 Ethiopian Calendar) namely the Government’s Resettlement and land redistribution Policy and the establishment of massive eucalyptus plantations aimed at providing fuel and timber products. Farmers were mostly interested in planting trees for income, fruits, soil fertility improvement, coffee shade, timber and fodder. However, the adoption of trees onfarm was challenged by free grazing livestock, land shortage, lack of suitable germplasm, labour shortage, and limited knowledge on ecological utilities of trees, tree crop interaction and tree management.

A study on local knowledge of farmers on trees and associated management in Gishwati, Rwanda was reported in Mukuralinda et al 2016a. Findings showed the main drivers of tree cover change loss was deforestation and forest encroachment to provide tree products, and land for agricultural expansion and settlement due to the increase in population (internally displaced persons and refugees) after the 1994/1995 Rwandan genocide. The study revealed low onfarm tree diversity and inadequate supply of germplasm for suitable tree species. Agricultural issues that farmers reported as being priority issues that trees could help ameliorate in Gishwati were: fruits for household consumption and income, soil fertility improvement, climbing bean support poles, soil erosion control, fodder and firewood. Factors limiting tree adoption included: limited land, lack of adequate and suitable tree propagative materials due to the top-down nature of seed and seedling sourcing system, and limited knowledge of tree utilities, tree crop interactions and ecological suitability of tree species. , A local knowledge study conducted in Bugesera, Rwanda showed that the niches with the widest range of species were fields, field boundaries and lakeshores. However, the diversity of species retained or planted on crop fields was found to be low and mainly confined to propagated exotics. Farmer preference for trees lied mostly in fruit and timber trees which provided them with marketable products. A demand/gap was however identified in tree species that provided fodder and soil fertility improvement. However farmers lack clear training on the management of leguminous trees including the transfer biomass to the soil and therefore failed to see any impacts from them. Similar to Gishwati, the top-down seed and seedling sourcing system constraint led to farmers not being interested in planting trees species whose selection they felt was dictated to them and not what they would actually wish to plant. Other challenges encountered included drought and insect attacks (especially termites) that destroyed young tree seedlings. Although farmers had detailed knowledge about a diverse set of trees, in practice, they concentrated on few species to secure the supply of high value products, regulating and cultural ecosystem services namely the home compound, along boundaries, soil conservation structures and woodlots. The study therefore helped identify gaps in knowledge that were limiting the adoption of agroforestry such as: limited knowledge on tree management, ecological functions of trees, and ecological suitability as well as address them as evidenced by for example establishment of RRCs and participatory trials (Mukularinda et al, 2016e)

A local knowledge study in Manafwa District, Eastern Uganda that explored the knowledge of local people on tree management and tree-crop-livestock interactions and examined the link between farmers‟ knowledge and their decision-making on planting and/or retaining certain tree species on their land. The study showed that farmers had extensive knowledge of native than exotic tree species in terms of their ecosystem services and agro-ecological interactions within the farm. However there appeared to be limited knowledge on propagation and management of these species. Most native seedlings were naturally regenerating and either being retained where they grew or were being transplanted by farmers from one farm to another. These findings demonstrated the need to train communities on propagation and management of native species to avoid loss of diversity and enhance resilience of the system (Tam L., 2015).

A local knowledge study conducted in Burundi (Muruta commune, Kayanza Province) showed that farmers traced changes in land use and tree cover over 5 decades, mainly attributed to government policy, population increase and the effects of the 1993-2005 civil war which led to deforestation resulting from increased demand for fuel and charcoal and the lack of stringent implementation of laws against deforestation. Tree cover was low and was continually decreasing due to high exploitation of trees to provide firewood, stakes for climbing beans and timber, population increase and land fragmentation, lack of quality germplasm. Tree planting was limited by small land sizes, lack of proper nursery management and skills on tree propagation and management among farmers as evidenced by the collapse of tree nurseries as soon as external (mostly non-governmental organizations) assistance is withdrawn and theft of tree propagative germplasm,. (Njenga et al, 2015. The study recommended establishment of tree nurseries of multipurpose and fast growing tree species, training and empowering farmers to establish private tree nurseries, training on improved techniques such as grafting to enable farmers grow improved fruit trees for provision of income (Njenga et al, 2015).

VECEA map

The Burundi vegetation map has been fully integrated into the vegetationmap4africa and its species selection and distribution tools made available from URL www.vegetationmap4africa.org (web-based maps are available from: http://www.vegetationmap4africa.org/Vegetation_map/Webmaps.html).

The vegetationmap4africa clearly shows the similarity between Rwanda and Burundi in distribution of potential natural vegetation types (these can be interpreted as agro-ecological zones) critical for scaling out purposes (Appendix 2).

Spatially Explicit Analysis

Spatially explicit analysis for improved targeting of interventions was also made, including identification of erosion hotspot mapping across action sites by combining the baseline information. For example, soil erosion is a key indicator of land degradation. In the field, soil erosion was assessed at 640 subplots per LDSF site. These field data were integrated into the land health database hosted at the ICRAF GeoScience Lab in order to create predicted surfaces of soil erosion prevalence (See report by Winowiecki and Vågen, 2016).

Erosion hotspot mapping for Ethiopia showed prevalence of erosion the Melkassa site in compared to the western sites near Bako. These erosion estimates allowed for spatially explicit targeting of soil water conservation interventions across the region.

Analyses for tree density done in Rwanda showed that households in the semiarid zones had higher PCA diversity scores for trees used for fuel, fruit and timber. Similar patterns were displayed in Ethiopia for the tree species used for farmer managed natural regeneration (FMNR).

1.3 Target and prioritize sites and farmer circumstances

A framework for landscape level policy dialogues was developed and implemented with partners in Ethiopia and Rwanda. In Ethiopia, seven core policy issues were prioritized at the Woreda level). In Ethiopia 25 constraints were raised at the Woreda level, but were reduced to seven key issues at the national level. These include: free grazing management; water stress; Land certification and tenure systems; farmer managed Natural Regeneration; tree selection/ knowledge awareness; pest and diseases; and market access for indigenous tree species.

In Rwanda, 17 constrains were identified at the district level and prioritized into seven main barriers at the national level. These were; land fragmentation; land consolidation policies where farmers are not allowed to plant what they want to; not all farmers are reached by current extension systems; not enough tree nurseries to provide seedlings; lack of specific extension packages for agroforestry; low education levels among farmers; poverty which limits purchase of inputs. This information provided the frameworks for prioritizing landscapes and farming systems for agroforestry interventions (Otiende et al, 2014 and Muller et al, 2014).

Work package 2; *To generalise predictions of impacts of trees species and management at field, farm and landscape scales, on crop productivity, water and nutrients to inform scaling up to improve food security and reduce climate risk.*

2.1 Extensive participatory and quantitative assessment of the performance of tree species and management options used in scaling up

The participatory trials were kicked off with workshops in Adama, Ethiopia (April 2013) and Musanze, Rwanda (October 2013) and Uganda in May 2014 (Barrios and Coe, 2013a & b and 2014). During these workshops, principles and examples of participatory research design were presented to a total of 67 researchers, extension agents and farmer representatives from Ethiopia and Rwanda. Concrete plans for participatory trials were developed during and after the workshops and implemented in the fields. The design, types of trials and results from these trials are contained in the country reports. Currently there are 3649, 2557 and 588 involved in participatory trials and associated tree planting activities in Ethiopia, Rwanda and Uganda respectively with 2300 farmers receiving various tree seedlings in Burundi, refer to the scaling up strategy at (Muthuri et al 2016b).

The trials in Ethiopia included comparing tree species performances under different planting niches, some assisted with soil moisture retention structures and composting and manuring.

The mean survival of different tree species under different land use categories and sites showed large differences between species and niche. Generally, there occurred a massive death of tree seedlings. The overall survival of *Mangifera indica* declined from 50.7% in year I to 13% in year II, *Persea americana* from 70% to 18%, *Grevillea robusta* from 73.6 to 65%, *Cordia africana* from 45.2 and 8% and that of *Moringa stenopetala* from 13.2 to 10%. The data in three sub-humid sites at 30-months showed that there are 353 trees in homestead areas, 391 in crop-lands, 552 in boundaries and 128 in soil bunds. Of these trees, *Grevillea robusta* constituted 63.8% and the remaining ten species constituted 36.2%.

For a given tree species, seedling survival is apparently a function of many things including the seedling vigour, resources the plants get for growth, physical damages from browsing and trampling, and age. Our results indicated decline of seedling survival through time (six month, one year and two-years). However, the seedling survival exhibited large differences between species and niche. This means that species have different responses to the different stresses they face. Despite all the confounding factors, results may be indicative of the most appropriate tree species for the agroecologies under consideration in assuring success in tree plantations.

Results on growth showed that significant differences among species and planting niches in the three sub-humid sites. The overall growth performance of the species in the sub-humid sites showed that two of the species, *Moringa stenopetala* and *Sesbania sesban* attained the highest growth (Figure 9).

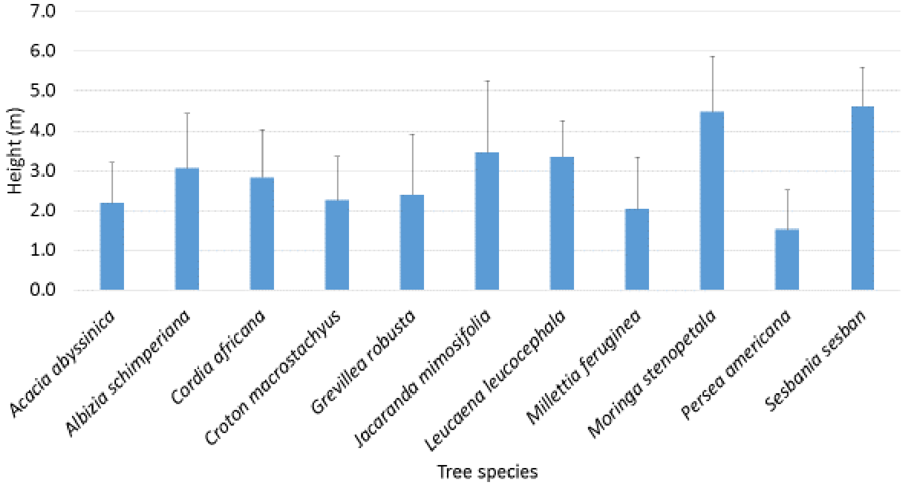


Figure 9. Average height of tree seedlings planted in three sub-humid sites at the age of 30 months

In Rwanda, the participatory trials consist of two experiments on i) stakes production for climbing beans in Bahimba sector, Rubavu district. (Gishwati) and ii) soil fertility amendment through biomass incorporation experiments. Findings from the stakes trials indicate that Acacia *angustissima* grown faster (4.2 m) than Alnus *acuminata* (3.2 m), Vernonia *amygdalina* (1.8 m) and Alnus nepalensis (1.5 m) after 12 months of planting for Season 2016 A. Acacia *angustissima* is also preferred by farmers as stakes for beans since its longer and stronger (its resistance to beans weight and wind) with only 1.4% of stakes from A. *angustissima* being broken after use in one season compared 56.2% of stakes from *Pennisetum purpureum.* From the biomass incorporation experiments results from Gishwati showed that after 2 seasons (2015 A&B), treatments of a combination of *A. acuminata* green manure of and mineral fertilizers (DAP+urea), mineral fertilizers (DAP +urea) alone and green manure alone treatments increased climbing beans yields by 115% and 48% and 54% respectively compared to the farmer practices. Equally the combination of organic and inorganic fertilizers increased potatoes production by 96.6% after 3 seasons compared to farmer practice. In Bugesera the participatory trials compared different options such as farmer practices, green manure from various species, mineral fertilizers (DAP+ urea) and the combination of organic + inorganic fertilizers in two sites, Juru and Rweru. In Rweru, that combination of green manure from *Calliandra calothyrsus*, *Gliricidia sepium*, *Leucena diversiflia*, *Vernonia amygdalina* and mineral fertilizers resulted in maize grain yield of between 5.9 to 6.9 t ha^{-1} (the highest being from *G. sepium* mineral fertilizer combination) compared to the farmer practices (Farmyard manure) where grain maize yield ranged from 3.1 to 3..9 t ha^{-1} . The same trend was observed in Juru, but the yields were lower 2.9 to 3.9 t ha$^{-1.}$

In Uganda trials were established to address challenges specific to communities along landscape categories. The lowland areas are concerned with river bank stabilization using trees, the midland is involved with tree species diversity and the upland areas are looking at measures to control soil erosion using appropriate tree hedgerows, and grass bands. The response variables being measured from these trials include seedling survival collar diameter, seedling height and number of branches (Buyinza et al., 2016).

2.2 Conduct controlled experiments and develop simulation models of tree and crop yield across biophysical gradients

Long term trials

Good progress has been made in the long-term experiment and modelling component of the project. Two long-term trials were established in semi- arid and humid areas respectively namely Karama and Karago RAB stations in Rwanda and in Melkassa and Bako in Ethiopia. Details on these trials and the data collected so far are provided in Rwanda and Ethiopia country reports and student's reports available in the website.

Ethiopia

At Bako, four tree species (*Acacia abyssinica*, *Cordia africana, Croton macrostachyus* and *Grevillea* robusta) are planted in RCBD design in three replications with a plot size of 64 plants planted at 5 m spacing. The treatments are four tree species planted as pure, one treatment planted as a mix of all the four, and finally one treatment is a control (crop alone). As of July 2016, 36-months after planting (season V), *G. robusta* and *C. africana* have attained mean heights of over 140 cm whereas the other two are between 80-120 cm. There was no significant difference in plant height of pure trees. However, trees in mixture had significantly tallest plants compared to *Moringa stenopetala* during season I. During season 2, *Cordia africana* produced significantly tallest plant (65.82 cm) followed by *Grevillea robusta* (50.31 cm) which was not significantly different from *Acacia abyssinica* (49.50 cm) and mixtures (47.07cm). Hence *Croton* is a year younger both in pure stand and mixture, the shortest plant height recorded for this seedling during season II is incomparable with others. *Cordia africana and Grevillea robusta* showed fastest growth whereas plant height for *Croton macrostachyus and Acacia abyssinica* remained below 100 cm during season IV (Figure 10).

At Bishola, Melkassa, four tree species (*Acacia tortilis, Cordia africana, Faidherbia albida and Moringa stenopetala*) are planted in RCBD design in four replication with a plot size of 64 plants planted at 5 m spacing. Based on the 36 months data, *Acacia tortilis* is apparently the best performing species in the area while *Faidherbia albida* happens to be the slowest of all (Figure 11).

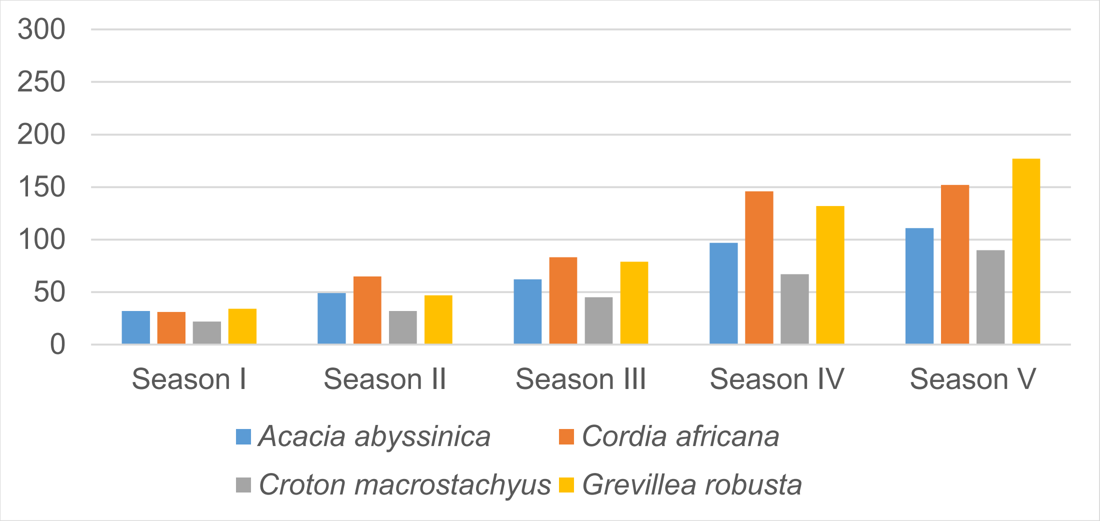


Figure 10. Mean Height of different tree species planted in Bako long term trial site

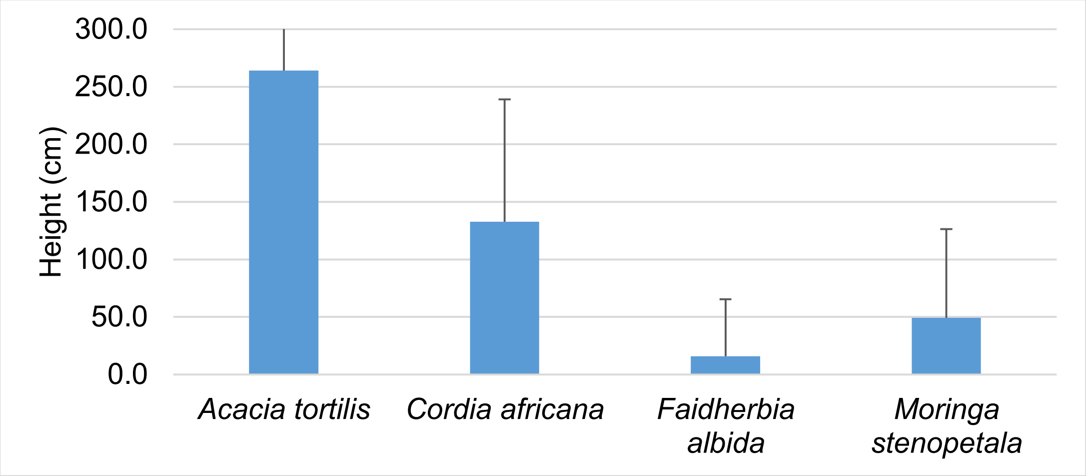


Figure 11 Mean height of four tree species 36 months after establishment of the trial

Rwanda

In Bugesera district, the long term trial was conducted in Karama RAB research station in semi-arid conditions. The tree species tested are *Grevillea robusta*, *Faidherbia albida*, *Markhamia lutea* planted alone, their combination and maize planted alone. The results showed that height of *F. albida* varied from 3.2 m when planted alone to 1 m when mixed with *G. robusta* while the mixed *F. albida* + *M. lutea* indicates intermediary result (2 m of height). The diameter of *F. albida* showed the similar trend as the height for different treatments. The height of *G. robusta* was 3.5 m planted alone and 3.0 m when mixed with *M. lutea* and 2.9 m when it is mixed with *F. albida*. The diameter followed the trend as the height. *M. lutea* showed lower height but followed the same trend for both height and diameter like *G. robusta* and *F. albida*.

The figure 12 gave more details on growth (diameter and height) after two of years of plantation (2014 -2016 years). On these curves some stagnation in growth were observed due to the drought. More details are available in Mukularinda et al. (2016).

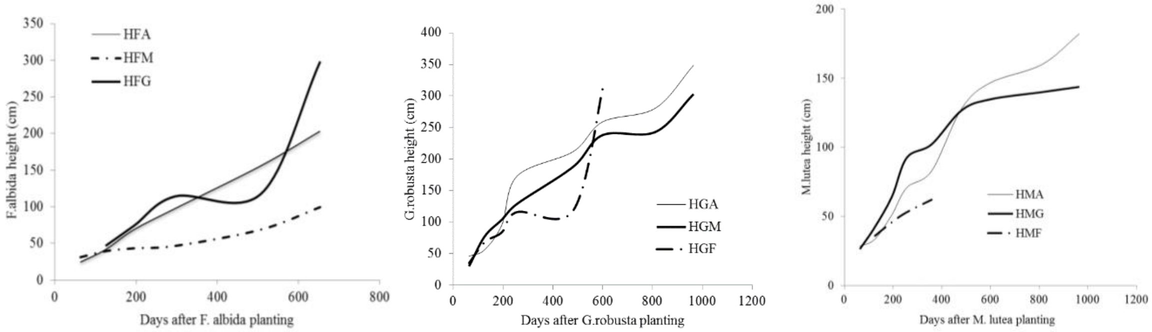


Figure 12: Tree height (cm) *G. robusta*, *F. albida* and *M. lutea* at Karama RAB research station Rwanda 2 years after planting (2014 to 2016)

At the humid Tamara station, result findings showed that after two years of planting (2014 to 2016), A*lnus acuminata* planted alone achieved higher height (5.9 m) than when combined with *Croton megalocarpus* (4.9 m) while *C. megalocarpus* planted alone (1.50 m) and *C. megalocarpus combined with A. acuminata (1.20 m) showed* slow growth. Trees planted alone grow faster than when they are combined (Figure 13a and b). On the other hand, *C. megalocarpus* intercropped with maize showed higher maize grain yields (4.5 t ha^{-1}) than *A. acuminata*, maize planted alone and combination of croton + *A. acuminata* treatment. The treatments where maize was intercropped with *A. acuminata* showed lower maize grain yield (2.8 t ha^{-1}) implying that *C. megalocarpus* intercropped with maize increased maize grain yields by 40.6% while *A. acuminata* treatment intercropped with maize reduced maize grain yield by 12.5%

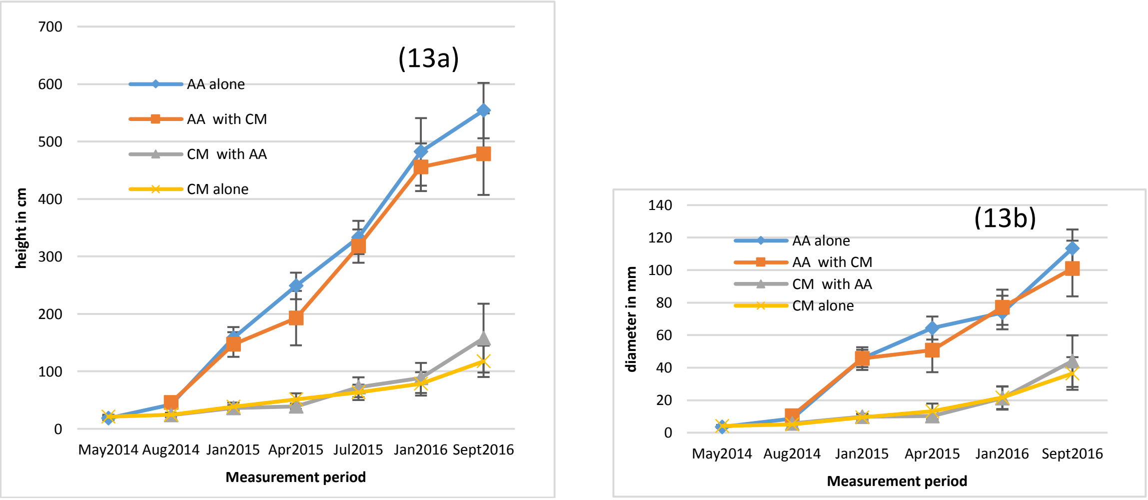


Figure 13. A. acuminata (AA) and C. megalocarpus (CM) growth after 28 months of planting at Tamira station in Rubavu District, Rwanda (3a) Height and (3b) Diameter.

b) Tree crop interactions experiments

Tree crop interactions (water, light, temperature, nutrients) on-farm controlled experiments were set up by ICRAF and CIMMYT in Ethiopia and Rwanda. This includes pruning treatments for *Faidherbia albida* and *Grevillea robusta* by ICRAF and experiments set up by CIMMYT which include *Cordia africana* and *Alnus acuminata* but without tree pruning treatments.

Rwanda

The detailed tree crop water interactions measurements with six setup on *G.robusta* mature trees reported daily sap flow volumes ranging from 7- 34 l day^{-1} compared to 70- 88 l day^{-1} for unpruned l 2014. For season 2015 A, the average daily sap volume was 47.5 l day^{-1} and 12.0 l day^{-1} for unpruned and pruned trees respectively while in season 2015 B, unpruned trees showed average daily sap volumes of 62.6 l day^{-1} and 21.8 l day^{-1} for pruned trees. In season 2016 A, average daily sap volumes was 61.3 l day^{-1} for unpruned tree and 26.1 l day^{-1} for pruned *G. robusta*. During the season 2016 B, average daily sap volume was 76.4 l day^{-1} for unpruned and 23.4 l day^{-1} for pruned trees. Higher sap flows were registered during the dry season compared to the wet season.

Monthly sap volumes are presented in figure 14 below. The Sap volumes are generally lower during the wet season compared to the dry season. In the wet season these volumes are 1,726.5 liters and 517.5 liters for the unpruned and pruned trees respectively while in the dry season the monthly sap volume were 3,425.8 litres for unpruned compared to 1,057.8 litres in pruned *G. robusta* trees.

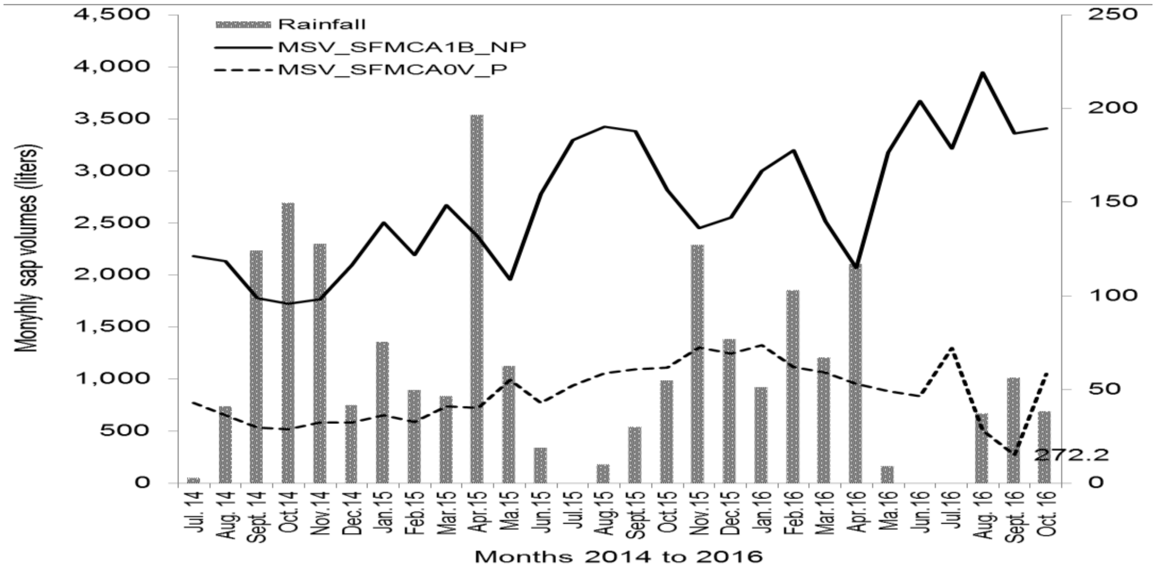


Figure 14: Mean monthly sap volumes in pruned (P) and unpruned (NP) G. robusta trees between July 2014 and October 2016 in Bugesera Rwanda

The average maize grain yield was recorded across 12 farms under pruned and unpruned grevillea. It showed higher maize grain yield (4.7 t ha^{-1}) under grevillea pruned than unpruned (2.8 t ha^{-1}). Grevillea pruned increased maize grain yield under canopy by 70%. Yields on the maize alone control was 4.9 t ha^{-1}

Similar observations were made in *F. albida* wheat systems in Modjo Ethiopia where pruning of *F. albida* canopy reduced water uptake (sap volumes) but performance of the wheat under unpruned trees were higher than under prunned (Assefa et al. 2016). This therefore means that retaining *F. Albida* canopy will be best for wheat productivity in the area and more farmers should be encouraged to do so particularly in phase 2.

In addition similar experiments by CIMMYT by without pruning treatment concluded that scattered *F. albida* appeared to improve wheat productivity by improving the quality of soil organic matter (higher mineralization). The buffering effect of wheat against extreme temperature and radiation was clearer. With heat and moisture stress (due to climate change) likely to be more frequent in the future, *F. albida* could be a starting point in designing more resilient farming systems reducing the impact of climate variability the yields of wheat under Faidherbia albida were shown to be significantly higher than away (Baudron et al. 2016).

More details of the findings from these studies can be found in (Mukularinda et al, 2016, Derero et al. 2016 and Baudron et al 2016) Training on instrumentation was also carried out including sap flow training and installation in the recently established experiments in Uganda for *Cordia africana* and *Albizia coriaria* (see Buyinza et al, 2016). Manuscripts are being drafted for submission later this year. Data collection for experiments on G×E×M set up by CIMMYT in Rwanda and Ethiopia in 2014 are ongoing (see Baudron et al 2016). Therefore the on-farm experiments have developed a rich data set that can explain to some extent tree-crop interactions across the study regions as well as for modeling purposes.

Modelling work under work package 2 started with a workshop in Addis Ababa from 2nd to 5th October 2012. Good agreement was reached on a strategy for further activities (see workshop report) and a modelling strategy report was prepared by CSIRO, together with ICRAF. To accommodate a two-dimensional agroforestry model, a new version of APSIM was developed called Next Generation, which is more modern and faster than previous versions of APSIM. The two main crop models needed for this project, wheat and maize, have been released already for public use in APSIM Next Generation. Also the oil palm and a simple pasture model are included (https://www.apsim.info/). The teff and potato models needed for Ethiopia and Rwanda respectively are under development. A pre-release version of the agroforestry model has been developed and available for use only within the project (Smethurst et al, 2016). More training workshops on use of APSIM in Rwanda and Ethiopia were done using secondary data and also data from different experimental site. Further, tree-crop simulations that include several validations and applications of the model are expected to continue leading into thesis chapters and publications during the course of year 2016 and beyond. Already a brochure has been produced that explains model developments and results of observed and predicted outputs presented. Two publications on model evaluating model's capability to simulate tree-crop interactions in Africa and Australia (Makoka, Malawi –Fig. 15, Machakos, Kenya and Warra, Australia (Fig 16)) are in review. Progress has been made to date with regards to developments of including a dynamic tree (gliricidia) in the agroforestry model. The gliricidia model is being based initially on data from Hawaii, Malawi, Zambia and Guadeloupe.

Examples of Simulations Using the Tree Proxy Model

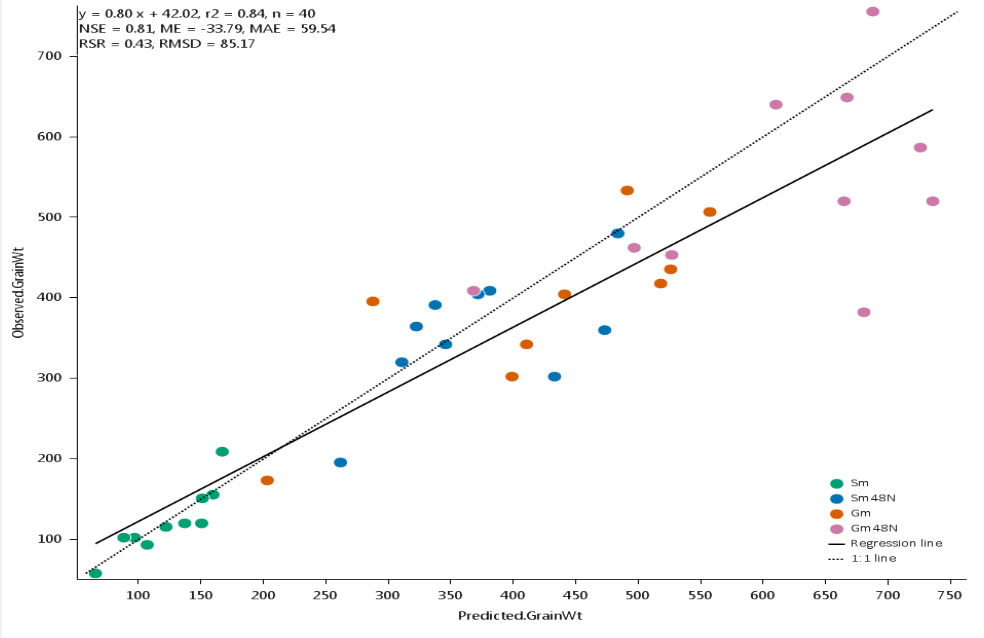
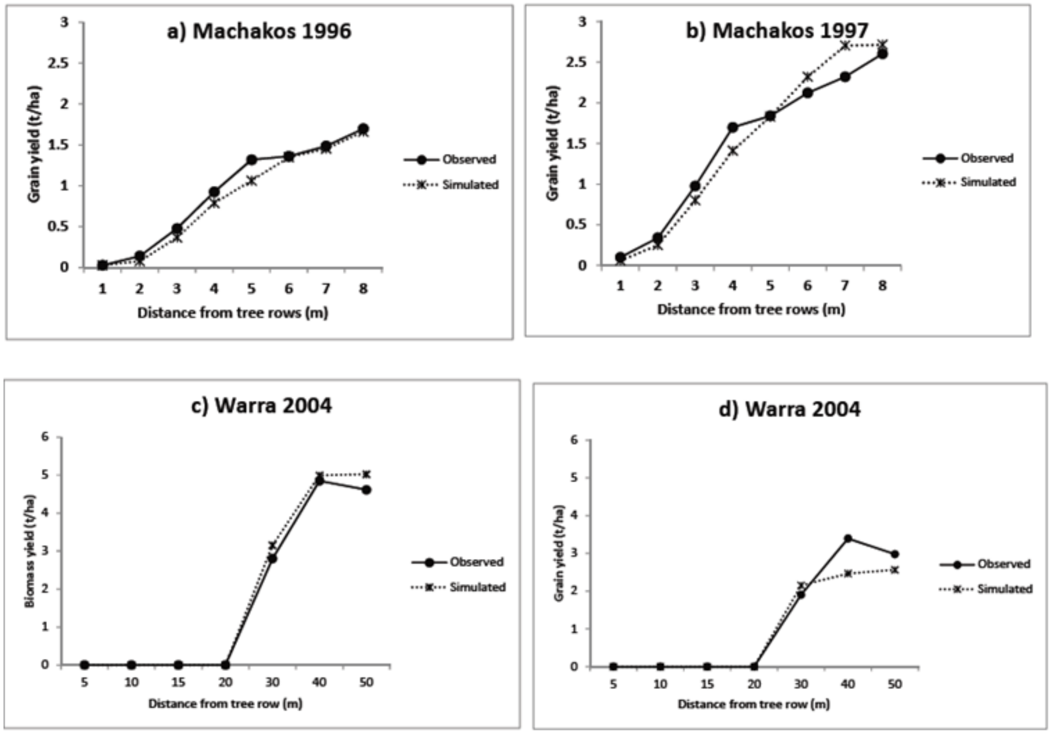


Figure 15: Predicted vs observed annual grain yield for each of 10 years at Makoka, Malawi, using the tree proxy. Treatments are Sm = sole maize, 48N = 48 kg N/ha applied at sowing, Gm = Gliricidia-maize with prunings applied 3-monthly.



*FI*gure 16: Observed and simulated maize grain yield in relation to distance from Grevillea during 1996 and 1997 at Machakos, Kenya and 2004 in Warra, Australia

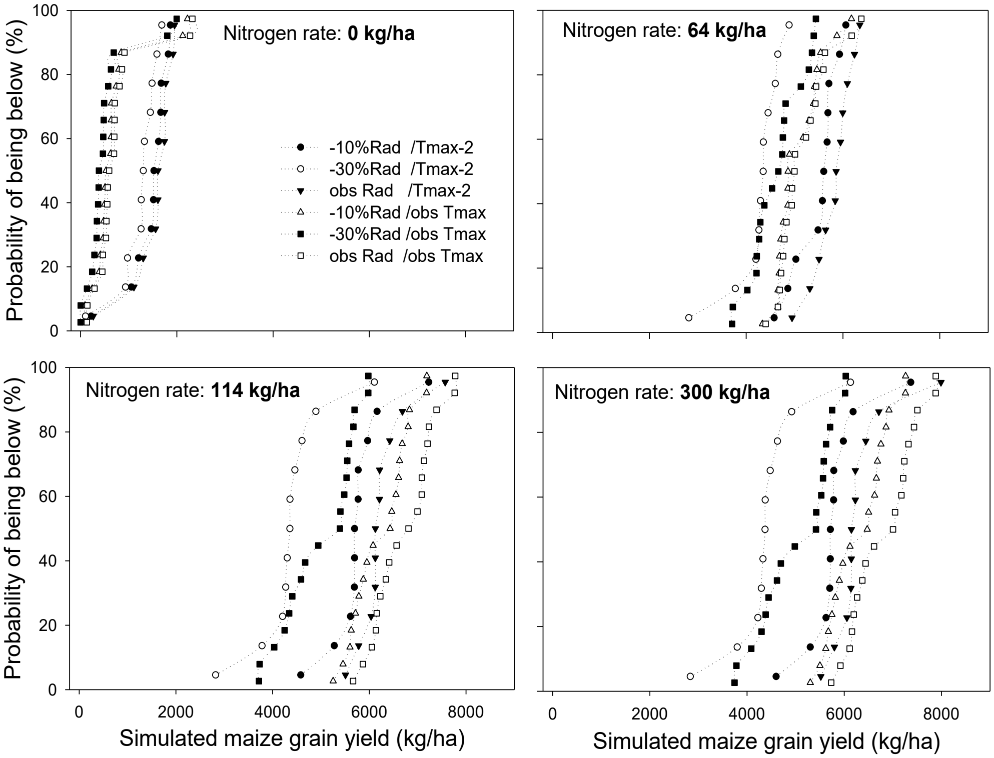


Figure 17: Sensitivity of maize grain yield to reduced and observed solar radiation, reduced and observed maximum temperature, and different rates of nitrogen fertilization. Radiation reduced by 10% (-10%Rad), by 30% (-30%Rad) and observed (obs Rad). Maximum temperature reduced by 2ºC (Tmax-2) and observed (obs Tmax) during simulation period (2005-2016), under Nitrogen rates of 0 kg ha^{-1}, 64kg ha^{-1}, 114kg ha^{-1}, and 300kg ha^{-1}.

Water management scoping was done in Ethiopia in October 2015. Prospecting of wells and installation started in December and most of the installations are in place (Details are provided in report by Murithi *et al*. 2016, Maimbo et al 2016). The activity resulted in greater appreciation for rainwater harvesting amongst government officials, technicians, artisans and the beneficiaries. At the government nursery, improvements in the water supply system have resulted in time saving, efficient and reliable water distribution. The tree seedling production capacity has been increased. At the community level, the quantity and quality of water has been increased thereby allowing farmers to irrigate their trees and crops. This development has resulted in improved tree survival rates.

2.3 Understand and model farmer decisions about adoption, adaptation and management of agroforestry practices and their impact on livelihoods

A database has been prepared based on results from the baseline surveys. The database contains all data from the socio-economic baseline, soil survey and local knowledge collection and is continually updated as more data is gathered. The data is accessible at http://thedata.harvard.edu/dvn/dv/icraf Reports from survey activities have been prepared, (see also reports and thesis under WP1 in the deliverable table and participatory trial under 2.1). Further, 3 PhD publications are still in preparation namely focusing on: 1. prioritizing local indicators of soil quality along a land degradation gradient and implications for land restoration in Rwanda; 2. Local knowledge on drivers influencing food sourcing distances by smallholder farmers along a land degradation gradient in Gishwati, Rwanda and 3. Applying farmers' knowledge to map the fluidity of ecosystem service flow boundaries and distance along a land degradation gradient in Rwanda. Through understanding the current local context, these research findings will go a long way into helping to understand the factors that influence farmers' actions, especially with regards to adoption, pseudo-adoption or lack of adoption of various agroforestry practices.

Work package 3. *To develop effective methods and enabling environments for scaling up and out adoption of trees on farms*

3.1 Develop efficient tree germplasm supply systems

Seed/seedlings surveys of key informants, national stakeholder workshops and surveys of nurseries were undertaken to understand the strengths and weaknesses of germplasm supply systems in Ethiopia, Rwanda, Uganda and Burundi. In Ethiopia, high cost of seeds from dealers and lack of dealers close to the woredas are major hindrances to tree germplasm access. In addition, the free grazing culture leads to destruction of the planted tree seedlings resulting in low tree survival rate. In Rwanda, technical capacity of nursery operators in seedling production was found limited. Seedling business was limited with little number of customers due to subsidies from government and free distribution of seedling by NGOS and projects. In Uganda, access to quality germplasm is a major challenge. To ensure access to quality germplasm, the project in collaboration with local partners has established RRCs in Ethiopia-2, Rwanda-2 and Uganda-1. They offer demonstrations on agroforestry technologies, inputs and services to meet farmer's needs (e.g. tree propagation i.e. grafting /budding, seed pre-treatment and establishment techniques). For example, in 2016, 247 farmers, 42 extension staff, 20 NGOs, 15 administrators and 215 schools had visited the Batu Rural Resource Centre in ZIway, Ethiopia.

3.2 Identify, test and promote effective extension methods for reaching farmers in different contexts

The most common methods of extension used in all the four countries are individual and group extension, the use of model/champion farmers, training, individual farm visits, field days and the use of demonstration plot. In Rwanda, the government has adopted a pluralistic model of extension where there are many providers of extension that include: farmer organizations, civil society, NGOs, churches, private sector , institutions of learning and financial institutions . The government also builds on existing initiatives such as Imihigo, Ubudehe, Integrated Development Program, Girinka, Agasozi Ndatwa, Umuganda and other related initiatives that emerge and prove to be effective or contribute to sustainable agricultural development. In Ethiopia, extension agents both group and individual methods in communicating new ideas to farmers. The specific methods used to introduce new technologies/practices include: arranging public meetings at a specified day and time through local leaders (religious leaders, leaders of local organizations & elders); through model farmers, contacting farmers individually and through Peasant Association officials. As there is a shortage of extension professionals in the country, extension agents prefer to introduce new technologies/practices through community leaders (peasant association officials and local leaders) and by arranging public meetings. In Uganda , the main extension methods include trainings (individual and group), demonstration., model farmers, radio outreach and follow up visits which are constrained by poor transport facilitation and understaffing. The Trees for Food Security project has built on the existing extension structures in the four countries to scale up agroforestry to farmers.

3.3 Engage stakeholders to create appropriate enabling environments for adoption of farm trees for food security

Market surveys were undertaken in Rwanda, Uganda and Ethiopia to identify bottlenecks and market opportunities in the agroforestry products' value chain that require interventions to enhance adoption. In the three countries, most crops/tree products are sold to middlemen, who play a fundamental role with the exception of coffee in Uganda. Another challenge is inadequate extension services on preferred crops/tree products. Due to political turmoil in Burundi, marketing study was delayed but data collection has been completed and the report and thesis finalized. Barriers to adoption include the free grazing system (Ethiopia), water stress, unavailability of quality germplasm, limited species diversity among other barriers. Barriers to adoption are being addressed through engaging farmers in agroforestry research groups to formulate by-laws that will help protect the trees from grazing by livestock, establishment of different types of water and soil conservation structures, diversification of tree species, soil conservation structures, promotion of fertilizer trees, training and setting up of RRCs by the project to enable farmers access quality germplasm.

3.4 Establish effective project communications

The project has developed various communication materials such as policy briefs, brochures and propagation protocols of various species. The project website http://www.worldagroforestry.org/project/trees-food-security-improving-sustainable-productivity-farming-systems-and-enhanced is also another area where communication of project activities are posted.

Work package 4. ***To develop databases and tools for monitoring and evaluation of the impact of scaling up and out the adoption of trees on farms.***

4.1 Engage partners to undertake preliminary planning of the project using appropriate tools and methodologies

Project partners and stakeholders were consulted during the inception workshops and subsequent meetings on designing and implementing an appropriate M&E strategy for the project. Based on these discussions, a series of draft indicators were developed, and feedback was solicited on their relevance and applicability. Appropriate research questions were also identified for the various work packages, balancing the need between data and information requirements, and the ease of answering those questions.

In March and April 2014, meetings were held in Ethiopia and Rwanda with relevant stakeholders from the respective countries, where a number of topics regarding Monitoring and Evaluation of the project were discussed. Included in the discussions were the indicators developed for all the project deliverables, allocation of responsibilities for tracking of each individual indicator, and reporting timeliness for the indicators. Also discussed were the key evaluations questions for the overall project, as well as country specific evaluation questions that revolve around key issues being faced by the project in the respective countries.

4.2 Develop a robust M&E strategy

In addition to the performance indicators, an overall M&E strategy / plan was developed and circulated for comments from the work packages, partners and ACIAR. A revised final version of the M&E strategy, incorporating all comments and changes, was prepared in the end of 2013, and sent to all work package leaders. The M&E strategy consists of data collection cycles, reporting mechanisms, and will provide the guide for future outcome and impact monitoring. In addition, key evaluation questions were identified for further investigation by the project team and external evaluators. An inventory of tools and methodologies modified or created for the project was also conducted in the respective countries that would help in relation to the final analysis of project outcomes and impacts. An M&E Plan for AIFSRC was also developed and the key project indicators under specific development outcomes agreed upon (Mohan et al. 2015). This was then periodically updated as per the agreed upon targets, the updated version at the end of the project is reflected in Muthuri et al, 2017.

4.3 Conduct regular performance data collection and periodic evaluations

Based on the indicators developed during the project design and in the M&E strategy, work packages have been regularly reporting on their progress. Final collation of all the data at the end of the project is also planned. Proceedings of the M&E meetings in Ethiopia and Rwanda were recorded and submitted (Mohan, 2014). Amongst the feedback received from the two countries were the (then) gaps and barriers that the country teams were facing in implementing and tracking the project. They were encouraged to fine-tune project activities and strategies to address as many of these gaps and barriers as possible. This was subsequently done in the months following the submission of the M&E meeting proceedings. From the list of evaluation questions from the M&E strategy, 4 key questions were identified, from different work packages, and short statements on these questions were finalized. Tracking / updating of the key indicators as per the M&E Plan for AIFSRC under each specific development outcomes agreed upon were carried out (Muthuri et al. 2017). More extensive evaluation studies will continue in phase two building on the framework of phase 1.

Work package 5: *To enhance capacity and connectivity of national partner institutions in developing and promoting locally appropriate options for adoption of farm trees*

Capacity strengthening was embedded in all the other work package activities. Capacity strengthening of researchers from educational institutions, research institution, farmers and extension workers was strengthened through the baseline survey enumerators training (14 in Ethiopia and 14 in Rwanda), modelling, participatory trials and design workshops (27) as well as the local knowledge training (14). Another 30 participants were trained during the participatory trials design workshop in Rwanda. Eight (8) PhD students and 17 MSc students are currently attached to the project and are at different stages of their program.

Capacity needs assessment of governmental agricultural planning and coordinating structures, governmental extension agencies, as well as NGOs and CBOs engaged in agricultural extension was carried out in August 2013 in Musanze, Rwanda involving participants from Rwanda, Burundi, Uganda and Ethiopia. The outcome of the workshop has been reported (see Hassan, et al. 2013a & b). Besides, the application of the rapid capacity needs assessment methodology adapted for Rwandan case has been submitted as an article in Development in Practice. The national project coordinators from Ethiopia, Uganda and Burundi were also trained in the capacity needs assessment methodology intended to conduct similar exercises in their countries in 2014.

A consultancy was commissioned and completed for Ethiopia to assess the synergies and tensions in agricultural, environmental, and rural development policies as a basis for engaging in a policy dialogue with the government. The final report of the consultancy has been received by the project (Birhane, 2014). A similar consultancy was commissioned end of May 2014 for Rwanda. Policy briefs for Rwanda and Ethiopia have already been produced and are to be interpreted into local languages for distribution to all stakeholders.

8 Impacts

The project has achieved scientific, capacity and community impacts in the last four years when it has been in operation. These impacts are detailed in the respective sections. It is crucial to note that the T4FS project will have a four-year follow up project to scale impacts of trees on food security and livelihood improvement in eastern Africa- also referred to as phase 2 of the project. As much as impact from phase one has been manifested in the last four years, a greater percentage will comprise phase two's activities that will mainly build on phase one's outcomes. Therefore some of the impacts described below in 5 years include expected outcomes from implementation of phase 2 activities.

According to the M&E Plan for AIFSRC the project contributed to the development outcomes summarised in the table below (Table 2 below)

Table 2: Pillar 1 – M&E of Development Outcomes

		FSC Intermediate development Outcomes	Project-specific Indicators	Updates as at November 2016
Baseline	*B1*	*To provide baseline data to assist analysing structure of farming system and agroforestry scaling up domains for improved income and food security for indicators below*	*Baseline data collected in Ethiopia, Rwanda Burundi and Uganda to determine the baseline conditions on agroforestry adoption, food security, etc. as well as to identify factors affecting their conditions (including gender, biophysical as well as socio-economic factors) to guide the interventions*	*Baseline data is available in the ICRAF dataverse and website. This has been used to prepare reports, maps and tools to guide and target interventions on the right trees for the right place hence maximizing or optimized resource use and provision of trees products and services.* *https://dataverse.harvard.edu/dataverse/T4FS and webpage http://www.worldagroforestry.org/project/trees-food-security-improving-sustainable-productivity-farming-systems-and-enhanced.*
Program 1. Sustainable and productive farming systems	1.1	Greater access to agroforestry innovations by female and male smallholders	% of integrated tree and cropping system innovations from those tested readily available to critical target groups of 30 000 women and men farmers (increase)	As at November 2016, **30,507** people had access to some type of agroforestry interventions. The farmers involved in participatory trials and associated tree planting activities are 3649, 2557, 802 in Ethiopia, Rwanda and Uganda respectively. This represents over 20% of the farmers having the different agroforestry innovations readily available to them. In Burundi 2000 farmers received various tree seedlings with 10% being followed by the project. These integrated options include incorporation of trees in different niches and for different purposes like fruits (improved mangoes, pawpaws, avocadoes, and tree tomato (Rwanda), timber, fuelwood, erosion control and fodder, alternative sources of stakes for climbing beans.
	1.2	Higher rates of adoption of agroforestry innovations	Number of women and men farmers within and outside the target group of 30 000 who adopt integrated tree and cropping systems	**Number: 9260** Currently, there are **3635** beneficiaries who have been reached through additional activities in the project, Umuganda in Rwanda and farmer

		FSC Intermediate development Outcomes	Project-specific Indicators	Updates as at November 2016
				collective action activities in Ethiopia, and **5625** through additional RRcs in Bale and Gergera Adoption rates will continue to be monitored in the second phase 2 of the project.
Program 2 Strong and equitable economic and social systems	2.1	Enabling sale of surplus production in local, regional and international markets	% of smallholder farmers with improved knowledge and negotiation skills (in target group of 30 000 women and men farmers) to better access to markets (increase)	3**0,507** people were reached through different project interventions. Approximately 9%, 19%, 18% and 6% of the 30,000 people reached underwent trainings in Rwanda, Ethiopia, Uganda and Burundi respectively. Of these the proportion of female was a 1/3 in Uganda nearly 1/2 in Rwanda and a1/5 in both Ethiopia and Burundi. The trainings enhanced farmers knowledge on their knowledge on propagation skills like grafting, running nurseries, managing trees on theirs farms. For example, training on establishing and managing tree nurseries for business was undertaken in Uganda (Buyinza and Opolot 2016). In Ethiopia, entrepreneurship training that was done at the RRC in 31st March 2015 and details of the training manual are contained in (**Eshetu, 2016)**. The component of training on grafting of improved fruit trees and establishing of tree nurseries was a source of business for co-operatives led nurseries. (See RRC fact sheets (Mukuralinda et al 2016) and Mbale RRC (Buyinza et al 2016).
Program 3 Food Nutrition and Safety	3.2	Improved efficiency of production of food through agroforestry innovations	% change in crop yields from integrated tree and cropping systems as supported through modelling (increase)	Change in yield under *Grevillea robusta* – Yields for maize decreased by 29% – 57% (unpruned), and by 15% - 29% (pruned) Change in yield under *Faidherbia albida* – Yields for wheat increased by 23% – 43% Details: Yields depend greatly on the context of where and how the crop is grown, including the Agro Ecological Zone (AEZ), site characteristics, the tree and the crop species being intercropped, and the management practices being used. In the *Grevillea robusta* maize intercrop in Rwanda, the yields of maize were calculated to be 1.5- 2.5 kg/ ha under the tree canopy (unpruned). When the trees are pruned, maize yields under the tree increased to 2.5 to 3 kg/ha. The yields under both unpruned and

		FSC Intermediate development Outcomes	Project-specific Indicators	Updates as at November 2016
				pruned grevillea are, however, lower than the 3.5-4 kg/ha maize yield in the control, which is a significant reduction. In the case of *Faidherbia albida* wheat intercrop, yields were enhanced as per our findings in Modjo, Ethiopia. Yields ranged from 2 – 3.3 t ha^{-}under Faidherbia compared to 2.6 t ha^{-}in sole wheat. Assume that the yield increase per hectare due to the incorporation of Faidherbia is 0.7 t/ha (difference of 2.6-3.3 t/ha) ACIAR socio-economic baseline survey indicated the average land holding in semi-arid Ethiopia sites was 3.7ha/household (Iiyama et al. 2017). Assuming a farmer use the whole land to grow wheat under Faidherbia albida, a farm household will gain additional 2.6 t wheat (0.7t/ha x 3.7/ha). This could contribute to satisfying subsistence needs and to incomes through the sales, or a farmer may devote 1 ha of his/her farm to more commercial crops to diversify their livelihoods and to augment their income/asset (as the wheat yield gain from 3.7t/ha can be equivalent to the original yield from 1 ha). Assuming many households benefitted from the technologies and expecting further impacts through the scale-up, the yield improvement by integrating trees on farm can contribute to food security in the region/Ethiopia which has been subject to recurrent food insecurity risks and grain price hikes due to droughts. Furthermore, as Iiyama et al. (2017) has proven, the integration of trees on farm has brought farmers with multiple ecosystem services, including fuel, fodder, fruits and climate amelioration, which will lead to the long-run stable food supply through modifying land degradation and resource degradation problems. We will illustrate this using fertilizer tree use in Rwanda. We take the median values for yield increment by integrating trees on farm with fertilizer against control (for maize, with fertilizer) to estimate the impacts on food security. We assume that in Gishwati, the northern Rwanda, the average household land holding is less than 1 ha, say 0.6ha, fragmented into a few to several parcels, and

		FSC Intermediate development Outcomes	Project-specific Indicators	Updates as at November 2016
				farmers strategically plant multiple crops, both staple and commercial. If assuming farmers are attempting to maximize yield gains as well as incremental income gains from integrating trees with fertilizer (in terms of weight) from their plots, they may allocate more land to potatoes, as their unit yield gain is the largest among the three crops – say, 0.4 ha to potatoes, while 0.1 ha to maize and bean respectively. Assuming the exchange rate of RWF 825/USD, additional income from three crops grown in the total farm of 0.6ha is estimated at 810.30/USD. If farmers are growing these crops 2 seasons per year, annual additional income will be 1,620 USD/year, which is significant, given the per capita income of USD 1343 in USD, the integration of trees. Similarly, the analysis from Bugesera with the assumption of the average land holding of 1 ha and growing 2 crops – maize/beans indicates that the integration of trees on farm with fertilizer will bring an additional income of 849.71 USD/farm per season or 1699.43 USD/farm/year if they grow 2 seasons. Impact for all agroforestry technologies will continue to be monitored even in phase 2.
Program 4 Communications and knowledge management	4.1	Innovations in information and knowledge-delivery mechanisms for agroforestry operational in target areas	Number of women and men farmers accessing innovations through rural resource centres (RRC) and nurseries who gain agroforestry knowledge and inputs	In Ethiopia, 539 farmers have visited the RRC and another 1842 have benefited from seedlings distribution. In Uganda, 922 farmers have visited the RRC and another 588 received seedlings. In Rwanda, 1781 farmers have benefitted from the RRC. . In Ethiopia, 3682 Farmers, 82 Extension staff, 43 NGO staff, 31 Policy makers (both at national and local levels) and 1787 Youth, women, and school community (both teachers and students) benefitted from the additional RRCs established in Bale and Gergera. The proportion of women to men is approximately a 1/3 to ¼ in Uganda and Rwanda and a 1/5 in Ethiopia and Burundi.

		FSC Intermediate development Outcomes	Project-specific Indicators	Updates as at November 2016
	4.2	Better informed and supported policy development	Number of cases with policy actors in partner countries using knowledge generated by Trees for Food Security research partners to support policy development and/or implementation	**Number: 6 cases** **Details:** 2 cases in Ethiopia • Tree selection knowledge and water stress • Farmer managed Natural Regeneration 3 cases in Rwanda • Capacity building for identification of suitable tree species and benefits on farm; • Government driven incentive programs for positive tree management • In all the three countries policy makers have committed to scaling up the RRC model by upgrading the existing tree nurseries for efficient and quality seedling supply and distribution.
Program 5 Education, training and capacity building	5.1	Adequate numbers of female and male targeted small holders trained to address a range of food security issues	Number of people from target group of 30 000 female and male farmers who are trained and number of people who adopt agroforestry innovations. *Training activities can be through volunteer farmer trainers, RRCs, farm demonstrations, farmer field days, working farmer groups etc. A survey / tool designed to document all these farmers will be implemented*	**Number Trained:** **Ethiopia – 2289 (1832 457)** **Rwanda – 1000 (512 488)** **Uganda – 594 (406 188)** **Burundi – 166 (130 36)** The numbers presented above are a combination of various trainings that were imparted in the respective countries. The adoption rate will be calculated at the end of the project.

		FSC Intermediate development Outcomes	Project-specific Indicators	Updates as at November 2016
	5.2	Stronger Institutional capacity available to address food security in the long term	Number of high quality and relevant capacity building activities undertaken for supporting agroforestry schemes that strengthen organisational/institutional ability to address (food security issues) in the long term	**Number: 27** **Ethiopia – 10** **Rwanda – 8** **Uganda – 7** **Burundi - 2** **Details:** A number of students involved in the project in different countries have been supported- that will lead to changes in national level and partner organization capacity the long term Ethiopia – 6 MSc and 4 PhD students supported Rwanda – 4 MSc and 4 PhD students supported Uganda – 5 MSc and 3 PhD student supported Burundi – 2 MSc students supported

8.1 Scientific impacts – now and in 5 years

The scientific impacts of the project are significant and have been well achieved through the all the objectives in this project.

A number of young researchers in Ethiopia and Rwanda were exposed to baseline research methods, by participating in baseline design workshops (25) as well as in training as household survey enumerators (40). As a result, enumerators acquired pertinent skills in household survey hence increasing their opportunities for employment as data collection experts. Further studies provided an understanding of barriers to adoption of trees on farm and a publication of a journal article describing patterns of adoption of trees on farms in Ethiopia was produced (Iiyama et al., 2016).

Local knowledge studies provided in-depth insights about what farmers knew about their bio-physical and socio-economic environments, which in return either influenced their behaviour, practices and interactions; and/or helped in identifying gaps that required interventions in order to ensure that agroforestry interventions that were implemented were socially acceptable, locally relevant, and ecologically suitable.

The suitable tree species selection and management tool for Rwanda and Ethiopia informs on the various tree species within the study sites, their uses/ benefits/ niches and biophysical characteristics. It complements the natural vegetation maps as it provides additional information on both native and exotic species unlike the vegetation maps which only have information on Indigenous and exotic species helps as such helps improve knowledge on matching and selecting suitable tree species for different contexts (Kuria et al 2016., a & b).

Through the participatory trials design workshops in Ethiopia, Rwanda and Uganda, guidelines on how to design scaling programmes that maximise opportunities for co-learning between researchers and farmers were developed. Appropriate species and management options were offered to farmers across different spatial and temporal scales subsequent to needs assessment conducted to identify best bet agroforestry options. Farmers are therefore trying out these options in their farms

The biophysical experiment trials improved understanding of tree-crop water- use interactions in different contexts. This information provided a foundation for developing tree-crop systems with positive soil, water, and livelihood impacts. Positive impact of trees and their management on water and crops was reported (Derero et al, 2016, Mukularinda et al, 2016 and Baudron et al., 2016). The tree-crop water-use studies, coupled with the development of APSIMX provide a robust data set and modelling framework to develop sustainable and adoptable tree-crop models with positive effects on soil and water resources as well as farmer livelihoods. The studies which are setup at landscapes and farms are perceived by farmers as contributing for the economy of knowledge-based decisions on the management of their trees and crops.

Enhanced tree crop modelling capability using a new version of Australia's agricultural production modeling framework (APSIM agroforestry Next Generation) was developed through partnership between CSIRO and ICRAF (Smethurst et al., 2016). The two main crop models needed for this project, wheat and maize, have been released already for public use in APSIM Next Generation. Also the oil palm and a simple pasture model are included (https://www.apsim.info/). The teff and potato models needed for Ethiopia and Rwanda respectively are under development. Software of APSIM agroforestry model for proxy and active trees with one of several crops (maize, wheat, pasture) and APSIM active tree model for *Gliricidia sepium* have been completed.

Efficient supply of quality germplasm and training through establishment six rural resource Centers (1 in Ethiopia and 1 in Uganda) and nurseries. The RRCs have also provided business opportunities for farmer groups and unemployed youth particularly through grafted fruit trees. For more details on numbers and species types please refer to (Mukuralinda et al., 2016b; Mekuria et al 2016 and Okia et al 2016b)

Collaborations for model application and improvement include Bosi C, University of São Paulo, Brazil – visiting PhD candidate 2017 researching eucalypt-pasture, particularly light interception; Figyantika A, University of Tasmania, Australia - PhD candidate 2016-18 researching eucalypt-maize in Indonesia; Valadares R, University of Vicosa, Brazil – visiting PhD candidate 2017 researching soil and rhizosphere C-N dynamics in eucalypt plantations and Lizhen Zhang, China Agricultural University, Beijing, China – collaboration on light interception modelling for agroforestry and intercropping systems in China.

There is also increased water availability and efficiency for centralised tree seedling production and irrigation.

Impact beyond 5 years

More farmers are expected to participate in the participatory trials. Already the studies which were setup at landscapes and farms are perceived by farmers as contributing to the economy of knowledge-based decisions on the management of their trees and crops. It is expected that the trees will have matured in five years and farmers will derive actual benefits from the trees' products and services *inter alia* food, fruits, fuel, timber, fencing materials, fodder improved soil fertility, decreased soil erosion and increased income from sale of tree products.

Data collection on the tree-crop water-use studies by the PhD students will continue. They will be encouraged to develop publications and outputs beyond a single thesis or dissertation. These publications are expected to greatly benefit other projects in the region and elsewhere. It is anticipated that more project beneficiaries will be reached by the project through scaling up strategies. The tracking tool (Kiptot et al, 2015) will be revamped to adequately record each individual who has benefited from the project at the country level. The tool will also track the existing beneficiaries and their performance across the phase two-duration.

The development of APSIMX is expected to be used world-wide as a standard for a model with the best balance for estimating both tree and crop performance in agroforestry systems.

Through the use of tree species selection tools local researchers, extension agents will be knowledgeable of the additional tree species suitable for their areas and their management options. This is expected to result in increased tree diversity and density in the study area and beyond.

8.2 Capacity impacts – now and in 5 years

In capacity development initiatives, the project has done exceptionally well. Capacity of staff from partner organizations in research and educational institutions, farmers and extension staff was enriched in the four countries. An incredible 1769 beneficiaries have benefitted from capacity development activities viz. trainings on soil and water management, tree planting and management, modelling workshops, participatory design workshops, baseline design workshops, sap flow use, and support in masters and PhD studies.

Local knowledge studies were a pre-requisite for training because they provided in-depth information elicited from farmers with regards to their current knowledge status. This information was then evaluated to identify and design targeted training needs, such as in the area of the production of quality germplasm, tree management, tree-crop interaction, tree utilities, tree seed nursery record keeping etc. 23 members were trained on local knowledge during workshops held in Ethiopia and Uganda while 424 farmers were reached during the local knowledge surveys.

The establishment six Rural Resource Centers (2 in Ethiopia 2 in Rwanda and 1 in Uganda and 1 in Burundi) and nurseries have provided good infrastructure for training and business opportunities for farmers, researchers and extension services which were nonexistent before the project.

Training and awareness creation through RRCs, farmer field schools, model farmers, field visits has resulted to increased knowledge, skills and attitudinal change within the communities. This has been evidenced by growth in demand for improved high value tree crop seedlings. Nursery activities have intensified thereby increasing the supply of quality germplasm. Also farmers are willing to purchase improved seedlings as opposed to planting the low quality germplasm available at little or no cost.

Awareness created among farmers that trees change livelihoods and landscapes has enhanced their willingness to protect and preserve tree seedlings planted.The attitudinal change was also evident from farmers in developing business models that they obtained from entrepreneurial training. Furthermore there is encouraging aspiration and desired participation of women and youth groups in all the countries.

Through the project, different partners and stakeholders have been involved in improving farmers' livelihood and landscapes by creating synergy in addressing the incorporation of trees in the farming system. Strong partnerships have developed with partners, both public and private, thereby making the implementation of project activities more successful in all the countries. In Rwanda for instance, more than 1500 farmers were trained on the importance of tree planting and further involved in the tree planting activities through the Umuganda initiative.

Increased research capacity of partner institutions in the four countries has been achieved. Twenty five students (17 master' and 7 PhD) across the four countries have benefitted from the project thereby contributing to scientific knowledge impacting development in the academic institutions.

Improved capacity in rainwater harvesting and management for staff, technicians and artisans; safer groundwater for domestic and agricultural use and improved tree seedling survival rates

Impact in 5 years

More capacity development activities will be effected through the existing RRCs as a result more farmers will be educated on improved practices such as grafting. Farmer capacity will also be enhanced to development of more training materials. As a result farmers are expected to sustainably adopt the technologies and retain them beyond the project scope.

Technology spill over is expected as a result of farmer to farmer extension. Trained farmers are expected to train other farmers within and beyond the project areas. It is envisioned that these farmers will adequately consist of women and youth.

Best-fit extension methods per country will be used to disseminate project technologies

Involvement of private sector in the project will be enhanced, especially in addressing issues on agroforestry value chains, processing and marketing of agroforestry products.

It is envisaged that more students will be involved in the project and research capacity of local researchers and partner organization will be further developed

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The impact of incorporating trees in farming systems in this project on food security and incomes is no doubt evident and varies from one country and site to the other. For example in Gishwati Rwanda, we take the mean values for yield increment by integrating trees on farm with fertilizer (tree biomass and inorganic fertilizer) against control (for maize, with fertilizer) from the participatory trials to estimate the impacts on food security. We assume that in Gishwati, the northern Rwanda, the average household land holding is less than 1 ha, say 0.6ha, fragmented into a few to several parcels, and farmers strategically plant multiple crops, both staple and commercial. If assuming farmers are attempting to maximize yield gains as well as incremental income gains from integrating trees with fertilizer (in terms of weight) from their plots, they may allocate more land to potatoes, as their unit yield gain is the largest among the three crops – say, 0.4 ha to potatoes, while 0.1 ha to maize and bean respectively. Assuming the exchange rate of RWF825/USD, additional income from three crops grown in the total farm of 0.6ha is estimated at 810.30/USD. If farmers are growing these crops 2 seasons per year, annual additional income will be 1,620 USD/year, which is significant, given the per capita income of USD 1343 in USD, the integration of trees. Similarly, the analysis from Bugesera with the assumption of the average land holding of 1 ha and growing 2 crops – maize/beans indicates that the integration of trees on farm with fertilizer will bring an additional income of 849.71 USD/farm per season or 1699.43 USD / farm/ year if they grow 2 seasons.

Integrating trees on farm not only provide farmers with higher yield and income, but also other benefits from trees – especially stakes for beans, fuel, construction materials, as well as environmental services such as erosion control and soil fertility amendments. The regions in Rwanda where the above crops are grown are experiencing soil degradation problems due to sloped landscapes and high population pressures. Provision of stakes for beans allows farmers to save money otherwise necessary, while that of fuel on farm saves women's time to collect fuelwood elsewhere. Integration of trees in Rwanda is driven by human needs to satisfy livelihood needs, enhance food security and improve resilience.

The RRCs in Ethiopia and Rwanda have been fundamental in improving farmer livelihoods. A group of 12 members, managing the Batu RRC in Ethiopia have largely benefited through sale of planting materials (seedlings, rootstock, and scions) and vegetables. Between August 2015 and February 2016 RRC activities earned members ETB 99,663 (USD 4,861) from sales of planting materials (seedlings, rootstock, and scions) and vegetables (Mekuria et al. 2016).

Karama RRC in Rwanda is managed by a cooperative of 166 members who have largely benefitted from training and tree planting materials and received technical support on various agroforestry technologies. The RRC has earned a total of US$ 2,000 from sale of fruit seedlings (Mukuralinda et al. 2016b).

The RRC achievements in Mbale Uganda, has also made significant economic impact on with 200,000 seedlings worth US$ 7,629 having being were raised to help farmers and community groups such as the Elgon Women Trust. (Okia et al. 2016b).

Several individual farmers have reported additional income as a result of project initiatives. In Ethiopia, Kuli Tiki reported an increase in income from sale of Sesbania seeds from trees provided by the project. *"I joined the project 3 years ago. I have benefited from the project through provision of tree seedlings such as Sesbania sesban, Grevillea robusta, avocado, mango, Cordia africana Moringa stenopetala. Unfortunately Moringa trees all died. So far I have seen direct benefits from Sesbania by selling tree seeds. I have also been trained on the* *various benefits of the multipurpose trees and tree management. Before the project I did not know of some additional/multipurpose use the trees. These trees will help me in future and that's why I manage them through watering, fencing". Kuli reported.*

Samuel (a former casual for the Elgon Trust Women Group who started his own nursery) in Uganda attributed his success in tree nursery management to skills gained from the project and support through polythene tubes. He reported to make up to US$ 300 from sale of tree seedlings. "I have four children whom I enrolled in a private school which is way more expensive than public schools and I haven't lacked fees to support them. I also use the proceeds from to purchase household items and sustain my family's needs. I owe my success to knowledge and skills got from the Elgon Trust Women Group and additional skills and support from the Trees for Food Security Project," stated Samuel. Similarly Clementine Mukarugwiza, a tamarillo farmer in Rwanda harvests 20kg of tamarillo fruit every season, three times an year and sells at RWF 500 per kg (USD $0.64). Joseph Desire, a climbing beans farmer, reported that his production has doubled from about 25kgs per acre to 50kgs from use of alternative stakes for climbing beans recommended by the project.

As a result of the influence of the project and implementation of tree management through pruning by farmers in Rwanda maize yields under pruned *G. robusta* have increased compared to under unpruned trees (4.7 t ha^{-1} under pruned compared to 2.8 t ha^{-1} under unpruned). This is a 70% increase in yield under the canopy which could result in the farmer saving money by not buying more maize for household use or selling some surplus. The prunings also provide firewood a highly sought out tree product in the area.

Impact in 5 years

A clear assessment and documentation of economic improvement in each of the countries through robust economic models developed from livelihood data will be done in the second phase. Moreover success of the famers will be assessed by quantifying on how the improved high value crops have impacted their livelihood.

A cost benefit analysis of different extension methods employed by the project will guide in applying the most appropriate methods in the specific countries in the efforts to disseminate innovations beyond project participants.

Having been successful in encouraging private sector in the form of small-business start-ups among farmers, women & youth, further development in Phase 2 especially with appropriate interaction with the VIP4FS project is expected.

8.3.2 Social impacts

As of November 2016 Trees for Food Security project directly reached over 30,000 beneficiaries in the project sites. Due to awareness creation and capacity building, the communities have taken up the culture of not only planting trees but also managing trees. In the three countries (Ethiopia, Rwanda and Uganda) there are over 6000 famers involved in participatory trials trying out different agroforestry options. This interest displays a cultural change.

In Ethiopia farmers are using fences to protect trees against livestock damage and also manuring to enhance tree growth. The provision of water through wells has also had great social impact in semi-arid Ethiopia. Personal testimonies from champion farmers is also an evidence that they are receiving many farmers request who would want to adopt the technologies these farmers are trying out after seeing the benefits (Derero et al 2015). Personal testimonies of the specific farmers can be viewed on the project website. For example

Wendemu Mendefro in Ethiopia reported to have made approximately 4000 birr in 2015 from pepper and chillies which he harvested only once due to low production that resulted from water shortage. With renovation of his shallow well facilitated by the project in 2016, the farmer approximated that he could make up to four times more income from his harvest

The RRC have been instrumental in developing social capital. In Ethiopia 539 community members have visited the Batu RRC, in Rwanda more than 1700 members have visited the RRC and more than 900 farmers in Uganda. In addition to being physical resources for training and demonstration of technologies, the RRCs provide a focal point for training and social self-organisation, they are also innovation platforms and hubs. In Ethiopia, Batu RRC farmers have developed their nursery business plans to sell high value tree crops seedlings to the farming community. They sell the grafted mangos, avocados and oranges in an outlet in the city centre. They now are negotiating with the mayor to lease them a land and a business shade to display and sell their tree seedlings which are in high demand by both city dwellers and the farmers. Five farmers (three are women) who have so far purchased and planted their improved mangoes and avocados are linking themselves with a Juice Cafe to sell their products as a group.

In all the countries the involvement of women and the youth in participating communities was paramount. Consequently the project has contributed to the assertiveness in women and youth as individuals and as groups. Women and girls have been involved in the project activities especially at community level. This is evidenced in the membership of the RRC cooperatives and in the management and ownership of farmer group nurseries. In Ethiopia, Magarissa cooperative group comprises 12 farmers, 5 men and 7 women. The Karama cooperative consists of 166 members (65 men and 10 women) and the Karama RRC is run by innovation platform (IP) members called "Imbarutso Y' Ubukungu" consisting of 36 women and 37 men.

Through the project beneficial country-level partnerships (EIAR, RAB, NaFORRI, and ISABU) have been underpinned. Project partners have shown great commitment to the project which has been encouraged because of the physical benefits such as the RRCs and long-term trials and also the opportunities accorded to staff members to undertake higher qualifications and other training.

Impact in 5 years

As a result of the policy dialogues a solid foundational understanding to create a better enabling environment for farmers to adopt tree planting is expected. Also project-induced opportunities for scaling up and scaling out an empowering environment for policy makers and actors to voice their commitment for sustainability will be created.

It is expected that the country-level partnerships will be harnessed through enhanced physical and human capacity building and social capital generated by having RRCs hence a permanent positive effect on user-directed research.

Social inclusion will be established through engagement of women and youth and data on this will be collected and analysed. Gender inclusion will be enhanced at the partner institutions conducting project activities and also at the technician level.

Key aspects such as social processes, attitudinal change, partial and dis-adoption processes, and diffusion to non-participant communities will be captured through monitoring and evaluation process.

8.3.3 Environmental impacts

Through the participatory trials and tree planting initiatives, project sites have witnessed increased tree planting and protection, wider diversity of trees planted as well as higher quality of trees gemplasm established. On-farm trials in Ethiopia and Rwanda have reported positive impact of trees and their management on water and crops. For instance in Grevillea maize trials in Rwanda have an average of sap volumes of 47-63 litres day-1 and 12-21 litres day-1 in unpruned and pruned trees. The corresponding maize grain yields under unpruned and pruned trees was 1441 kgha-1 and 2462 kgha-1 leading to over 71% yield increase maize grain yield, rising from an average of 1.44 t ha-1 to 2.46 t ha-1. (Mukularinda et al. 2016). In Modjo Ethiopia, average water use of pruned *Faidherbia albida* was 24 l day-1 compared to 144 l day-1 in unpruned trees during the dry season (January- April), while wheat grain yield was higher under unpruned *Faidherbia albida* with a yield of 2.2 t ha-1 under the canopy compared to 1.5 t ha-1 away from the canopy (Mukularinda et al. 2016) at the same time. On the other hand shade from *Faidherbia albida* trees has been shown to ameliorate high temperatures and increase yield through extending the grain filling period in cereals (Baudron et al., 2016)

Positive environmental impacts are evident in Gishwati- Rwanda as a result of planting *Acacia angustissima* tree species. The trees are fast growing and as a result soil erosion in the area has significantly reduced. Umuganda initiatives that reached more than 1500 farmers further contributed to restoration of degraded land in Gishwati and Bugesera.

Construction of new shallow wells in Ethiopia and improvement of the existing ones has been achieved.

Impact in 5 years

Benefits from the trees planted through the participatory trials are expected to accrue in the next five years. Maturing of the trees is expected to yield tree based products and services. Further, positive results from the tree crop water interactions will not only encourage farmers to adopt trees on farm but also encourage proper management practices.

Soil erosion is expected to reduce significantly in Gishwati area- Rwanda following the maturing of the already established *Acacia angustissima* species. Furthermore tree cover on land is expected to increase through mainstreaming agroforestry practices into the *Umuganda* initiatives a process that begun towards the completion of the project.

In Ethiopia farmer livelihood is expected to increase from the wells constructed on farmers land. It is expected that farmers will engage in irrigation activities mainly for high value tree crops that will contribute to increased income.

With planting of more trees there will be enhanced tree diversity and accompanying provision of appropriate ecosystems services which impacts on the environment. Impact of these tree cover changes will even be projected using the APSIM new generation model.

8.4 Communication and dissemination activities

The project has put in place robust intra and intercommunication system in place namely the communication strategy (Muthuri et al 2013). Internal communication is enhanced through publication of success stories in ICRAF transformations and blogs. Project website plays a significant role in communicating to the external audience http://www.worldagroforestry.org/project/trees-food-security-improving-sustainable-productivity-farming-systems-and-enhanced .

Success stories from farmers are also posted in the project webpage. Other success stories are captured elsewhere e.g. an article on the climbing beans was published in the East African newspaper in March 12 2016. Magazines, policy briefs and factsheets published for have also been useful in informing the policy makers, advocacy and governance systems.

Dissemination activities are through RRCs (where farmers access quality germplasm and training), other project trainings, propagation protocols, demonstrations plots, field visits and farmer to farmer learning.

9 Conclusions and recommendations

9.1 Conclusions

The trees for food security project demonstrated the importance of trees in fields and farming landscapes for enhancing and sustaining crop yield and food security as well as their role in managing provision of ecosystem services at landscape scales in eastern Africa. A number of promising climate smart agroforestry practices were developed, improving crop yield and in the longer term soil health, water use efficiency, carbon storage and livelihood outcomes. The project revealed that farmers want greater diversity of trees on their farms than had been previously appreciated. Local knowledge studies played a key role in helping to characterize and understand the local context from the farmer's perspective and captured the fine-scale variations in the bio-physical and socio-economic environment. This in return informed the design of agroforestry interventions that were customized to the local context and farmer circumstances, which enhanced their success, adaptability, acceptance and sustainability.

Based on the findings from participatory trials & biophysical on farm experiments (Musana et al 2016, Tenge et al 2016, Sida et al 2017 and Asseffa et al 206) trees on farm or their biomass have impact on crop yields. For instance, the use of Alnus acuminata for example resulted in increases of yields for maize, potatoes and beans translating to an increase in income of 1,620 USD / year for the average 0.6 ha farm (See more details in the M&E plan (Muthuri *et al.* 2016b). Similarly, the analysis from Bugesera with the assumption of the average land holding of 1 ha and growing 2 crops – maize/beans indicates that the integration of trees on farm with fertilizer will bring an additional income of 849.71 USD/farm per season or 1699.43 USD/farm/year if they grow 2 seasons. On the other hand for Ethiopia by growing wheat under *Faidherbia albiba* a farm household will gain additional 2.6 t wheat (0.7t/ha x 3.7/ha) for the 3.7 ha average land sizes in the area. Economic analysis on the impact of the other agroforestry technologies like tree tomato and stakes for climbing beans in Rwanda, impact of water and improved fruit trees in Ethiopia and that of the RRC, fruit trees and satellite nurseries in Uganda amongst others is ongoing.

From the participatory trials it was also clear that farmers express preferences, they are actually interested in planting a diversity of tree species on their farm – up to 10 in some cases as opposed to a single tree species. They also chose to plant in multiple niches. A more striking result is the variation in survival rate of trees across farms especially in Semi-arid Ethiopia highlights the complexity of tree survival and the potential for learning from this sort of trials that involves many farmers (Derero et al., 2016). Highly successful technologies include the use of green manure from *Alnus acuminata* (Gishwati) and *Gliricidia sepium* shrub (Bugesera), planting of grafted fruit trees in all the counties and tree tomato in Rwanda, soil erosion control, planting trees in the right niches with homesteads having the highest survival rates and stakes for climbing beans. The demand for these technologies is high as evidenced by the many farmers adopting them.

Tree crop interactions work clearly showed that trees in agricultural systems can be either competitive (Grevillea / maize systems) or complementary (Faidherbia / wheat systems) to the accompanying crops management through pruning can help reduce competition. *Faidherbia albida* impact enhances wheat growth and productivity in Ethiopia hence creating a complementarity effects which is however reduced by pruning. On the other hand *G. robusta reduces maize growth and yields under the canopy meaning it has a competitive* effect on maize systems in Rwanda. However pruning reduces this effect and maize yields under the canopy increases. In these experiments, prunning reduced water uptake in both *G. robusta* and *F. albida* and part of the gains in crop yields under the pruned *G. robusta* could be attributed to the water conserved and taken by reverse flow being accessible to maize.

A major breakthrough was to develop the CSIRO APSIM crop modelling framework's capacity (Luedeling et al., 2016) to handle tree-crop interactions within (APSIM X AF) For the first time, this allows reliable predictions of tree and crop yields for combinations of soil and climate globally, including climate change scenarios. Reliable yield predictions are essential for informing policy decisions relating to food security. At present APSIM X AF handles only a few tree species / genus (*Grevillea robusta, Gliricidia* and *Faidherbia albida* for model evaluation) interacting with wheat and maize. This provides a key opportunity to revise global estimates of impacts of agroforestry on key cereal yields.

The project has been successful in reaching over 30,000 beneficiaries by building on existing extension approaches in the respective countries rather than introducing new ones. These included the use of Umuganda and farmer promoters in Rwanda, Farmer Training Centres and champion farmers in Ethiopia. The project also adopted the use of several extension approaches in the respective countries that were complimentary. The setting up of RRCs in particular enabled farmers to access germplasm. The project also took into cognizance the fact that complementarities and potential synergy of different actors in agricultural development (farmers' organizations, research, extension, agricultural education institutions, input supply, NGOs and other public and private partners are important in scaling up.

The T4FS project established six RRCs, 2 in Ethiopia, 2 in Rwanda and one each in Uganda and Burundi to provide agroforestry training opportunities for farmers and improved access to tree germplasm. RRCs provided a platform for training and peer learning, created business opportunities, enhancing knowledge on locally appropriate agroforestry technologies and scaling up of the same hence empowering local communities and improving their livelihoods.

The project identified the most promising agroforestry tree products as well as the major constraints in their value chains. Findings indicate that in Rwanda, smallholders face constraints in accessing high quality tree products. The supply of these products in the markets is less than the demand and there is poor access to post-harvest technologies, also the transportation costs to the markets are high therefore discouraging farmers to take their products to the market for sale. In Ethiopia major challenges encountered include lack of access to credit facilities, lack of post- harvest technologies for perishable fruits, high transaction costs resulting from farmers being unable to access market information and low bargaining power. In Uganda high transportation costs, poor access to credit, lack of post-harvest technologies, poorly functioning relationships among various actors are the major constraints to value chain development while in Burundi lack of quality planting materials and small land sizes were the main limiting factors. These constraints increase production and marketing risk, especially for smallholder households endowed with modest financial, human and physical assets.

Rainwater harvesting is essential for supporting agroforestry and other interventions especially in areas affected by climate variability and economic water scarcity. Rainwater offers a reliable source of water supply for tree seedling production and establishment of tree seedlings in the field. However, communities are not well equipped to map, prospect, design and construct water harvesting and management options especially groundwater.

9.2 Recommendations

The prioritization exercise on tree species and planting niches clearly revealed that diverse tree species can be used in tree scaling up activities on farmlands. Farmers are interested in planting a diversity of species, not just 'top priority' species If a project fails to respond to this then (a) it will not be meeting farmers needs and interests (b) landscape-level tree species diversity will be much less than it could be.

The participatory approach in selecting these species and technologies to test is key to having many farmers embracing the technology. Therefore lessons learnt from the trials in phase 1 should be used to refine these technologies, incorporate new ones and scale up to more farmers.

From the tree crop interaction studies, management through shoot pruning was shown to significantly reduce competition and enhance maize yields. Therefore the predominant practices of pruning / pollarding of Faidherbia tree should be discouraged in Semi-arid Ethiopia to maximise crop productivity. In Bugesera Rwanda, the practice of pruning Grevillea trees in semi-arid Bugesera needs to be encouraged to enhance maize yields, improve timber quality and produce firewood. This will be incorporated in the participatory trials design in phase 2. In addition other priority tree species need to be studied to influence their management of farm for optimised systems productivity. As much as RRCs have been instrumental in making germplasm accessible to farmers, mechanisms need to be put in place to ensure farmers are more engaged and directly run RRCs while generating income to ensure sustainability.

Understanding the reasons for variation in trees survival across farms and niches can come from participatory assessments. For example, there is some evidence that survival is lower when farmers plant a lot of trees, perhaps because they have trouble caring for large numbers at the same time. If that is confirmed then it would suggest that regular small plantings might be more effective in the long term than 'campaigns' when farmers are encouraged to plant a lot of trees at once. In addition, if farmers who achieved high and low survival discuss together their experiences then reasons and good practices are likely to emerge and this will be followed up in the second phase. Since planting niches have also showed differences, the recommendations have to do with matching species with planting sites (niches).

Results also indicated that farmers want to have fruit trees entirely and solely in their homesteads. Hence creation of home-gardens where farmers can growth fruit trees, coffee and vegetables in this areas needs to be given high priority, and such an intervention can drastically improve the food security conditions of the smallholder farmers. However, households need to have access to sufficient water for irrigating their plants. In addition, the gap in tree survival among farmers should be narrowed down through farmer-to-farmer exchange of innovative ideas to protect and care for the plants in their homesteads. Thus, stronger seedling protection through individual seedling fencing and community bylaws need to be put in place so as to improve seedling survival in the niches outside homesteads areas. Without such interventions, diversifying tree species could be far from practical, and the landscapes would be dominated only with trees that are not susceptible to browsing damages such as the eucalypt.

The mapping of rainwater harvesting potentials in all projects sites to determine the available water (rainwater, runoff, surface and groundwater); determination of the water harvesting and management options applicable to the various context; to design, cost and rank options; participatory engagement of communities to gather local knowledge and experiences; to conduct capacity building (for technicians, artisans and lead farmers) aimed at upscaling the relevant options; documentation and publishing of lessons to inform policy, science and development practitioners.

Partnerships with wide range of actors is key to ensuring sustainability of extension systems. Towards this end, capacities of NARs need to be built so that they are up to date with the current knowledge on improved practices.

RRCs have been instrumental in making germplasm accessible to farmers however mechanisms need to be put in place to ensure farmers are more engaged and directly run RRCs while generating income to ensure sustainability. Partnerships with wide range of actors is key to ensuring sustainability of extension systems. Towards this end, capacities of NARs need to be built so that they are up to date with the current knowledge on improved practices.

A participatory monitoring and evaluation system needs to be put in place where farmers are also involved in tracking progress of the project activities and identifying any change in their livelihoods as a result of the same.

Establishment of a rigorous data collection, analysis and reporting system. Options for electronic data collection system can be explored where real time data can be collected from the field and sent to the relevant work package leaders

Development of a strong M&E plan is critical. This will ensure good baseline evaluation to determine the status of farmers' livelihood at the beginning of the project and compare it with their status at the end of the project to determine any changes that can be attributed to project interventions.

10 References

10.1 References cited in report

1. Abingoye, M. I. Factors influencing small holder farmers’ participating in timber production and marketing in Burundi: The case of Muruta commune of Kayanza province. Master’s Thesis. (2016). Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, Kenya.
2. Ajayi, F., Akande, S. R. Odejide, J. O; Idowu, B., 2010. Nutritive evaluation of some tropical under-utilized grain legume seeds for ruminant’s nutrition. Journal of American Science. 6 (7): 1-7
3. Akinnifesi, F.K., Makumba, W., Sileshi, G., Ajayi, O.C. and Mweta, D. 2007. Synergistic effect of inorganic N and P fertilizers and organic inputs from Gliricidia sepium on productivity of intercropped maize in Southern Malawi. Plant Soil 294:203–217
4. Asantewaa, M. (2013). Local Knowledge of Farmers on Farm Tree Management, East Shewa Zone, Ethiopia. Master’s Thesis. Bangor University, Bangor, United Kingdom.
5. Assefa Awol, Catherine Muthuri, Gebrekirstos Aster, Fetene M. 2016. Impact of Agroforestry Tree Species and Their Management effect On Water Resources and Crop Productivity in East Shewa Ethiopia. PhD progress report.
6. Ayda, R. (2013). Local knowledge about tree management and impact of management on trees’ phenology in Oromiya Region, Ethiopia. Master’s Thesis, Bangor University, Bangor, United Kingdom.
7. Ayenkulu, E., Iiyama, M., Coe, R., Shepherd, K. (2014a). Assessment of land health and targeting Sustainable Land Management interventions in in smallholding farming systems in Ethiopia. World Agroforestry Centre (ICRAF), 31pp.
8. Aynekulu, E., Iiyama, M., Mukuralinda, A., Segatagara, M., Muthuri, C., Shepherd, K. (2014b). Evaluating indicators of land degradation and targeting agroforestry interventions in smallholder farming systems in Rwanda. World Agroforestry Centre (ICRAF), 7pp.
9. Barnes, R.D., Fagg, C.W. 2003. Faidherbia albida. Monograph and Annotated Bibliography. Tropical Forestry Papers No 41, Oxford Forestry Institute, Oxford, UK. 281 p
10. Barrios E., Sileshi G.W., Shepherd K. and Sinclair F., (2011). ‘Agroforestry and Soil Health: trees, soil biota and ecosystem services’ in Wall, D.H. (Ed.) The Oxford Handbook of Soil Ecology and Ecosystem Services. Oxford University Press, Oxford, UK.
11. Barrios, B & Coe, R. 2013a. Participatory Trials Design Workshop Uganda. World Agroforestry Centre (ICRAF) Nairobi, Kenya, 10pp.
12. Barrios, B & Coe, R. 2013b. Melkassa Participatory Trials Design Workshop Report-Ethiopia. World Agroforestry Centre (ICRAF) Nairobi, Kenya, 8pp.
13. Baudron, F., Shiferaw, T., Ndoli, A., & Kim, H, K. (2016). Highlights of CIMMYT’s achievements in the project ‘Trees for food security'. International Maize and Wheat Improvement Center (CIMMYT), World Agroforestry Centre (ICRAF), 7pp.

14. Barrios, B and Coe, R. 2014. Participatory Trials Design Workshop- Rwanda. World Agroforestry Centre (ICRAF) Nairobi, Kenya, 7pp.
15. Bayala, J., Sileshi, G.W., Coe, R., Kalinganire, A., Tchoundjeu, Z., Sinclair F. and Garrity D. (2011). Cereal yield response to conservation agriculture practices in drylands of West Africa: A quantitative synthesis, Journal of Arid Environments, doi:10.1016/j.jaridenv.2011.10.011
16. Birhane, E. (2014). Agroforestry Governance in Ethiopia. Mekelle University, World Agroforestry Centre (ICRAF), 50pp.
17. Boffa, J. M. 1999. Agroforestry Parklands in sub-Saharan Africa. FAO Conservation Guide 34, Food & Agriculture Organization, Rome. 254 pp.
18. Brenner, A.J. 1996. Microclimate modifications in agroforestry. In: Ong, C.K. and Huxley, P. (eds.), Tree-Crop Interactions - A Physiological Approach, CAB International, Wallingford, UK, pp. 319-364.
19. Buyinza, J. Okia, C., Agaba, H., & Muthuri, C. (2016).Trees for Food Security Project Uganda Final report (2012-2016). National Forestry Resources Research Institute (NaFORRI), Uganda and World Agroforestry Centre (ICRAF), 24pp.
20. Buyinza, J. 2016. Tree nursery establishment and tree management; Community Tree Nursery Operators. Training Report 14pp
21. Buyinza, J. and Vincent I Opolot 2016. Tree nursery establishment and tree management. Training Manual for Community Tree Nursery Operators and Tree Farmers. 17pp.
22. Coe, R., Sinclair, F. and Barrios, E. (2014). Scaling up agroforestry requires research 'in' rather than 'for' development. Current Opinion in Environmental Sustainability 6(2014):73–77.
23. Dawit, S. (2014). Assessment of Tree Species Diversity Patterns and Socio-economic Uses on Agricultural Landscapes Case of Western Oromia. Master's Thesis, Jimma University College of Agriculture and Veterinary Medicine, Ethiopia.
24. de Dieu Habiyaremye, J., Muthuri, C., Matiru, V., Nyaga, J., Mukuralinda, A., Ruganzu, V., & Sinclair, F. (2015). Occurrence and abundance of arbuscular mycorrhizal fungi (AMF) in agroforestry systems of Rubavu and Bugesera Districts in Rwanda. African Journal of Microbiology Research, 9(12), 838-846.
25. De Willigen, P., & Van Noordwijk, M. (1994). Mass Flow and Diffusion Of Nutrients To A Root With Constant Or Zero-Sink Uptake Ii. Zero-Sink Uptake. Soil Science, 157(3), 171-175.
26. Dedefo, K., Derero, A., Tesfaye, Y., & Muriuki, J. (2016): Tree nursery and seed procurement characteristics influence on seedling quality in Oromia, Ethiopia. Forests, Trees and Livelihoods, DOI: 10.1080/14728028.2016.1221365
27. Deo, H (2015). A study of challenges and opportunities for tree seedling production in Bugesera and Muruta areas of Burundi. Master's Thesis, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.
28. Derero, A., Mekuria, A., Negussie, D., Tadesse, S., Baudron, F., Tofu, A., Assefa, A., Gebru, G., Argaw, M., Alemie, A., Kiptot, E., Iiyama, M., Mohan, S., Smethurst, P., Kinuthia, R., Hadgu, K., & Muthuri, C. (2016). Trees for Food Security Project Ethiopia Final report (2012-2016). Ethiopian Environment and Forest Research Institute (EEFRI) Addis Ababa, Ethiopia, World Agroforestry Centre (ICRAF), World Vision Addis Ababa

University (AAU), Mekele University (MU), Ethiopia International Maize and Wheat Improvement Center (CIMMYT) Commonwealth Scientific and Industrial Research Organisation (CSIRO), 7pp.

29. Derero, A., Mekuria, A., Hadgu, K., Muthuri, C., Negussie, D., Kinuthia, R., Tadesse, S., Iiyama, M., Tofu, A., Kiptot, E., Assefa, A., Betemariam, E., Carsan, S., Kuria, A., Barrios, E., Baudron, F., Smethurst, P., Mowo, J., & Sinclair, F. (2016a).Trees for Food Security Project: A Glimpse of Ethiopia, [Project Summary Magazine]. World Agroforestry Centre (ICRAF).
30. Derero, A., Mohan, S., Iiyama, M., Kiptot, E., Betemariam, E., Kanampiu, F., & Hadgu, K. (2012, August). Trees for food security project Inception Workshop. Ethiopian Institute of Agricultural Research (EIAR), World Agroforestry Centre (ICRAF), 50pp.
31. Derero, A., Tadesse, S., Birhan, B., Muthuri, C., Hadgu, K., & Sinclair, F. (2016b). Long term trials at Melkassa and Bako. Ethiopian Institute of Agricultural Research (EIAR), World Agroforestry Centre (ICRAF), 33pp.
32. Derero, A., Tadesse, S., Negussie, D. (2016c). Report on Agroforestry Long Term Field Day and Tibe Rural Resource Center Inaugural. Ethiopian Environment and Forest Research Institute, Central Ethiopia Environment and Forest Research Center (EEFRI/CEEFRC), 7pp.
33. Endale, Y. (2014). Assessment of Tree Species Diversity Patterns and Socio-economic Uses on Farmland in Oromia Regional State: The Case of Eastern Shewa Zone. Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
34. Endale, Y., Derero, A., Argaw M., & Muthuri, C. (2016). Farmland tree species diversity and spatial distribution pattern in semi-arid East Shewa, Ethiopia. Forests, Trees and Livelihoods. DOI: 10.1080/14728028.2016.1266971
35. Favreau, G., B. Cappelaere, S. Massuel, M. Leblanc, M. Boucher, N. Boulain, and C. Leduc. 2009. Land clearing, climate variability, and water resources increase in semiarid southwest Niger: A review, Water Resour. Res., 45, W00A16, doi:10.1029/2007WR006785.
36. Garrity, D.P., Akinnifesi, F.K., Ajayi, O.C., Sileshi G.W., Mowo, J.G., Kalinganire, A., Larwanou, M. and Bayala, J. 2010. Evergreen agriculture: a robust approach to sustainable food security in Africa. Food Security. DOI 10.1007/s12571-010-0070-7
37. Gyau, A., & Muthuri, C. (2016). The socio - economic potential of under of utilized species to small holder farmers: The case of Khat (Catha edulis) in Ethiopia. African Journal of Business Management Volume; 10 Issue, 11 Pages 279-287.
38. Hadgu, K.M., Mowo, J., Garrity, D.P., Sileshi, G. (2011) Current extent of Evergreen Agriculture and Prospects for Improving Food Security and Environmental Resilience in Ethiopia. International Journal of Agricultural Sciences Vol. 1(1), pp. 251- 262.
39. Hassan, M., Hadgu, K., Birhane, E., Muthuri, C., Mwangi, A., Sinclair, F & Mowo, J. (2015a). Harnessing Agroforestry in Ethiopia to boost crop productivity and strengthen food security. Policy Brief No.30. World Agroforestry Centre (ICRAF).
40. Hassan, M., Mukuralinda, A., Bizoza, A., Muthuri, C., Mwangi, A., Mowo, J., & Sinclair, F. (2015b). Harnessing the potential of agroforestry to boost yields and strengthen food security in Rwanda. Policy Brief No.31. World Agroforestry Centre (ICRAF).

41. Iiyama M, Derero A, Kelemu K, Muthuri C, Kinuthia R, Ayenkulu E, Kiptot E, Hadgu K, Mowo J, & Sinclair F. (2016). Understanding patterns of tree adoption on farms in semi-arid and sub-humid Ethiopia. Agroforestry systems. DOI 10.1007/s10457-016-9926-y
42. Iiyama, M., Ayenkulu, E., Kindt, R., Kuria, A., Tanui, J., Kiptot, E., Kinuthia, R., Hadgu, K., Derero, A., Kelemu, K., & Muthuri, C. (2014a). ACIAR WP1 mid-term Report- Ethiopia. World Agroforestry Centre (ICRAF), Ethiopian Institute of Agricultural Research (EIAR), 29pp.
43. Iiyama, M., Ayenkulu, E., Kindt, R., Kuria, A., Tanui, J., Kiptot, E., Kinuthia, R., Mukularinda, A., Mutaganda, A., Nabahungu, L & Muthuri, C. (2014b). ACIAR WP1 mid-term Report- Rwanda. World Agroforestry Centre (ICRAF), Rwanda Agricultural Board (RAB), 19pp.
44. Inter-Academy Council. (2004). Analysis of the potential for agroforestry in Africa and the Hunger Task Force report to the General Assembly of the United Nations. Inter-Academy Council and the World Agroforestry Centre.
45. Kassim, T. (2014). Assessment of tree seedling nurseries for a climate smart agriculture in selected districts of Oromia Regional State. Master's Thesis, Hawassa University, Wondo Genet, Ethiopia.
46. Keating, B.A., Carberry, P.S., Bindraban, P.S., Asseng S., Meinke H., and Dixon J. (2010). Eco-efficient Agriculture: Concepts, Challenges, and Opportunities. Crop Science 50 (Suppl. 1), S109–S119
47. Kiptot, E., Kinuthia, R., Mowo, J., & Muthuri, C. (2015). Trees for food security Project Tracking Tool 2015. World Agroforestry Centre (ICRAF).
48. Krampien, J. (2015). Faidherbia albida water use and impacts on teff growth in a sub-humid area environment of Modjo Ethiopia. Master's Thesis, Oregon State University, Corvallis, Oregon, United States.
49. Kuria, A., Dawit, S., Endale, Y., Derero, A., Iiyama, M., Muthuri, C., Hadgu, K., Kinuthia, R., Betemariam, E., Asantewaa, M., Muriuki, J., Kindt, R., Dedefo, K., Senbeto, M., Njenga, M., Lamond, G., Pagella, T., & Sinclair, F. (2016a). Suitable tree species selection and management tool for Ethiopia. [Database], World Agroforestry Centre (ICRAF).
50. Kuria, A., Uwase, Y., Mukuralinda, A., Iiyama, M., Twagirayezu, D., Njenga, M., Muriuki, J., Mutaganda, A., Muthuri, C., Kindt, R., Betemariam, E., Cronin, M., Kinuthia, R., Migambi, F., Lamond, G., Pagella, T., & Sinclair, F. (2016b). Suitable tree species selection and management tool for Rwanda. [Database], World Agroforestry Centre (ICRAF).
51. Anne Kuria, Tim Pagella, Catherine Muthuri, Edmundo Barrios, Athanase Mukuralinda, Fergus Sinclair (2016c). How 'local' is local knowledge? the potential for utilising farmers' knowledge to inform management of tree-based ecosystem services across scales for improved livelihoods in Gishwati, Rwanda. PhD - Local Knowledge Progress Report. 32pp
52. Kuyah Shem, Ingrid Öborn, Mattias Jonsson, A Sigrun Dahlin, Edmundo Barrios, Catherine Muthuri, Anders Malmer, John Nyaga, Christine Magaju, Sara Namirembe, Ylva Nyberg & Fergus L Sinclair (2016). Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa. International Journal of Biodiversity Science, Ecosystem Services & Management Volume 12, 2016 - Issue 4

53. Lamond, G., Cronin, M., Alemu, E., Ataa-Asantewaa, M., Dawit, S., Debele, D., Gebremedin, G., Heinze, A., Kuria, A., Mukangago, M,. Ngenzi, G., Schmidt, M., and Twagiramungu, J-C. (2013). Local knowledge training using the AKT5 software and methodology, funded by the ACIAR Trees for Food Security project: Initial findings from a two week research study in Ejersa Joro Kebele in Oromiya Region, central Ethiopia. Bangor University and World Agroforestry Centre (ICRAF), 31pp.
54. Luedeling E, Smethurst P J., Baudron F, Bayala J, Huth N I., van Noordwijk M, Ong C K., Mulia R, Lusiana B, Muthuri C, L. & Sinclair F (2016). Field-scale modelling of tree–crop interactions: Challenges and development needs. Agricultural Systems 142: 51-69
55. Luedeling, E., (2012). Design of a Strategy for Biophysical Modelling of Agroforestry Systems workshop report. World Agroforestry Centre (ICRAF), 66pp.
56. Makumba, W., Akinnifesi, F.K., Janssen, B. and Oenema, O. 2007. Long-term impact of a gliricidia-maize intercropping system on carbon sequestration in southern Malawi. Agriculture, Ecosystems and Environment 118: 237–243.
57. Maimbo, M. 2015. Rapid Assessment of potential water harvesting interventions to support the ACIAR project in Ziway, Ethiopia. World Agroforestry Centre (ICRAF), 10pp.
58. Mekuria, A., Carsan, S., Kiptot, E., Derero, A., Hadgu, K., & Muthuri, C. (2016). Batu Rural Resource Centre: A community based approach to deliver agroforestry technologies to rural farmers. [Fact sheet]. World Agroforestry Centre (ICRAF).
59. Mohan et al., 2014. Proceedings of M&E workshops in Ethiopia and Rwanda, workshop report. World Agroforestry Centre (ICRAF), 6pp.
60. Mukularinda, A., Bernard, M., Gislain, T., Mwungura, M., Migambi, F., & Dieudonne, S. (2016). ACIAR-T4FS project Rwanda Final report (2012-2016), Rwanda. World Agroforestry Centre (ICRAF), Rwanda Agriculture Board (RAB), 30pp.
61. Mukuralinda, A., Ngonga, T., Musana, B., Muthuri, C., Mutaganda, A., Ndoli, A., Iiyama, M., Dieudonne, S., Kuria, A., Betemariam, E., Kiptot, E., Barrios, E., Kinuthia, R., Mwangi, A., Carsan, S., Tanui, J., Gyau, A., Mowo, J., & Sinclair, F. (2016a). Trees Playing a Key Role in Food Security and Livelihoods in Rwanda: Highlights from the T4FS Project, [Project Summary Magazine]. World Agroforestry Centre (ICRAF).
62. Mukuralinda, A., Carsan, S., Muthuri, C., Kiptot, E., Kuria, A., & Mwangi, A. (2016b). Karama and Karago Rural Resource Centres: A new approach to delivery of Agroforestry technology in Rwanda. [Fact sheet]. World Agroforestry Centre (ICRAF).
63. Mukuralinda, A., Kiptot, E., Nabahungu, L., Iiyama, M., Serge.,Tukahirwa, J., Nzeyimana, I., & Bizoza, A. (2012, August). Trees for food security project Inception Workshop. World Agroforestry Centre (ICRAF), Rwanda Agricultural Board (RAB), 44pp.
64. Mukuralinda, A., Kiptot, E., Twagirayezu, D., Muthuri, C., & Musana, B. (2016c). Alnus acuminata protocol. World Agroforestry Centre (ICRAF).
65. Mukuralinda, A., Mutaganda, A., Twagirayezu, D., Kiptot, E., Muthuri, C., & Musana, B. (2016d). Cyphomandra betacea protocol. World Agroforestry Centre (ICRAF).
66. Muller, C., Mesi, W., Tanui, J., SRI Team. (2014). ACIAR Trees for food security Project Rwanda National policy Dialogue, Rwanda. World Agroforestry Centre (ICRAF), 23pp.
67. Muriithi, W., Derero, A., Hadgu, K., Asfaw, K., Walelinyii, A., Malesu, M., & Oduor, A. (2016). Improving Water Access through Shallow Wells and Improving Irrigation in East Shewa Zone, Ethiopia. World Agroforestry Centre (ICRAF), 38pp.

68. Muthuri, C., Mohan, S., Iiyama, M. Tanui, J., Kiptot, E., Kinuthia Ruth and Sinclair F (2017). Trees for food security project Monitoring and Evaluation Plan_AIFSC. World Agroforestry Centre (ICRAF).
69. Muthuri, C.W., Ong, C.K., Craigon, J., Black C.R., Ngumi V.W., Mati B.M. 2009. Gas exchange and water use efficiency of trees and maize in agroforestry systems in semi-arid Kenya. Agric. Ecosyst. Environ. 129, 497-507.Muthuri, C., Derero, A., Mukularinda, A., Okia, C., Hadgu, K., Nkurunziza, C., Agaba, H., & Kinuthia, R. (2015).Trees for food security Project Scaling up Strategy. World Agroforestry Centre (ICRAF).
70. Muthuri, C., Derero, A., Mukuralinda, A., Buyinza, J., Nkurunziza, C., Kinuthia, R., & Mwangi, A. (2016a). Trees for Food Security Overview and Achievements [Fact sheet], World Agroforestry Centre (ICRAF).
71. Muthuri C, Mukuralinda A, Hadgu K., Okia C., Derero A., Nkurunziza C., i Iiyama M, Kinuthia, R., H. Agaba, T. Ngoga, E. Kiptot, Musana B., Neguse A., Kinuthia R,, Kuria, A., Mowo J.,, Sinclair 2016b. Scaling up strategy for the trees for food security project 5 Pg
72. Muthuri, C., Kiptot, E. (2013). Project communication strategy. World Agroforestry Centre (ICRAF). 21pp.
73. Muthuri C. W., Ong, C.K., Black C.R., Mati, B.M., Ngumi, V.W., and Van-Noordwijk M. 2004. Modelling the effects of leafing phenology on growth and water use by selected agroforestry tree species in semi-arid Kenya, Land Use & Water Resources Research 4 1-11.
74. Neufeldt, H., Wilkes, A., Zomer, R. J., Xu, J., Nang'ole, E., Munster, C., Place, F. 2009. Trees on farms: Tackling the triple challenges of mitigation, adaptation and food security. World Agroforestry Centre Policy Brief 07. Nairobi, Kenya: World Agroforestry Centre.
75. Njenga, M., Kuria, A., Lamond, G., Muthuri, C., Sinclair, F. (2015d). Local Knowledge of farmers on the role of trees and associated management in food security in Muruta commune, Kayanza Province, Burundi. World Agroforestry Centre (ICRAF), Bangor University, 46pp.
76. Njoroge, J & Muthuri, C. (2015). Monitoring tree water use in the field: Training template. World Agroforestry Centre (ICRAF).
77. Nkurunziza, C., Kinuthia, R., Muthuri, C., Havyarimana, D., Kindt, R., Kiptot, E., Kuria, A., Njenga, M., Muriuki, J., Gyau, A., & Mowo, J. (2016). Trees for Food Security Project Overview in Burundi. [Project Summary Magazine]. World Agroforestry Centre (ICRAF).
78. NKURUNZIZA Claudette (2015). Guide De Formation Techniques De Lutte Anti-Erosive - A training guide for soil erosion control techniques in Burundi
79. Nyaga, J. Barrios, E., Muthuri, C.W., Oborn, I, Matiru, V. and Sinclair, F.L. (2015). Evaluating factors influencing heterogeneity in agroforestry adoption and practices within smallholder farms in Rift Valley, Kenya. Agriculture, Ecosystems and Environment 212: 106-118Lamond, G & Kuria, A. (2014). Local knowledge training using the Agro-ecological Knowledge Toolkit in Namabya Sub-county, Manafwa District, of Eastern Uganda. Bangor University and World Agroforestry Centre (ICRAF), 23pp.
80. Ngoga T.G., C.W. Muthuri, A. Mukuralinda and Fergus Sinclair (2016) Effect of pruning Grevillea robusta on tree water and maize productivity Bugesera semi-arid region Rwanda. Project report Biophysical experiment.
81. Okia, C., Buyinza, J., Agaba, A., Muthuri, C., Kiptot, E., Kinuthia, R., Lamond, G., Gyau, A., Carsan, S., Muthuri, M., Mowo, J., & Sinclair, F. (2016a). Trees for Food Security

Project, A Glimpse of Uganda. [Project Summary Magazine]. World Agroforestry Centre (ICRAF).

82. Okia, C., Buyinza, J., Agaba, H., Carsan, S., Kiptot, E., & Muthuri, C. (2016b). Mbale Rural Resource Centre: A community based approach to deliver agroforestry technologies to rural farmers in Eastern Uganda [Fact sheet]. World Agroforestry Centre (ICRAF).
83. Ong, C.K., Black, C.B. and Muthuri, C.W. 2006. Modifying forestry and agroforestry to increase water productivity in the semi-arid tropics. CAB Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 2006 1, No. Reviews: 065 pg 1-9
84. Ong, C.K., Wilson, J., Deans, J.D., Mulatya, J., Raussen, T. and Wajja-Musukwe, N. 2002. Tree-crop interactions: manipulation of water use and root function Agricultural Water Management 53: 171-186.
85. Otiende, V., Muller, C., Derero, A., Hadgu, K., Tanui, J., SRI team. (2014). ACIAR Trees for food security Project Ethiopia National policy Dialogue Ethiopia. World Agroforestry Centre (ICRAF), 23pp.
86. Roupsard O., Ferhi A., Granier A., Pallo F. Depommier D., Mallet B., Joly H.I., Dreyer E. 1999. Reverse phenology and dry-season water uptake by Faidherbia albida (Del.) A. Chev. in an agroforestry parkland of Sudanese west Africa. Functional Ecology 13: 460-472.
87. Salami, A., Kamara, A. B., & Brixiova, Z. (2010). Smallholder agriculture in East Africa: Trends, constraints and opportunities. Tunis: African Development Bank.
88. Sanou, J.; Zougmore, R.; Bayala, J.; Teklehaimanot, Z. 2010. Soil infiltrability and water content as affected by Baobab (Adansonia digitata L.) and Nere (Parkia biglobosa (Jacq.) Benth.) trees in farmed parklands of West Africa. Soil Use and Management 26, 75-81.
89. Schmidt, M. (2013). Exploring the diversity of tropical soils: Using local knowledge to understand soil properties and land management in Ongobo bakanisa, Ethiopia. Master's Thesis, Bangor University, Bangor, United Kingdom.
90. Shitumbanuma, V. 2012. "Analyses of Crop Trials under Faidherbia albida: Results for the 2010/ 2011 agricultural season and overall summary of yields and yield trends in from 2008 and 2011." Conservation Farming Unit, Lusaka, Zambia.
91. Sileshi, G., Akinnifesi, F.K., Ajayi, O.C., Place, F. 2008. Meta-analysis of maize yield response to planted fallow and green manure in sub-Saharan Africa. Plant and Soil 307: 1-19.
92. Sileshi, G.; Akinnifesi, F.K.; Debusho, L.K.; Beedy, T.; Ajayi, O.C.; Mng'omba, S. 2010. Variation in maize yield gaps with plant nutrient inputs, soil type and climate across sub-Saharan Africa. Field Crops Research 116 (1-2), 1-13.
93. Smethurst PJ, Huth N, Fainges F, Masikati F, Baudron F, Gebru G, Musana B, Dilla A, Mukuralinda A, Muthuri C, Sinclair F (2016a) APSIM Agroforestry Model Development and Application in the ICRAF-ACIAR Trees-for-Food-Security Project – Summary Report. CSIRO Client Report.
94. Smethurst, P., Huth, N., Masikati, P., Fainges, J., Muthuri, C., & Sinclair, F. (2016b). Trees now part of a global crop modeling framework (APSIM). [Fact sheet]. Commonwealth Scientific and Industrial Research Organisation (CSIRO), World Agroforestry Centre (ICRAF).

95. Tam Le Thi (2015). Does knowledge influence practice? Tree planting and /or retention on smallholder farms in Namabya sub-county, Manafwa district, Eastern Uganda. Master's Thesis, Bangor University, Bangor, United Kingdom.
96. van Breugel, P, Kindt, R, Lillesø, J-PB, Bingham, M, Demissew, S, Dudley, C, Friis, I, Gachathi, F, Kalema, J, Mbago, F, Moshi, HN, Mulumba, JW, Namaganda, M, Ndangalasi, HJ, Ruffo, CK, Minani, V, Jamnadass, R & Graudal, L. (2015). Potential Natural Vegetation Map of Eastern Africa (Burundi, Ethiopia, Kenya Malawi, Rwanda, Tanzania, Uganda and Zambia). Version 2.0. http://vegetationmap4africa.org
97. Wilson, M. (2015). Agroforestry tree products, markets and decision making- A grounded theory study of smallholders' experience of market participation in Manafwa District, Uganda. Master's Thesis, University of Copenhagen, Denmark.
98. Winowieck, L., & Vågen, T-G. (2016). Spatially Explicit Analysis for Improved Targeting of Interventions. World Agroforestry Centre (ICRAF), 9pp.

10.2 List of publications produced by project

1. de Dieu Habiyaremye, J., Muthuri, C., Matiru, V., Nyaga, J., Mukuralinda, A., Ruganzu, V., & Sinclair, F. (2015). Occurrence and abundance of arbuscular mycorrhizal fungi (AMF) in agroforestry systems of Rubavu and Bugesera Districts in Rwanda. African Journal of Microbiology Research, 9(12), 838-846.

   http://www.academicjournals.org/journal/AJMR/article-full-text-pdf/9134F8851796

2. Dedefo, K., Derero, A., Tesfaye, Y., & Muriuki, J. (2016): Tree nursery and seed procurement characteristics influence on seedling quality in Oromia, Ethiopia. *Forests, Trees and Livelihoods*, DOI: 10.1080/14728028.2016.1221365.

   http://dx.doi.org/10.1080/14728028.2016.1221365

3. Endale, Y., Derero, A., Argaw M., & Muthuri, C. (2016). Farmland tree species diversity and spatial distribution pattern in semi-arid East Shewa, Ethiopia. Forests, Trees and Livelihoods. DOI: 10.1080/14728028.2016.1266971

4. Fredrick Charity, Muthuri Catherine, Ngamau Kamau, Sinclair Fergus (2016) Provenance and pretreatment effect on seed germination of six provenances of Faidherbia albida (Delile) A. Chev Agroforest Syst DOI 10.1007/s10457-016-9974-3

5. Fredrick C, Muthuri C., Ngamau K. and Sinclair, F. (2015). Provenance variation in seed morphological characteristics, germination and early seedling growth of *Faidherbia albida. Journal of horticulture and forestry; Volume 7 (5) pp 127-140*

6. Gyau, A. Invited paper presented at the 4th International Conference of the African Association of Agricultural Economists, September 22-25, 2013, Hammamet, Tunisia

   http://www.worldagroforestry.org/output/invited-paper-presented-4th-international-conference-african-association-agricultural

7. Gyau, A., & Muthuri, C. (2016). The socio - economic potential of under of utilized species to small holder farmers: The case of Khat (Catha edulis) in Ethiopia. African Journal of Business Management Volume; 10 Issue, 11 Pages 279-287.

8. Hassan, M., Hadgu, K., Birhane, E., Muthuri, C., Mwangi, A., Sinclair, F & Mowo, J. (2015a). Harnessing Agroforestry in Ethiopia to boost crop productivity and strengthen food security. Policy Brief No.30. World Agroforestry Centre (ICRAF).

9. Hassan, M., Mukuralinda, A., Bizoza, A., Muthuri, C., Mwangi, A., Mowo, J., & Sinclair, F. (2015b). Harnessing the potential of agroforestry to boost yields and strengthen food security in Rwanda. Policy Brief No.31. World Agroforestry Centre (ICRAF).
10. Iiyama M, Derero A, Kelemu K, Muthuri C, Kinuthia R, Ayenkulu E, Kiptot E, Hadgu K, Mowo J, & Sinclair F. (2016). Understanding patterns of tree adoption on farms in semi-arid and sub-humid Ethiopia. Agroforestry systems. DOI 10.1007/s10457-016-9926-y
11. Kindt R, van Breugel P, Orwa C, Lillesø JPB, Jamnadass R and Graudal L (2015) Useful tree species for Eastern Africa: a species selection tool based on the Vegetationmap4africa map. Version 2.0. World Agroforestry Centre (ICRAF) and Forest & Landscape Denmark. http://vegetationmap4africa.org
12. Luedeling E, Smethurst P J., Baudron F, Bayala J, Huth N I., van Noordwijk M, Ong C K., Mulia R, Lusiana B, Muthuri C, L. & Sinclair F (2016). Field-scale modeling of tree–crop interactions: Challenges and development needs. Agricultural Systems 142: 51-69
13. Luedeling, E, Kindt, R, Huth, N I, & Koenig, K. 2014. Agroforestry systems in a changing climate- challenges in projecting future performance. Current Opinion in environmental sustainability 6:1-7 http://www.worldagroforestry.org/publication/agroforestry-systems-changing-climate-challenges-projecting-future-performance
14. Luedeling E, Smethurst PJ, Baudron F, Bayala J, Huth NI, van Noordwijk M, Ong CK, Mulia R, Lusiana B, Muthuri C, Sinclair FL (2016) Field-scale modeling of tree-crop interactions: challenges and development needs. Agricultural Systems 142: 51-69. http://ac.els-cdn.com/S0308521X15300457/1-s2.0-S0308521X15300457-main.pdf?_tid=d70edde2-db78-11e5-a6de-00000aacb362&acdnat=1456374955_c1c62b9784b5b133cdb1b35eefafa36e
15. Masikati et al (2017) Crop production and soil water dynamics in semi-arid agroforestry systems of Kenya and Australia: simulating tree-crop interactions with the APSIM model. (in review)
16. Smethurst PJ, Huth NI, and Luedeling E (2014) Tree-Crop Modelling Strategy for the ICRAF-ACIAR Project Trees-for-Food-Security, East Africa. CSIRO, Australia. 18p. http://outputs.worldagroforestry.org/cgi-bin/koha/opac-detail.pl?biblionumber=5756
17. Smethurst P, Huth N, Masikati P, and Fainges J J., Muthuri, C., & Sinclair, F. (2016) Trees now part of a global crop modeling framework (APSIM). ICRAF Brochure.
18. Smethurst PJ, Huth NI, Masikati P, Sileshi GW, Akinnifesi FK, Wilson J, Sinclair F (2017) Accurate crop yield predictions from modelling tree-crop interactions in gliricidia-maize agroforestry. Agricultural Systems Volume 155, July 2017, Pages 70–77

Other reports and documents can be accessed following the link below: http://www.worldagroforestry.org/project/aciar/outputs

Journal articles under review

1. Dilla, A., Smethurst, P. J., Parsons, D., Barry, K., & Denboba, M. (in press). Potential of the APSIM model to simulate impacts of shading on maize productivity. *Agroforestry Systems.*
2. Iiyama, M., Neufeldt, H., Njenga, M., Derero, A., Ndegwa, G.M., Mukuralinda, A., Dobie, P., Jamnadass, R., & Mowo, J. (in press). The charcoal-agriculture nexus to understand the socio-ecological contexts underlying varied sustainability outcomes in African landscapes. Frontiers in Environmental Science.

3. Ndoli, A., Baudron, F., Schut, T., Mukuralinda, A., & Giller, K. Disentangling the positive and negative effects of trees on maize on smallholdings in Northern Rwanda. Submitted to Field Crops Research
4. Sida, T.S., Baudron, F., Adugna, D., Deme, D.A., Tolera, M., & Giller, K.E. Ageing of Faidherbia albida (Del. A. Chev) trees threatens the persistence of a climate-smart production system in the Central Rift Valley of Ethiopia. Submitted to Journal of Applied Ecology
5. Sida, T.S., Baudron, F., Haekoo, K., & Giller, K.E. Climate-smart Agroforestry: Faidherbia albida trees modify microclimate to buffer wheat against climatic extremes in the Central Rift Valley of Ethiopia. Submitted to Agricultural and Forest Meteorology.

10.3 Appendix 1: AKT5 Methodology

Over recent years, there has been increasing awareness that local knowledge and practices should be recognised in developing initiatives aimed at sustaining and improving the livelihoods of farming communities and the environment. Interest amongst research, education and development institutions to investigate and document local knowledge has grown significantly over the last few years. Bangor University is a leading institution in the development of a knowledge-based systems methodology and software called the Agro-ecological Knowledge Toolkit (AKT). The AKT5 software was developed by Bangor University in conjunction with the Department of Artificial Intelligence at Edinburgh University. Through a close partnership, Bangor University works with the World Agroforestry Centre (ICRAF) to integrate AKT into international research and development projects in order to design more effective interventions that work on the ground. The aim of the toolkit is to elicit local ecological knowledge in a rigorous and systematic way in order for it to be robust enough to be useful for informing projects. It was designed to provide an environment for knowledge acquisition in order to create knowledge bases from a range of sources. It allows representation of knowledge elicited from farmers and scientists or knowledge abstracted from written material. The use of formal knowledge representation procedures offers researchers the ability to evaluate and utilise the often complex, qualitative information relevant stakeholders have on agro-ecological practices and the knowledge underlying these practices. The methodology associated with knowledge elicitation for the AKT5 system allows for formalized flexible knowledge bases to be created.

Local ecological knowledge refers to what people know about their natural environment, based primarily on their own experience and observation. Where management has a large impact on the natural resource base, it is useful to refer to it as agro-ecological knowledge, to emphasise the management component. The tool enables explicit representation of local knowledge through the use of a knowledge based systems approach. This is a methodology for formally representing qualitative knowledge on a computer. It is based on the premise that most knowledge can be broken down into short statements and associated taxonomies of the terms that are used in them. These can then be represented on a computer as a knowledge base using a formal grammar and a series of hierarchies of terms. Connections amongst statements can be explored by viewing sets of related statements as causal diagrams. The formal recording of knowledge in this way also makes it possible to use automated reasoning procedures to help evaluate and explore complex knowledge domains.

The toolkit has been used successfully in a number of projects in Asia, Africa and Latin America and has been adopted globally by ICRAF. Projects have included development of multi-strata cocoa and non-timber forest products in Ghana and Cameroon; jungle rubber, soil conservation and Javanese home garden systems in Indonesia; participatory plant breeding for cassava in Colombia; fodder systems in Nepal; forest gardens and smallholder rubber in Sri Lanka; range management in South Africa and Lesotho; trees in crop fields and rangelands in Kenya and Tanzania. A Spanish language version is used in Latin America by the Tropical Agricultural Research and Higher Education Centre (CATIE) and a Thai version has been developed in conjunction with the Department of National Parks, Wildlife and Plant Conservation in Thailand. The tool is also available in French and Spanish languages. For the Trees for Food Security project, AKT studies were carried out across all four countries.

10.4 Appendix 2: Vegetation map for Burundi

A draft of an interactive species selection map has been developed for Burundi, based on an expansion of a map and application of methodologies developed by an earlier project (the 'VECEA' [Vegetation and Climate Change in East Africa] map; URL www.vegetationmap4africa.org). The main baseline map selected for Burundi was Pouilloux 1979 (Figure 1a) which was georeferenced and digitized by the geospatial laboratory at the World Agroforestry Centre (ICRAF). Other baseline maps included historical soil maps (Van Wambeke 1957) and maps of vegetation belts in western Burundi (Lewalle, 1972) as shown in Figure 1b.

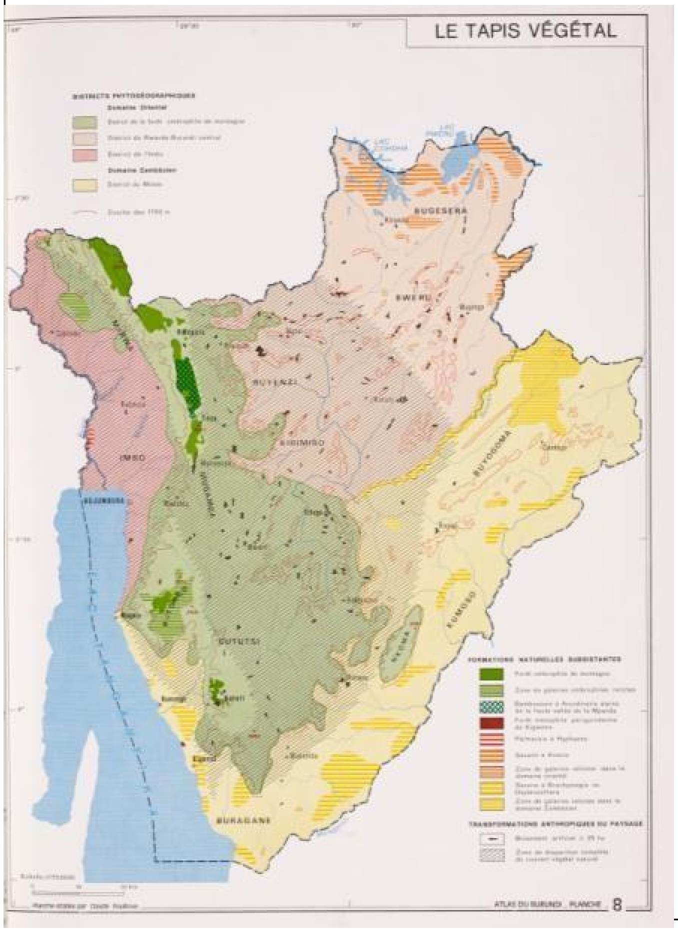
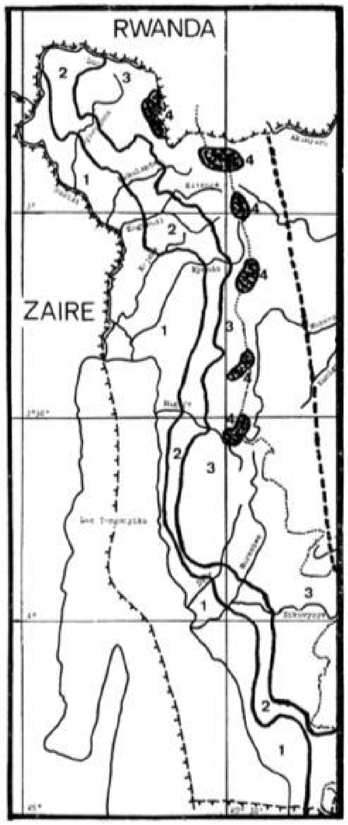
1 a	1 b
	 Fig. 29. — Burundi occidental : étages de végétation. 1, étage inférieur; 2, étage de transition; 3, étage montagnard; 4, étage afro-subalpin.

Figure 1. Some of the baseline vegetation maps that were consulted when developing the interactive vegetation map. 1a: vegetation map developed by Pouilloux for the Atlas of Burundi (1979); b: vegetation belts described by Lewalle (1972) in eastern Burundi.

In parallel to developing the documentation and species assemblages for the vegetation map, a master list of 2367 plant species known to occur in Burundi was obtained by compiling information from Lewalle (1972 ; 1714 current species names), the List of East African Plants (LEAP; Knox & Vanden Berghe 1996; 895 species) and species listed to occur in Rububu national park (Masharabu 2011; 506 species). 545 of these species were listed to occur in specific vegetation types and have been included into 'species selector' Excel sheets for each vegetation type, including 256 'useful tree species' compiled for useful tree species interactive maps for eastern Africa (the VECEA map; URL www.vegetationmap4africa.org) or continental africa (URL www.worldagroforestrycentre.org/our_products/databases/useful-tree-species-africa). A standardized nomenclature was applied to the species lists by combining information from the Taxonomic Name Resolution Service (http://tnrs.iplantcollaborative.org/TNRSapp.html) with information from the African Flowering Plants database (URL http://www.ville-ge.ch/musinfo/bd/cjb/africa/recherche.php?langue=an), thereby allowing full referencing between species lists and tables with documented uses and environmental services of tree species and full referencing with the Agroforestry Species Switchboard (http://www.worldagroforestry.org/products/switchboard/index.php/name_like/melia%20volkensii).

The vegetation classification system obtained for Burundi was re-confirmed with the VECEA regional classification system based on documented correspondences from literature. Once the correspondence between vegetation typologies was re-confirmed, species known to occur in Burundi (i.e. the masterlist of 2367 species) and also known to occur in particular vegetation types in other countries, but that were not listed to the same vegetation type in Burundi were allocated to the Burundi vegetation types, using a methodology developed for the VECEA map. This methodology was particularly useful for the eastern part of Burundi where available references listed only a relatively small subset of characteristic species. In 2015, the Burundi map (Figure 2) was fully integrated into the VECEA map and its species selection and distribution tools made available from URL www.vegetationmap4africa.org

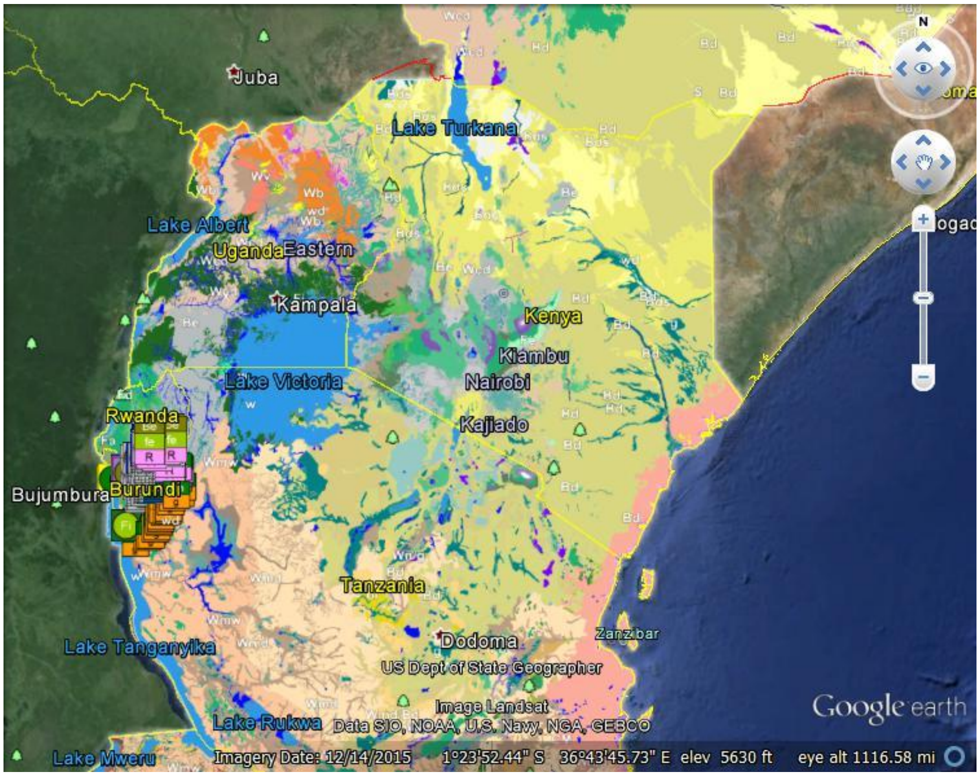


Figure 2: Burundi vegetation map

10.5 Appendix 3: Methodology for policy dialogues

The format of the participatory workshop for the policy dialogues was designed on the premise of the scalability of the benefits from the district level to the national level, with recognition of the constraining policy factors to fully foresee the free flow of these benefits. This scenario can be visually articulated through an hourglass with recognition that the household benefits of increased adoption of trees on farm, could be scaled up through to landscape benefits. It is, however, the policy environment that provides the enabling environment through the removal of the constraints inhibiting the scalability of trees on farm. The workshop design explored the key policy areas identified from the district dialogue and carried them through to the national discussion to establish their relevancy in inhibiting the scaling up adoption of trees on farm.