IKI Trees on Farms Investment Scenarios:

Target 1: Integrate Well-managed Indigenous Tree into Coffee-banana Systems in Mt Elgon

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1. Introduction

Uganda has experienced a sharp decline in forest cover, from 24% in 1990, to 9% in 2015. To mitigate this, the country has prioritised forest restoration as envisaged in existing targets provided in vision 2040, subsequent National Development Plans (I, II&III), and the National Forestry Plan (2011/12-2021/22), in which the national target is to restore forest cover to 24% (1990 levels) (IUCN, 2020). Uganda made a commitment to restore 2.5 million hectares of deforested and degraded land by 2020 under the Bonn Challenge. In a recent assessment, The Government of Uganda has identified over 8 million hectares of land that could potentially be restored through several afforestation and agroforestry activities (MWE and IUCN, 2016).

Agroforestry is the practice and science of the interface and interactions between agriculture and forestry, involving farmers, live- stock, trees and forests at multiple scales. Interactions between trees and other components of agriculture may be important at a range of scales: in fields (where trees and crops are grown together), on farms (where trees may provide fodder for livestock, fuel, food, shelter or income from products including timber) and landscapes (where agricultural and forest land uses combine in determining the provision of ecosystem services) (Coulibaly et al., 2017; Noordwijk et al., 2016).

Integration of trees on farmlands as an agroforestry intervention brings forth one of the most viable options of mitigating land degradation which is reported to be highest under annual cropping systems. The latest IUCN (2016) report puts degradation on annual cropping systems at 17 – 86.8 mt. ha^{-1} yr^{-1} as compared to 19.6 –44.9 mt. ha^{-1} yr^{-1} and 25.1 –27.9 mt. ha^{-1} yr^{-1} in the coffee and banana systems, respectively (MWE and IUCN, 2016). These figures suggest that integration of a perennial component in a cropping system subdues the rate of degradation by stabilizing the soil structure, a factor that can be greatly improved by optimizing the integration of trees on croplands.

The Sustainable Development Goals, in putting a strong emphasis on the environment, recognize the close link between human well-being and a healthy, stable natural environment

Public incentives are policy instruments given in various forms to stimulate specific actions and behavioral changes in target groups. Some examples of these mechanisms are the direct payments or grants against results (pay for performance), credits and guarantees (conditional loans), tax relief (tax reductions with credits), and technical assistance. Adapted from different sources, including Haltia and Keipi (1997), Waggener (1985), and Wunder et al. (2008)
(Zamora-Cristales et al., 2022)

Nature-based solutions are Actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human wellbeing and biodiversity benefits IUCN 2016
(Zamora-Cristales et al., 2022)

Definition of Nature-based Solutions
Nature-based Solutions are defined as “actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."

2. Overarching goal of Nature-based Solutions
The goal of Nature-based Solutions is “to support the achievement of society’s development goals and safeguard human well-being in ways that reflect cultural and societal values and enhance the resilience of ecosystems, their capacity for renewal and the provision of services;

Nature-based Solutions are designed to address major societal challenges, such as food security, climate change, water security, human health, disaster risk, social and economic development”

2. Background and context

The project Trees on Farm (TonF) which seeks to transform agriculture into an enhancer of biodiversity through increasing the share of tress on farm which will ultimately lead to increased biodiversity in the farmlands was piloted in the Bugisu sub-region in Eastern Uganda (Figure 1). The sub-region consists of 6 districts namely, Bududa, Bulambuli, Manafwa, Mbale, Namisindwa and Sironko with an estimated population of 1,000,000 people according to the National Population Census of 2002. The principal city in the region, Mbale City is located about 245 km from Uganda’s capital Kampala. Notably, this region also borders Kenya at a significant landmark, Mountain Elgon (Elevation, 4,321 m above sea level) according to Uganda Investment Authority (UIA), 2018. The high altitude of the region gives a unique climate pattern which favors the high value coffee species (*Coffea arabica*). In Uganda, Bugisu sub-region is most famous for production of arabica coffee normally in mixed systems with trees and other crops such as banana, ground nuts, bush or climbing beans, as well as cereals like wheat, barley, maize, and sorghum.

The coffee-banana system is the most predominant agricultural system in the highland area of Bugisu sub-region. The two main crops (coffee and banana) are mainly intercropped with Irish potatoes, peas, beans fruits and other horticultural crops. On the other hand, the lowlands are characterized by groundnuts, maize, sorghum, millet, cotton, soyabeans, bush beans, sweet potatoes, sunflower, and rice.

The region is also crisscrossed with a good road network to border posts of Suam and Lwakhaka which increases access to markets hence driving cash-crop production. Also, the location of the region around mountain Elgon with a 3frican National Park promoted tourism as another economic activity. In addition to the beautiful scenery, the park has a diversity of animal species including buffaloes, antelopes, forest monkey, elephants and many more animal species. The Park is also a home to 299 bird species with some locally endemic to the Mountain Elgon area. The mountain is a significant watershed for several rivers such as River Sipi on which the famous Sipi falls are located (UIA, 2018). Other tourist attractions include hot springs in some craters on the mountain as well as an ancient cultural painting near a trail head in Budadiri, in addition to the renowned Imbalu dances which mark an initiation into adulthood of the male children.

The region is also endowed with several processing plants that are not only in the mining industry but also in the manufacturing and agro-processing sectors. Notably, the two largest Coffee cooperative unions in Uganda are in the area and are responsible for coffee value addition before export through Mombasa port in Kenya. The region also has several maize processing plants where the products generated have a ready market in Kenya and the Republic of Southern Sudan. According to National Statistics, the production of maize is estimated about 60,000 metric tons per district whereas that of beans is estimated at 25,000 metric tons. This makes the region a food basket for the whole East African region (Uganda Bureau of Statistics, 2020).

In this study, we discuss the costs and benefits associated with the current practices (Business as Usual Scenarios) as well as the costs and benefits that might be realized if farmers are to integrate Trees on Farm (TonF) options for improved livelihoods and/or biodiversity conservation. The three targets, each developed for a land-use system are:

- Target I: Maintain or integrate at least 30% of indigenous tree species on farmlands in the coffee and banana system;
- Target II: Increase tree cover at landscape level without interfering with farm operations through guided and systematic integration of TonF options; and
- Target III: Alternative species to eucalyptus promoted leading to a diversified woodlot system.

3. Methodology and data

3.1. *General assumptions for modelling investment costs*

All farmers' costs are expressed on the basis of a single hectare for a single year, for all the annual crops, two planting and therefore harvesting seasons have been considered across all the targets. On the other hand, institutional costs have been expressed on the basis of single nursery bed of 1 ha capable of supplying seedlings, capacity building and related services to 100 farmers with a single hectare each. The current US $ rate (1 US $ = Ugx 3700) has been used in all the financial estimations whereas the prevailing local market prices have been used for estimating the values of the component crops and farm inputs in the system.

Under the baseline scenario of Target 1, 2 annual crops are integrated; beans and maize at an average spacing of 0.5x0.5m and 1x1m hence a population density of 40,000 and 10,000 plants, respectively per hectare per season. Therefore, for the 2 seasons in a year the density has been multiplied by 2 after which all configurations are deduced on an annual basis. The perennial crops, coffee and banana on the other hand are spaced at 5x5m and 6x5m hence a plant density of 400 and 278 plants per ha, respectively. Also, in this scenario, trees are normally randomly scattered within the landscape at a density of 50 *P. americana*, 200 *M. Lutea*, 100 *G. robusta* and 80 *E. grandis* trees.

In scenario 2, the two annual crops, maize and beans and the two perennial crops coffee and banana are maintained, however at new respective spacing, 1x1, 0.6x0.6, 5x5, 6x6m, respectively hence plant densities of 10,000, 27,778, 400 and 278 plants, respectively. In addition to maintain, the available trees, new tree species, 8 *A. coriaria*, 8 *C. Africana* and 8 *M. eminii* trees are introduced at a spacing 40m between rows and 30 m within rows. Also, 200 *C. calothyrsus*, 20 mangoes and 25 avocado trees are introduced alongside the plot boundaries.

On the other hand, in scenario 3, in addition to the 2 annual crops, maize and beans at a spacing of 3x3m and 0.8x0.8m, and 2 perennial crops, coffee and banana at a spacing of 4x4m and 12x12m, respectively, new annual and perennial crops are introduced. These include, groundnuts at 1x1m, pumpkin at 10x10m, and peanuts 1x1m hence densities of 10,000, 100, and 100 plants, respectively.

3.2. *Eliciting farmers preferred attributes for tree species using a Discrete Choice experiment*

A DCE was used to analyze farmers' preferences for different companion tree features in coffee-banana farming systems. In a DCE, respondents are presented with alternative descriptions of a good, differentiated by attribute levels, and are asked to choose one of the alternatives (Holmes and Adamowicz, 2003). To identify contextually relevant attributes and levels, eight key informant interviews with scientists, community leaders, district foresters, and agricultural extension officers were conducted in addition to six focus group discussions with farmers during a preliminary field visit to the study area. Based on their feedback, six attributes with two to six levels that were deemed important in a companion tree were selected (Table 1).

The six attributes and different levels imply a full factorial design with 960 ($5^1 \times 4^2 \times 3^1 \times 2^2$) combinations. Theoretically, each unique combination of attribute levels represents a specific companion tree species. To produce a more manageable experiment, a d-optimal design was used to generate a subset of companion tree species that covers the range of variability between all possible combinations (Hensher et al., 2015). In total, 32 choice sets were included in the design. These choice sets were further divided into four subsets containing eight choice sets each. To reduce the response burden and avoid fatigue, respondents were randomly assigned one of these four subsets, with an even number of households allocated to each of the subsets. A choice set consisted of two alternative companion tree species (A and B) and a status quo (none of the trees) option (Figure 1). The status quo option is provided because a respondent might not prefer either of the companion tree species listed. For a detailed explanation, see Ihli et al. (2022).

Table 1: *Overview of attributes and levels used in the choice experiment.*

Attributes	Definition	Attribute levels
Tree products	Products provided by companion trees	1. Fruit 2. Timber 3. Fuelwood 4. Fodder

Ecosystem services	Regulating services provided by companion trees (i.e. microclimate, soil fertility, pest and disease control, and weed control)	1. Buffering temperature extremes and conserving soil moisture 2. Producing mulch and controlling erosion 3. Fewer problems of White Coffee Stem Borer and Coffee Leaf Rust 4. Suppressing weed growth
Tree growth rate	Growth rate of companion tree species	1. Slow-growing 2. Medium-growing 3. Fast-growing
Seedling price	Cost of one tree seedling of companion tree species	1. 0 Ush (USD 0.00) 2. 200 Ush (USD 0.10) 3. 500 Ush (USD 0.10) 4. 1,000 Ush (USD 0.30) 5. 1,500 Ush (USD 0.40)
Shade quality	Shade quality of companion tree species	1. Light, mottled shade 2. Dense shade
Tree height	Maximum tree height of companion tree species	1. Short (< 5 m) 2. Tall (> 5 m)

Notes: Seedling prices are displayed in Ugandan shilling (Ush). US dollars are indicated in parentheses. Exchange rate: 1 USD = 3,700 Ush (May 2019).

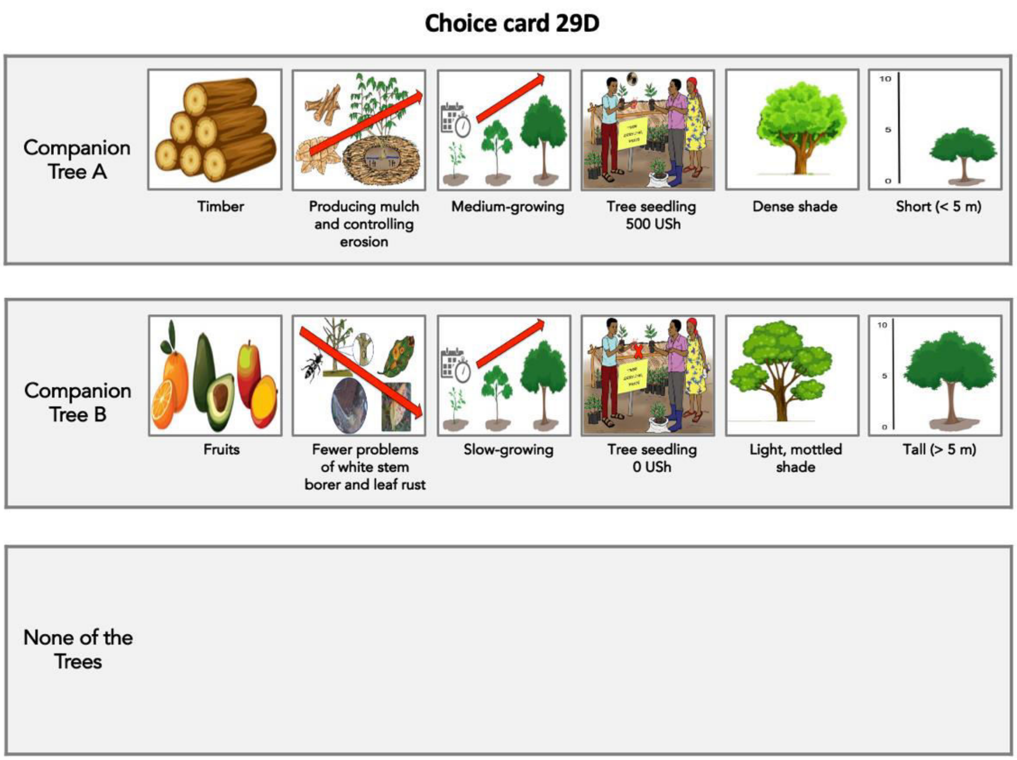

Figure 1: Example of a choice card.

4. Investment costs associated with different scenarios for Target 1

4.1. Description of the investment scenarios

4.1.1. The BAU scenario of coffee-banana systems in Mt Elgon

We consider the business-as-usual scenario as a state which assumes that there will be no mitigation policies, measures or interventions that will be implemented beyond those that are already in operation hence no significant change in farmers' livelihood strategies, attitudes and priorities. The BAU is an essential baseline/point of reference/counterfactual construction on which change can be measured i.e., the change in investment costs associated with integrating trees on farms under different agroforestry regimes or designs.

The BAU scenario consists of trees that are not optimally managed due to poor spacing, no pruning or thinning, and poor shade management. Figure 2 illustrates a typical shaded coffee-banana system in Mt Elgon. The few scattered trees in the system are not properly managed leading to poor yields on crops, especially coffee, and has an overall impact on the crop-water usage. Trees are not optimized for the benefit of the farmers since the focus is on shade alone. The BAU is constrained by a lack of capacity for proper management of trees, poor extension system, poor quality and unreliable germplasm, too much shade and increased competition, and lower crop yields (UCDA, 2019).

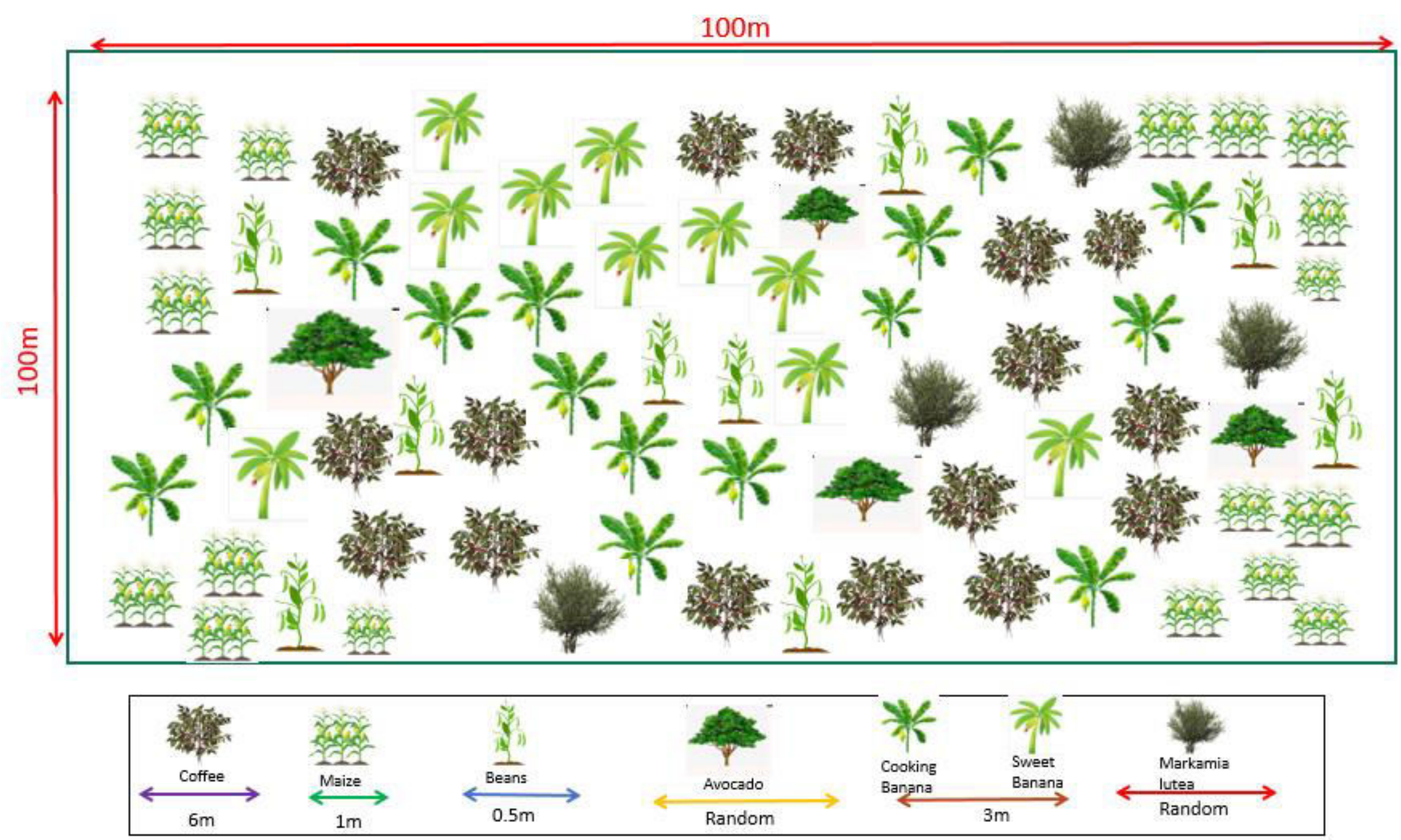

Figure 2: Target I, BAU scenario of a typical coffee-banana system in Mt Elgon

If there is no deliberate intervention or shift in policy and the BAU scenario persists, poor management of trees and selection of species that are unsuitable for the context can lead to a reduction crop yields of perennials (i.e., banana and coffee) and annuals (i.e., maize and groundnuts) through several ways. Trees compete with crops for sunlight due if they have large canopies if not pruned, and also soil moisture and nutrients if they do not have a deep tap root system (Bayala and Prieto, 2020). As a result, farmers will have low income due to less sales obtained from the little harvest made from all the components. Since the trees are not optimized for ecosystem services such as soil conservation, there is a risk of continuous increase in soil erosion. This has a negative compounding effect of increasing the risk of siltation and thereby reducing both water quantity and quality downstream.

4.1.2. The alternative scenarios with well managed shade trees

The broad target that we focus on in this study was to transform the current coffee-banana systems by integrating well managed indigenous species. The specific target is to integrate about 30% of indigenous tree cover. Scenario 2's main objective is to optimize the BAU through TonF interventions that increase indigenous tree species and improve their management regime to provide tangible and direct benefits such as food, fodder, timbers, and shade for coffee. indigenous trees and improving the management of existing trees in the landscape. This can be in line with the national programmes under the Ministry of Agriculture. Scenario 3 involves integrating high biodiversity tree species from e.g., The IUCN Red List Index that is used by the Convention on Biological Diversity (CBD) to monitor progress towards achieving the Aichi Targets[1]. ed list, endangered trees, indigenous trees, trees that are important for foraging or breeding sites).

4.2. Annual investment costs associated with the BAU scenario

This section summarizes the investment costs in the BAU scenario as well as the incremental costs associated with the potential adoption of two alternative agroforestry interventions. Table 2 provides a picture of what the investment costs are like in the BAU with the assumption that farmers continue with their current practices as outlined in the previous section. This implies that for the 30-year period considered for this target there are no institutional costs since there are not shifts in mitigation policy or interventions. In terms of the nominal costs that are incurred by farmers. On the other hand, farmers incur recurring annual costs associated with production of both annual and perennial crops. The total costs per hectare that farmers typically incur are around US$ 824, with the majority of these expenses (US$537) being for the purchase of inputs such as seeds, chemical fertilizers, and manure. A total of US$286 allocated for labor provision for various activities such as land preparation, weeding, harvesting etc. As we consider only the nominal values, investment costs are constant across the 30 years.

Table 2: Costs associated with the BAU Scenario for Target 1 in US$ per ha per year

Investment costs in the business as usual scenario	**Time horizon**			
	Year 1	*Year 10*	*Year 20*	*Year 30*

[1] https://www.iucnredlist.org/

Institutional costs	Total costs of establishing nurseries	$0.00	$0.00	$0.00	$0.00
	Total costs for training & capacity building	$0.00	$0.00	$0.00	$0.00
	Total Institutional Costs (USD)	$0.00	$0.00	$0.00	$0.00
Costs to the farmers	Total labor costs to farmers per ha	$286.37	$286.37	$286.37	$286.37
	Total input costs to the farmer per ha	$537.31	$537.31	$537.31	$537.31
	Total individual costs to farmers per ha	$823.68	$823.68	$823.68	$823.68

4.3. Incremental costs associated with integrating indigenous TonF for food security, nutrition and income

Table 3 and Figure 4 show the institutional costs and individual farmer costs associated with optimizing the BAU into two alternative scenarios. The main objective under scenario 2 is to ensure that the indigenous tree species introduced will provide tangible benefits to households in the form of income and food security and nutrition. This objective is matched to the attributes preferred by farmers in Mt Elgon based on experimental field evidence highlighted in the methods section 3.2 and more in detail in Ihli et al., (2021).

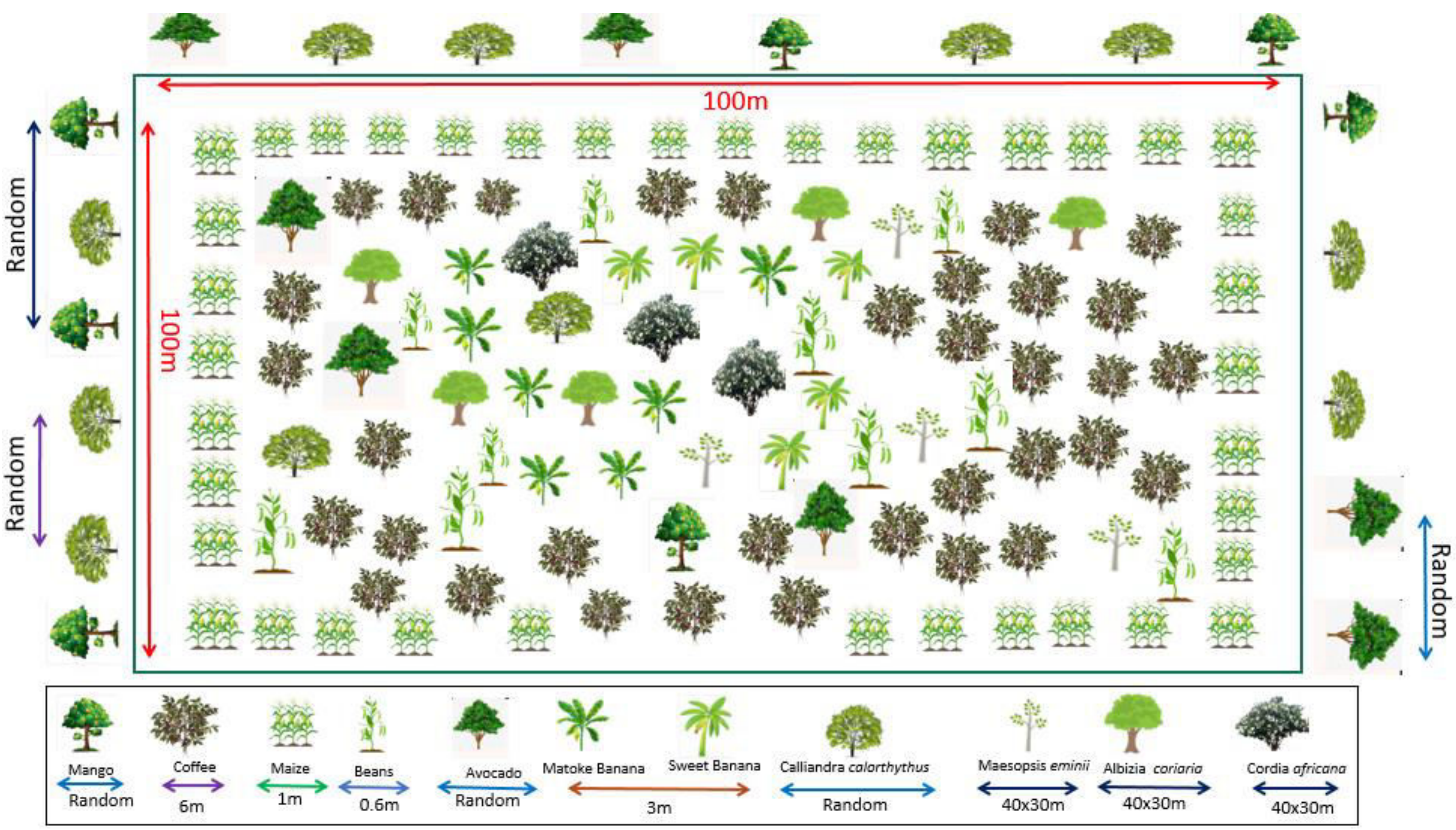

Figure 3: Target I, scenario 2 of a typical coffee-banana system in Mt Elgon

4.4. Investment costs for institutional services

We start by looking at the institutional services that need to be in place to create an enabling environment of transforming the BAU into the alternative scenarios 2 and 3, shown in Table 3 and Figure 4. The total investment costs needed in the first year to provide sufficient institutional services for both scenarios 2 and 3 are just over US$ 41,000. Of this cost, about US$ 14,550 will be required for establishing a 1 ha tree nursery that supplies quality tree planting material for indigenous tree species with a capacity to produce about 100,000 seedlings every year to supply approximately 100 farmers, each with an average landholding of about 1 ha of land.

Table 3: Costs associated with the integration of trees associated with scenario 2 and 3

Institutional costs	BAU	Scenario 2 and Scenario 3			
		Year 1	*Year 10*	*Year 20*	*Year 30*
Costs of establishing and/or maintain nurseries	$0	$14,550.81	$7,431.08	$7,431.08	$7,431.08
Costs for training and capacity building	$0	$26,486.49	$2,648.65	$2,648.65	$2,648.65
Total institutional costs	$0	$41,037.30	$10,079.73	$10,079.73	$10,079.73

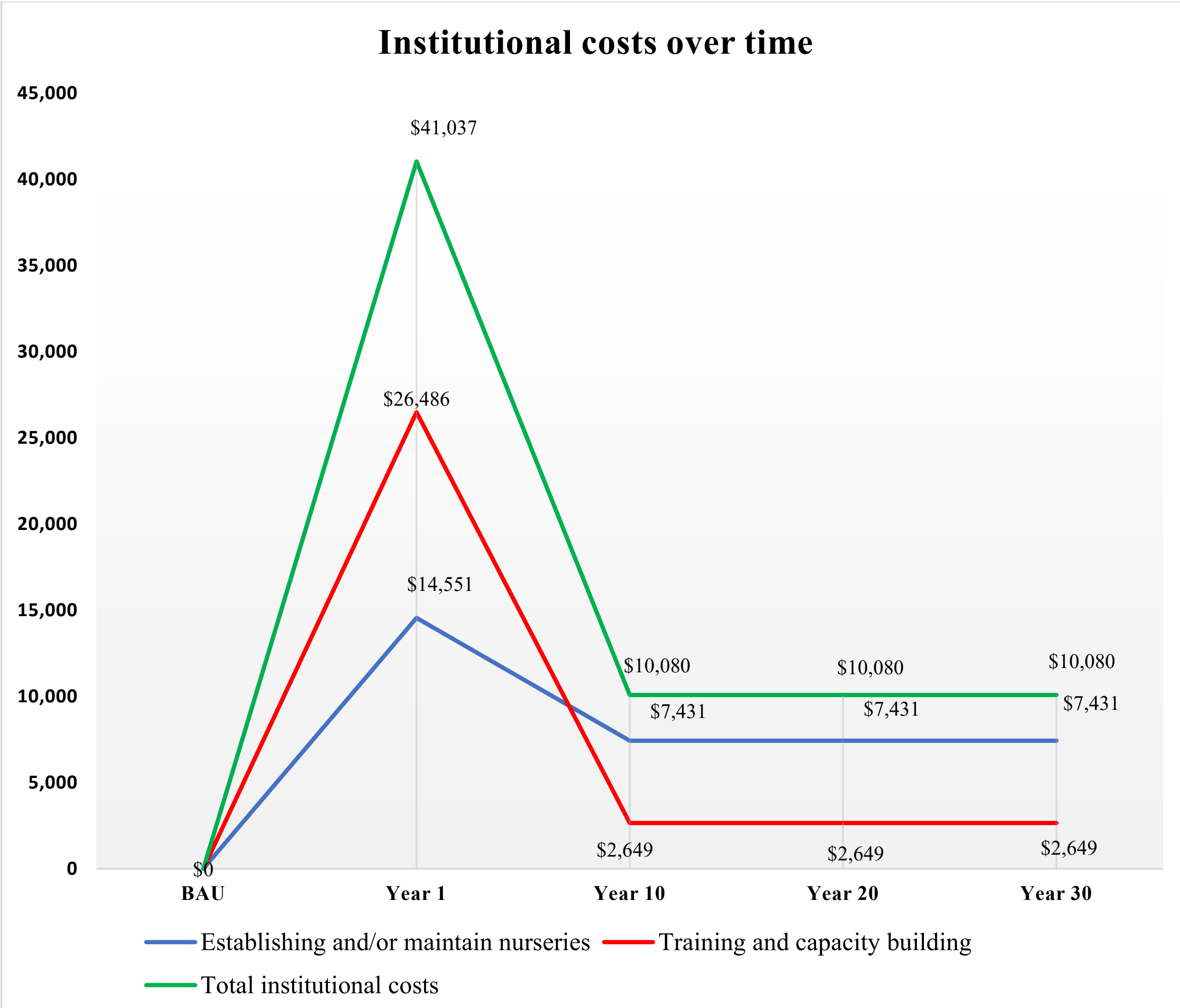

Figure 4: Institutional costs over time in (US$)

The investment costs associated with establishing a tree nursery for indigenous species include the purchase of the land and its development (i.e., construction of an office, shed, beds and irrigation systems) as shown in Table 4. A recent study, Odoi et al. (2019), using data from interviews of key informants from Mt Elgon and other districts in Uganda shows that there are indeed limited sources of high quality germplasm available for farmers mainly due to lack of knowledge on seedling production technologies. Furthermore, the study also asserts that existing tree nurseries are mostly dominated by exotic tree species such as *Eucalyptus grandis*, *Pinus caribaea*, and *P. oocapa* with little or no attention to indigenous tree species. So, such an investment is vital in creating an enabling environment for farmers to adopt indigenous tree species. These costs, in nominal terms, will reduce to around US$ 10,000 in the 10th, 20th and 30th year of operation to cover the costs of maintaining the nurseries.

Table 4: Investment costs in nursery establishment and maintenance in the first year

	Unit/measurement	Costs associated with Scenario 2 and 3
Establishment of a nursery		
Purchase plot for nursery	ha^{-1}	$5,405.41
Nursery plot development	ha^{-1}	$1,351.35
Shed construction	ha^{-1}	$810.81
Substrate preparation	ha^{-1}	$1,351.35
Irrigation system	ha^{-1}	$1,351.35
Bed construction	ha^{-1}	$45.68
Bed sowing	ha^{-1}	$70.27
Weeding	ha^{-1}	$35.14
Bed sorting	ha^{-1}	$35.14
Root pruning	ha^{-1}	$35.14
Nursery materials and inputs		
Lump sum		$2,929.19
Seedlings	kg	$1,459.46
Pesticides	Liters	$40.54
Grass for mulching (on top)	Bundles	$24.32
Fungicides	Liters	$108.11
Forest soil	Trip	$324.32
River sand	Trip	$43.24
Machete / panga	Piece	$8.11
Rakes	Piece	$8.11
Polythene bags / potting bags	kg	$689.19
Spade	Piece	$8.11
Mats	Piece	$81.08
Top rails	Piece	$21.08
Poles	Piece	$56.76
Watering cans	Piece	$13.51
Slasher	Piece	$10.81
Hoes	Piece	$5.41
Tarpaulin	Piece	$27.03
Other (pricking)	per pot	$81.08
Other (potting)	per pot	$135.14
Personnel and Administration (nursery)		
Communications	Per Year	$162.16
Nursery management (Personnel)	Per Year	$972.97
Total costs of establishing nurseries		$14,550.81

The remaining US$ 26,000 for the first year will be for training and capacity development of extension staff from government, NGOs, community-based organizations and lead farmers that will support the day to day operations of the nursery. Capacity development the process by which individuals, groups, and institutions develop, enhance, and organize their systems, knowledge, and resources. Capacity development and training have been a critical method of building community capacity to adopt agroforestry practices. Some of the recommended management practices by the Uganda Coffee Development Authority (UCDA) for farmers to be trained on include proper canopy management, weed control, mulching, irrigation, soil and water conservation, use of cover crops, training or bending and pruning and de-suckering (UCDA, 2019). The costs however reduce to about US$ 2,648 representing about (90% decrease compared to the first year) in the 10^{th}, 20^{th} and 30^{th} year. Table 5 shows the breakdown of the training and capacity development that are needed and their respective costs.

Table 5: Investment costs in training and capacity development in the first year

Training and capacity development in agronomic practices		**Costs associated with Scenario 2 and 3**
Project and training manager	per year	$2,594.59
Training of Gvt/extension staff	All sessions per year	$1,081.08
Training of lead or promoter farmers	All sessions per year	$216.22
Training of other staff	All sessions per year	$216.22
Training of farmers	All sessions per year	$162.16
Stationary for all training	All sessions per year	$54.05
Meals and per-diems for participants	All sessions per year	$6,486.49
Meals and per-diems for trainers	All sessions per year	$540.54
Vehicle hire for trainers (preparation, training and field visits)	Days	$1,891.89
Training and capacity building (Gender mainstreaming)		
Project and training manager	All sessions per year	$2,594.59
Training of Gvt/extension staff	All sessions per year	$1,081.08
Training of lead or promoter farmers	All sessions per year	$216.22
Training of other staff	All sessions per year	$216.22
Training of farmers	All sessions per year	$162.16
Stationary for all training	lump	$54.05
Meals and perdiems for participants	session	$6,486.49
Meals and perdiems for trainers	session	$540.54
Vehicle hire for trainers (preparation, training and field visits)	Days	$1,891.89
Total costs for training & capacity building		$26,486.49

4.5. Incremental investment costs to potential adopters

Table 6 shows the farm level costs associated with integrating trees under alternative Scenarios 2 and 3. As shown in Table 2, the total individual costs to farmers of producing one hectare in the BAU scenario are US$ 823.68. Integrating well manged trees increases for food security (scenario 2) and for biodiversity (scenario 3) increases the total individual costs to farmers to US$1,415.03 and $ 1,361.52, respectively in the first year. In terms of incremental costs, potential adopters will incur an additional cost of about US$ 592 (approx. 71%) under scenario 2 and US$ 568 (approx. 65%) under scenario 3. This means that integrating trees on farmers' fields is associated on average, with a 68.5% increase in the individual costs to farmers costs per hectare in the first year. The costs however reduce to about US$ 1,053 representing about (28% increase compared to the baseline) in the 10^{th}, 20^{th} and 30^{th} year.

Table 6: Incremental costs associated with the integration of trees in scenario 2 and 3

Type of investment costs		Time horizon			
		Year 1	*Year 10*	*Year 20*	*Year 30*
BAU	Total labor costs to farmers per ha	$286.37	$286.37	$286.37	$286.37
	Total input costs to the farmer per ha	$537.31	$537.31	$537.31	$537.31
	Total individual costs to farmers cost to the farmer per ha	$823.68	$823.68	$823.68	$823.68
Scenario 2	Total labor costs to farmers per ha	$624.21	$407.99	$407.99	$407.99
	Total input costs to the farmer per ha	$790.82	$645.42	$645.42	$645.42
	Total individual costs to farmers cost to the farmer per ha	$1,415.03	$1,053.41	$1,053.41	$1,053.41
Scenario 3	Total labor costs to farmers per ha	$624.21	$407.99	$407.99	$407.99
	Total input costs to the farmer per ha	$737.31	$645.42	$645.42	$645.42
	Total individual costs to farmers cost to the farmer per ha	$1,361.52	$1,053.41	$1,053.41	$1,053.41

Integrating trees in agricultural lands can require careful management and thus tends to be labour intensive and costly to farmers in terms of additional inputs required. More specifically, integrating well managed trees increases labor costs by from about US$ 286.38 in the BAU to about US$ 624.21, which is about a 118% increase in cost per ha for both scenarios 2 and 3. The breakdown of costs of labor requirements are illustrated in Table 7 and Table 8.

Table 7: Labor costs investments associated with the integration of trees

Type of farmer related costs	**Unit/measurement**	**BAU**	**Scenario 2**	**Scenario 3**

Labor costs associated with annual crops				
Annual crop sowing: maize	Mandays ha^{-1} $year^{-1}$	$16.15	$16.15	$16.15
Annual crop sowing: short beans	Mandays ha^{-1} $year^{-1}$	$10.77	$10.77	$10.77
Permanent shade pruning	Mandays ha^{-1} $year^{-1}$	$16.77	$16.77	$16.77
Weeding	Mandays ha^{-1} $year^{-1}$	$14.90	$14.90	$14.90
Pesticide application [Purchase/labor]	Mandays ha^{-1} $year^{-1}$	$71.28	$71.28	$71.28
Manure application	Mandays ha^{-1} $year^{-1}$	$13.51	$13.51	$13.51
Harvesting	Mandays ha^{-1} $year^{-1}$	$12.78	$12.78	$12.78
Labor costs associated with permanent trees/perennials (Coffee, Cocoa, Banana, Timber.)	Mandays ha^{-1} $year^{-1}$			
Pruning and de-suckering	Mandays ha^{-1} $year^{-1}$	$5.05	$5.05	$5.05
Pesticide application	Mandays ha^{-1} $year^{-1}$	$71.28	$71.28	$71.28
Manure application	Mandays ha^{-1} $year^{-1}$	$13.51	$13.51	$13.51
Harvesting	Mandays ha^{-1} $year^{-1}$	$40.38	$40.38	$40.38
Labor costs associated with integrating TonF interventions	Mandays ha^{-1} $year^{-1}$			
Digging planting holes	Mandays ha^{-1} $year^{-1}$	-	$135.14	$135.14
Transplanting	Mandays ha^{-1} $year^{-1}$	-	$81.08	$81.08
Watering	Mandays ha^{-1} $year^{-1}$	-	$81.08	$81.08
Mulching	Mandays ha^{-1} $year^{-1}$	-	$13.51	$13.51
Pesticide application	Mandays ha^{-1} $year^{-1}$	-	$13.51	$13.51
Manure application	Mandays ha^{-1} $year^{-1}$	-	$13.51	$13.51
Total labor costs to farmers per ha		$286.38	$624.21	$624.21

Table 8: Commercial input costs associated with the integration of trees

Input costs associated with annual crops		BAU	Scenario 2	Scenario 3
Sowing seeds (Beans)	kgs ha-1 year-1	$36.49	$36.49	$36.49
Sowing seeds (Maize)	kgs ha-1 year-1	$30.55	$30.55	$30.55
Herbicides	liters ha-1 year-1	$64.86	$64.86	$64.86
Top dressing fertilizer (NPK)	kgs ha-1 year-1	$54.05	$54.05	$54.05
Other (Ground nuts)	kgs ha-1 year-1	-	-	-
Other (Pumpkin)	seedlings	-	-	-
Input costs associated with permanent trees/perennials (Coffee, Cocoa, Banana, Timber species, etc.)				
Manure costs	kgs ha-1 year-1	$75.68	$75.68	$75.68

Fruit Fly traps	units ha-1 year-1	$243.24	$243.24	$243.24
Pesticides	liters ha-1 year-1	$32.43	$32.43	$32.43
Input costs associated with integrating trees				
Seedlings	nits	-	$145.41	$91.89
Manure costs	kgs ha-1 year-1	-	$81.08	$81.08
Mulching	ha-1 year-1	-	$27.03	$27.03
Total input costs to the farmer per ha		$537.31	$790.82	$737.31

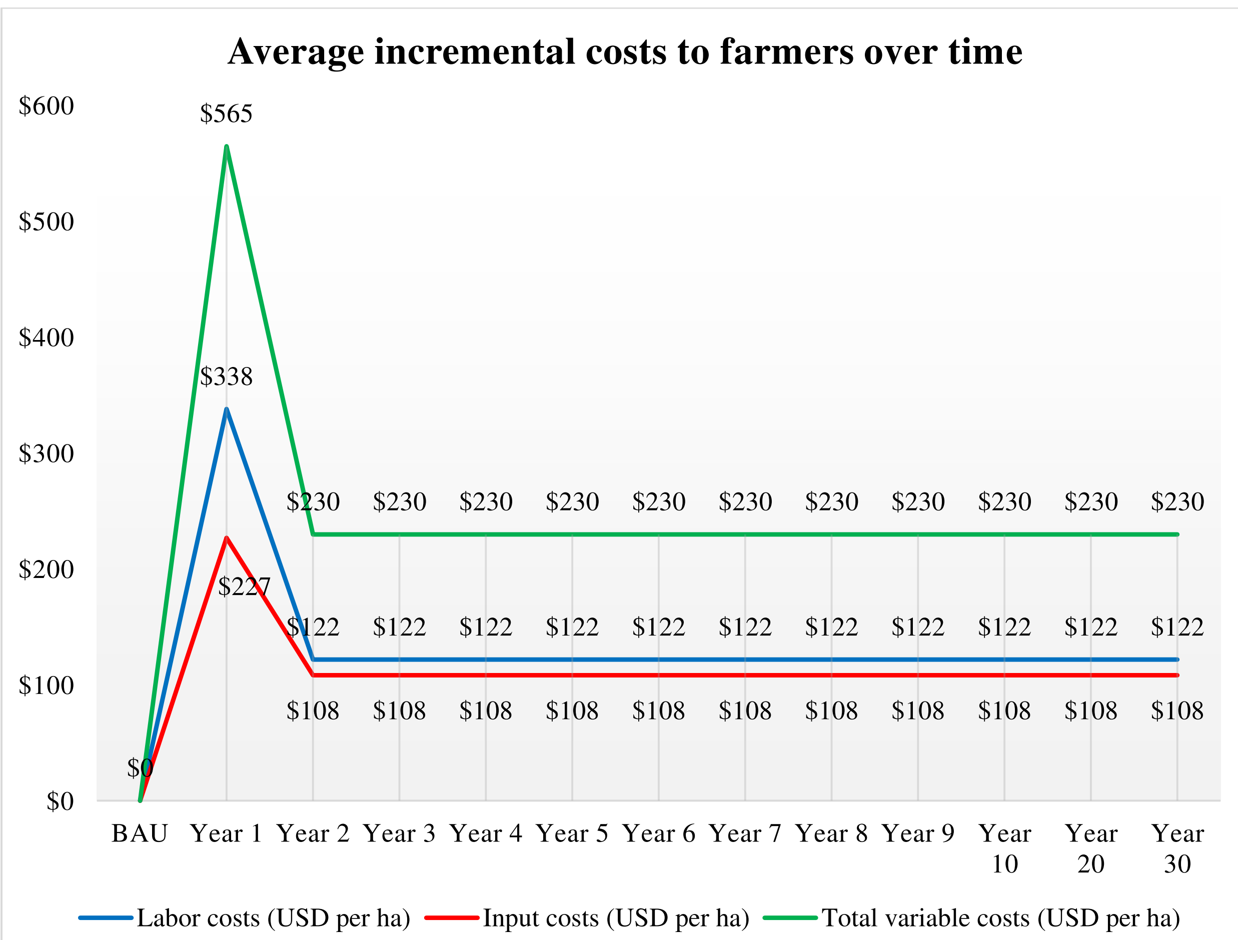

Figure 5: Incremental costs to farmers over time (in USD per ha per year)

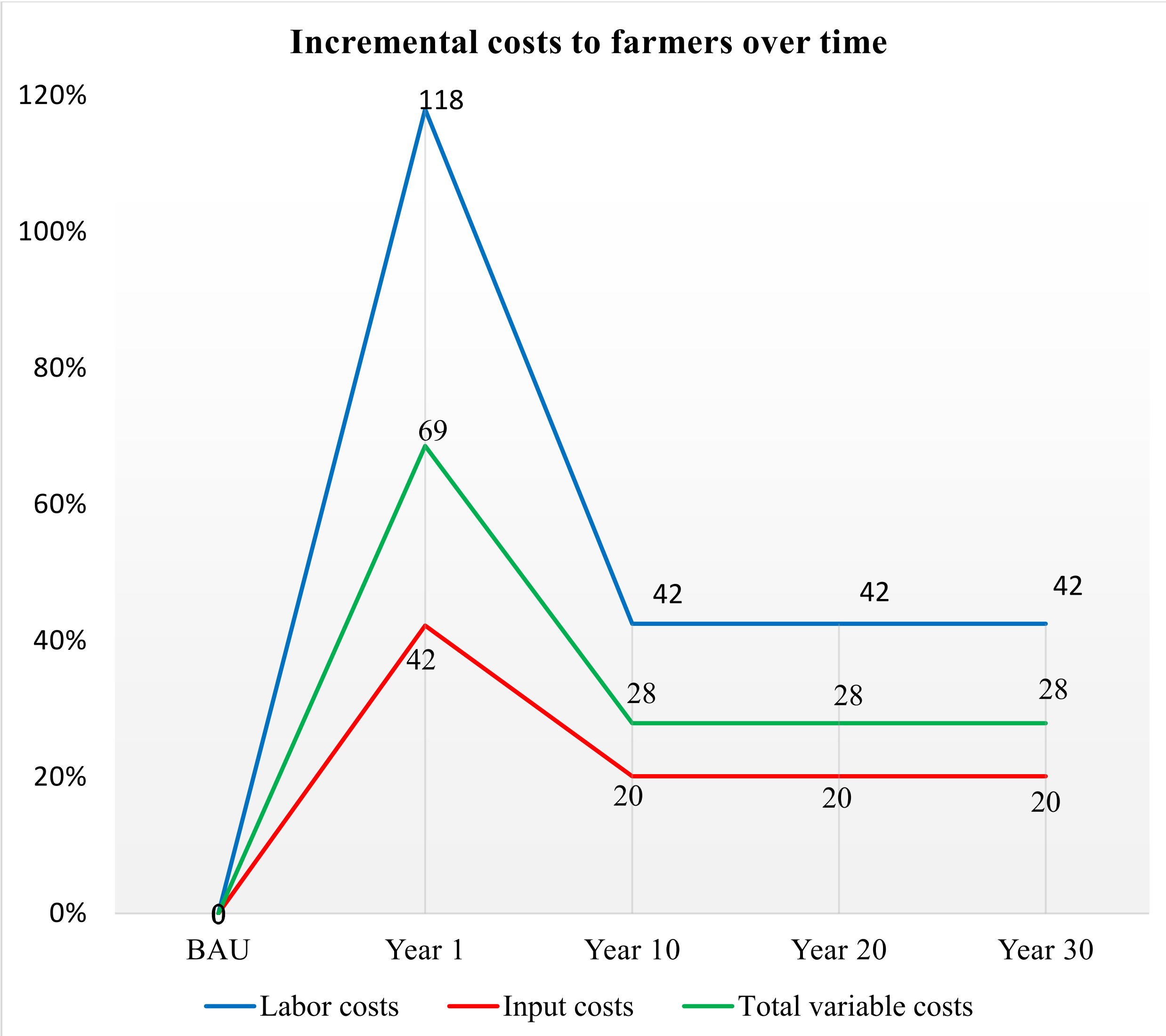

Figure 6: Incremental costs to farmers over time (in % per ha per year)

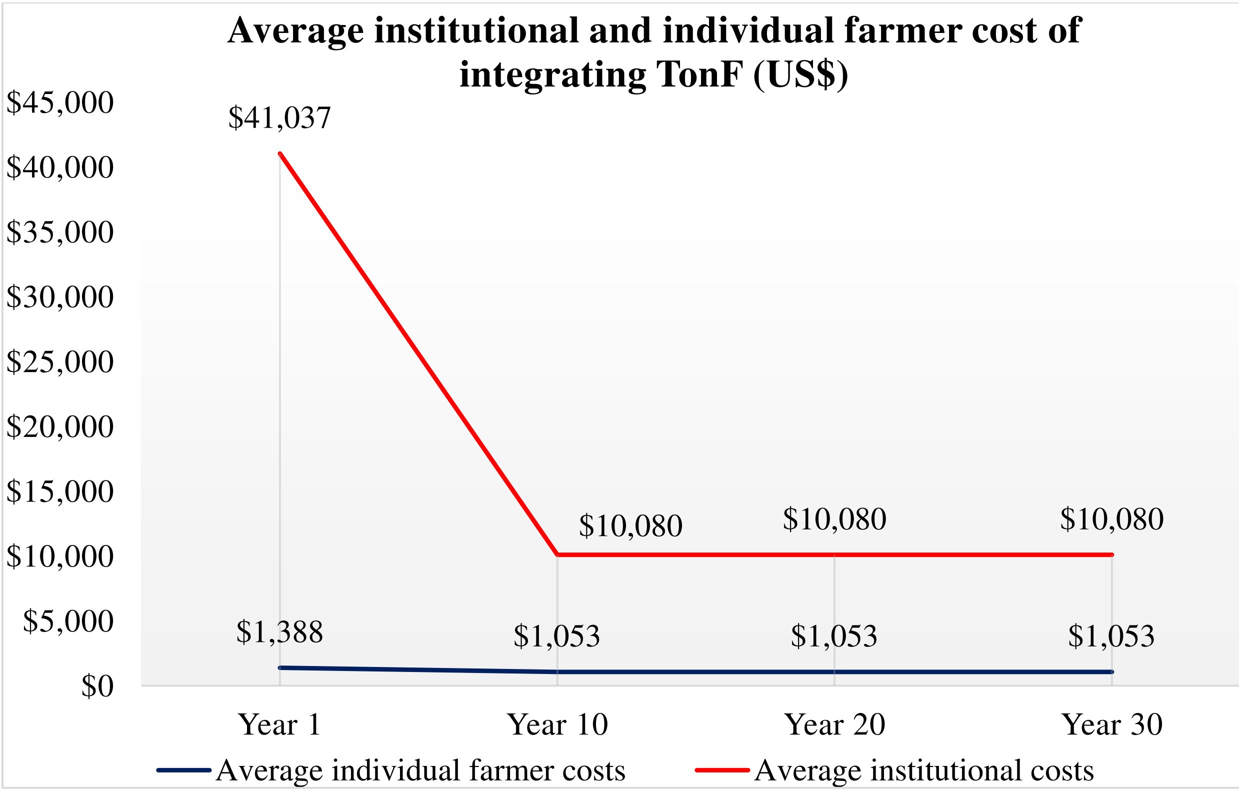

Figure 7: Average institutional and individual farmer costs associated with integrating TonF

Discussion and conclusions

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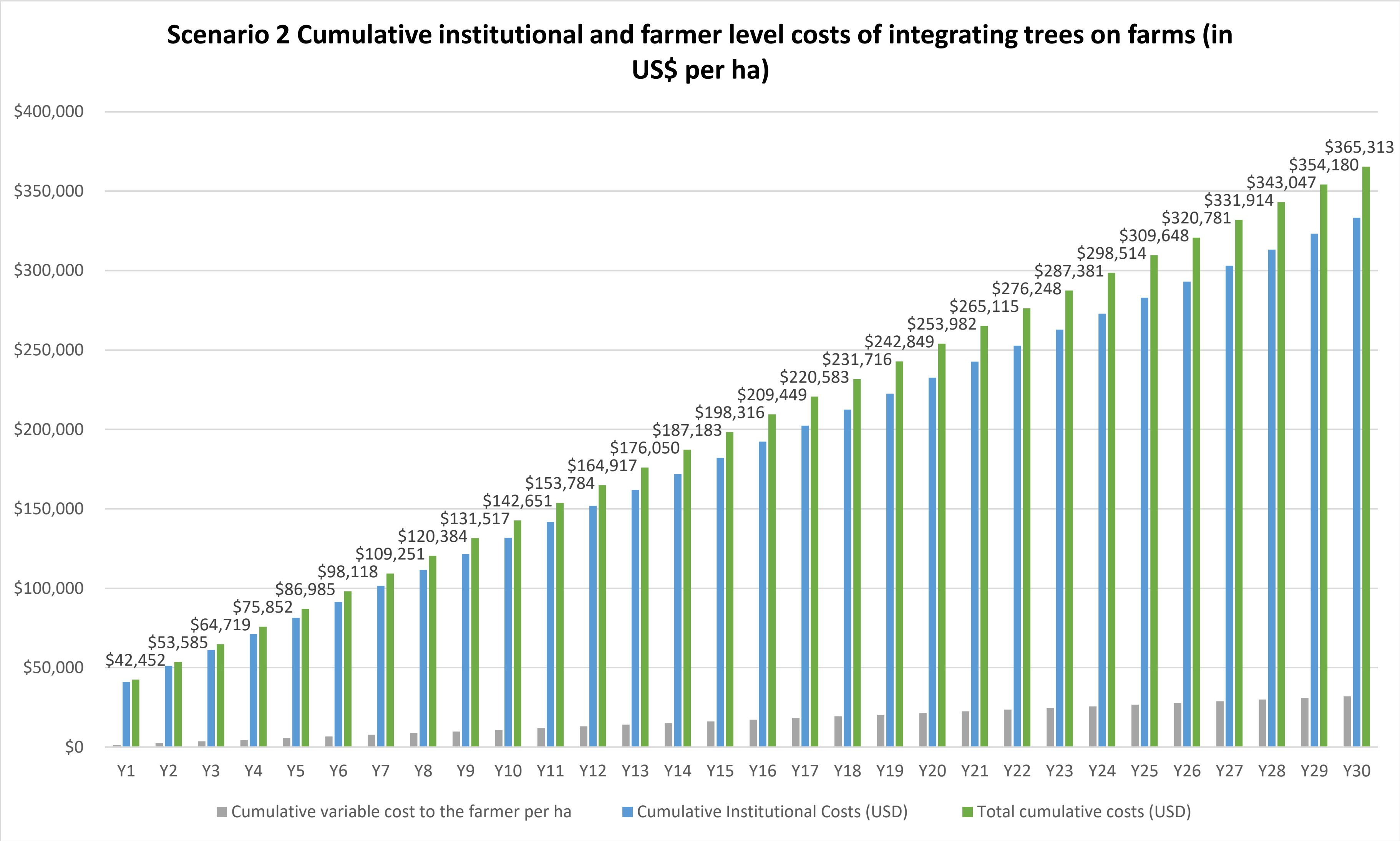

Figure 8: Cumulative institutional and farmer level costs of integrating trees on farms (in US$ per ha): Scenario 2

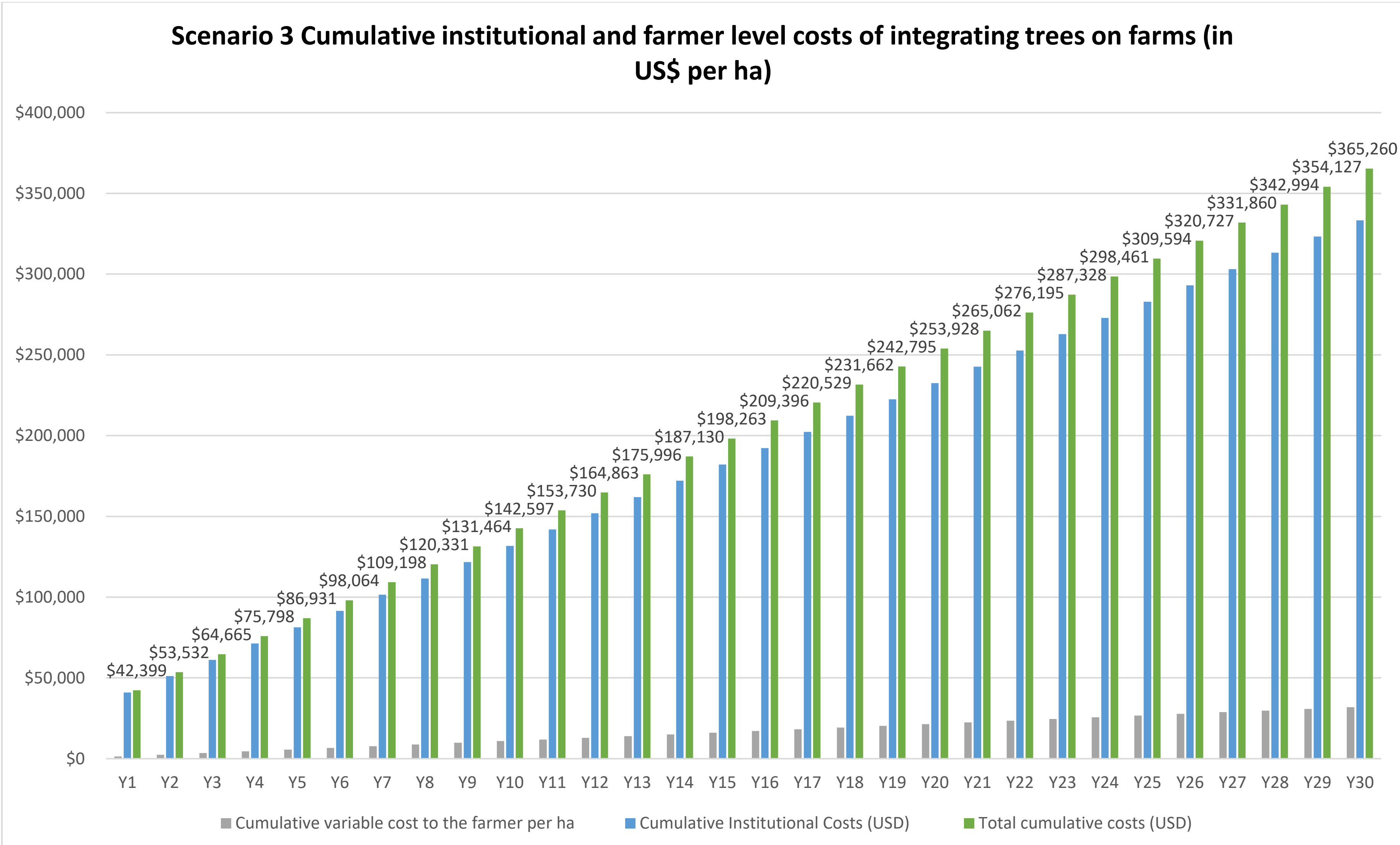

Figure 9: Cumulative institutional and farmer level costs of integrating trees on farms (in US$ per ha): Scenario 3

Target I: Scenario 3 investment costs associated with "Biodiversity TonF practice" Adjusting of BAU scenario to include more high biodiversity tree species (red list, endangered trees, indigenous trees, trees that are important for foraging or breeding sites)

Scenario 3 focuses on incorporation of specifically high biodiversity trees, like scenario 2, the farmer can still get more benefits in the long term compared to farmers under BAU scenario (Table 3). In this scenario (Scenario 3), the overall investment costs will include institutional costs as well as slightly higher individual costs to farmers compared to BAU scenario. Much as the integration of the high biodiversity trees on farmlands affects the net benefits in the first years of investment, the unprecedented benefits that arise in Year 10 if the assumption of harvesting half the number of the trees in the system by year 10 is held are a strong motivation for adoption of scenario 3 by the farmers.

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Ugandan government visualizes restoring the forest cover from 9% (1.8 million hectares) to 24% of the total land area by 2040 (National Planning Authority, 2013). Uganda also pledged to restore 2.5 million hectares of deforested land by 2020 in the Bonn Challenge (Ministry of Water and Environment, 2016). These commitments, to be realized, require combined efforts from several actors and well-thought interventions, for example, incentivized tree planting.

Tree planting can be influenced by several factors including demographic (education, sex, age, religion, etc.) and socio-economic factors (land, income, and skills) (Iiyama et al., 2017; Kakuru et al., 2014; Kallio, 2013; Kulindwa, 2016). Incentive schemes further influence some people to plant, grow, and conserve trees (Foundjem-Tita et al., 2013; Frayer et al., 2014; Ruseva et al., 2015).

Figure

Figure 10: Target I, BAU scenario of a typical coffee-banana system in Mt Elgon

BAU scenario of a typical coffee-banana system in Mt Elgon

We discussed today that
Set up a meeting with Laurent to discuss the content of the policy briefs (preferably early next week)
You to start writing up a first draft of the results of the TonF target cost estimations using the 3 targets for Uganda and the 1 target for Rwanda. I would like to get first the story line right between the tree of us (you, Phil and myself),

- **what have we learned about institutional costs vs farmers costs?**
- **what have we learned about incremental costs when the objective of agroforestry not only includes food security, but also environmental and biodiversity objectives**
- **what are the key take home messages once institutions and programs move from tree planting projects to integrated farming programs with tree and tree products being an essential component**

1. Summary of conclusions

In summary, Target I which seeks to maintain or integrate at least 30% of indigenous tree species on farmlands in the coffee and banana system is associated with introduction of new tree species in 2 subsequent scenarios. This comes at a cost to both the farmers and any institutions that maybe supporting TonF integration. If the latter costs are not borne by the farmers, the difference caused by integration of TonF options in the BAU is about US $ 300. Although this may not attract investment due to increased cost of production, the future returns in the TonF scenarios which greatly outweigh those in the BAU if explain to farmers can be a good incentive for TonF adoption.

Similarly, Target II, which focuses on "increasing tree cover at landscape level without interfering with farm operations through guided and systematic integration of TonF options" the additional costs to the farmer affects the net benefits in the initial years of investment. However, the net value of the integrated trees after maturity far outweighs the BAU net benefits and can serve as incentive for TonF integration by the farmer. Moreover, during training and capacity building, farmers should be educated about the financial returns associated with TonF options in addition to the environmental benefits of both scenarios 2 and 3.

For Target III, the focus is on finding and promoting alternative species to eucalyptus hence leading to diversified woodlot systems. The alternative equally fast-growing species identified include, *N. cadamba*, *M. eminii*, *G. robusta*, *M. lutea* among others. The investment costs modelling indicated that farmers may suffer a negative return on investment in the first years. However, with time, the profits accumulated in diversified woodlots far outweigh the returns in eucalyptus mono-woodlots.

Attributes

A DCE was used to analyze farmers' preferences for different companion tree features in coffee-banana farming systems. In a DCE, respondents are presented with alternative descriptions of a good, differentiated by attribute levels, and are asked to choose one of the alternatives (Holmes and Adamowicz, 2003). To identify contextually relevant attributes and levels, eight key informant interviews with scientists, community leaders, district foresters, and agricultural extension officers were conducted in addition to six focus group discussions with farmers during a preliminary field visit to the study area. Each group consisted of five to eight farmers from the Bulambuli and Kapchorwa districts. Based on their feedback, six attributes with two to six levels that were deemed important in a companion tree were identified (Table 3). The first attribute relates to the products (i.e., provisioning services) provided by companion trees, namely fruit, timber, fuelwood, and fodder. The ecosystem regulating services provided by companion trees are the second attribute, with four levels of microclimate (i.e., buffering temperature extremes and conserving soil moisture), soil fertility (i.e., producing mulch and controlling erosion), pest and disease control (i.e., decreasing incidence of white coffee stem borer and coffee leaf rust[i]), and weed control (i.e., suppressing weed growth). The third attribute is the growth rate of companion trees, which was defined in three levels of slow- (>15 years), medium- (10–15 years), and fast-growing (5–10 years). The fourth attribute is the seedling price, categorized into five levels of 0 USh (US$ 0.00), 200 USh (US$ 0.10), 500 USh (US$ 0.10), 1,000 USh (US$ 0.30), and 1,500 USh (US$ 0.40). The fifth attribute concerns the shade quality provided for coffee in two levels of light and mottled shade and dense shade. The final attribute is the maximum tree height of the companion tree, either short (< 5 m) or tall (> 5 m).

[Table 9 near here]

The six attributes and different levels imply a full factorial design with 960 ($5^1 \times 4^2 \times 3^1 \times 2^2$) combinations. Theoretically, each unique combination of attribute levels represents a specific companion tree species. To produce a more manageable experiment, a d-optimal design was used to generate a subset of companion tree species that covers the range of variability between all possible combinations (Hensher et al., 2015). In total, 32 choice sets were included in the design. These choice sets were further divided into four subsets containing eight choice sets each. To reduce the response burden and avoid fatigue, respondents were randomly assigned one of these four subsets, with an even number of households allocated to each of the subsets. A choice set consisted of two alternative companion tree species (A and B) and a status quo (none of the trees) option. The status quo option is provided because a respondent might not prefer either of the companion tree species listed. Moreover, illustrations were included in the choice sets to increase respondents' comprehension of the attributes and levels (Figure 3). Prior to conducting the DCE, it was explained to the respondents that the drawings used hypothetical companion tree species rather than real ones. The attributes and levels used were carefully described. Respondents were also informed that the choices they made in the experiment would not have any immediate consequence. It was clarified that the results would be used more generally to better understand farmers' preferences for particular characteristics of companion trees to inform project design or future project implementation.

[Figure 11 near here]

Concerning the selected attributes, our main hypotheses and conjectures are the following. Farmers were expected to have positive preferences for tree products and the ecosystem regulating services provided by companion trees. Companion trees can provide high-value marketable products and diversify income sources. At the same time, they can provide agronomic benefits, such as pest and diseases control, soil nutrient enrichment and microclimate regulation (Jha et al., 2014; Smith Dumont et al., 2019). Furthermore, based on previous research, farmers were expected to prefer fast- and medium-growing companion trees, short trees, and trees that provide light, mottled shade (Jacobson et al., 2018; Valencia et al., 2015). Shorter trees are considered to be easier to manage than taller trees, specifically to maintain appropriate shade. In contrast, the branches of taller trees may be more difficult to trim to regulate shade. Moreover, in the event of a fall, large trees may cause greater damage to coffee shrubs. Concerning the shade quality of companion trees, referring to shade density and pattern, farmers were expected to prefer shade that permits the passage of light in a mottled pattern and contributes to a fresh microclimate; conditions that support coffee bush growth and development and sustainable yields (Valencia et al., 2015). Finally, concerning seedling price, rational farmers were expected to prefer tree seedlings that are sold at a lower price (Jacobson et al., 2018). Farmers were also expected to have a negative preference for slow-growing companion trees (Verdone and Seidl, 2016).

Beyond these general hypotheses, subsets of hypotheses were formulated regarding expected interactions between farmer preferences for tree attributes and risk and time preferences, in addition to expected interactions between farmer preferences in relation to ecosystem regulating services and altitude. Farmers with higher levels of risk and loss aversion were expected to place less relative importance on improving soil fertility (i.e., mulch and erosion control). This assumption mirrors Teklewold and Kohlin (2011), who showed that a high degree of risk aversion has a negative effect on the adoption of labor-intensive soil conservation practices such as erosion control. They hypothesized that more risk-averse farmers are reluctant to sacrifice short-term returns for less certain long-term benefits of conservation practices. Farmers with higher levels of risk aversion were also expected to prefer fast-growing companion trees compared to those with lower levels of risk aversion (Clot et al., 2017). Moreover, impatient (i.e., high discount rate) and present-biased farmers were expected to prefer fast-growing companion trees with more readily available benefits than those of slow-growing companion trees (Clot et al., 2017; Clot and Stanton, 2014).

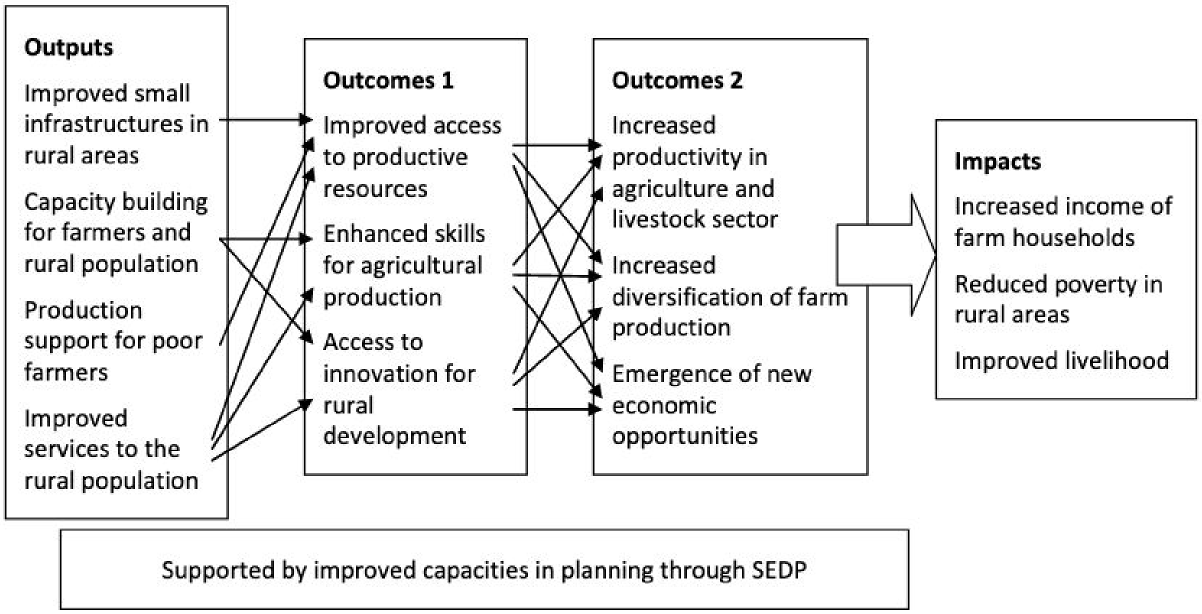
In terms of farmer preferences regarding the ecosystem regulating services provided by companion trees and their relation to altitude, farmers with farms located at lower altitudes were expected to attribute a higher relative importance to ecosystem regulating services than did farmers at high altitudes. According to Bunn et al. (2015) and Laederach et al. (2013), climate change affects Arabica coffee most at lower altitudes, since these areas are exposed to higher temperatures, prolonged drought, and higher water and heat stresses. Coffee pests and diseases, which are already problematic, are likely to be aggravated by the effects of further climate change and variability. Specifically, more variable seasonal patterns can affect regular vegetative and reproductive growth cycles, and are likely to alter related biotic constraints such as pests and diseases (Davis et al., 2012; Liebig et al., 2016; Schroth et al., 2000). In this context, farmers at lower altitudes were hypothesized to require a wider set of ecosystem regulating services and to more highly value all ecosystem regulating services that help sustain coffee production by buffering climate change impacts and increasing the resilience of coffee production.

Table A1: Assumptions used to calculate revenue for each land use and restoration intervention.

Restoration transition	Assumptions behind revenue calculation
TAG→AFCL	1. Sale of crops is the only source of revenue and revenue is calculated from simulated crop yield regression. 2. Maize and beans can be sold at market for 515 RWf and 374 RWf per kilogam, respectively. 3. Agroforestry would add 300 additional trees per hectare and tree fodder would be used to feed livestock reducing annual cost of organic fertilizer. 4. We assume the interaction between trees and crops can alter crop yields by -35% to 60% compared to yields of traditional agriculture. 5. At the end of 20-year rotation trees are harvested and their volume is sold for timber for a price of 10,900RWf per cubic metre.
PME→IMP	1. Poorly managed woodlots stock 1100 trees per hectare. We assume improved management plants 1,600 trees per hectare. 2. Trees are coppiced every 7 years if the wood is being produced for fuelwood, but timber is harvested at the end of a 28-year rotation interval. 3. After year 1 we assume 30% of seedlings are replaced for PME and 15% for IME, a process known as "Beating-up". 4. After the 4th year 250 trees are removed from the site and sold for poles for 2,000 RWf per pole. 5. Fuelwood is sold for 8,800 RWf per steere and timber is sold for 10,900RWf per cubic metre.
DL→NR	1. Natural regeneration occurs on deforested land that generates no revenue. 2. We assume natural regeneration occurs over a period of 20 years. 3. Carbon can be sold on the voluntary carbon market for a price of $7.50 or 4,950RWf per ton of CO_2e.
DL→PF	1. Protective forests are located on deforested land that generates no revenue. 2. We assume a thirty year timy horizon. 3. Carbon can be sold on the voluntary carbon market at the end of 30 year for a price of 4,950RWf per ton of CO_2e
	Notes: All revenue streams were discounted at a rate of 7%.

3.6 Impact chains: how to allocate benefits?

The benefits of the small projects implemented through PSARD are manifold. The following sketch is an attempt to illustrate the situation of PSARD. Besides the lack of solid quantitative information about benefits, another issue is proper allocation to interventions and policies. We will discuss benefits and their attribution for each small project category in chapter 5.



(Guenat and Uyen 2014)

Shade trees should be planted in rows throughout the coffee garden and care should be taken to avoid too many shade trees as they may compete with coffee for moisture and nutrients in addition to over-shading the coffee trees. It is recommended that the spacing of the shade trees be approximately 20-40m apart depending on the tree species and expected canopy profile. In warmer and drier areas such as the mid-north of Uganda, shade tree spacing should be planted at shorter distances, but after recommendation from the field extension officer, while on site. Once shade trees are established it is necessary to carry out proper pruning to allow for sufficient aeration as well as sunlight in the field. This is important in order to avoid high relative humidity that results from too much shadow due to plant congestion in the garden - a condition favorable to disease and pest development such as coffee leaf rust and/or black coffee twig borer. Shade trees should be pruned at the beginning of the rainy season. Keep the trees at a maximum height of 4-5m to facilitate easier management. Advantages and disadvantages of shade trees are listed in Table 4.

Advantages of shade trees

●● Shade trees protect the coffee bushes from heavy rainstorms and hailstorms.

●● Shade trees reduce the intensity of wind speeds and soil erosion and act as windbreakers.

●● Shade trees protect coffee plants from high solar radiation and limit evapotranspiration

●● Shade trees limit weed growth.

●● Reduces decay rate of organic matter in soil.

●● Increases biodiversity by promoting higher populations of birds, predators of coffee pests and

pollinators of coffee plants thereby improving fruit formation.

●● Shade trees slows down coffee cherry ripening, thereby improving bean density and cup flavour.
●● Shade trees play a role in efficient utilization of nutrients by taking up leached nutrients that are outside the reach of the coffee tree root zone and returning these nutrients to the top soil through litter fall which acts as mulch.
●● When leguminous trees are used as shade trees, they fix nitrogen from the air to restore soil fertility and structure.
●● Shade trees provide diversified income from products like firewood and also the pruned shade tree branches provide fuel for farm activities like the drying furnace

and cooking

●● Reduces plant metabolism and encourages more regular flowering.

●● Helps to stabilize the soil, reduce soil erosion and water runoff.

●● Shade trees is a requirement for sustainable coffee farming.

Disadvantages of shade trees
Shade trees may compete with coffee for nutrients and water.
●● Requires regular loping and thinning which is labour intensive.
●● Shade if poorly managed reduces photosynthetic activity and causes elongation of internodes both of which result in lower yields.
●● Risk of Coffee Leaf Rust is more rampant in coffee with shade trees.

COFFEE FARM ESTABLISHMENT AND FIELD MANAGEMENT PRACTICES

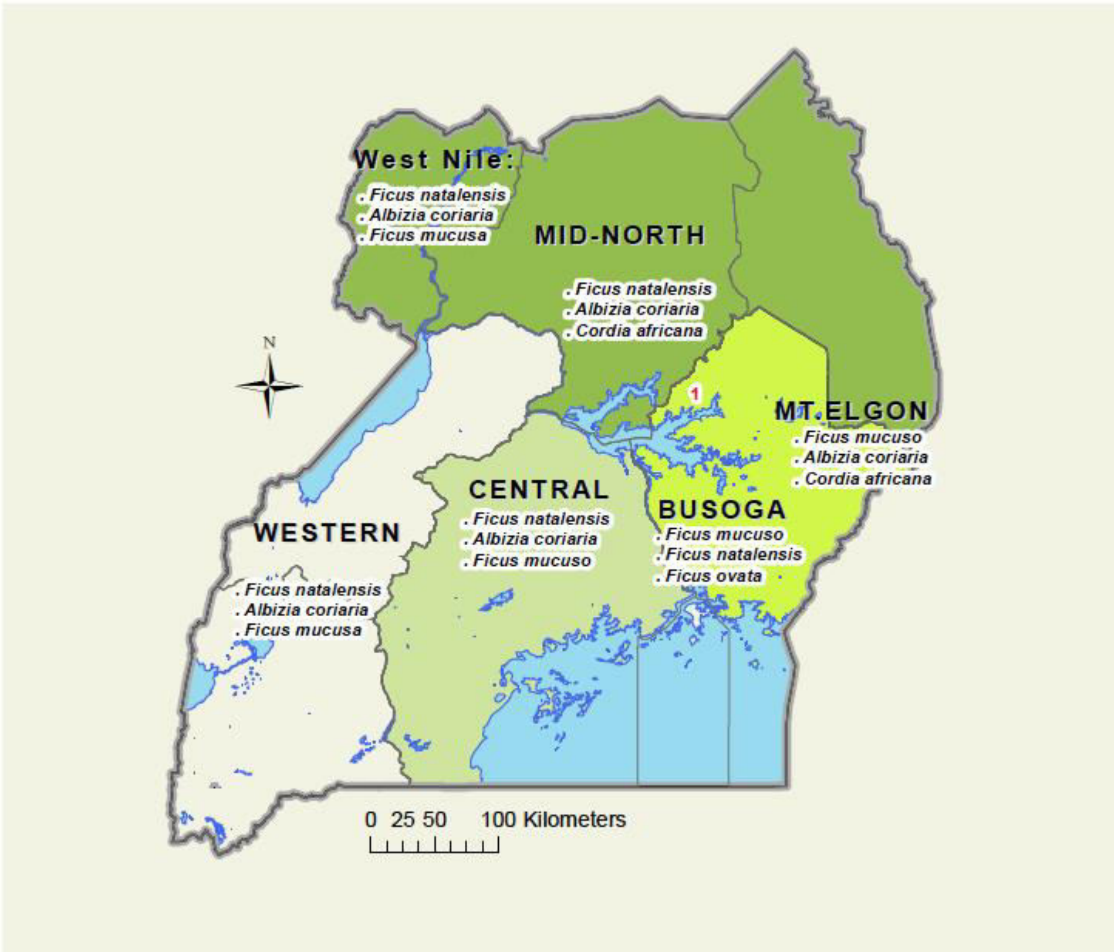


Figure 7. *Map of Uganda showing recommended shade trees by region*

Table 6. Labour use (mean man-hours/ha) for banana and coffee in Kisekka sub-county, Uganda.

Crop	Family	Hired	Total
Banana	781	214.1	995.1
Coffee	460	194.0	654.4
Maize	515	-	518.1
Beans	-	-	564.6
Sweet potatoes	-	-	709.5
Cassava	-	-	708.2
Groundnuts	-	-	646.6

(Frison et al., 1998)

[i] White coffee stem borer and coffee leaf rust are the major pests and diseases in coffee systems in the study area.