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A study on silvopastoral knowledge and practices of cattle farmers of the Biological Corridor of Talamanca's volcanic chain (Costa Rica):

Identification of the determining factors for management and adoption of silvopastoral systems

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Thesis report
Double-degree Msc Agroecology
95th promotion

November 2016

Abstract:

Costa Rica is known for its exemplarity in terms of nature conservation. However, the majority of its agricultural land-use is dominated by livestock farming. Silvopastoral systems (SPS) have been investigated for their capacity to restore ecological connectivity in agro-landscapes while maintaining a sustainable cattle production. That is also the challenge that is facing the Biological Corridor of Talamanca's Central Volcanic chain (CBVCT) where cattle farming is the dominant agricultural activity in terms of surface. This study aimed to describe the types of SPS used in cattle farms of the CBVCT as well as tree uses and services perceived by cattle farmers of this area. The next objective was to identify determining factors for the adoption and management of silvopastoral practices. 30 semi-structured interviews were conducted with cattle farmers. Traditional SPS were the most represented in our sample such as live fences (LF) and tree isolated in pastures (TIP). Farmers mentioned 48 tree species to be present in their SPS but only few species were recurrent between the farms. Farmers valued trees for their economic, environmental and social value but the economic benefits were the most mentioned. In a general way, farmers reported limitations to the SPS management but mentioned as well breaks for SPS adoption. We established a farm typology that we related to a typology of knowledge on SPS. Dairy farmers tended to have smaller extensions and higher animal load than extensive meat farms. They were also characterized by a more limited knowledge on SPS while extensive farmers presented knowledge more focused on tree species diversity and SPS. Each type of farms presented different opportunities for SPS adoption and improvement. We identified LF as a very interesting feature as they could be multipurpose and could permit to increase the efficiency of the land-use.

Key words: silvopastoral systems, farmer perception, determining factors, Biological Corridor of Talamanca's Central Volcanic chain (Costa Rica)

Acknowledgments:

“Mucha gente pequeña, en lugares pequeños, haciendo cosas pequeñas, puede cambiar el mundo” Asociación Ecológica La Pastora (Costa Rica)

First of all I would like to thank all the farmers that accepted to participate in this study. Thank you for sharing your knowledge and being so generous. A special thanks to Francini Vega and Rodolfo Salas who gave me a huge help by coordinating interviews with the producers from their associations

I would like to thank the GAMMA program and all the people that welcomed me during those six months. Thanks to Jimena Esquivel, my supervisor in GAMMA for her precious advices and support during all the thesis process. Thanks to Nancy Merlo that accompanied me for the first interviews. Your experience and support was very enriching.

I would like to thank Nicole Sibelet that accepted to look at my project and shared her expertize on the methodology in social sciences. Thank you, Nayara Moreira for sharing the experience of your thesis and always being so encouraging.

I would like to thank staffs of CATIE which were very nice with me and especially Eduardo Corrales for his help concerning the statistical analyses.

I would like to thank Alexis Annes from Purpan that accepted to be my supervisor in France and gave me very valuables contribution on my thesis writing. Additionally, I would like to thank Egbert Lantinga, my supervisor from Wageningen University. This experience of double-degree was incredibly rich for me.

At the end, I would like to thank all the students and interns of CATIE that I had the chance to meet during this stay. Thank you for your support and all the things we shared. I learned so much from the Latin American culture. I would like to thank my family and friends that supported me in this amazing adventure.

¡Pura Vida!

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Abbreviations:

ASORPOA: Asociación de Productores Agropecuarios de Santa Cruz de Turrialba (Association of Producers of Santa-Cruz of Turrialba)

CATIE: Centro Agronómico Tropical de Investigación y Enseñanza (Tropical Agriculture Center of Research and Education)

CBVCT: Corredor Biológico Volcánica Central Talamanca (Biological Corridor of Talamanca's Central Volcanic chain)

FB: Fodder Bank

FONAFIFO: National Fund for Forestry Financing (Fondo Nacional de Financiamento Forestal de Costa Rica)

GDP: Gross Domestic Product

GHG: Greenhouse Gasses

HDI: Human Development Index

LF: Live fences

MAG: Ministerio de Agricultura y Ganadería (Ministry of Agriculture and Livestock)

MBC: Mesoamerican Biological Corridor

PES: Payment for ecosystem services

SOM: Soil Organic Matter

SPS: silvopastoral systems

SPSi: intensive silvopastoral systems

SWOT analysis: Strength Weakness Opportunity and Threats analysis

TIP: trees isolated in pastures

UCR: University of Costa Rica

General Introduction:

Costa Rica is a small country of Central America that is recognized by the international community for its efforts in terms of nature conservation. Costa Rica is considered as exemplary in the domain of sustainable development for its high investments in education and health but as well in the environmental sector (NEF, 2016). It is the only country that managed to reverse the deforestation phenomenon in Central America. Indeed between 1970 and 1980, the annual deforestation rate was between 40 000ha and 60 000ha but then, in the 90's, it dropped to 8500ha/year(RAMOS URZAGASTE, 2003).

However, cattle farming is still the dominant agricultural land-use in Costa Rica in terms of surface (RAMOS URZAGASTE, 2003). Cattle farming was recognized as a main driver for deforestation in the Central-American region (MURGUEITIO et al., 2011). It caused the decrease in tree cover in many landscapes leading to land degradation and reduction of agricultural production. After, observing the negative impacts of this intensification, researchers from different institutions started to study a traditional practice in Central-American cattle farms: silvopastoral systems (SPS). SPS can be defined as the interaction of farm animals with grassland and woody perennials species within the same production system (VILLANUEVA; MUHAMMAD; HAENSEL, 2010). SPS were identified as an alternative to counteract the deforestation but as well in restoring land fertility. They can bring many benefits at the farm scale (economic, social and environmental) but also at the landscape scale by restoring ecological connectivity. They could play an important role in the implementation of the Mesoamerican Biological Corridor (MBC) that spreads from Mexico to Panama (RAMOS URZAGASTE, 2003).

The Biological Corridor of Talamanca's Central Volcanic chain (CBVCT) situated in the center of Costa Rica is also part of the MBC. Its agricultural land-use is currently dominated by cattle farming. Today, the challenge of this territory is to reconcile farming activity with ecological connectivity (CHAMAYOU, 2011). Few studies had been leaded to identify farmers' silvopastoral practices and determining factors related to the adoption and management of SPS systems in this specific area. This thesis aims to characterize SPS practices and farmer knowledge on SPS in the CBCVT. The final objective is to study the determining factors and limitations for the adoption and management of SPS in the CBVCT. To reach this goal, semi-structured interviews were conducted with cattle farmers after having reviewed the literature that was available on this theme and region. Both qualitative and quantitative analyses were used to explore the data collected during the interview. Finally, we would propose recommendations to improve SPS adoption and management within the farms investigated.

Chapter 1: SPS in Latin-America and Agricultural context of Costa Rica

1. Agricultural sector and cattle farming in Costa Rica

As this study took place in Costa Rica, we will start by describing the local context of this country of Central America. We will go through general elements and then focus on Costa Rican agriculture and cattle sector activity.

1.1. Costa Rica: general context

Costa Rica is an independent country of Central America bordering with Nicaragua in the north, Panama in the south and Ecuador with ocean frontiers (figure 1). The population in 2013 was 4,875 million of habitants with a density of 75 habitants/km2. The rural population is representing 25% of the total. The population is dominated by descendants from European origins and mixed origins. However, it remains about 1,7% of native people, 1,9% afro-descendants and 0,2% of Chinese origin over the total population (FAO, [n.d.]).

The GDP is about 49 6200 millions of USD where agriculture is counting for 5,6% of the GDP behind the third sector and industry (FAO, [n.d.]). In 2006, agricultural importations represented about 9,1% of the total importations (mainly maize, soybean and wheat were imported in 2011). Concerning agricultural exportations, they represented about 31% of the total of exportation with pineapple, bananas and sugarcane being the main commodities exported in quantity in 2011 (FAO, [n.d.]; FAOSTAT, [n.d.]). It is interesting to observe that although the quantity of coffee exported is very few compared to others commodities cited, it ranks at 4th place in terms of value (FAOSTAT, [n.d.]). This is making this production quite important for the economy of Costa Rica.

Concerning the HDI (Human Development Index), Costa Rica is reaching a value of 0,763 (FAO, [n.d.]). Thanks to the combination of political stability and steady economic and social growth over the past 25 years, Costa Rica reached one of the lowest poverty rates in Latin America and the Caribbean. In 2014, it remained 12% of the population that was considered poor, and 4.6% extremely poor (about half of the Latin America and Caribbean average) (WORLD BANK GROUP, 2016). 19,5% of the poverty is concentrated in rural areas (FAO, [n.d.]).

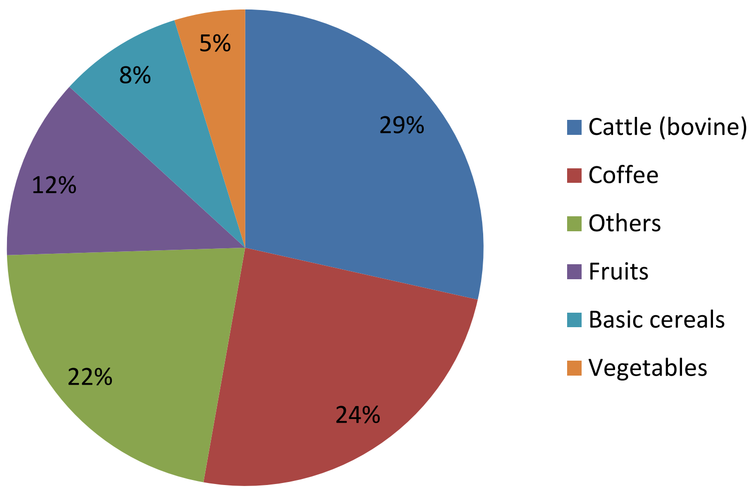
The life expectancy is about 78 years for man and 82 years for women. The alphabetization is very high with a value of 97,4% in 2012. Moreover there is almost no differences between man and women for alphabetization rate (FAO, [n.d.]).

Figure 1: Map of localization of Costa Rica (www.lahistoriaconmapas.com)

1.2. Cattle activity at the national scale

As we saw in the previous introduction, Costa Rica as a quite strong and stable economy compared to the others countries of the area. Agriculture is representing about 35% of the whole country area which means about 1819 thousands of ha. As an indication, forest counts for 51% of the land-use (FAOSTAT, [n.d.]).

Although livestock farming is not mentioned as a main exportation product, it is an important activity for the agricultural sector. In 2014, a national census was carried out for agricultural activities. Resulting that coffee and cattle farming were the main occupations of the farms in Costa Rica as it can be observed in the figure2. This is implying that crops destined to exportation like bananas or pineapples are found in large farms. Moreover, the average farm size for the country is about 26ha where the province of Cartago has the smallest farm size average with 9,7ha and Guanacaste the highest with 54,6ha (INSTITUTO NACIONAL DE ESTADÍSTICAS-INEC, 2015). This shows that the agricultural activity in Costa Rica remain quite small scale.



Other: is including timber plantation, sugarcane, natural forest, ornmental, palmoil, pastures, tubercules,tourism rural and other landuses

Figure 2: Distribution of farms of Costa Rica (%) by production type (INSTITUTO NACIONAL DE ESTADÍSTICAS-INEC, 2015)

Concerning livestock farming, it is dominated by bovine farms. Indeed, 48% of the livestock farms are dealing with bovines, 19% with pigs, 3% with goats and 2% with sheep. The two provinces that have the highest cattle number are Guanacaste and Alajuela located in the northern side of the country. The dairy production concentrates especially in Alajuela whereas the meat is located in Guanacaste, as it is shown in figure 3.

From a land-use point of view, livestock farming represent 33% of the agricultural area where 38% of the farms are double-purpose, 34,1% of the farms produce meat, 20,9% produce milk and 7,1% are dedicated to animal breeding (VERGARA et al., 2015).

In conclusion, cattle farming is representing in important sector of agricultural activity in Costa Rica. A lot of farmers' communities are depending on this activity, and it is bringing dynamism and economic benefits that help them to ensure their livelihood strategies in rural areas. However, it is well known that intensification of cattle farming can lead to massive deforestation, which is an issue that is well known in the region of Central America (FAO, 2009). Costa Rica is a country that is recognized for its efforts to conserve biodiversity

(INSTITUTO NACIONAL DE BIODIVERSIDAD, 2014), thus looking for alternatives to conciliate agricultural activity and biodiversity conservation seem to be very relevant for this country.

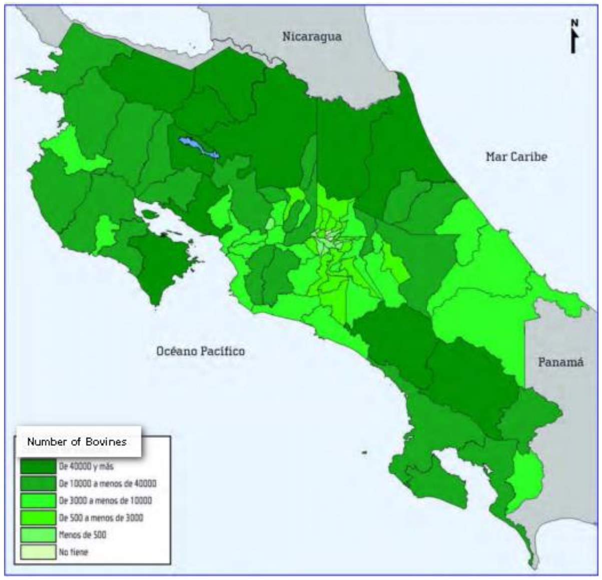


Figure 3: Distribution of bovine animals per district (INSTITUTO NACIONAL DE ESTADÍSTICAS-INEC, 2015)

2. SPS in Latin America

We can define silvopastoral systems (SPS) as an option of agricultural production where woody perennials species (trees, shrubs or palms) interact with herbaceous specie and farm-animals in an integrated system. The aim is to maximize the economic, social and ecological farm benefits (VILLANUEVA; MUHAMMAD; HAENSEL, 2010). Those systems, that at the beginning were traditional practices, drew attention of scientists to answer specific issues of agricultural intensification in Latin America.

2.1. Latin American issues with deforestation and land degradation: how SPS can help?

The tropical areas of Central America and Latin American bring attention to the scientific community because of their vulnerability to the issues of deforestation and land degradation. Indeed, in tropical region, during the years 2000-2005, deforestation rates increased by 8.5% which represent 10,4 million of ha/year. Latin America and the Caribbean continue to account for the largest percentage of forest losses, that reached 4,7% in 2000-2005. The deforestation due to over-grazing is a common characteristic of Central America and Latin America (FAO, 2009). This is mainly due to shifting cultivation to large scale agriculture and livestock is often cited as a major driver for tropical deforestation. Those industrial systems are more and more criticized because they appear to be less productive than expected. The damages caused to ecological services of the landscapes by industrial agriculture are recognized to lower production yields (MURGUEITIO et al., 2011).

Another anthropic threat to tropical forests is population growth and agricultural pressure on natural areas caused by this growth. Indeed, population grew from 300% from 1961 to 1999 in Central America. The area under pasture increased by 67% during this time (DAGANG; NAIR, 2003). In 1970, 60000ha of tropical forest had been converted to pasture in Costa Rica. Much or the deforestation took place in the North Atlantic zone which includes the region of San Carlos (which produces now about 60% of the national milk production)

(MOULAERT et al., 2002). The deforestation for cattle production without any environmental concern has leaded to land degradation in many countries. From Central America to Latin-America, there are many examples of this phenomenon. Only in Brazil, about 50% of pastures are degraded or are starting to degrade (FAO, 2000). The situation in Central America shows that most of the landscapes are fragmented and deforested because of agricultural pressure. 40% of the landscape is used for grassland and 40 to 60% of that grassland is degraded. Pasture degradation is leading to many negative consequences for environment but also for agricultural productivity: erosion, losses in fertility, desertification, losses of biodiversity, water contamination and emission of CO2 (TOBAR LOPEZ; MUHAMMAD, 2008a; VILLANUEVA; MUHAMMAD; HAENSEL, 2010). Deforestation and land degradation are the main responsible factors for GHG emissions in extensive grazing systems (FAO, 2009).

To respond to this situation in the Latin and Central American context, silvopastoral systems (SPS) appeared to be part of the solution. They have brought a lot of attention in scientific communities in all Latin American countries for their potential to respond to issues of deforestations and losses of productivity (DAGANG; NAIR, 2003).

2.2. The types of SPS in Latin-America

2.2.1. General typology:

The concept of SPS is very broad, that is why some authors intended to set-up a typology according to what could be found in traditional framing systems but also what has been designed by researchers in this field. The types of SPS can be separated into two big groups : the systematic SPS and the non-systematic SPS (FAO, 2000; RIVERA HERRERA, 2015; VILLANUEVA; MUHAMMAD; HAENSEL, 2010).

- Systematic SPS are designed by human; they usually have uniform special distribution of trees. In this group we can find the following modalities:

Forest plantations with cattle grazing: Cattle play a secondary role in this system. It is used for controlling the understory growth (to limit fire, limit invasive plants, etc.). The principal activity is timber production.

Photo 1: *Pinus sp.* associated with sheep grazing in a meat farm visited during our study

Fruit plantation and grazing: This modality is similar to previous but species are used for fruit production like citruses, mango, avocado, guava etc.

Live fences (LF): The most common SPS in the rural tradition and landscape. This system is reported to use more than 100 species(VILLANUEVA; MUHAMMAD; HAENSEL, 2010). It ensures connectivity of landscapes; it has the potential to evolve into micro-biological corridors.

Wind breaks: They are constituted of simple or multiple lines of trees to reduce wind's negative effect on animals (especially young ones that are more sensitive).

Grasslands with trees planted in lines: Trees are associated with fodder production (cut and carry system) or can be grazed directly. The objective is to improve nutrient cycling, limit erosion and reduce negative impacts of cattle trampling.

Multiple strata SPS, cut and carry systems: It can be applied to multiple farming systems from agribusiness to small producers to produce fodder. Tree/shrubs species are cultivated alone or with other vegetation layers. It is especially adapted for fragile soils.

Fodder banks (FB): It is a variation of the previous system but with specialized plants to transform solar energy into soluble sugar or starch. It is using crops like sugarcane, yucca, sweet potatoes, oil palm, other native species of palm mixed with trees.

SPS with high tree density or intensive SPS (ISPS) : ISPS are mainly present in Columbia (MONTAGNINI; IBRAHIM; MURGUEITIO RESTREPO, 2013) : it is a combination of fodder banks with woody species planted at high density (more than 10000 trees/ha). It aims to reach a higher yield or/and a better animal's weight gain, with low inputs and modern technics of rotational grazing (RIVERA HERRERA, 2015). It also was successfully adopted in some regions of Mexico and Panama (MURGUEITIO et al., 2011).

Photo 2: Lives fences in a farm landscape visited during our study

- Non-systematic SPS: contrary to the systematic SPS, the trees have a heterogenic distribution within the pasture and most of them come from natural regeneration.

Isolated trees in pastures (TIP): This phenomenon is very frequent in Latin America with species that can adapt a wide range of conditions. In most of the cases, those species are coming from natural regeneration and are selected and maintained by farmers.

SPS with management of vegetal succession: management of invasive tree/shrub species into the grassland. It is a very economical solution to establish SPS but need a good knowledge of native species.

2.2.2. Focus on SPS in Central America

If we now focus on the case of Central America, lives fences, wind break and dispersed trees are considered as a traditional practice and they can be widely observed in this area (HARVEY et al., 2005, 2011; PÁVEL, 2012; TOBAR LOPEZ; MUHAMMAD, 2008a).

Studies have identified some main characteristic of SPS in Central America. In productive areas, trees in SPS come from 90% of natural regeneration and 5% are planted. Farmers usually manage less than 35 species and within those, 10 are dominants ones of the area (TOBAR LOPEZ; MUHAMMAD, 2008a). Dispersed tree in pasture usually come from natural regeneration or forest remnants (HARVEY et al., 2011).

2.3. The positives externalities of SPS

The SPS focus the attention of the researchers of Latin America and Central America, because they could bring a lot of benefits to the farmer while contributing to environmental issues. The following section lists those positives externalities of SPS addressing environmental, social and economic benefits.

2.3.1. Environmental benefits

Concerning the environmental point of view SPS bring some benefits to the agricultural system.

1.1.1.1. Climate change mitigation

SPS help to mitigate climate change and increase carbon sequestration. Indeed, by natural processes SPS remove GHG of atmosphere and can be a tool to reach positive balance in the farming system (NARANJO et al., 2012). However, the amount carbon sequestrated varies according to the SPS (it all depends on the design, soil and climatic conditions). For example, timber and fruit tree species attain the highest values of carbon sequestration (MONTAGNINI; IBRAHIM; MURGUEITIO RESTREPO, 2013). However, it is still not clear if the carbon sequestration is always higher in SPS than in a conventional systems without trees (MOSQUERA et al., 2012; VILLANUEVA-LOPEZ et al., 2015). In another hand, SPS contribute to climate change mitigation at the farm level by providing shade and creating a microclimate. It helps to improve animal well-being by enabling them to regulate their corporal temperature through the provision of shady areas (MONTAGNINI; IBRAHIM; MURGUEITIO RESTREPO, 2013).

1.1.1.2. Effect on biodiversity

SPS are considered to support biodiversity in agricultural landscapes by providing habitats for some species but as well to improve ecological connectivity at the landscape level. Harvey and Haber in 1999, found 90 woody species in pastures on a single farm in Costa Rica, and indicated that dispersed and remnant trees can shelter and nourish forest animal species (DAGANG; NAIR, 2003).

This applies especially for birds in LF (live fences) as trees are important food source and enable them to move into the landscape. It be could observed that birds prefer trees with big diameters, high and large crown width (HARVEY et al., 2005). In southern Mexico, a study of Estrada in DAGANG and NAIR (2003), observed the presence of 98 different bird species along a 6km live fence of *Gliricidia sepium* and *Bursera simaruba*. However, all species cannot strive in such landscape. Indeed most of the birds observed by HARVEY et al. (2005) were generalist and there was few forest related species. Nevertheless, LF are an opportunity to enhance on-farm biodiversity but also connectivity of the landscape without much reduction of farm production and complication in farm management (HARVEY et al., 2005).

Because they promote biodiversity, SPS represent good opportunities for ecological corridors, which are based on landscape connectivity (MURGUEITIO et al., 2011).

1.1.1.3. Effect on soil fertility

SPS are also recognized to have a positive effect on soil organic matter (SOM). VILLANUEVA-LOPEZ et al. (2015) have shown that SPS with LF have greater potential to increase SOM than grass monocultures. Although the amounts of carbon stored in the soil by SPS with LF and grass-monoculture were quite similar in this study. The production of leaf litter from the trees increased the annual flow of carbon in SPS by 3.5 %. Even if live fences (LF) were reported to contribute modest amounts of carbon, leaf litter acts as mulch and reduces evaporation, surface runoff and erosion. *Gliricidia sepium* trees improve soil nitrogen content through the biological fixation of microorganism. By doing so they help to maintain a neutral pH (VILLANUEVA-LOPEZ et al., 2015). The carbon in phytomass varied between 7 and 13 Mg C ha-1 respectively in no-tree pastures and SPS in PÁVEL (2012).Considering the nutrient cycling aspect, SPS help to increase SOM and that leads to a higher turnover of nutriments by the degradation of organic elements like leaves and roots. The use of leguminous species that fix nitrogen is also very interesting in terms of soil fertility. Species like *Leucaena leucocephala* have a ratio of 75% of their nitrogen content coming from biological fixation. *Gliricidia sepium* was reported to produce 112kg N/ha during 8 month period when grown in pasture (JAYASUNDARA; DENNETT; SANGAKKARA, 1997). Moreover, it has be showed that nitrogen transfer exist under certain conditions between tree and grasses (DAGANG; NAIR, 2003). There are other beneficial interactions that can occur between grass specie and tree in SPS at the soil level. *Brachiaria brizantha* appeared to stimulate tree root production resulting in an increase in soil organic carbon of up to 9.9 Mg ha-1 year-1 (PÁVEL, 2012).

1.1.1.4. Landscape

At the landscape level, LF have been the most studied for their spatial patterns. They have been reported to act like firebreak, to decrease pressure on forests and to add esthetic value for the landscape(VILLANUEVA; MUHAMMAD; CASASOLA, 2008).

2.3.2. Economic benefits

There are a lot of studies about the economic benefits of SPS but the conclusions are quite mitigated.

1.1.1.1. Effect of shade on grassland

The main issue is related to the reduction of light intensity by the presence of trees. It has been investigated that 15% of shade is the maximum that the pastures can take without decreasing biomass production (SOTO, 2016). However, some grass species are reported to maintain their yield under higher shade conditions (PACIULLO et al., 2014). For example, moderate shade (30-40%) did not affect growth of *Brachiaria* *decumbens* (PACIULLO et al., 2011). Moreover, trees had no effect upon grass yield in experiments with *Brachiaria brizantha* grass after four years (ANDRADE, 2007). *Brachiaria* species are considered like a common forage in Latin America (ANDRADE, 2007).

On the another hand, some studies reported a higher quality forage from trees (especially with species like *Gliricidia sepium, Erythrian poeppigiana*) (DAGANG; NAIR, 2003) and improved pasture characteristics (PACIULLO et al., 2014) in SPS. However, too much shade will certainly reduce pasture production. It was established that the tree's crown size is a factor which contribute to lower grass yield (RUSCH et al., 2014).

Some studies based on the concept of facilitation/compensation derived from ecological theory help to understand wherever SPS are really beneficial for the grassland productivity. For example, there is higher facilitation effect in more extreme environment. In opposition to benign conditions, competition is predominant. Trees would be more beneficial to pasture productivity in difficult situations (dry conditions, low soil fertility, etc.) (RUSCH et al.,2014).

1.1.1.2. Effect on animal productivity

About animal's performance, the results of studies on SPS effects are globally positive. The increase of production is mainly due to access to shade (linked to a better thermic comfort) and additional fodder/fruit sources. It is especially true during the dry season where fodder resources might be more limited. (VILLANUEVA; MUHAMMAD; CASASOLA, 2008). Increase in milk yield and live weight gain have been reported when cattle was fed on lignin products. During the dry season, an increase of 1,6l/cow/day in milk yield had been observed (TOBAR LOPEZ; MUHAMMAD, 2008). In Costa Rica, *Cratylia argentea* still produce 40% of its total dry matter in the dry season (DAGANG; NAIR, 2003).

Moreover, SPS are also more efficient to rear heifers, thanks to thermal comfort (PACIULLO et al., 2011). However, the increase of production does not happen in all conditions. YAMAMOTO; DEWI; IBRAHIM (2007) reported that higher milk yield happened under a certain threshold of 20% tree cover.

The use of multipurpose trees decrease dependence on external inputs and diversify the income of cattle farm (TOBAR LOPEZ; MUHAMMAD, 2008).

2.3.3. Social benefits:

It also exists social benefits of SPS reported by TOBAR LOPEZ; MUHAMMAD (2008). Indeed, tree presence enables diversification in farm production through varied feed and food sources (fruits, leaves, etc.) that will result in high farm resiliency.

At a more cultural and subjective level, having trees on farm can increase emotional link between the family and the farm. The transmission of trees through generation of farmers was recognized to have strong inheritance value (CHAMAYOU, 2011). Tree can also be an opportunity to increase job offers in rural areas through the extraction of timber, the maintenance of SPS or even fruits recollection (FAO, 2000).

As we saw in this section, SPS enable to respond environmental issues from the intensification of livestock farming (such as deforestation, pasture degradation, GHG emission). Different modalities of SPS have been identified thorough the Latin-American continent. LF and TIP being traditional systems, they are the most common in the rural context of Central America. SPS are not only valuable for their positives externalities on the environment. They would also bring an economic advantage to the farmer and increase resiliency of the farm. In the next section, we will investigate the perception of cattle farmers of Central America on SPS and as well their knowledge about them.

2.4. Farmers perceptions of SPS

Because SPS have been part of the cattle farms for a long time with the practice of traditional systems like LF and TIP (PÁVEL, 2012), it is important to investigate what are the uses and the tree benefits perceived by cattle farmers in CA. In order to be able to understand the decision taking processes of the farmers concerning tree cover and which are the limitations that they meet related to SPS.

2.4.1. On farm-tree uses and benefits

The on farm trees uses and benefits perceived by farmers is referring to the concept of local knowledge. Indeed, local knowledge includes the learning, reasoning and perception that inhabitants of a locality share and that can be used to predict future events (MOSQUERA ANDRADE, 2010).

Farmers make use of the trees in many ways and they are also aware of the services provided by those trees (RAMOS URZAGASTE, 2003). Trees are providing valuable products such as fruit for human consumption, firewood, timber for construction, posts for fencing and fodder (CHAMAYOU, 2011; MOSQUERA ANDRADE, 2010). Services brought from trees are also recognized by farmers. On this theme, local knowledge is very rich. It addresses provision of shade for the cattle, wind protection, erosion control, improvement of the soil fertility, watershed protection, drought mitigation, biodiversity conservation and medicinal uses (MOSQUERA ANDRADE, 2010).

Trees have very diverse purposes in each landscape depending on the context. The use of the tree depends on farmer’s resources and dependence on wood resource for energy. For example, in rural areas of Guatemala and Nicaragua, provision of firewood for cooking is a very important use of the tree. In Costa Rica, the purpose of trees in SPS is timber extraction. In sub-humid areas of Nicaragua and Belize, the trees are mainly used as a source of fodder for cattle (PÁVEL, 2012).

Moreover farmer can have very specific knowledge related to tree traits or species. They can identify which trees have a shade with positive or negative influence on grassland production (MOSQUERA ANDRADE, 2010).The local knowledge reflects well the strategies of the farming activity and how the community is learning and adapting to its environment. With the identification of the main tree uses and services, it is possible to understand better the objectives of the farmers and thus their decision making process.

2.4.2. Decisions-making processes

Farmers manage tree cover depending on various factors. They can be related to the socio-economic situation of the farm like: capital availability, abundance of labor force, necessity of wood products. The factors can also be linked to the characteristic of the tree like the dimension of the crown which influence the degree of shade (VILLANUEVA et al., 2003). The presence of shade that benefits cattle was considered a key element in the decision-taking process (RAMOS URZAGASTE, 2003). Moreover, farmers have shown to have a sophisticated understanding of the interactions between tree cover, grass production and cattle. They look for an equilibrium between the positives and negatives effects of tree (HARVEY et al., 2011).

Farmers can make decisions that either have a positive or a negative impact on tree cover leading to extinction of native species. Practices such as weed control, collection of trees for domestic use and pruning can have negative consequences. The decisions that impact tree cover vary from a place to another according to climatic conditions, socioeconomic, cultural and production systems (VILLANUEVA et al., 2003). Cultural and social aspects can play an important role when it comes to farmer's preferences on tree species. Specie selection does not only depend on silvicultural or technical aspects. Indeed, exotic species in forest plantation have been widely investigated but they are still not preferred by farmers (RAMOS URZAGASTE, 2003).

To conclude, we can say that SPS are appearing to be an alternative to issues of land degradation and deforestation in Latin America. They bring diverse benefits to cattle farming system at the economic, environmental and social level. Farmers are aware of those benefits as well and are transmitting this knowledge. However, sometimes their practices are leading to the decrease of the tree cover and predominance of specific species. Investigating farmer knowledge and silvopastoral practices appear to be fundamental if we want to increase SPS adoption and guaranty a sustainable cattle farming in Latin America.

3. Presentation of the study

3.1. Collaboration with CATIE

The Tropical Agricultural Research and Higher Education Center (CATIE) is a regional institution which aims to train professionals in sustainable agriculture, management and conservation of natural resources. Additionally, it is a research center where many projects are leaded. The countries members of CATIE are Belize, Bolivia, Colombia, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Venezuela and the State of Acre in Brazil (CATIE, [n.d.]).

In 1943, the IICA ("Instituto Interamericano de Ciencias Agricolas" or Inter-American institute of Agricultural Sciences) was founded by the Organization of the States of America in the same location of the actual CATIE. Today, CATIE has merged with the IICA. Its mission aims to: "*Increase sustainable and inclusive human well-being in Latin America and the Caribbean, promoting education, research and outreach for the sustainable management of agriculture and conservation of natural resources*."(CATIE, [n.d.])

To achieve this, the different research bodies are promoting the development of climate-smart territories which are a tool to reach sustainable development for the territories (CATIE, [n.d.]).

The CATIE is offering masters in the field of Agroforestry and Sustainable Agriculture, Management and Conservation of Tropical Forests and Biodiversity, Integrated Water Management and Economy, Development and Climate Change and finally Climate Change Mitigation and Adaptation.

The research is CATIE is focusing on nine themes that are climate change and water management, food security, forests, agroforestry, value chain and ago-business, sustainable livestock production, gender, environmental economy, territorial approaches. Those themes are divided with 5 chair groups as it shown in the figure below.

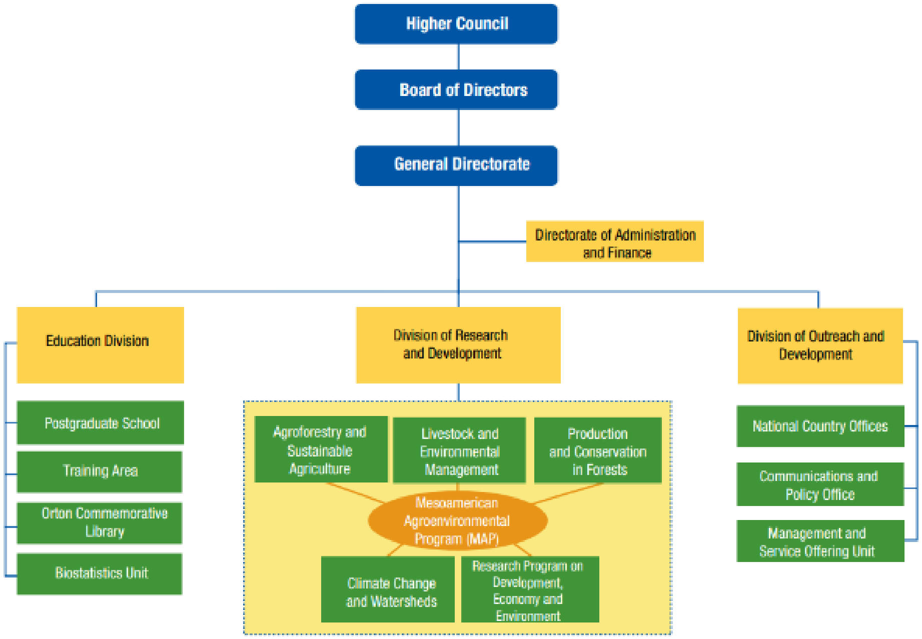


Figure 4: Organizational chart of the CATIE (CATIE, [n.d.])

The study that is presented in this thesis had been realized in the Livestock and Environmental Management Program called GAMMA ("Ganaderia y Manejo del Medio Ambiente").

GAMMA program is working on different aspects of sustainable livestock production:

- Productivity and profitability of cattle farms to develop tools for farm management and SPS management.
- Adaptation and mitigation of climate change
- Environmental services like biodiversity, carbon storage, water quality and conservation
- Policies and economic incentives: we can cite Payment for Environmental Services (PES), farm certification, green credits, analysis of value chains (GAMMA, 2015)

GAMMA is involved in different projects, most of them at the international scale focusing on issues of Central and Latin America cattle farming. The main countries of investigation are Nicaragua, Costa Rica, Panama, Honduras and México. Those projects benefits most of the time of international funds (CATIE, [n.d.]).

3.2. Aim of the study

This study was leaded independently, as it was not part of a research project and responded to individual initiative. The topic of the study was proponed by Jimena Esquivel Phd., researcher at the GAMMA program. The definition of the objectives and the supervision at CATIE were effected by her. The GAMMA program and the CATIE facilitated tools and infrastructures to lead this study (like the access to the library, provision of an office, assistance with statistical analysis etc.).

3.2.1. Objectives

This study was leaded in an exploratory way and would respond to the following main objectives:

- Describe local knowledge on trees species , tree uses and benefits perception of cattle farmers of the Biological Corridor of Talamanca's Volcanic Chain (CBVCT)
- Identify determining factors for the adoption and management of SPS in cattle farms of the CBVCT

3.2.2. Justification of the study

The study was leaded in the CBVCT. The main objective of the local committee of the corridor is to conserve the environment by involving the local population through sustainable development practices (CANET DESANTI, 2008). With respect to this objective, SPS are an interesting opportunity to increase ecological connectivity through the landscape through maintaining sustainable farming activity (CHAMAYOU, 2011). Moreover, grassland under tree-cover is the second land-use of the CBVCT and it represents about 24% of the total area (CANET DESANTI, 2008). Those trees located outside forest have not yet been investigated within the CBVCT but they surely would play an important role within the conservations objectives of this territory (CHAMAYOU, 2011).

This study is aiming to provide more information about the types of SPS present in the ecological corridor and help to understand cattle farmer's motivation and limitation to increase on-farm tree-cover.

3.2.3. Research question

In this study, we will address the following research question: "What are the determining factors for SPS adoption and management in cattle farms of the CBVCT?"

To answer properly this research question we propose to structure into 4 different sub-questions:

1) What are the characteristics of the farms and the farmers?
2) What are the types of SPS that can be observed in those farming systems?
3) What are the uses of trees and which benefits are perceived by farmers?
4) What are the determining factors for adoption and management of SPS?

The first question aims to understand the general context of the farm. Many variables can be investigated but we are interested in the farmer socioeconomic characteristics in order to understand their needs, their objectives and motivations. That step is necessary to understand how they manage trees on their land and what can limit them in the practice of SPS. Moreover, recognizing the drivers of farm management is a very important for the determination of a viable and appropriate research target. The research on SPS should be able to address the specific needs of the whole diversity of cattle farming systems (DAGANG; NAIR, 2003). Furthermore, by understanding the drivers of farm management and farmer's objectives, it will be possible to classify the farms visited into a typology according to those socioeconomic characteristics (SALAZAR OVIEDO, 2012).

Additionally, we would need to describe the type of SPS that can be found on those farms. To help us with this we can use the classification of SPS from the FAO(2000). As it was planned to only conduct interviews and not inventories of tree species, this information would be only based on farmers 'sayings. In this phase, we would be able to describe the diversity of SPS within the group farmers interviewed. Once again, that information will help us to understand the drivers of farm management and tree's management.

From this information that help us only to describe the farming system, we can continue with the next step which is more related to the knowledge of the farmer and his motivations and limitations concerning tree cover and tree management. We ask farmers about the uses of the trees and the benefits that are perceived by them. We go further by asking the motivations and limitation to increase the tree cover on the farm (and especially in pastures).

The end-goal of all this process is of course to identify limiting factors to the adoption and management of SPS but as well to describe specific limitation and opportunities concerning SPS for each farm type.

Additionally, we ask the farmer about their knowledge's on specific species used in an experimental module of CATIE's farm. The details of this study are not presented in this thesis but we mention it here because we used part of the results to answer our research question. The list of specie is presented in annex 1.

Chapter 2: Methods

1. Study Site: the Biological Corridor of the Central Volcanic chain of Talamanca (CBVCT)

The “Corredor Biológico Volcánica Central – Talamanca” or CBVCT (Biological Corridor of Talamanca’s Central Volcanic chain) was chosen to be our area of study. It is situated in both the province of Cartago and the province of Limon with an extension 72.028ha (figure 5). The main urban center is the town of Turrialba. The CATIE is located nearby this town.

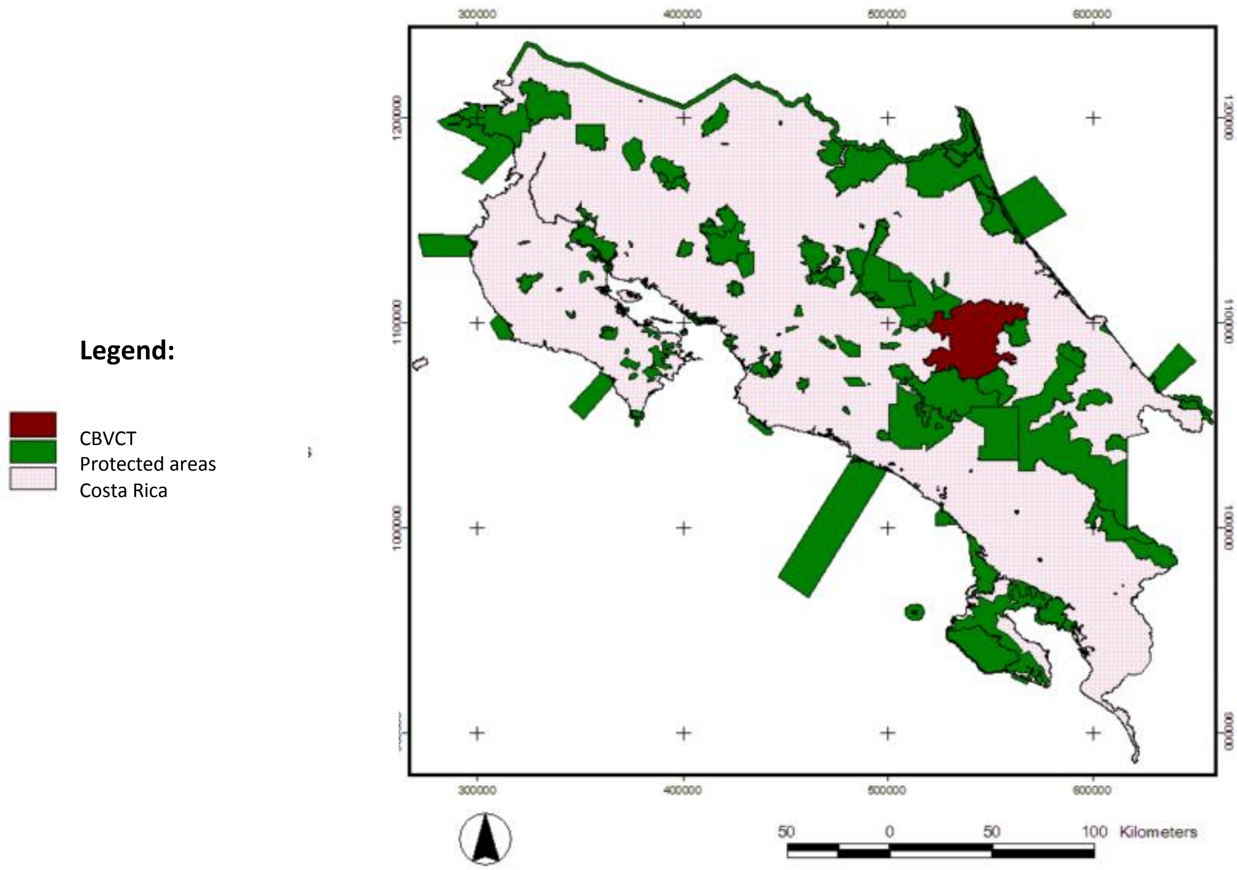


Figure 5: Map of the localization of the CBVCT within the Protected forests area of Costa Rica (CANET DESANTI, 2008)

The CBVCT was created in 2003 with the objective to establish ecological connectivity between the biospheres of “Cordillera Volcanica Central” and “La Amisad”. It is also a key element that gather important features such as Turrialba volcano and the “Monument National Guayabo” located at the northern side of the corridor, as well as the “Zona protectora de la Cuenca del Rio Tuis” and the “Reserva Privada de Vida Silvestre La Marta” in the south. It is also included in the Mesoamerican Biological Corridor that goes from the south of Mexico to Panama (RAMIREZ CHAVEZ, 2006).

The conservation aspect is not the only objective of the CBVCT, there is also the mission to improve the quality of the environment and by doing so upgrade the quality of life of the local populations (CANET DESANTI, 2008).

The CBVCT was chosen to be the area of study because of its mission of conciliation between nature conservation and agricultural activity provided a perfect framework for our study on silvopastoral practices.

Improving SPS adoption and management within the cattle farms of the CBVCT is a key issue to establish ecological connectivity at the level of the corridor (CHAMAYOU, 2011). Moreover, CATIE is a key partner for the CBVCT through its research projects and support to the missions of the CBVCT.

1.1. Biophysical characteristics: an heterogeneous zone

74% of the corridor is situated in the Cartago province and 25% in the Limon province. It is characterized by a wide range of altitudes (from 339m to 3340 m above the sea level) (RAMIREZ CHAVEZ, 2006). The highest point is Turrialba volcano (CANET DESANTI, 2008).

The climate is mainly influenced by the Alize winds from the Caribbean Sea. They bring a high percentage of humidity that is distributed along Talamanca's volcanic chain which runs along Costa Rica from north to south. In the valley of Turrialba, the rainfall averages 2693,1 mm with May and December being the rainiest months of the year. The average temperature is 21,8°C with a maximum of 27,5°C and a minimum of 18°C. There is a quite level of high relative humidity (88,1%) (CANET DESANTI, 2008). Indeed the area can be divided into two distinct climatic zones (TENECIO C, 2014):

- High sub-tropical humid area: from 1600 to 3000m above the sea level, is characterized by volcanic soils. The average temperature is 17°C and annual precipitation of 2600mm. It includes the foothills of Turrialba volcano.
- Humid tropical forest area with an average temperature of 27% and 3200mm of annual precipitations. The soils types are from atosol and aluvional origin.

1.2. Biodiversity: a place of great richness

The biodiversity is an important aspect of Costa Rica, as it is considered one of the 20 countries with greater biodiversity in the world. About 4% of the total specie biodiversity can be found on its territory that represents about 0, 03% of the world's surface. 25% of the area of Costa Rica is under protection, with the aim to conserve this exceptional biodiversity (Instituto Nacional de Biodiversidad, 2014).

Concerning the CBVCT, it is reported to be a very important area of richness of species of birds and mammals. About 70% of birds and mammals species of Costa Rica are present in the corridor (CANET DESANTI, 2008).

1.3. Historical context: the native's people roots still remain

Turrialba, the main town of the CBVCT is a main center of activities for the populations living in the area. In natives people's language it was called *Turiariba* and the Spanish transformed it in Turrialba. But, this name could come also from the white tower of ashes from the Turrialba volcano which gave its name to the city ("torre blanca"). In the 20th century, the agricultural and industrial expansion of the region of Turrialba took place. At this time, it became a site of great importance for the transit between "la Meseta Central" and the Atlantic side of Costa Rica. That is why in 1943, the IICA (Instituto Interamericano de Ciencias Agricolas or Inter-American institute of Agricultural Sciences) was founded by the Organization of the States of America. Today, the IICA and the CATIE have merged.

Although the quite important development, some communities of natives' people remain. To confirm the importance of native's people culture in the area, the Monument National of Guayabo is the largest and the most important archeological site of Costa Rica (CANET DESANTI, 2008).

1.4. An area of economic importance

The first district of the canton of Turrialba is main the agglomeration eastern of the Central Region. There is a concentration of infrastructures to satisfy the needs of the populations. The town of Turrialba is the key point of the area: it concentrates more than one third of the inhabitants of the canton.
This region is one of the most developed of Costa Rica and the configuration of Turrialba as a dynamic key point of the central region explain this phenomena. There is a low level of analphabetism, as the opportunity to study and to access higher education is good. The presence of a hospital and two clinics is also important to mention. There is a high level of electrification and access to phone communications. Concerning transportations, the main roads infrastructures have been improved during the last years, especially the road from the Central Valley and to the Caribbean sea (only way between San José, the capital and Puerto Limon main town of the Caribbean side). However it remains some concerns about sanitary issues and environmental contaminations. The main problems are coming from water contamination and treatment of wastes (from households or from industries).The total population of the canton of Turrialba was 68,510 inhabitants in 2010 with a density 20,9 inhabitants/km2 . About 60% of the population lives in rural areas(CANET DESANTI, 2008).

1.5. Land use in the CBVCT: focus on agriculture and cattle farming

The forest represents the main land use with 52% of the total area as it can be observed in the figure 6. Grassland with tree cover is the second land-use as its represents about 24% of the total area. Coffee is coming next with about 8% of the surface (CANET DESANTI, 2008).

As it can be observed from this data, the CBVCT is a quite rural area where agricultural activity and cattle production are important in terms of land-use. Even if the forest represents the majority of the landscape, its biological connectivity is threatened by agricultural activity (especially sugarcane and pastures). Thus, it is very important to ensure this connectivity in the agro-landscape. The way to manage the agricultural landscape will highly determine the capacity of the biological corridor to reach its conservations objectives (CANET DESANTI, 2008).

RAMIREZ CHAVEZ(2006) estimated that the average farm size was between 20ha and less than 5h showing that most of the farms are from small holders. Dairy farms tend to be a bit smaller (13,7ha on average) than meat producing farms (24ha on average) (TENECIO C, 2014).

Considering the economic value, the coffee is the first production with 28% of the total agricultural value in the area and milk is the second one with 25%. Thus, dairy farming appears to be an important activity for this region. In 2013, it was produced 190 501 295kg of milk (TENECIO C, 2014), especially in the area of Santa Cruz on the flanks of Turrialba volcano. This area is famous for its cheese (VERGARA et al., 2015). It is estimated that about 1025 families produce milk in the sector of Turrialba. Farmers are grouped into producers associations to facilitate marketing and the selling of their products. The ASOPROA-SC (Associations of producers of Santa Cruz) is the main organization and it is committed to protect the denomination of origin “Queso tipo Turrialba” and improve the dairy activity (by providing courses or contracts with private companies).The association is counting 215 members (MINISTERIO DE AGRICULTURA COSTA RICA, [n.d.]). As, it can be observed on the figure 7, grasslands are concentrated in the northern part and central western part of the corridor. In the CBVCT there is about 8 farmers associations grouped by communities to share knowledge and define collective marketing strategies.

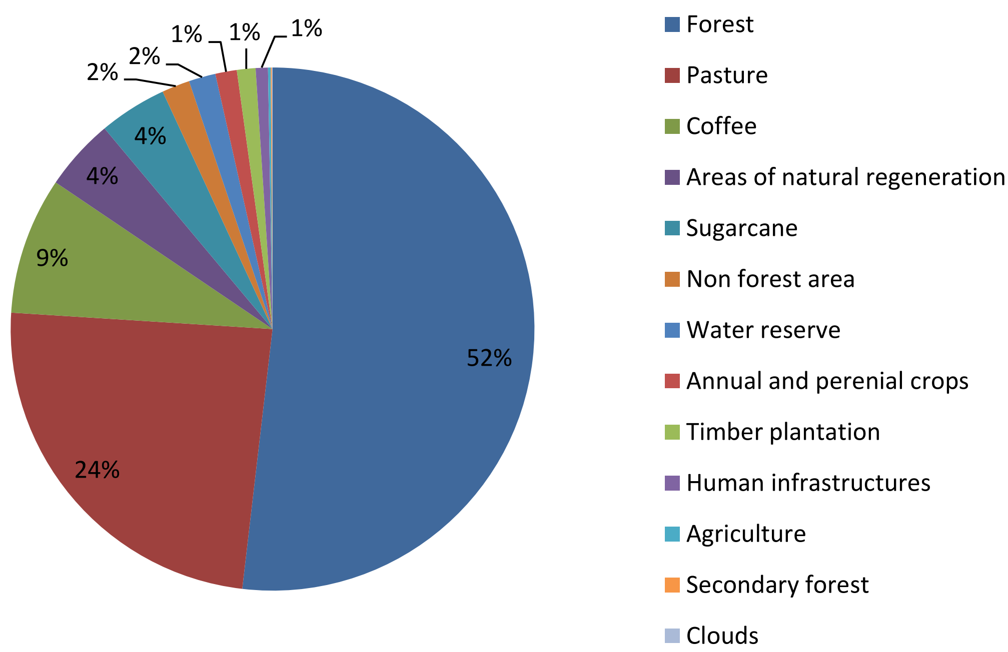


Figure 6: Distribution of the Land use in the CBVCT (CANET DESANTI, 2008)

2. Farm selection

We choose our study area to be the territory of the CBVCT (see figure 7) and we decided to conduct interviews with cattle farmers within this area. The number of 30 interviews was chosen. It is the minimum recommended for qualitative studies (SIBELET et al., 2013). This number was in accordance with the means and time that were dedicated to this study.

The selection of farm was realized taking into account different criteria. Cattle activity should be the main production of the farm and the person interviewed should be involved in this activity. There were no predefined lists of farms that could be surveyed. We mostly counted with the help of farmer association's representatives (presidents or administrator) to facilitate the contact with farmers. The associations contacted are listed below:

- Association of producers of El Sauce (ASOPROLESA)
- Association of dairy farmers of Santa Teresita
- Association of producers of Santa-Cruz (ASOPROA)
- Association of producers of Turrialba (ASOTURGA)

The contact with farmers was also established through lists of participation to trainings provided by the CATIE. We also relied on snowball sampling (asking a surveyed farmer for additional contacts) and farmers met by chance (at the bus station or at the market for example).

The figure 7 is showing the location of the communities where the interviews where leaded. We counted 11 communities in total: Santa Cruz, La Pastora, El Guayabo, Santa Teresita, El Sauce, Alto-Vajas, Sitio Mata, Platanillo, Cien Manzanas, El Colorado and Pacaytas.

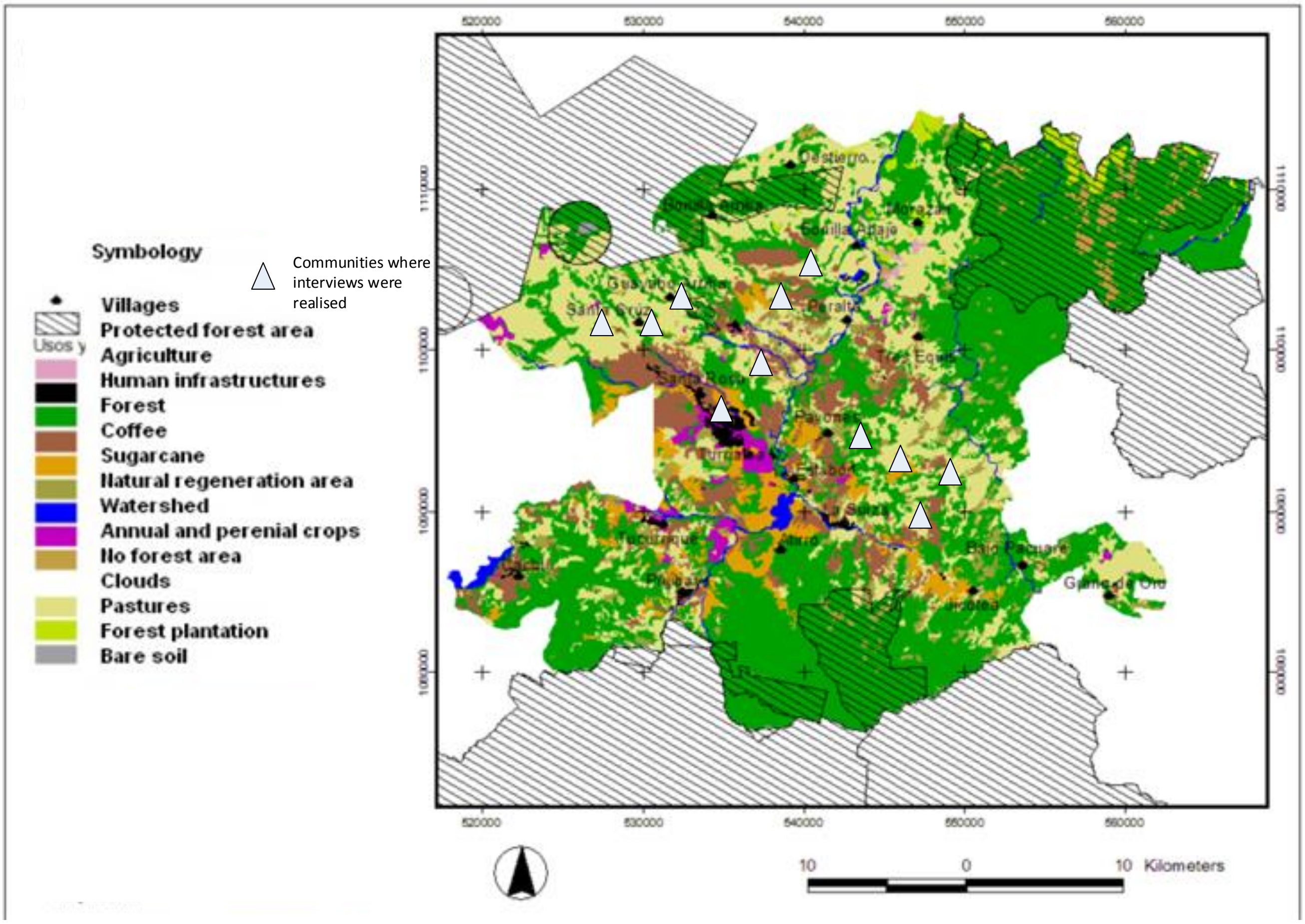


Figure 7: Land use of the CBVCT and localization of the interviews (original map from Canet Desanti (2008)**)**

We aimed survey the most complete diversity of production systems (both meat and dairy farms). We identified 4 different systems:

- Dairy farms with a number of 19 interviews
- Fattening cattle with a number of 6 interviews
- Weanlings production with a number of 4 interviews
- Cattle for reproduction with a number of 1 interview

3. Methodology of the semi-structured interview

3.1. Choice of the method of interviews

This study is aiming at recollecting different types of variables (quantitative, qualitative and categorical). Indeed, farmers' knowledge and perception of SPS are mainly described by qualitative variables whereas socio-economical characteristics of the farmers and SPS types correspond to a more quantitative and categorical variables. From this set of variables, we need to define a proper method to lead our interviews. In the online course called "Qualitative survey method applied to natural resource management", SIBELET et al. (2013) are exposing different methods to lead an interview. The closed interview corresponds to a method where the exchange with the interviewer is strictly leaded by the use of an interview guide and where questions are asked in a pre-determined order. Whereas in a semi-structured interviews, the questions are less numerous and more open. The structure of the interview guide is more flexible and can be adapted to the flow of thoughts of the person interviewed. Moreover, this method of interview enables the person interviewed to freely express opinion and knowledge (MOSQUERA ANDRADE, 2010).

Closed interview method appears to be more suitable for quantitative data collection whereas semi-structured method is more adapted to studies that aim to discover new factors (SIBELET et al., 2013). In the case of our study, we choose semi-structured method of interview because we wanted to understand farmer's objectives and decision making processes related to the practice of SPS. Semi-structured method enables more freedom in the discussion and was more adapted to the objectives of our study.

3.2. Choice of variables

For each research question, we need to determine the variables that we want to recollect (table 1,2 and 3).

1) What are the characteristics of the farms?

According to what was found in the literature, we choose to investigate a certain number of variables (SALAZAR OVIEDO, 2012). The variables are listed in table 1 (the complete list is presented in annex 2). They can be grouped into 4 groups:

- Farmer characteristics/household characteristics
- Farm characteristics
- Cattle activity characteristics
- Grassland characteristics

Table 1: Variables related to farm and farmer characteristics

Groups of variables	**Type of Variable**	**Variable**
1°Farmer characteristics	Quantitative	Age
	Qualitative	Education level
1°Household characteristics	Qualitative	Involvement of family members in the farm work.
	Qualitative	Relative importance of the farm as a main/additional resource of the household
1°Farm characteristics	Qualitative	Origin and ownership of the farm
	Quantitative	Altitude of the farm
	Quantitative	Farm size
	Qualitative	Farm productions
	Qualitative	Land uses on the farm (crops, natural forest, etc.)
	Qualitative	Marketing strategy
	Quantitative	External labour force
1°Cattle activity	Quantitative	Number of animals (in total, in production, dry, heifers, etc.)
	Qualitative	Type of production (milk/meat/cheese/animals/etc.)
	Quantitative	Level of inputs (use of feed concentrates)
	Quantitative	Years of experience of the farmer in cattle farming
	Qualitative	Ancient land-use
1°Grassland characteristics	Quantitative	Area of grassland
	Qualitative	Type of grassland (natural/improved)
	Qualitative	Species in fodder bank
	Quantitative	Size of the fodder bank

2) What are the types of SPS that can be observed in those farming systems?

To respond the 2nd research question which aim to describe the SPS, we chose our variables based on the classification of SPS by the FAO (2000). We have two groups of variables that are:

- Type of SPS present on the farm
- Tree species cited by the farmer that are present on the farm

Table 2: Table of variable related to silvopastoral practices

Groups of variables	Type of Variable	Variable
2° Generalities and Type of SPS	Qualitative	Does the farmer know the technical terminology of SPS?
	Qualitative	What type of SPS are present in the farm?
	Qualitative	Localization of the trees within the farming system (in SPS, along river banks, in natural forest, in timber plantation) Identification of the trees species in each area
2°Trees species present on the farm and in each SPS	Qualitative	Identification of SPS present on farm Identification of the species present in each SPS

3) What are the uses of on-farm trees and which benefits are perceived by farmers?
4) What are the determining factors for adoption and management of SPS?

To respond those two research questions we chose variables that were not categorical or quantitative but more qualitative in order to answer those question in an exploratory way. We group those variables into groups:

- General knowledge of the farmer on SPS, trees benefits and uses
- Motivations and limitations to increase on-farm tree cover

Table 3: Table of variables related to the uses of trees and determining factors in SPS adoption and management

Groups of variables	Type of Variable	Variable
3° General knowledge of the farmer on SPS, trees benefits and uses	Qualitative	Products and services brought by trees
	Qualitative	Origin and management of the trees
4°Determining factors	Qualitative	Motivation and limitation to increase farm tree-cover
5°Species of the module	Quantitative	Knoweldge on the species present on CATIE's the experimental module
Additional	Qualitative	Technical support or participation to trainings?

3.3. Design of the interview guide and conduction of the interviews

The interview guide is comporting 3 parts addressing 3 mains themes:

- The characteristics of the farmer, the household and the farm
- The trees species presents of the farm and SPS
- The determining factors in SPS adoption and management

Although, we aimed at recollecting some quantitative data we designed the guide in order to conduct the discussion in a natural flow, first asking open questions and then deepening with secondary questions that were more specific. We used with the technics of dialogue from GEILFUS (2002) which intend to put people in confidence while keeping attention on their sayings. Respect their thinking by not interrupting. Get deeper into people sayings by using stimulant question such as “what do you mean?” and use open questions (why, how, when etc.) to extract the most complete information possible. Avoiding the use of difficult questions or depreciations is also an important point. The complete interview guide can be found in annex 3.
Additionally, we asked farmers if they knew about tree species that where present in experimentation of the CATIE’s farm. The information collected is not used in this study. We only used the number of species known to help us to characterize farmer’s knowledge. The complete list of species is presented in annex 1.

We conducted the interviews at the farm when it was possible at a time that was convenient for the farmer to not interfere with the farm work. We first conducted the interview in a quiet and comfortable place to draw the complete attention of the farmer on the interview process (SIBELET et al., 2013). Then we asked for a rapid tour of the farm if it was possible. The interviews were recorded with the authorization of the interviewee as the discussion was in Spanish. A transcription of each interview was made in English.

4. Data analyses

The analyses of the results were conducted in two steps:

- In a first phase, the qualitative and descriptive analysis of the silvopastoral practices met during the interviews was conducted. Then, we described the uses and benefits of trees species mentioned by farmers and the limitations to adoption and management of SPS as well. The objective this phase, was to have a clear vision of the importance and uses of trees in cattle farms of the CBCVT and to identify limitations and motivations mentioned directly by farmer surveyed.
- In a second phase, from the results found during the first phase, we aim to push further the analysis and lead some statistical descriptive on the initials variables or news variables that were deducted from the qualitative analysis. The aim of this second phase is to explore relations between the farmer and farm characteristics on one-side and the silvopastoral practices and knowledge of the farmer concerning SPS on the other side. Additionally, this analysis can help us confirm the sayings of the farmers but also identify another type of limiting factors that were not mentioned during the interviews.

The figure 8 is representing the process of elaboration of the interview, data collection and analyses.

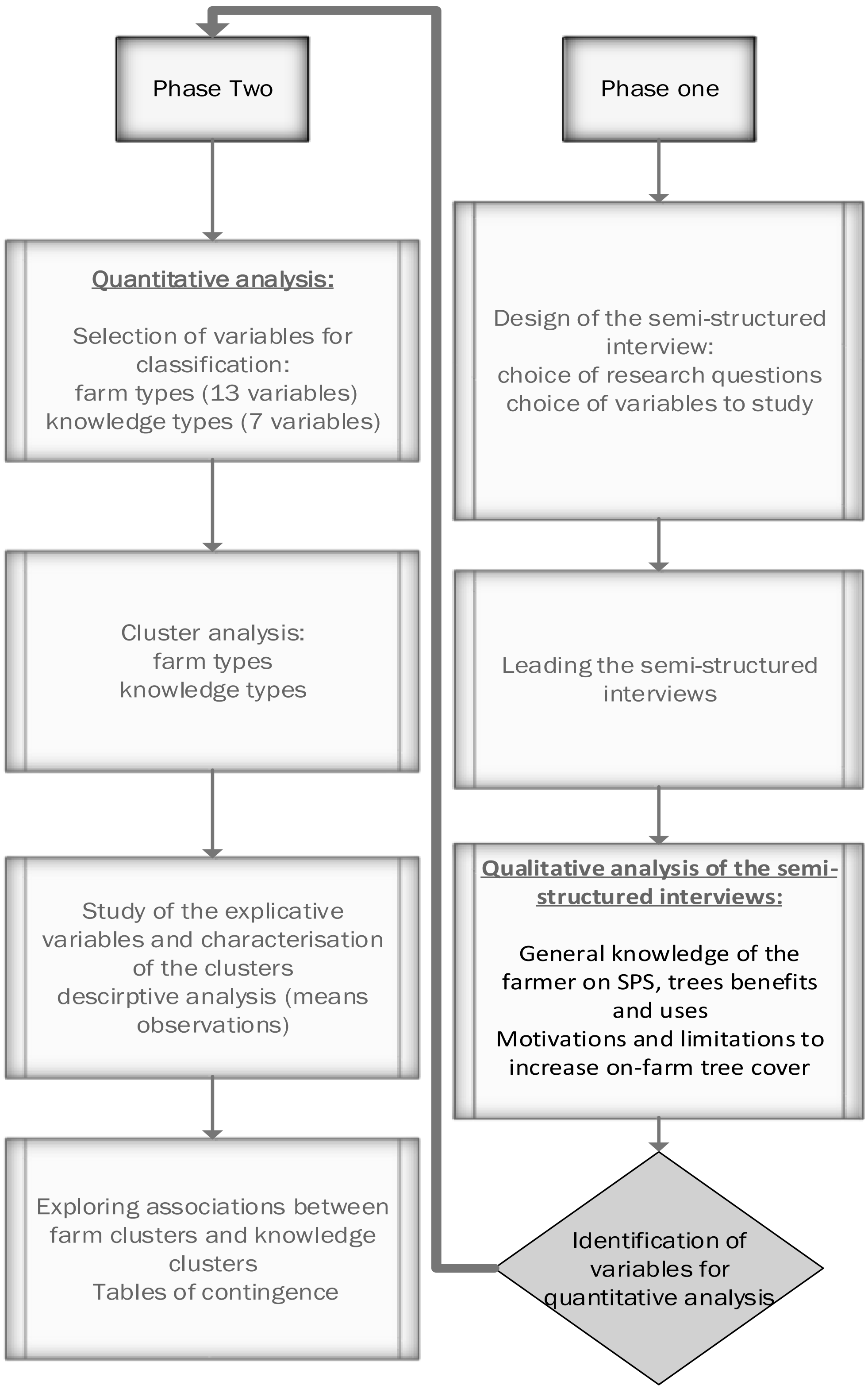


Figure 8: methodologic scheme representing the different steps of the study

4.1. Qualitative analysis of the interviews

It was decided to analyze qualitatively the variables related to the perception of the benefits and uses of the trees present on the farm and determining factors for the adoption and management of SPS (research question 3) and 4). Two main type of analyzes can be leaded to analyze the data collected during semi-structured interviews. The first one is the content analysis which can be done by counting terms thanks to specialized software. The second one is the thematic analysis. It is a subjective way to analyze the semi-structured interviews. It leaves more space to interpretation and do not require the quantification of the data (SIBELET et al., 2013). This last analyze was preferred to identify the main limiting factors of SPS because it seemed more adapted to the design of our study. Moreover, we were looking for recurrent themes mentioned through the interviews that could be identified as determining factors in SPS management and adoption.

The "meta-plan" tool was used to enable to identify main themes that were recurrent in the interviews. The objective of this tool is to "extract ideas and structures in an operative content" which enables to establish a logical demonstration. It permits also to relate and observe points of convergence and divergence within each theme according to what was said during the semi-directive interviews (SIBELET et al., 2013).

4.2. Quantitative analysis of data collected during the interview:

From the results of the analysis of the interviews, we followed by a quantitative analysis to confirm some previous of results and try to find associations between farm and farmer characteristic's, and silvopastoral practices and farmers knowledge related to SPS. At the end of the first phase, we identified new quantitative variables presented in table 4 that would be used for the statistical analysis.

The objective of this phase is to observe trends that occurred in this study as the number of observation is quite low (n=30) and that there was no design of surveys that can justify a deeper statistical analysis. The statistical analyses leaded did not aim to extrapolate to the total population of cattle farmers of the CBVCT. We insist on the fact that our results are only valid for our sample and descriptive analyses will be used to present our results. The software InfoStat was used to lead the statistical analysis on the data collected.

4.2.1. Typology of farms

Firstly, we grouped the farms surveyed into different clusters. We choose to base our typology on the farm characteristics but as well on farmer characteristics. As we collect a high number of variables, we needed to make a selection for the ones we wanted to include in our analysis.

We selected the variables that would be used to lead the cluster analysis according to some criteria:

- Variables available for all the farms surveyed and the access to the information was easy (most of the time the farmer was confident in his answer, the information asked was easy to verify)
- Exclude variables that can be considered as standard (the answer is always the same, like the ownership of the land for example)

13 variables were chosen to lead a cluster analysis (see detail table 4). The method of aggrupation used for the cluster analysis was Euclidean because all the variables utilized were quantitative and categorical variables (with categories identified by numbers and ordered along a gradient). The method of Ward was used as a measure of distance.

Table 4: Variables selected for statistical analysis

Type of Variable	Variable	Variable ID	Unit	Unit categorical
Category	Education level	Fer_Edu		Value None =0 /primary=1/secondary=2/technic=3/ university=4
Quantitative	Altitude	Far_alt	meters	
Quantitative	Size of the farm	Farm_ha	ha	
Quantitative	Numbers of days of external labour/week	Farm_lab	Days/week	
Quantitative	Years in cattle activity	Farm_catt_age	years	
Quantitative	Animal load	Cat_AU/ha	AU/ha	
Category	Type of production	Far_typ_prod		dairy =4/ weanlings=1/ fattening=3/ both suclker cows and fattening=2
Quantitative	Use of feed concentrates	Cat_conc	Kg/cow/week	
Quantitative	Proportion of grassland in land use	Past_prop	%	
Quantitative	Size of fodder bank	Past_FB	ha	
Quantitative	area of natural forest	SPS_forest_ha	ha	

4.2.2. Typology of knowledge on on-farm trees benefits, uses and silvopastoral practices

The methodology used identify types of knowledge was similar to the one used for the farm typology. We first selected our variables that characterize better the knowledge of the farmer on the on-farm tree uses, benefits and silvopastoral practices.

From the results of the qualitative analysis, we identified 7 variables that we jugged relevant for this analysis:

- Number of on-farm tree species mentioned during the interview
- Number of tree species mentioned to be present in LF
- Number of tree species mentioned to be present into pastures
- Number of tree species mentioned to be present in BF
- Number of tree species of the experimental module known by the farmer
- Number of tree uses and benefits mentioned
- Number of limitations of SPS management or adoption mentioned

We conducted the same cluster analysis with the Ward measure of distance and Euclidean method of aggrupation (all of our variables used are quantitative as well).

4.2.3. Characterization of types of farms and knowledge found

In a cluster analysis, each individual is considered homogenous within its group but heterogeneous between the groups (MUÑOZ QUINTERO, 2014). However, this analysis does not provide the information that characterize each type or which variables are discriminative. We studied the means of the variables for each cluster in a descriptive way. For the results of this phase, we can only deduce tendencies.

At the end of this stage, based on the information provided by literature and descriptive statistics, we identified 4 types of farms and 3 types of knowledge. The next step was to find associations between them.

4.2.4. Associations between farms types and knowledge types

For this last stage, we used tables of contingence that were relating the types of farms with the type of knowledge. We decided to interpret those tables in descriptive manner because the number of interviews was too small to generalize to the total population. However, our objective was to observe how farm types and knowledge on SPS associate in this study.

Chapter 3: Results

In this chapter, we will present the results of our study. We will start by describing the type of SPS we observed in this study. Then, we will expose the perception of tree uses and benefits of farmers interviewed. Finally, the limitations of SPS mentioned by farmers will be described. In a second step, the results of the quantitative analysis will be exposed: the farm typology we came-up with, the knowledge characteristics of the farmers and how those two can associate with each other.

1. Types of SPS and trees species mentioned by farmers

During the interviews, we asked if farmers were aware of the terminology "SPS": only 13 out of 30 knew about it. However, all of them responded to be aware of this concept when we explained the meaning of SPS (see table 5). Then, we investigated which type of SPS was present on each farm. We identified the SPS based on the classification of the FAO (2000). According to this typology we found 3 main SPS in all the farms we visited:

- Lives fences (LF)
- Trees isolated in pastures (TIP)
- Fodder banks with tree species (FB)

Additionally, we observed only one example of timber plantation associated with sheep grazing. We will not focus on this SPS in this study.

Table 5: summary table of SPS characteristic of the farms investigated

Farmers :	Number	%
know about the SPS terminology	13	43%
have SPS on their farm	27	90%
have LF in their farms	24	80%
have TIP in their farms	18	60%
have FB associated with trees in their farms	5	17%

1.1. Live fences

24 farmers out of 30 reported to use LF as a delimitation of pastures. As most of the farmers were practicing rotational grazing, the LF were used to divide the grassland into pastures of smaller area. About 19 species entered in LF composition were cited during the interviews. But as it could be seen in table 5, this composition was dominated by 3 species (for the complete list of specie see annex 5). *Erythrina species, Trichanthera gigantea, Gliciridia sepium* represent the large majority of tree species used according to farmers' sayings. On average, farmers mentioned to manage only 2,4 species in their LF which shows a tendency for a quite simple structure (VILLANUEVA; MUHAMMAD; CASASOLA, 2008).

Table 6: Main species mentioned by farmers which enter in LF composition

Scientific name	Comon Costarican name	cited in LF
Erythrina costaricensis	Poro	19
Gliciridia sepium	Madero negro	16
Trichanthera gigantea	Nacedero	13

Photo 3: Live fence of *Gliricidia sepium* in a dairy farm

Although the composition and the management of LF appeared to be quite uniform through the study, some farmers had innovative ideas about LF purpose, management and use. For example, *Annona muricata* was integrated to LF for double purpose objective: to provide shade for animals and fruits to sell for human consumption. Some farmers used trees in LF as fodder banks to provide extra-protein source using *Trichanthera gigantea* and *Tithonia diversifolia*.

Trichanthera gigantea had a lot of popularity as it also provided a source of fodder rich in proteins. Farmers liked it because it was resistant to diseases, to cow damages and has a good root system to control erosion: "*I like "Nacedero" better, because it produces more fodder than "Poro" or "Madero Negro", it can be used as post, which is not possible with "Morera", and also fix nitrogen […]. The "Nacedero" is a tree which is different from shrubs like "Morera" and "Boton de Oro".*" (meat farmer).

The design of LF can be very innovative and make an efficient use of the land. LF represents a key element to increase SPS adoption and to improve SPS management as well. Farmers are interested in LF, because the trees used can be multipurpose: "*I would like to have more trees in fences […] it would be double-purpose, those trees would be used as posts for fences, shade and also timber*." (dairy farmer).

Moreover, LF does not require an important initial inversion and are quite cheap to set-up. Farmers reported to use plant cuttings (vegetative reproduction) instead of buying seedlings from nursery. However, they can have a cost of maintenance, through the pruning that need to be realized and the replacement of trees: "*The live fence has a low cost of establishment but a high cost of maintenance and it is the contrary for dead fences*" (meat farmer).

Photo 4: *Trichanthera gigantea* in a dairy farm

1.2. Trees Isolated in Pastures

18 out of 30 farmers reported to have trees growing in their pastures. Those trees were said to come from natural regeneration or to be remnants from coffee plantation like *Erythrina poeppigiana* and *Cordia alliodora*. Indeed, in this region, coffee is cultivated under shade as an agroforestry system. Farmers are letting them into pasture because they provide services that will be detailed in the next section.

Farmers cited 42 species that were present in the grassland with a dominance of *Erythrina poeppigiana, Cordia alliodora, Cedrela odorata* and *Ficus sp.* as species mentioned (see table 7 and complete list in annex 5). On average, the farmers reported to have 3,2 species of TIP on the farm.

Table 7: Main species mentioned by farmers which enter in TIP composition

Scientific name	Comon Costarican name	Cited in TIP
Erythrina poeppigiana	Poro	13
Cordia alliodora	Laurel	8
Cedrela odorata	Cedro	6
Ficus sp.	Higueron	6

Photo 5: Natural regeneration of *Ficus sp.* in grassland of a dairy farm

1.3. Fodder banks associated with tree species

9 farmers out of 30 mentioned this SPS to be present on their farm. Only two tree species were mentioned: *Erythrina poeppigiana* (mentioned one time in FB) and *Trichanthera gigantea* (mentioned 9 times). Those species were cultivated alone or associated with *Tithonia diversifolia* or *Morus sp.* . The trees were planted in lines and the pruning was done regularly in order to maximize biomass production. This SPS enables farmer to find an alternative to reach a more efficient management of the pasture area (VILLANUEVA; MUHAMMAD; HAENSEL, 2010).

Photo 6: Fodder bank of *Erythrina poeppigiana associated with Tithonia diversifolia*

To conclude, we can say that the practice of SPS was quite uniform in our sample. The large majority of farmers were aware of the concept of SPS and the large majority conducted silvopastoral practices. Only 3 types of SPS were identified as common practice for the area.

Additionally, Farmers mentioned 48 tree species to be part of SPS (the complete list of tree species in presented in annex 5). Among those species: 19 were mentioned to be found in LF, 42 in TIP and only 3 in FB. This shows an interesting species diversity, even if in each type of SPS, some species much more frequently cited than others.

2. Farmers' perception of tree uses and services

We described the SPS types met in farms during our study in the previous section. Now, we would like to study a bit deeper perceptions that farmers told us about trees on their farm: which are the tree uses and if they perceived any benefit due to their presence. In this section, we do not restrain ourselves to the only trees in SPS. We are taking into account tree located along water bodies, tree in areas of natural regeneration or natural forest. Although some of those trees are not directly linked with cattle activity, they are part of farmers' perception of on-farm tree and are linked to their motivation to maintain or increase on-farm tree-cover. Farmers mentioned 69 tree species to be present on their farms, the complete list of those species cited is presented in annex 5.

During this study, farmers mentioned 3 uses (fodder, timber and fruits) and 9 services that are listed in the table 8 below. In our study, farmers attached economic, environmental and social values to trees present on their farm.

Table 8: Tree uses and services mentioned by farmers

	Tree uses and benefits provided by trees	Number of farmers that mentioned it	% of farmers
Economic value	Fodder source	24	80
	Shade for cattle	22	73
	Timber	21	70
	Nitrogen fixation	8	27
Environmental value	Water protection	19	63
	Wildlife conservation	15	50
	Erosion control	7	23
	Carbon storage	3	10
	Climate change mitigation	1	3
	Windbreak	1	3
Social value	Beauty of the landscape	12	40
	Fruit for human consumption	6	20

2.1. Economic value

2.1.1. Source of fodder

It appeared to be an important use of trees, especially in LF and FB. It was mentioned in 80% of interviews. Most of farmers used leaves and branches to provide fodder when trees in LF were pruned. This can provide a substitute to the use of feed concentrates and thus decrease production costs. However, in most of the cases, the fodder from trees in LF was used in a sporadic way and the trees were not really managed to produce important quantity of fodder. However, it was mentioned that the leaves could be used to permit the cattle to remain additional time in one pasture plot. As well, this resource was reported to be a source of fodder in case of emergency: "*There is times where there are not enough pastures, then we use the branches for feed […] but when there is enough pasture we use them as posts*." (meat farmer).

However, some farmers made the choice to manage more intensively their trees through fodder banks of tree species associated with herbaceous species like sugarcane or *Tithonia diversifolia* which is also an interesting source of proteins (GALLEGO-CASTRO; MAHECHA-LEDESMA; ANGULO-ARIZALA, 2014). The trees were planted a specific plot and pruned regularly to provide a continuous supply to the cows. In most of the case this practice was related to an objective to decrease costs from extra-feed and increase independency from external inputs: *"In the protein bank we have "Morera", "Boton de Oro" […] at the end the objective is to create a source of proteins not to depend on feed concentrates*." (meat cattle farmer). Branches and leaves were harvested, chopped and brought to the cows when they were kept at the stable after milking or brought into the pasture. However some farmers reported that the cows did not find those species palatable and cows needed to adapt: *"You need to start giving it from their young age so they will develop their taste for those species"* (meat farmer).

Photo 7: Fodder trees chopped and mixed, ready for the cows to eat after milking

2.1.2. Shade for cattle

It is an important service brought by trees especially for cattle. In CR, the thermic stress can be very high during the day and it can have very important consequences on animal productivity (PACIULLO et al., 2011). Indeed, providing shade to cattle is recognized to increase animal well-being and thus production. It was mentioned in about 76% of the interviews (23 farmers out of 30). That shows that farmers are aware of animal welfare and also that their animals will produce more is they have better confort: "*The cows want shade and want water […] I imagine myself sitting here in the full sun and that must be so exhausting*." (dairy farmer). Some farmers even planted *Erythrina poeppigiana* into their pasture to provide shade to their animals.

Photo 8: cows hiding from the sun beneath a tree in the pasture in the farm of CATIE

2.1.3. Timber

It was also mentioned as a dominant use of trees in the farm. Some farmers dedicated part of their land-use to timber production but only one farm combined grassland with timber production. Most of the farmers were using the wood only when the tree fell naturally or when they needed timber for personal use (to build house, barn, fences, etc.). *Cedrela odorata* and *Cordia alliodora* were the most common species used for domestic use. When farmers supplied timber for commercial purpose, they usually chose tree species such *Cedrela odorata*, *Eucalyptus sp*., *Pinus sp.*, *Cupressus Benthami* or *Alnus acuminate*. The use of timber was mentioned in 21 interviews (70% of the farms). However, only 3 farms were really managing timber plantations as a real commercial production.

2.1.4. N fixation to improve soil fertility

This theme appeared to be less frequently mentioned by farmers although it is a very important service that could be brought by tree in SPS. Only 26% of the farmers mentioned this benefit during the interview (8 farmers). Farmers perceived the positive action of trees on soil fertility as an economic benefit. *Erythrina poeppigiana* and *Gliricidia sepium* were the main species cited for thier proprieties to fix nitrogen, improve soil fertility and even sometimes to substitute fertilizer: "*This nitrogen which is necessary for the pasture, we try to find it in a natural way with the "Poro". This specie is good for nitrogen fixing*." (meat farmer)

It was reported that the entire trunk of *Erythrina poeppigiana* could be chopped and applied directly to the pasture as an organic amendment: "*The leaves when they fall down, they do not have nutrients anymore, but the rest of the tree still has […]. The tree is cut when the diameter is superior to 40cm […]. It is a cheap way to fertilize the soil*." (meat farmer)

2.2. Environmental value

2.2.1. Water protection

The farmers that disposed of water resource recognized the importance to protect it by letting tree growing or planting trees around the spring, the river or the ditch. Indeed, trees around water bodies prevent erosion and keep the ground stable. Additionally, some farmers decided to recollect rainwater for washing equipment and stable but also for fertilization (by mixing it with manure and applying it to the pasture). *Trichanthera gigantea*, *Inga sp.*, *Pithecolobium sp.* were cited to be used for this purpose. Although in this context, the water issue was not considered significant by farmers: "*Water is not a limitation.*" (meat farmer)

2.2.2. Wildlife and biodiversity conservation

50% of the interviewees mentioned wildlife conservation as a service brought by on-farm trees. Some species of trees like *Cecropia sp*, *Acnistus arborescens*, *Phoebe sp., Brosimum sp.* and *Citharexylum caudatum* were reported to provide feed sources to wildlife like birds and monkeys: "*It is looking nice when birds are coming to eat.*" (dairy farmer)

In some cases, farmers were attached to see wild animals roaming in their farm. They were even ready to plant some of the previously mentioned tree species to sustain the wildlife. A project of the establishment of an ecological corridor to bind two natural areas surrounding a farmer's propriety was even mentioned: "*I am going to plant 15 different species in this corridor […] It is very nice because the jaguar is coming back*." meat farmer

2.2.3. Control of erosion

23% of the farmers mentioned specific species that were used to control erosion in pastures or in sloppy area of the farm. *Pithecolobium sp.* and *Yucca elephantipes* are good examples: *"Sotacabaillo is a specie with a nice cover and it is maintaining well the soil to prevent erosion*." meat cattle farmer

2.2.4. Carbon storage

Carbon sequestration by trees was not mentioned by many farmers in this study (3 farmers out of 30). However, we can expect this theme to become more important since Costa Rica affirmed its willingness to reach carbon neutrality in 2021 (DIRECCIÓN DE CAMBIO CLIMÁTICO MINAET, 2016). Some farmers are making huge efforts to reach this neutrality at the farm scale in order to get international certification. One of the farms visited was one of the first certified carbon-neutral in Costa Rica thanks to the conservation of the trees: "*My farm is carbon positive; it had fixed about 100 tons of carbon […] and this is because I take care of the trees.*" (meat cattle farmer)

2.2.5. Climate change mitigation and Windbreak:

Those two aspects were very little mentioned (only by one farmer). It showed that cattle farmers were not concerned by climate change and the strength of winds.

2.3. Social Value

2.3.1. Beauty of landscape

40% of the farmers mentioned the trees to have an important role for the farm scenery. Trees are bringing a lot esthetical value to the landscape and some farmers were really looking for it by planting ornamental species like *Spathodea campanulata*, *Tabeluia chrysantha*, *Tabeluia rosa*, *Ceiba pentandra*.

Photo 9: View of a meat cattle farm where an imposing *Ceiba pentandra* (tall tree in the middle) is adding aesthetical value to this agro-landscape

2.3.1. Fruit for human consumption

The farmers in Costa Rica do not really seem to depend exclusively on the farm resources to fulfill their basic needs; they have access to external resources (shops, electricity, etc.). Thus this theme was not primordial in this study and the fruit recollection was more assimilated an activity of leisure than an economic one for cattle farmers. However, about 20% of the interviewers mentioned this theme (6 farmers): "*It is nice to have fruit trees in the farm. If someone is getting hungry while walking in the pastures, it is possible to eat a fruit*." (meat cattle farmer). *Psidium Guajava* grew commonly in pastures and was mentioned to bring fruits to cattle and for domestic consumption.

2.3.2. Farmer's perception of tree as cultural feature of the landscape

Some cultural and personal values were also linked to the presence of the trees. In some cases, the benefits that trees could bring in the future were mentioned. Some of those benefits were recognized as a capital or a security on the long term: "*Having a tree is like having a child*" dairy farmer. Big and old trees had also a sentimental value and linked to the story of the farm: "*I seeded those trees in memory of my father that taught me a lot of this farm*" (dairy farmer)

Concerning the cultural aspect, the conservation of native tree species has been mentioned as well: "*It is important that we are not losing native' trees species.*" (dairy farmer). *Cordia collococca* and *Phoebe sp*. were the native species cited with important cultural value. In general farmers had a positive opinion about the presence of trees on their farm and showed interest to preserve this resource: "*When someone cuts a tree, he needs to plant two*" meat farmer.

In conclusion, farmers were generally aware of the role that can be played by trees in their farming systems and they were aware of the positive influence that the tree brings to their farm at an economic level but also environmental and social level. Some uses and services were more frequently mentioned than others. That was the case for "Fodder source", "Shade for cattle", "Timber" and "Water protection". The detailed results are presented in table 8.

3. Limitations to SPS

In this part, we will go through the main limitations of SPS that were mentioned during the interviews. Farmers cited limitations both linked to the management of the SPS and linked to thier adoption (presented in table 9).

Table 9: Limitations of SPS mentioned by farmers

	Limitations mentioned by farmers	Number of farmers	% of farmers
Limitations related to the adoption of SPS	Conflicts between trees and grassland productivity	18	60
	Time and economic limitation	12	40
	Lack of information about suitable species or technical assistance	12	40
	Regulation on forest management limiting the freedom to use trees planted in SPS	2	7
Limitations related to the management of SPS	Trees that are growing in pastures are getting dry	15	50
	Cattle damaging trees into pastures	14	47
	Soil and climatic issues	9	30
	Difficulty to manage some species in LF	7	23
	Diseases and pests are highly affecting trees in SPS	5	17
	Natural risks linked with the presence of trees	2	7

3.1. Limitations related to the adoption of SPS

There were many factors feared by farmers when they want to establish SPS. The establishment of SPS can affect the overall farm productivity at the beginning. As well, resources such as capital, financial but also labour could be insufficient to sustain the establishment phase. Farmers can also lack information and technical support to adopt or improve their silvopastoral practices.

3.1.1. Conflicts between trees and grassland productivity

It is the limitation the most mentioned by farmers (18 times out of 30). Their main arguments referred to the limitation of the area. Indeed, very small farms were interviewed and the farmers responded trees were taking space and that they couldn't afford it due to this area limitation: *"This is for large farms. In smaller areas, it is more difficult to mix grassland and trees."* (dairy farmer)

The reduction of the productivity of the pasture was also a fear linked to the presence of tree in pastures. Farmers were selecting and cutting some trees that were growing spontaneously into the pasture in order to maintain equilibrium between tree-cover and grass production.

Farmers were talking about finding an adapted tree density and to mitigate shade by pruning: *"When they [the trees in pastures] are becoming thicker, I am pruning them a bit to avoid too much shade"* (meat farmer). This selection of species that were going to be eliminated of the grassland was based on some morphological characteristic of the tree: "*The specie is not so important for me. Any tree that let the light enter is interesting. It only needs it to have fine leaves or to be tall.*" (meat farmer).

Shade was not the only factor that could lower the production in grassland. Farmers reported that during the raining season, due to water dropping from the leaves, mud tended to be very important underneath trees: *"During winter (rainy season) I don't like having shade […] because there is a lot of humidity and it turns into mud."* (meat farmer)

However, some farmers were more optimistic and judged that with an adapted management of the tree cover they could limit the reduction in pasture production: *"In the farm, we have 50 trees per hectares but they have fine leaves that do not affect the grassland."* (meat farmer)

3.1.2. Time and economic limitations

This limitation was mentioned by 12 farmers out of 30. For some farmers, tree cultivation to produce timber lasted too long to be interesting. They did not value the possible benefits that it could bring at the long term: *"Imagine, it would take 10 to 15 years to wait. It is not a short term process to produce timber.*"(dairy farmer).

Moreover, SPS required additional work that could demotivate farmers at the beginning. The initials cost of establishment of SPS were cited to be important, especially the costs of tree protection. Many farmers considered that they did not have the economical capacity and neither the time to take care of recent tree plantation. In some case the farming was considered as an additional activity and the farmer had another job. Thus, it could explain that they did not want to invest more time and money in the activity. They also mentioned that contracting external labour force was expensive and it would not make sense to employ someone for that: "*There is to pay a wage for that and it is very costly for a small farm.*" (dairy farmer)

Additionally, we observed cases where farmers wanted to experiment silvopastoral practices but its professional circle was not supporting it: *"The people I am working with do not believe in this."*(meat farmer). Some farmers lived outside the farm and left the daily management to their employees. That could results in failure of implementation of SPS if the person was not prepared to take care of a tree plantation.

3.1.3. Lack of information about suitable species or technical assistance:

12 farmers mentioned the lack of information as a limitation to SPS adoption. Although, they were willing to plant more trees, sometime farmers were limited by their knowledge and incertitude concerning the specie that would adapt to the farm conditions and fulfil their specific need. Several farmers reported difficulties to have access to seeds. Of course, common species were easy to obtain (from the neighbours for example) but for more specific demands, the access might be more difficult. For example, the *Alnus acuminate* was mentioned to be more difficult to find.

Farmers mentioned the following themes where they would like to get more information:

- Farmers in higher areas would like to know which specie can stand the cold to produce timber
- The species that are multipurpose and could be used in LF
- The species that would be able to control erosion in sloppy areas of the farm
- The species that bring nutrients to soil and improve fertility

In general, the study area was characterized by many small producers having limited access to information: "*In the district of Turrialba and Jiménez, small farms are dominating […] they do not know much about how to make their farm more efficient.*" (meat farmer). Some institutions were cited to provide information like the MAG (Ministry of Livestock and Agriculture). The CATIE was cited by to farmers on different themes and especially courses on SPS. However, farmers tended to lose confidence in those institutions because some projects did not reach their goal or the farmer did not see the benefits: "*The MAG is not helping, there is too much paperwork and when they want to help, they give it to the people that do not know or are not interested. They are not helping people that really need*." (meat farmer). Some farmers even mentioned the lack of communication to local communities about research conducted in CATIE: *"CATIE is a "monster of knowledge" and it is very close from here. But there is no sharing of the information*." (dairy farmer).

3.1.4. Regulation on forest management limiting the freedom to use trees planted in SPS

Although, it was only mentioned by 2 farmers out of 30, this aspect is quite important to take into account when implementing SPS. Indeed, Costa Rica has very strict regulation on trees permits for timber exploitation. That could represent a very serious limitation for the adoption of SPS: *"One time we were going to plant on a large scale. But they put clauses that were frightening […]the day you would need to cut a tree for timber, you would have to ask for permits and do a lot of paperwork […] Then, it seems that you are not the owner anymore. Better no to plant anything!"* (meat farmer).

Indeed, the government is making big efforts to conserve its natural resources and strengthen reforestation which is quite unique in Latin America (RAMOS URZAGASTE, 2003). The Forest Law 7575 is specifically dealing with the aspect of wood exploitation and protection of some specific areas (along rivers for example) (LA ASAMBLEA LEGISLATIVA DE LA REPUBLICA DE COSTA RICA, 1996).

3.2. Limitation related to the management of SPS

The management of SPS can present some limitations and even sometimes those factors can lead to the abandonment of the practice.

3.2.1. Trees that are growing in pastures are getting dry

This phenomenon was reported by half of the farmers (15 out of 30). Especially, it was reported from trees that were remnants from coffee plantations or forest plantations. Farmers observed that when they changed the land use and implanted grassland some trees started to dry progressively and finally died. The species mentioned to be suffering from the change of land use were *Erythrina poeppigiana*, *Cedrela odorata*, *Cupressus Benthami*, *Pinus sp.*, *Eucaliptus sp*., *Cordia alliodora*, *Psidium Guajava*. Some farmers advanced the hypothesis of the competition with the grass species. *Brachiaria* especially, were suspected to have a very dense root system, very competitive for the water resource and that could result in the degeneration of trees: "*Guava is growing in my pasture but the Brachiaria is not letting it grow, I understood it was a very "dry" specie*" (dairy farmer).

The real cause of this issue is still unknown. Some farmers reported that they did not believe in such phenomenon and some technicians were very suspicious as well: "*We have noticed that in improved pastures, we are losing trees […] and there is quite some producers that said it to me. Technicians say there is no reason but it is happening anyway*.*"* (meat farmer). Deeper investigation is needed to understand the causes of this issue.

3.2.2. Cattle damage trees into pastures

14 farmers mentioned having issues managing cow and trees in the same plot. Cows were reported to eat the trunk or scratch themselves which is part of their natural behaviour. Farmers said that the compaction of soil due to their trampling could affect trees as well, especially fruit species. That could threaten the practice of SPS or even discourage the farmer: "*Cattle is eating everything, it breaks the bark […] it takes too much time*

and money" (dairy farmer). Young trees were reported to be the most vulnerable to cows and difficult to maintain in the pasture without protection: *"The cattle is naturally attracted by trees that were recently planted. I don't know, but some of them intrigue cattle […] they start playing until it breaks."* (meat farmer). A possible solution would be to prohibit the entry of cows while young tree are growing but this practice seem difficult to imagine for farmers with limited land access. The natural regeneration into pasture was also reported to be affected by cows.

Interestingly, some farmers did not meet this problem and defended the argument that their animals did not lack of minerals or feed: *"Here the cows do not harm trees […] In general, they do this when they are hungry or when they are lacking of minerals."* (dairy farmer). From an animal welfare point of view, it is a good sign that cows are attracted by the tree but of course the animal load should be well balanced to avoid too severe damages.

Photo 10: Cattle damage on *Gliricidia sepium* in Commercial farm of CATIE

3.2.3. Soil and climatic issues

As we exposed in the first chapter, the CBVCT is presenting many different climatic conditions due to the wide range of altitude. This had a quite important impact on the species that could be used in the SPS and as well the growth of the trees. 9 farmers out of 30 said that their issues to grow trees where linked to abiotic factors. The farmers located in high areas (Santa Cruz and surroundings) reported difficulties to implement LF with common species like *Gliciridia sepium*: "*This "Madero negro" do not grow here, it is too cold.*" (dairy farmer). However, *Erythrina sp.*, *Trichanthera gigantean* and *Sambucus sp*. were reported to be used in the village of Santa Cruz (1300m) in LF. For the farms located higher (1800m and more) *Psidium savannarum*, *Drimys Winteri* and *Reynosia latifolia* were reported to be used in LF. This shows the specificity of those areas and how farmers adapted their practices to local conditions. Thus, slower growth and failure in vegetative reproduction was mentioned to happen in highlands.

Concerning the issues related to the soil, high water content was mentioned as a limiting factor, as well as intensive previous land use with crops like sugarcane: "*The land is tired*." (dairy farmer).

3.2.4. Difficulty to manage some species in LF

7 farmers out of 30 mentioned difficulties to manage trees in LF. Although, it was the specie the most cited, *Erythrina costariciensis* did not have the approbation of all farmers. They reported difficulties to reproduce it and its sensibility to cattle. Moreover its spines made it complicated to manage: *"I don't like "Poro" […] I don't like it, the timber cannot be used, it has spines and a ugly shape. Its branches are irregular."* (dairy farmer).

3.2.1. Diseases and pests are highly affecting trees in SPS

Trees used in SPS can also be affected pest and diseases. 5 farmers reported that trees were affected by biotic agents. Leafcutter ants (*Atta sp.*) were the most feared as they could cause very severe damages:*"I seeded a lot of "Poro" into pastures and half of them were eaten by leafcutter ants […] it is almost impossible to win the battle, this is a real pest* "(meat farmer).

Cedrela odorata have been reported to be very sensitive to a pest *Hypsipyla grandella* (called "palomita") which is a butterfly and its larvae are devastating young *Cedrela* trees (CORDERO; BOSHIER, 2003).

Photo 11: Leafcutter ants defoliating a young tree (commercial farm CATIE)

3.2.2. Natural risks liked with the presence of trees

Having tree in the farm could present some risks. When tree are high and old, branches could fall. The most dangerous could be lightening falling on high trees that could harm humans or cattle. However, this limitation was rarely mentioned (2 farmers out of 30).

In conclusion, the limitations mentioned by farmers are diverse and are both related to the establishment of SPS and to their management. The ones that were mentioned the most frequently were: the conflict between trees and productivity, the problems of trees getting dry into pastures and the cattle damaging trees (see table 9).

4. Identification of farm and silvopastoral practices/knowledge types

From our quantitative data, we were able to identify farm types and silvopastoral practices types. In this section, we first described each type from both classifications. In a second step, we associated types of farm with types of silvopastoral practices and farmer's knowledge on this theme.

4.1. Typology of farms

To determine the typology of the farms, we used 7 variables. The table 10 is showing which they are.

Table 10: Variables to determine the farm typology

Type of Variable	Variable	Variable ID	Unit	Unit categorical
Category	Education level	Fer_Edu		Value None =0 /primary=1/secondary=2/technic=3/university=4
Quantitative	Altitude	Far_alt	meters	
Quantitative	Size of the farm	Farm_ha	ha	
Quantitative	Numbers of days of external labour/week	Farm_lab	Days/week	
Quantitative	Years in cattle activity	Farm_catt_age	years	
Quantitative	Animal load	Cat_AU/ha	AU/ha	
Category	Type of production	Far_typ_prod		dairy =4/ suckler cows=1/ fattening=3/ both suclker cows and fattening=2
Quantitative	Use of feed concentrates	Cat_conc	Kg/cow/week	
Quantitative	Proportion of grassland in land use	Past_prop	%	
Quantitative	Size of fodder bank	Past_FB	ha	
Quantitative	area of natural forest	SPS_forest_ha	ha	

From the results of the cluster analysis, we were looking at the possible ways to group our observations into farm types (see figure 9). It is the decision of the researcher to choose how many clusters will be retained. Some criteria of selection were used to select the number of clusters. The, first one was related to the total distance obtained from the cluster analyses, using the number of group divided by the vertical line at the middle of the total distance (located in the x axis of the dendrogram). In our case, the middle is located around 8,62 and it would divide the cluster in 5 groups of farms. However, as it can be seen on figure 9, the green root node is very close to that limit, and keeping 5 groups would imply that one group will be composed by only two farms (13 and 9). It would be very difficult to justify the decision of keeping this additional cluster of two farms because they are not so "distant" from the rest of the cluster. Therefore we decide to keep 4 clusters.

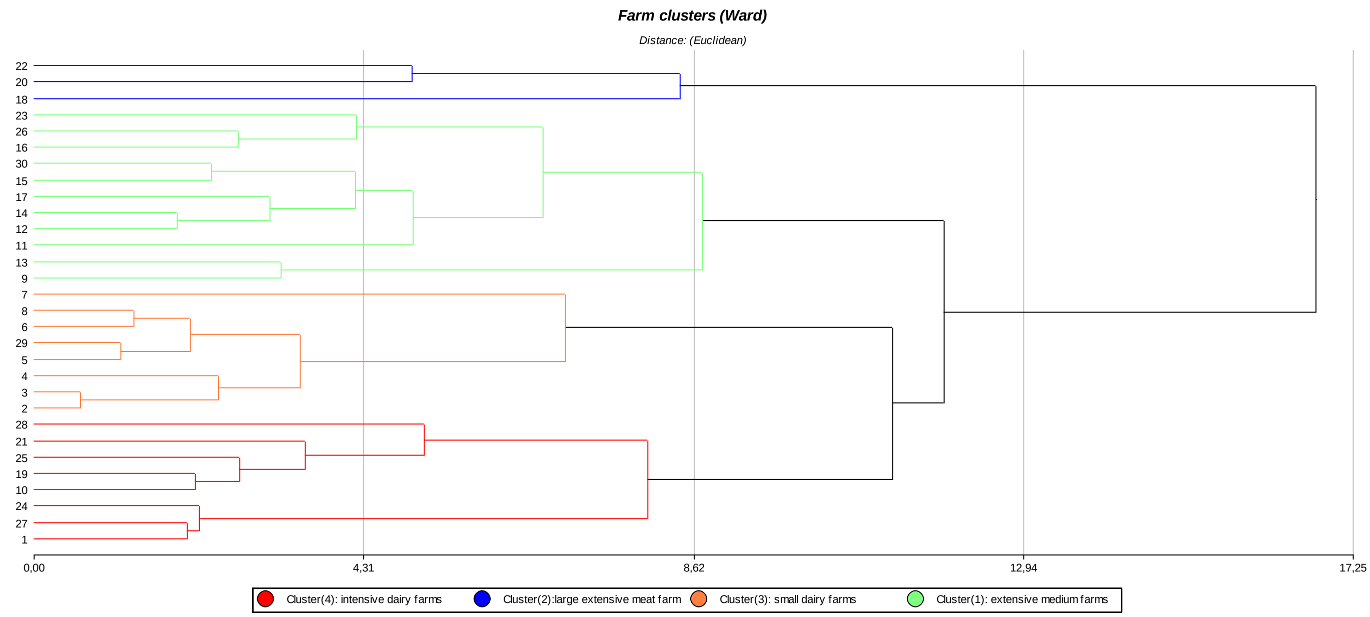


Figure 9: Dendrogram of farm clusters with 13 variables

The means of each variable for each group is used to identify the specific characteristics of each cluster. We identified two extreme groups that concentrate highest and lowest means values: small dairy farms and large extensive farm, meanwhile, 2 other clusters can be considered as intermediary groups: intensive dairy farms and medium extensive farms. We are now going to describe each cluster according to the values of means present in the table 11.

Table 11: Means of the 13 variables used in cluster analysis and table of contingency for categorical variables

clusters	Far_alt	Farm_ha	Farm_lab	Farm_catt_age	Cat_AU/ha	Cat_conc	Past_prop	Past_FB	Past_prop_imp	SPS_forest_ha	SPS_timber_ha	n
small dairy farms	843,75	3,16	0,37	11,38	3,98	22,74	100,00	0,41	0,88	0,00	0,00	8
intensive dairy farms	1531,82	6,51	4,94	28,27	5,71	25,23	76,18	0,44	0,80	6,03	0,00	11
medium extensive farms	818,75	22,38	9,04	11,50	2,20	9,25	77,46	0,71	0,96	4,31	0,00	8
large extensive farms	1100,00	115,00	13,17	49,33	1,81	0,48	64,58	1,02	0,78	17,00	7,67	3
Values for the sample												
Mean	**1115**	**20,7**	**5,64**	**21,4**	**3,92**	**17,83**	**81,71**	**0,56**	**0,86**	**5,06**	**0,77**	
Minimum	600	1	0	3	0,76	0	20	0	0	0	0	
Maximum	2500	190	31	50	11,8	46	100	3	1	34	10	

Type of production	**Weanlings**	**Fattening and weanlings**	**Fattening bulls**	**Dairy**	**Total**
small dairy farms	0	0	1	**7**	8
intensive dairy farms	0	0	2	**9**	11
medium extensive farms	**3**	1	1	3	8
large extensive farms	**2**	0	1	0	3
Total	**5**	**1**	**5**	**19**	30

Education level	**primary**	**secondary**	**technical**	**university**	**Total**
small dairy farms	**8**	0	0	0	8
intensive dairy farms	**4**	0	3	**4**	11
medium extensive farms	1	1	2	**4**	8
large extensive farms	1	0	1	1	3
Total	**14**	**1**	**6**	**9**	30

- *Cluster 3 (n=8): Small dairy farms*

This group has the lowest mean values for the variables farm size (Far_ha) ($\bar{x}$=3,16 ha), external labour contracted (Farm_lab) ($\bar{x}$=0,37 days/week), experience in cattle farming (Farm_catt_age) ($\bar{x}$=11,38 years) and proportion of grassland in the total land-use (Past_prop)($\bar{x}$=100,00%).

Additionally when looking at the tables of contingence (table 11) for the categorical variables educational level of the farmer (Fer_Edu) and the type of production (Far_typ_prod), we can see that only the category of primary education is present in this cluster and most of the farms are into dairy production (7 farms out of 8).

- *Cluster 4: (n=11): Intensive dairy farms*

The group present the highest mean values for the variables altitude of the farm (Far_alt) ($\bar{x}$=1531,82 m), the animal load (Cat_AU/ha)($\bar{x}$=5,71 AU/ha) and use of concentrates (Cat_conc)($\bar{x}$=25,23kg/cow/week). Concerning the type of production, the majority of the group has a dairy activity (9 farms out of 11). The size of their farms tend to closer to the cluster of the "small dairy farmers" ($\bar{x}$=6,51ha).This group appears to have more resources than the cluster 3, as they have the highest animal load, and a higher mean value in concentrate use.

- *Cluster 1: (n=8) Medium extensive farms*

This group only has the lowest mean value for Far_alt ($\bar{x}$=818,75 m) and then intermediary values for the rest of the variables. However, we can notice than the mean value for Farm_ha is higher than cluster 4 and 3 ($\bar{x}$=22,38ha) and they have the second lowest value for Cat_AU/ha ($\bar{x}$= 2,20 AU/ha) . The type of production is quite mixed in this cluster: weanlings producing farms (3 out 8) and dairy farmer (3 out of 8) are the dominant categories.

- *Cluster 2* (*n=3*): Large extensive meat farms.

This group has the highest mean values for the variables Farm_ha ($\bar{x}$=115,00 ha), Farm_lab ($\bar{x}$=13,17 days worked/week), Farm_catt_age ($\bar{x}$= 49,33 years), area of natural forest (SPS_forest_ha)($\bar{x}$=17,00ha) and area of timber plantation (SPS_timber_ha)($\bar{x}$=7,67ha). Additionally, this group has the lowest means values for the variables Cat_AU/ha($\bar{x}$=3,16 AU/ha), Cat_conc($\bar{x}$=3,16 kg/cow/week) and Past_prop ($\bar{x}$=64,58%). There are only meat farmers present in this group (two farms for weanlings and one is fattening activity). Although the size of this cluster is quite small, this group appears to be very specific. It is the group of largest farms with an extensive activity (very low animal load and low uses of feed concentrates). Their land use is diversified with area planted with trees for timber production and areas of conservation of natural forest. The table 12 is presenting the main characteristics of the farm clusters we just described.

Table 12: Summary table of farm clusters characteristics

Small dairy farm	**Intensive dairy farm**
• Few experience in cattle farming • Low level of education • Few external labour contracted • Important use of feed concentrates	• High animal load • Important use of feed concentrates • Quite experience in cattle farming
Medium extensive farm	**Large extensive meet farm**
• High education level • Include both dairy and meat farms • Mostly located in lower lands	• Lot of external labour contacted • Presence of timber plantation • Presence of natural forest • Low animal load

4.2. Typology of farmer's knowledge and silvopastoral practices

To determine the knowledge classification of the farmers, we used 7 variables. The table 13 shows which they are.

Table 13: Variables used for the determination of knowledge clusters

Type of Variable	Variable	Variable ID	Unit
Quantitative	Number of tree species cited during the interview that are present on the farm	Knwl_nb_sp	number
Quantitative	Number of tree species cited in LF	Knwl_nb_LF	number
Quantitative	Number of tree species cited in TIP	Kwl_nb_TIP	number
Quantitative	Number of tree species cited in FB	Kwl_nb_FB	number
Quantitative	Number of tree species known of the module	Knwl_nb_mod	number
Quantitative	Total number of services and uses of trees recognized	Ben_nb	number
Quantitative	Total number of limitation of SPS mentioned	Lim_nb	number

The process to lead this cluster analysis was similar to the one used for farm typology. At the end, we choose to retain 3 groups of knowledge based on the same criteria we used for the farm typology. The middle of the x axis of is located at 7,77 and divide the dendrogram (figure 10) in 3 clusters. Moreover, we decided to keep those 3 classes because they were found to be easier to interpret than 4 and reflected better our perception of the reality. Following the same process that was used for farm types, we describe each cluster through the value of its means (shown in table 14).

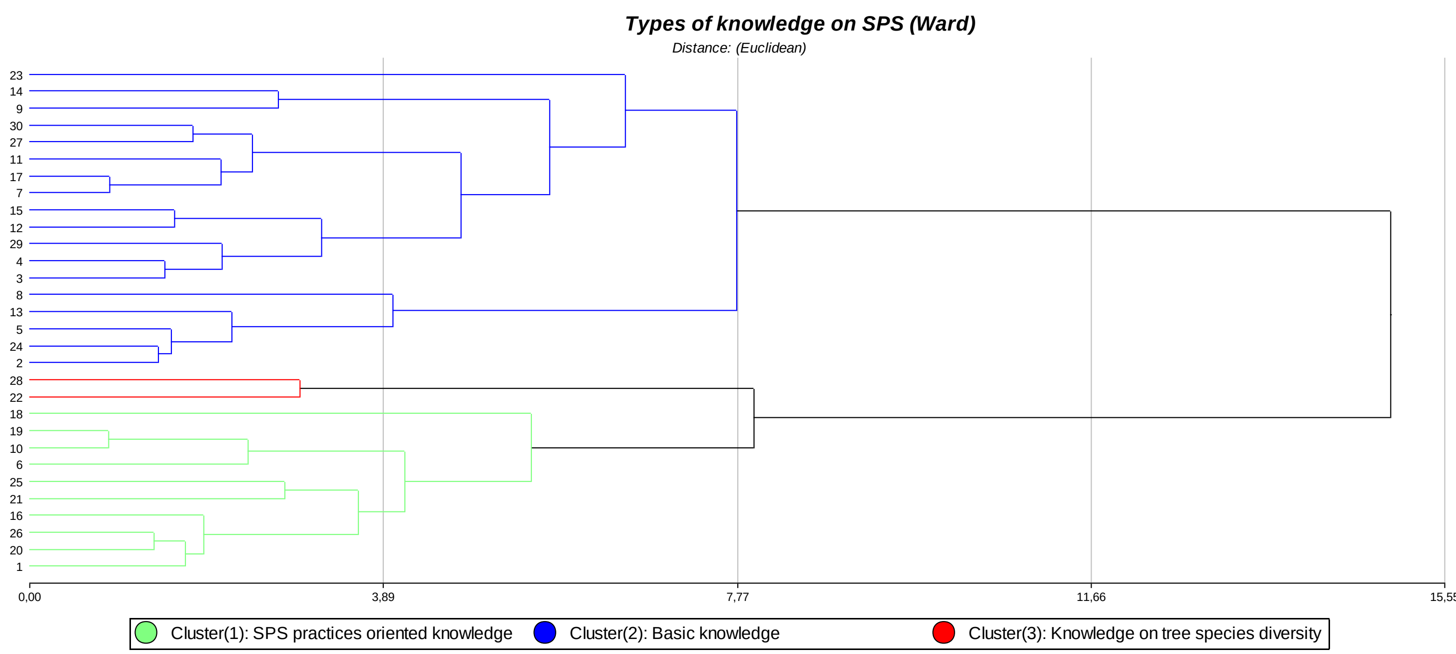


Figure 10: Dendrogram of knowledge clusters with 7 variables

Table 14: Means of the 7 variables used in cluster analysis

Cluster	Knwl_nb_ sp	Knwl_nb_ LF	Kwl_nb_ TIP	Kwl_nb_ FB	Knwl_nb_ mod	Ben_nb	Lim_nb	n
Knowledge on tree species diversity	16,5	2	11,5	0	13,5	4	3,5	2
Basic knowledge	7,67	1,83	2,5	0,44	11,11	3,72	2,28	18
SPS oriented knowledge	12,1	3,6	2,9	0,1	13,9	6,5	4,8	10
Parameters of the total sample								
Mean	**9,73**	**2,43**	**3,23**	**0,3**	**12,2**	**4,67**	**3,2**	
Minimum	1	0	0	0	1	1	0	
Maximum	30	5	13	3	16	9	7	

- *Cluster 3* (n=2): Knowledge on tree species diversity:

This cluster present the highest mean values for the variables number of species mentioned during the interview (Knwl_sp) ($\bar{x}$=16,50) and number of species mentioned in TIP (Kwl_nb_TIP) ($\bar{x}$=11,50). Although the size of this cluster is quite small we can say that the farmers of this group were able to cite a lot of tree species that were present in their farm and also to recognize an important number of species that were growing in their pasture. However, they are reported to have few species in their LF ($\bar{x}$=2,00). This type of knowledge tends to focus more on the diversity of tree species than the practice of the SPS. From those observations, it could be said that this type of knowledge focuses more on tree diversity and species conservation.

- *Cluster 2* (n=18): Basic knowledge

This cluster present the lowest means for Knwl_nb_sp ($\bar{x}$=7,67), number of species mentioned in LF (Knwl_nb_LF) ($\bar{x}$=1,83), Knwl_nb_TIP ($\bar{x}$=2,50), number of tree benefits mentioned (Ben_nb) ($\bar{x}$=3,72), number of SPS limitation mentioned (Lim_nb) ($\bar{x}$=2,28) and the highest mean value for number of species cited in FB (Knwl_nb_FB) ($\bar{x}$=0,44).This cluster gathers the farmers that tend to cite less tree species and show a tendency for a more limited knowledge on tree species and SPS. However, we can notice that this group is having the highest number of tree integrated to the fodder bank. They might use few tree species and their knowledge focuses on the productive aspect of SPS.

- *Cluster 1* (n=10): SPS oriented knowledge

This cluster present the highest mean values for the variables Knwl_LF ($\bar{x}$=3,6), Ben_nb ($\bar{x}$=6,5) and Lim_nb ($\bar{x}$=4,8). The farmers of this cluster seem to have a good knowledge in SPS as they integrate a larger number of tree species in their SPS and they seem to cite more tree uses/benefits and SPS limitation that the other clusters. This type of knowledge seemed to be more oriented to the practice of SPS.

Additionally, mean values for number of species known from the module (Knwl_nb_mod) were close to the overall mean ($\bar{x}1$=13,50, $\overline{x2}$=11,11, $\bar{x}3$=13,90 and $\bar{X}$=12,2).The number of species from the experimental module recognized by farmers were similar in each cluster. It tends to show that this knowledge was not linked to the silvopastoral practices.

The table 15 is presenting the main characteristics of the knowledge and silvopastoral practices clusters we just described.

Table 15: Summary table of knowledge and silvopastoral practices cluster characteristics

Knowledge on tree species diversity	Basic knowledge
• Highest number of tree species mentioned during the interview • Highest number of tree species in TIP mentioned • Do not have trees in FB	• Are using trees in FB • Lowest number of tree species in SPS • Lowest number of tree species mentioned • Lowest number of tree uses and SPS limitation identified
SPS oriented knowledge	
• Highest number of species identified in LF • Highest number of tree uses and services identified • Highest number of SPS limitation identified	

4.3. Exploring associations between type of knowledge and farm groups

At this stage we have grouped our observations into two distinct types of classification: farm types and knowledge type. Now, we want to investigate if there are some associations that can be observed between those two classifications. For that, we made a table of contingency (table 16) with the types of farms in rows and the types of knowledge in columns. For the same reasons cited previously and due to the small the number of observations (n=30), we will analyze this table in a descriptive way.

Table 16: Tables of contingency showing associations between farm types and silvopastoral practices/knowledge

Absolute frequency				
*	**Knowledge clusters**	**	***	****
Farm clusters	SPS oriented knowledge	Basic knowledge	Knowledge on tree species diversity	Total
medium extensive farms	**5**	2	1	8
large extensive farms	2	0	1	3
small dairy farms	1	**7**	0	8
intensive dairy farms	2	**9**	0	11
Total	10	18	2	30

Relative frequency (total)(shown as percentages)				
*	**Knowledge clusters**	**	***	****
Farm clusters	SPS oriented knowledge	Basic knowledge	Knowledge on tree species diversity	Total
medium extensive farms	**16,67**	6,67	3,33	**26,67**
large extensive farms	6,67	0	3,33	**10**
small dairy farms	3,33	**23,33**	0	**26,67**
intensive dairy farms	6,67	**30**	0	**36,67**
Total	**33,33**	**60**	**6,67**	**100**

If we look at relatives frequencies in total, the highest frequency is relating the “intensive dairy farm” cluster and the “basic knowledge” cluster (f= 30,00%). This type of knowledge seem to be associated with small dairy farms as well (f=23,33%). Additionally, the “SPS oriented knowledge” cluster seem linked with “mediums extensive farms” cluster (f=16,67%). As well, it is interesting to observe that this type of knowledge is the only one represented in each farm cluster. This could show that farm and farmer characteristics are not the only factors that explain knowledge about SPS and the implementation of silvopastoral practices. However, we have to take into account that some cluster have very few number of observation such as the “large extensive farms”(n=3) and the “knowledge on tree species”(n=2).

The following graph (figure 11) shows relatives frequencies by farm types (by rows). 81,82% of intensive dairy farms and 87,5% of small dairy farms are falling into the “basic knowledge” category and none of them are associating with the” knowledge on tree species”. As it was said previously, this tends to show that those types of farms are more focusing on the productive aspect of SPS than tree species diversity. Having larger farms is also increasing the number of species present on the farm.

In opposition, the large extensive farms are associated with both SPS oriented knowledge (2 farms out of 3) and knowledge on tree diversity (1 farm out of 3). None of them is present in the “basic knowledge” cluster. Large farms seem to present a distinct knowledge from the small dairy farms types.

Concerning the extensive mediums farms, they present all categories of knowledge but it is not surprising at it seem to be a very heterogeneous group that includes various types of production systems. However, 62,5% of those farms are associating with the knowledge type which seem to be the most advanced in terms of silvopastoral practices.

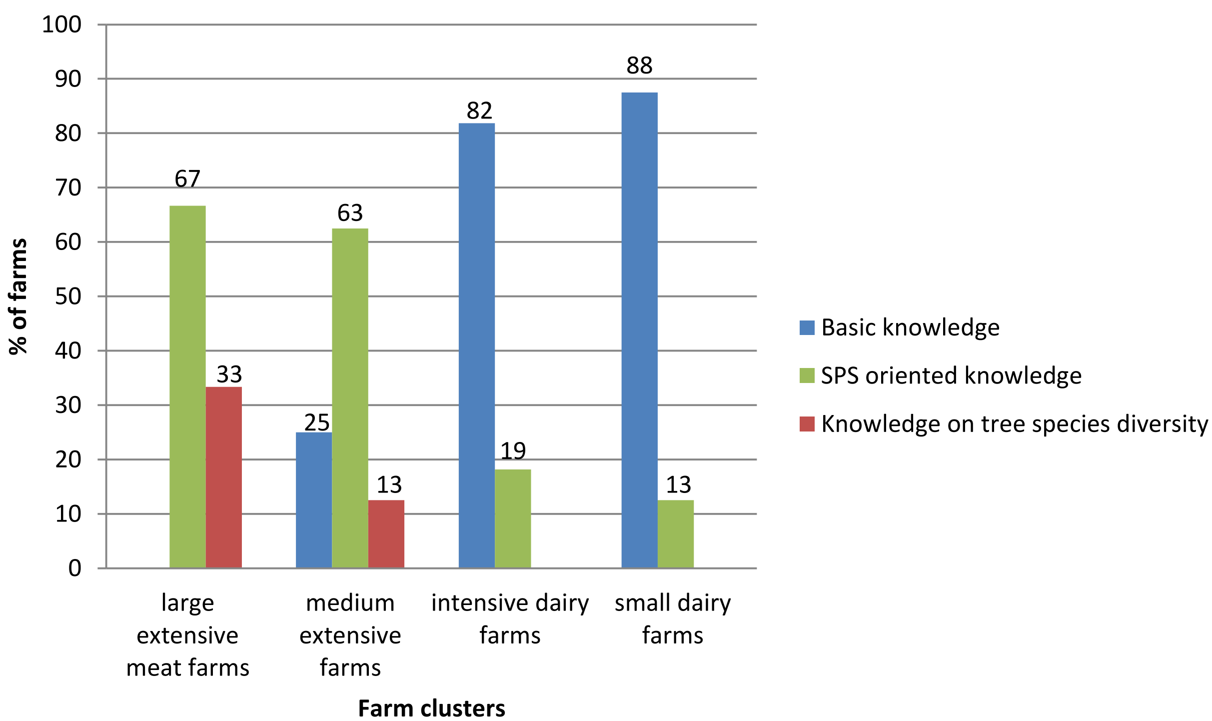


Figure 11: Relatives frequencies of knowledge types by farm clusters

5. Further interpretation of farm typology: is there a link between farm characteristics and silvopastoral practices?

In this section, we try to further interpret the results we found in the previous section using additional data and elements of context. For each type, we present a summary table with the means values, minimum and maximum for each variable (table 17, 18, 19, 20).

5.1. Small dairy farms (n=8)

As it was said in the previous section, this group is gathering very small dairy farms (going from 1ha to 5,50ha). This category appears to be the one that has the less access to capital in our study. Most of them (7 farms out of 8) are located in the community of the Sauce and its surroundings (east of Turrialba volcano, with an altitude of 850m). From what was mentioned during the interviews, this area used to be coffee production but due to the fall of coffee prices 10 years ago, the agricultural activity went into a transition to cattle activity. Indeed, the International Coffee Organization reported a very severe crisis in the coffee sector due to 5 years of overproduction (from 1998 to 2003) (OSORIO, 2004). This group practiced cattle farming since 11 years on average. 5 farmers out of 8 mentioned their farming activity as their main source of income for their family. The land use was not very diversified (due to the small size of the farm). Most of them used family work force (7 out of 8) and there was very few workers contracted. These observations support the idea of a family based farming system.

As we saw previously, they are also using feed concentrates ($\bar{x}$=22,74kg/cow/week). Concerning the type of production, this cluster is composed of 7 dairy farms and 1 meat farm. The grassland is managed in small plots following the rules of rotational grazing in line with what VERGARA et al (2015) observed in the dairy farms of the CBVCT during his study.

The producers of this category have the advantage to benefit from the presence of the producers association that takes care of the transformation of their milk production into dairy products such as cheese, cream, etc. 7 farmers out of 8 have reported to depend on the association of producers to commercialize their production.

Concerning the knowledge on SPS, none of the farmers of this group were aware about the term “silvopastoral systems” but most of them, were using LF in their farm (6 out of 8) and 4 farmers even adopted FB with trees species like *Trichanthera gigantea*. The potentiality to have TIP in their pasture was reduced due to the small area they disposed. In general, we would say that farm size would be a specific limitation to SPS adoption for this cluster.

Table 17: Summary table of the cluster "small dairy farms"

Cluster 3: small dairy farms	Mean	Minimum	Maximum
Altitude of the farm (m)	**843,75**	800	850
Size of the farm (ha)	**3,16**	1	5,5
External labour force (days/week)	**0,38**	0	1,5
Experience with cattle (years)	**11,38**	8	18
Number of animals/ farm	**13**	9	19
Animal load (AU/ha)	**3,98**	2,48	7,2
Feed concentrates used (kg/cow/week)	**22,74**	0	38,5
Proportion of pastures in the land use (%)	**100**	100	100
Size of the fodder bank (ha)	**0,41**	0	0,8
Proportion of improved pastures in the land use (%)	**0,88**	0	1
Area of natural forest (ha)	**0**	0	0
Area of timber plantation (ha)	**0**	0	0

5.2. Intensive dairy farms (n=11)

According to the results exposed in the previous chapter, this group is gathering larger farms than the previous category (from 2,8ha to 17,5ha). 9 farms were dairy farms and 2 others were meat production farm because they presented similar characteristics than dairy farmers of this group (size of the farm, animal load, etc.). Concerning the localization of the farms of this cluster, the majority farms were located in the surroundings of Santa-Cruz (La Pastora, El Guayabo, Santa Cruz districts) which is characterized by altitudes above 1100m on the southern side of the Turrialba volcano.

We already know that the higher parts of the flanks of the Turrialba volcano had tradition in dairy farming and cheese making and this activity has quite some economic importance for the district of Turrialba (MINISTERIO DE AGRICULTURA COSTA RICA, [n.d.]). The "Turrialba cheese" is produced there since more than 100 years and famous in the whole country (CHAMAYOU, 2011). All of those information explained why this cluster is gathering farms with quite experience in cattle farming (29 years on average) and the majority of farms were mentioned to be dedicated to cattle before the actual farmer took over (9 farms out of 11). 6 out 11 farmers mentioned that the farming activity was the main source of income and 5 farmers were not using family work force as a labour resource. This shows the tendency of this cluster to be less family based system but more entrepreneurial. On average, they contracted external workers 5 days/week.

Concerning cattle activity, it is the cluster with the highest average value of animal load ($\bar{x}$=5,71 AU/ha) and using the most concentrates ($\bar{x}$=25,23kg/cow/week).The farms in this cluster were qualified of intensive because of their animal load and high use of inputs. The use of feed concentrates could reach 80% of the production costs in Santa Cruz specialized farms when it reached only 60% in less specialized farms (MINISTERIO DE AGRICULTURA COSTA RICA, [n.d.]).

Additionally, the association of producers of Santa-Cruz (ASOPROA-SC) is playing an important role in the improvement in dairy activity and sharing of technical information.

Concerning the knowledge on SPS, 5 farmers out of 11 knew about the technical term of "silvopastoral" systems and 8 of them had LF in their farm. 3 of them reported to have FB associated with tree species. The table of contingence showed that their knowledge on tree species was more basic and related to the productive aspect of the on-farm tree presence. A specific limitation that seemed linked to this cluster was the lack tree species that could be used in SPS that are adapted to the altitude and lower temperatures. That was mentioned by several farmers during the interview and confirmed by the observations of VERGARA et al (2015). CHAMAYOU (2011) also mentioned in her study that the use of tree as fodder source was not common in the area of Santa Cruz due to the climatic conditions. She also affirmed that natural regeneration of tree in pastures is weak in this area and that confirmed what we found in this study (only 4 farmers out of 11 said that they had quite an amount of TIP in their farm). We cannot affirm if it is only due to the climatic conditions. The intensive management of grassland that seemed to be practiced on those farms could also have an effect on natural regeneration. However, those conditions did not prevent farms to count with areas of natural forest in their land-use (6ha on average).

Table 18: Summary table of the cluster "intensive dairy farm"

Cluster 4: intensive dairy farms	Mean	Minimum	Maximum
Altitude of the farm (m)	**1531,82**	600	2500
Size of the farm (ha)	**6,51**	2,1	17,5
External labour force (days/week)	**4,94**	0	12
Experience with cattle (years)	**28,27**	5	46
Number of animals/ farm	**25,64**	7	52
Animal load (AU/ha)	**5,71**	2,06	11,8
Feed concentrates used (kg/cow/week)	**25,23**	0	46
Proportion of pastures in the land use (%)	**76,18**	20	100
Size of the fodder bank (ha)	**0,44**	0	1
Proportion of improved pastures in the land use (%)	**0,8**	0	1
Area of natural forest (ha)	**6,03**	0	31
Area of timber plantation (ha)	**0**	0	0

5.3. Medium extensive farm (n=8)

This cluster is gathering a diversity of farming systems and it is less easy to find a common localization or a common historical context as it was the case for the two previous types. Nonetheless, those farms had several common points: their size was larger than the previous groups (from 9ha to 37ha) and they seemed to be distributed in lower lands (from 1000m and below). In this group, 3 farms were dairy farms, 1 was fattening cattle, 2 were producing weanlings, one was mixed fattening and weanlings and one bred animals to sell for reproduction. Concerning the history of cattle activity of those farms, it was also diversified: mixing farmers with quite long experience (30 years was the maximum) and recent farmers in conversion (3 years was the minimum) with very different ancient land-uses. However 6 farms out of 8, had agriculture before livestock activity (coffee, sugarcane).

Concerning the importance of the farming activity as a source of income, only two farmers declared that the farm was the main source of income. Moreover only two farms were working with family members and on average the farmers contracted 9 days/week of external labour force. This shows more distinctly that, those farms are moving towards another farming model, independent from the family situation, where the farming activity is considered as an additional activity.

They were qualified as extensive farms because the animal load was quite low compared to the previous types of farm (2,20AU/ha).Additionally, they generally used less feed concentrates, than the categories described before. They seemed to manage their farm in a more extensive way as they had a lower value of animal load. Moreover, they could count with some patches of natural forest in their land use (4,31ha on average). For the marketing of the products they were not characterized by a specific strategy.

Only one farmer in this category did not know about “silvopastoral” system as a technical term. This is interesting because this group mainly concentrates farmers with university and technical level of education. Only one farmer is not using LF and the large majority of the cluster had reported to have TIP growing in their grasslands. Two farms were using FB associated with tree species, mainly using *Trichanthera gigantea.* According to the results of the contingency table, they were the category of farmers that had the most complete knowledge on SPS (5 farmers out 8 are “classified” in this type of knowledge). Innovative silvopastoral practices were mainly found in this category of farms.

Table 19: Summary table of the cluster “medium extensive farms”

Cluster 1: Medium extensive farms	Mean	Minimum	Maximum
Altitude of the farm (m)	**818,75**	650	1000
Size of the farm (ha)	**22,38**	9	37
External labour force (days/week)	**9,04**	0	18
Experience with cattle (years)	**11,5**	3	30
Number of animals/ farm	**35,75**	16	60
Animal load (AU/ha)	**2,2**	1,05	4,45
Feed concentrates used (kg/cow/week)	**9,25**	0	25,88
Proportion of pastures in the land-use (%)	**77,46**	22,97	95
Size of the fodder bank (ha)	**0,71**	0	2
Proportion of improved pastures in the land-use (%)	**0,96**	0,7	1
Area of natural forest (ha)	**4,31**	0	22
Area of timber plantation (ha)	**0**	0	0

5.4. Large extensive meat farm (n=3)

This group is only containing 3 farms but they had very specific characteristics, first by their farm size and second by their management. Farms were way larger than the rest of the farms of this study (from 55ha to 190ha). They were farmers with a long experience in cattle activity. They were contracting many external workers (with an average of 40 days worked/week). One farmer was considering his activity as his main source of income, and for the other two, it was additional.

The type of production was only meat production with 2 farms in weanlings’ production and one in fattening. They had a very low value for animal load (1,81 AU/ha on average). Only one was using feed concentrates.

Moreover, all farms counted with the presence of another commercial production (sheep, coffee, bananas or sugarcane). They owned large areas of natural forest (17ha on average) and all of them had timber plantations (from 3 to 10ha).Concerning the marketing of the products, the strategies were also very diverse between each farm but also within each farm (auction market, sell to companies, local meat shop, restaurants and diverse clients in the neighborhood or situated more far away).

Concerning the knowledge on SPS, only one farmer knew the specific term. However they were all using LF and reported to have quite some TIP in their pasture. None of them was using FB associated with tree species. Looking at the contingency table, one farmer had a good knowledge on tree species diversity and two other had good knowledge on SPS.

Table 20: Summary table of the cluster "large extensive meat farms"

Cluster 2: Large extensive meat farms	Mean	Minimum	Maximum
Altitude of the farm (m)	**1100**	850	1600
Size of the farm (ha)	**115**	55	190
External labour force (days/week)	**13,17**	0	31
Experience with cattle (years)	**49,33**	48	50
Number of animals/ farm	**127,67**	70	225
Animal load (AU/ha)	**1,81**	0,76	3,77
Feed concentrates used (kg/cow/week)	**0,48**	0	1,45
Proportion of pastures in the land use (%)	**64,58**	47,37	76,36
Size of the fodder bank (ha)	**1,02**	0	3
Proportion of improved pastures in the land use (%)	**0,78**	0,5	0,95
Area of natural forest (ha)	**17**	7	34
Area of timber plantation (ha)	**7,67**	3	10

6. Conclusion

If we remember the research questions we had for this study, we are now able to bring elements of answers.

To answer the first question: "*What are the characteristics of the farms and the farmers surveyed?*", we were able to identify 4 types of farms: small dairy farms, intensive dairy farms, medium extensive farms and large extensive meat farms. We cannot affirm that those types are representing all the diversity that can be found in the CBVCT but it can help to understand the context and the different types of cattle farming in the area.

For the second question: "*What are the types of SPS that can be observed in those farming systems?"*, we saw that the practice of SPS was quite uniform among the 30 farms surveyed. We identified 3 types of SPS: LF (live fences), TIP (trees isolated in pastures) and FB (fodder bank) associated with trees. LF and TIP were present in the majority of the farms and FB was less practiced. Farmers were able to cite about 40 species to be present in SPS but there was few species that were dominant for each system. LF was mainly composed of *Gliricidia sepium, Erythrina costariciensis* and *Trichantea gigantea.* TIP were a bit more diversified as the trees found into the grassland were mainly coming from natural regeneration. However, the species *Erythrina poeppigiana, Cedrela odorata, Cordia alliodora* and *Ficus sp.* were the most mentioned by farmers. Concerning FB, farmers were using either *Trichantea gigantea* or *Erythrina poeppigiana.* Additionally, farmers were attracted by trees presence because they could be used for different purposes and they could adapt to the farm situation. We identified LF as being a very interesting feature to improve SPS adoption and management.

Concerning the third question: "*What are the uses of on-farm trees and which benefits are perceived by farmers?"*, farmers mentioned 3 uses of the trees and 9 services perceived from the trees that are present on the farm. The most cited were the production of fodder, the provision of shade, the use of timber and the protection of water sources. This is showing that trees are considered part of the production system by farmers because they bring important inputs to the cattle activity (the provision of fodder and shade for the cattle). They are also multi-purpose and farmers are recognizing also their environmental and social value.

Finally for the last question: *What are the determining factors for adoption and management of SPS?,* farmers mentioned limiting factors to the adoption and management of SPS. Conflicts between trees and grassland productivity, trees in pastures getting dry and cattle damaging the trees were the limitations the most cited. Additionally, we can identify determining factors for SPS adoption from the results of the associations of farm types and knowledge types. The knowledge on SPS and tree species seemed to be linked to farms types "large extensive meat farm" and "medium extensive farms". While "small dairy farmers" and "intensive dairy farmers" are still using SPS but their knowledge focused on the productive aspect of SPS (provision of fodder, shade and timber). Thus, the type of farm (size, type of production, animal load, etc.) and the characteristics of the farmer (education, access to capital, etc.) seemed to have an impact on silvopastoral practices.

Chapter 4: discussion and opportunities to improve SPS adoption

This study focused on a particular study area of Costa Rica: the CBVCT. It would be interesting to compare with similar studies at different scales of Costa Rica or Central America. We hope to get more insight on the outcomes of this study by doing so. Firstly, we need to expose the limitations of this work and then we will discuss the results. At the end of this section, we will try to identify opportunities to improve SPS adoption and management by proponing recommendations for each farm type we identified.

1. Limitations of the study

In this section, we expose the main limitations of this study that are linked to the methods and the analysis leaded.

1.1. Method of recollection: bias in farm selection

Because we disposed of few means of transportation, leading the interview at the farm was not always possible. We can imagine that this could have consequences on the number of tree species cited or others aspects of the tree management that the interviewee could have forgotten because we were not in the real conditions of the farm. 18 interviews out of 30 were conducted at the farm.

The choice of the farms was also limited by the easiness of access. We privileged farms that were easy to access with public transportation. Thus, this might introduce a bias in the sampling of this study.

1.2. Analysis: choice of variables to investigate

We recollected information on the qualitative aspect of SPS such as species, uses and services provided by trees but we do not have information on the quantitative aspect of SPS such as tree density or quantitative representation of each species. Further investigation would be needed to deepen the characterisation of silvopastoral practices within the CBVCT.

Concerning the knowledge of the farmer, the choice of indicators we took to characterize it is very disputable. Knowledge has various aspects and it would need a specific study to really approach all its diversity and complexity. Additionally, knowledge of the farmer and characteristics of the farms might not be sufficient to explain the implementation of silvopastoral practices. The processes of adoption of good management practices might be explained as well by other scientific domains such as environmental psychology.

However, most of our results are still coherent with what was found by current research on SPS. In the next part, we compare our findings with what was found in the literature.

2. Discussion

2.1. Types of SPS: the impact of farm management on tree diversity

The farmers were able to recognize 48 trees species in their SPS in our study. This shows a quite interesting diversity at the level of our study area. Moreover, farmers were able to recognize most of the tree species in their farm. In a study in different landscapes of Costa Rica and Nicaragua, cattle farmers were able to recognize 70 to 84% of the trees species present in their pasture (HARVEY et al., 2011).

TIP and LF, that are the dominant SPS in our study, were recognized by several authors to be part of the traditional landscape of cattle farms in Central America (AINSWORTH; MOE; SKARPE, 2012; HARVEY et al., 2005, 2011; PÁVEL, 2012). LF being a very common feature as they are occurring from 49% to 89% of the cattle farming landscapes of Costa Rica and Nicaragua (HARVEY et al., 2005).

2.1.1. LF: choice of species adapted to the needs of the farmer

HARVEY et al (2005), in their study in Nicaragua and Costa Rica, advanced that the main function of LF was to delineate farm boundaries and divide pastures. The LF abundance was related to the level of farm intensification in her study. She explained that more LF would mean smaller paddocks and a higher turnover of pastures in rotational grazing. That trend was also observed in our study. LF in our study had a quite low specie richness according to farmers sayings: 3 species are the most common by far and on average farmers mentioned only 2,4 species in their LF. The same phenomenon of dominance of few trees species was occurring as well in other studies (HARVEY et al., 2005; TOBAR LOPEZ; MUHAMMAD, 2008). The management of the farm and environmental factors are also influencing specie richness and abundance across farms and landscapes (HARVEY et al., 2005). In LF, we observed that the species planted by the farmer were mainly bringing economic benefits (through production of fodder or timber and provision of shade for cattle). Those trees should also present interesting characteristics for the farmer: they establish rapidly with vegetative reproduction, they have a rapid growth, they can support the fencing. *Gliricidia sepium* is a very good example (MOSQUERA ANDRADE, 2010).

2.1.2. TIP: a decrease in species diversity

The diversity of TIP is also highly linked to the management strategies of the farm. Indeed, according to our results, 42 species were mentioned in TIP but only 4 were really recurrent through all the interviews. In a study in the province of Rio Frio in Costa Rica, *Cordia alliodora* was also the dominant specie of TIP representing 25,9% of the tree species (VILLANUEVA; MUHAMMAD; HAENSEL, 2010). However, the composition of TIP highly depends on the ecological conditions (HARVEY et al., 2011). Indeed, the majority of TIP are not seeded but from natural regeneration and selected by farmers for its benefits (MOSQUERA ANDRADE, 2010). Thus, it is normal to observe that trees favoured by farmers and pioneer species will be dominant in TIP. This phenomenon of tree selection can, over the years, decrease diversity of species and threaten both biodiversity conservation and farm productivity (HARVEY et al., 2011).

Farmers are selecting species in their SPS, this can have both positive and negative effects on species diversity. There is the need for strategy at the landscape scale to ensure the species diversity and to maintain good biodiversity within SPS (HARVEY et al., 2011).

2.2. Trees uses and benefits perceived by farmers: focus on the economic benefits

The main uses of trees mentioned in our study were the production of fodder and the production of timber. Those uses are related to economic objectives. That is a key observation that is recurrent in many studies. SALAZAR OVIEDO (2012) identified the provision of economic benefits as a main driver in farmers species selection. The most common uses are timber, firewood, fencing, fruits and fodder (HARVEY et al., 2011; MOSQUERA ANDRADE, 2010; SALAZAR OVIEDO, 2012). However, the uses of the trees are depending also of the socio-economic context of the farm (HARVEY et al., 2005).

The morphological traits of trees were mentioned to be important for the choice of tree species. Farmers reported to prefer certain types of shade: tall trees with reduced crown size to permit the light to enter were the main characteristics mentioned. As well, SALAZAR OVIEDO (2012) mentioned the size of the crown as a determining factor in SPS design.

However, even if farmer mentioned many uses of tree, we observed that in most of the case the management of the LF and other trees did was not especially focused on those uses. Most of the farmers were using tree as a source of fodder in a sporadic way. In HARVEY et al(2005), less than 10% of the farmers pruned deliberately their fence to make forage. Most of them were letting the branches of the trees in pasture for the cattle when the LF were pruned for their maintenance. The main objective of having LF remains in organizing the grazing area and ensuring a good rotational grazing.

Concerning tree services mentioned by farmers, the provision of shadow and the protection of water sources were the main services mentioned. Shade for animals is a source of a rich local knowledge where farmers associate tree species to different types of shade having distinct effects on pastures and animals (MOSQUERA ANDRADE, 2010). The protection of water sources is also mentioned in the study of Chamayou (2011), that took place on the flanks of Turrialba volcano in the CBVCT. It appears that cattle farmers of our area study are quite aware of the issues related to water protection. This might be due to the Forest Law 7575 of Costa Rica that define the areas around the water bodies as protected area (LA ASAMBLEA LEGISLATIVA DE LA REPUBLICA DE COSTA RICA, 1996). Although in practice the minimum distance of protection is rarely respected (CHAMAYOU, 2011).

On another end, the uses of tree mentioned in our study might represent only a part of the reality. Indeed the uses and services of tree mentioned can vary according to the gender. Women show a knowledge more detailed than men about medicinal and food uses of trees, they also know a higher number of species (MARTINEZ RAYO, 2003). This possible bias is to take into account because on a total of 30 interviews only 3 were women.

2.3. Limitations to the adoption and management of SPS: how to conciliate farmers needs and research recommendations?

The literature is mentioning various limiting factors to the implementation and adoption of SPS (CHAMAYOU, 2011; RAMOS URZAGASTE, 2003; VILLANUEVA; MUHAMMAD; HAENSEL, 2010) that were in accordance with the ones founded in our study.

One of the most common is the competition between trees and pasture. The reduction of pasture productivity is the main reason to eliminate trees in pastures (SALAZAR OVIEDO, 2012). There are also limitation related to the access to capital and the high cost that can be the establishment of SPS, they are mentioned to be the two most important barriers to SPS adoption (MONTAGNINI; IBRAHIM; MURGUEITIO RESTREPO, 2013). The establishment indeed requires supplement labour force and can imply that an area of the grassland cannot be used during a certain time (DAGANG; NAIR, 2003). That can have some implication on farm productivity and profitability; the farm must be economically strong enough to handle it. Hopefully, some alternatives can be found to avoid such negatives consequences. It is possible to use companion planting during the establishment of trees, so the land keeps on being productive. Using species that offer multiple purpose can also help to mitigate in high initial investments(DAGANG; NAIR, 2003).

One of the limitations also mentioned in literature that was confirmed by our study is the lack of knowledge (MURGUEITIO et al., 2011). From the point of view of our participants, they lack information about SPS management and adapted species that could be used. While in the literature review, farmers are reluctant to integrate SPS that are based on research models (non-traditional practices) because they fear the risks and that the technology generation process is too distant form the reality of the farm (DAGANG; NAIR, 2003). The limited access to credit, the high interest rates and the difficulty to find banks that support that kind of project is also to mention as limitation (SALAZAR OVIEDO, 2012). Financial incentives associated with technical assistance was mentioned to be part of the solution to improve SPS adoption (MURGUEITIO et al., 2011).From what was said during the interviews, it seems that there is an effort to make in terms of communication of the SPS research. As a proof, most of the farmers in our study are not aware of the term “SPS” but knew the concept. Several of them mentioned that the institutions that were implicated in agricultural research were not communicating enough about their findings and that technical support was absent.

Concerning the management of SPS, leaf cutter ants were identified as the most important pest for timber species at young stages. They could cause very high losses, above 85% was reported in a study in Costa Rica (MOULAERT et al., 2002). The topography is also a limiting factor for the adoption of SPS. The very sloppy grasslands are more difficult to design with LF and also complicate the interventions (planting, pruning, etc.). This was recognized as a main limitation of SPS in the CBVCT in the study of VERGARA et al (2015).

We also noticed that the phenomenon of trees drying in pastures due to the competition with grassland species was never mentioned in the literature we reviewed. It is only recognized that there is very little information about the compatibility between grasses and SPS with native timber species (ANDRADE, 2007). Technicians of the INTA (National Institute of Innovation and Agricultural Technology Transfer), mentioned that *Brachiaria* grass species brought by the agricultural intensification, were very aggressive with respect to water competition. This factor is reinforced by the increase of animal load and to the death of trees in pastures. However, it has been reported that some species might be more competitive like *Gliricidia sepium , Citrus species* and *Inga species, Cordia collococca* (SOTO, 2016).

2.4. Comparing farm typologies

We decided to compare the farm typology found in this study to other typologies found in literature elaborated at different scales of CA. The aim is to validate our results although the sample size was low.

According to Sánchez (cited by MUÑOZ QUINTERO (2014)), cattle farms in Mesoamerica can be classified as:

- Extensive cattle farming oriented to fattening and weanlings’ production. It can be found in lowlands and they use few inputs and local fodder resources
- Cattle farming specialized in dairy production: localized in higher lands, this type of farming use high level of inputs and adopt modern technology
- Double-purpose cattle farming: this type of farming is not specialized in meat or dairy production, but it is adapting to the demand and depends a lot on the stability of the prices of the livestock products.
- Subsistence cattle farming: localized in marginal agricultural lands.

We can find some correspondences of this classification proposed by Sanchez in 2007 and the classification we choose to adopt in our study. At a more local scale, VERGARA et al(2015) conducted a study on the land use of 21 farms localized in the CBVCT. The way farms were classified in this study is very similar to ours. The study is describing 3 types of farms:

- The dairy farms located on the high land of the CBVCT, with land-use dominated by grassland without trees. This category includes the dairy farms of Santa-Cruz, well known for their cheese. In those type of farms the main costs are labour and feed concentrate (MINISTERIO DE AGRICULTURA COSTA RICA, [n.d.]). They are managing pasture in an intensive way (small plots, short occupation time)(VERGARA et al., 2015)

- The meat farms located in the lowlands of the CBVCT: They are recognized to have a larger farms and larger herd than dairy farms. Their land use is dominated by forest area, agroforestry and pastures. They lead an extensive management of pastures with large plot size and longtime occupation.
- The double-purpose farms: they are described to have a management similar to dairy farms but the size of the farm is closer to the ones of meat farms. Their dominant land use is forest, pastures with tree cover.

This typology is supporting what we found in our study although we did not meet the double purpose type of farm. However, we can observe the altitudinal gradient that tends to distribute dairy farms in highlands and meat farms in low lands. Additionally, it is important to remember that, there are many ways of classifying farms and neither of them is perfect. What is determining is the goal of the study and what the researcher want to demonstrate (RAMOS URZAGASTE, 2003). In our case this typology aimed to help to understand the context of the cattle farming in the CBVCT and explain differences between silvopastoral practices among the producers interviewed. The establishment of a typology of farms can contribute to the development of tools to improve the adoption of sustainable practices. It makes possible the identification of specific threats and opportunities that need to be taken into account when designing development policies (MUÑOZ QUINTERO, 2014).

2.5. Determining factors for SPS adoption: a complex process

Concerning the knowledge of the farmer, some aspects were identified as factors that facilitate the adoption of conservation practices such as SPS. We can cite the access to capital (such as the income, the farm size, etc.) that seem liked to a certain economic level (GARBACH; LUBELL; DECLERCK, 2012). Interestingly, we found similar results in our study, where large and medium extensive farms which are supposed to have a better economic situation also concentrate knowledge and innovative SPS practices. However, economic factors cannot explain the adoption of SPS alone. It is important to remember that access to technical assistance and information sharing within the community are also powerful tools. It has been shown more farmers have access to a diverse source of information, more they tend to adopt conservation practices (GARBACH; LUBELL; DECLERCK, 2012). However, our results tend to show that those economic and educational factors might not be the only ones to explain the process of “good practices” adoption by farmers. However, our results tend to show that those economic and educational factors might not be the only ones to explain the process of “good practices” adoption by farmers. Other domains such as environmental psychology might play a role.

3. Opportunities to enhance SPS adoption and diversify silvopastoral practices

We synthetized strengths and weaknesses of each farm type thanks to the SWOT analysis (tables 21, 22, 23, 24). This process helped us to identify opportunities to develop the adoption of SPS at the scale of the CBVCT. From those strategies, the CBVCT in collaboration with the CATIE could determine strategies targeted to each type of farm, in order to improve SPS adoption and meet the CBVCT’s conservation goals.

3.1. Small dairy farms

This type was identified as the most vulnerable due to their low access to capital and land. Moreover, they are very sensitive to the price of the milk. Their knowledge of SPS focuses on the productive aspect of the tree presence because they look for a maximum efficiency in their farming system.

Table 21: SWOT analysis of SPS improvement of the cluster small dairy farms

Strengths	**Weaknesses**
• Organized in farmers associations • Farming is the main source of income • Positive attitude related to the presence of trees on the farm	• Low access to capital • Limitation of farm size • Lack of information on SPS • Production is not diversified
Opportunities	**Threats**
• Target for trainings or technical support • Target for PES • Local credit • SPS opportunities: LF, FB	• Very dependent on the price of the milk • Low risk acceptance

LF are an SPS that is relevant to all types and size of farms (FAO, 2000). For this type of producers, increasing the diversity of species in LF would be a possible opportunity to improve their SPS. Moreover, increasing the diversity of trees in LF would provide additional services and uses that can diversify the resources of the farm (SANCHEZ et al., 2013) while economizing space. Moreover, there is the need to increase species diversity in LF to maintain a good functionality of ecological services (HARVEY et al., 2005). FB are also a SPS opportunity for this category, because it enables the farmer to produce more biomass on the same area and make a more efficient use of the land.

To help them in this process, economic incentives such as PES (payment for ecosystem services) could be part of the solution. It is an incentive from the state which started in 1997 to counteract the ongoing deforestation. The funds are coming from the FONAFIFO (National Fund for Forestry Financing). It aims at providing financial incentive to private landowners for them to implement conservation practices. It used to be applicable only for forest protection but now PES start to be applied for SPS as well. Moreover, PES have a very positive influence on the adoption of LF (GARBACH; LUBELL; DECLERCK, 2012). In this way, it could be possible to improve the adoption of LF in those farms while supporting the farmers in their decisions. However, local institutions involvement and assistance would be highly required to help the small producers to get through the heavy administrative procedure for applying to PES (CHAMAYOU, 2011).

We observed some examples of micro-credit companies that were financing projects of rural development initiated by farmers. Those type of initiatives were recognized as an opportunity to improve the quality of life of poor rural population through the world (Calvin Miler, 2005). We think they represent an interesting opportunity to develop SPS by providing financial support. Moreover, they require a lighter procedure than PES.

More than being a way to sell their production, farmers associations also give more cohesion within the farmer community and make them more reachable for trainings programs and technical support (VERGARA et al., 2015). Those associations of dairy farmers should be targeted by local institutions such as CATIE or CBVCT to provide technical and administrative support.

For this category, the strategy should focus on increasing farm resiliency to economic and climatic events (diversifying farm production, propagation of tree species that are multipurpose, etc.).

3.2. Intensive dairy farms

Those farms are mainly facing limitations due to climatic conditions. It greatly reduces the potential for SPS to develop. Moreover, the intensive management of the pasture leaves little space for tree natural regeneration to occur.

Table 22: SWOT analysis of SPS improvement of the cluster intensive dairy farms

Strengths	**Weaknesses**
• Organized in farmers associations	• Climatic conditions make it difficult to find adapted species • Management is intensive and can limit the presence of trees • Production is not diversified • Lack of information on SPS and tree species
Opportunities	**Threats**
• Target for trainings or technical support • Target for PES • Local credit • SPS opportunities: LF, FB	• Very dependent on the price of the milk • Low risk acceptance • Lack of technical assistance

However, they are grouped in farmers' association that can facilitate technical assistance and trainings. They present the same opportunities than the previous group but it is important to take into account the selection of adapted species. The establishment of SPS is a difficult step that is why PES could be an interesting tool to support the practice of LF in those farms.

For this category, the strategy should focus as well on farm resiliency and research to find adapted species to the local conditions and farmer's needs (that provide fodder and timber, control of erosion, etc.)

3.3. Medium extensive farms

This group has good access to capital and to information (due to higher education and the practice of another professional activity). However, the fact that the farm is an additional activity can also be a limitation because the farmer can be less involved in it. Furthermore, contracting additional labour force for establishment of new SPS is costly. Labour can represent from 41% to 72% of the total cost of establishment (VILLANUEVA; MUHAMMAD; HAENSEL, 2010).

Table 23: SWOT analysis of SPS improvement of the cluster medium extensive farms

Strengths	Weaknesses
• Good education level • Size of the farm enable more flexibility • Innovative practices and good SPS knowledge	• Farming is not the main activity (less involvement)
Opportunities	**Threats**
• Link with agricultural institutions (CATIE, EARTH university, UCR) • Farmers meeting to exchange on their practices • SPS opportunities: LF,FB, SPSi, TIP	• Cost of external labour • Lack of technical assistance

SPS modalities that are interesting for this group are LF, FB and TIP but we could also mention SPSi (intensive SPS) that need more technical knowledge but represent an interesting alternative to produce high quantities of biomass while using few inputs. This option might need technical assistance to guaranty a successful establishment. A recommendation for this group of farmers could be to gather and meet each other to exchange on their practices. Indeed, this group was identified as the main one having adopted and designed innovative silvopastoral practices.

The strategy for this category would focus on communication and exchange: most of the farmers of this category have willingness and means to adopt silvopastoral practices that are can be considered as innovative. They like to be challenged and are always looking for new opportunities to increase the efficiency of their farms. We can also recommend to the research institutions of the area, such as UCR (University of Costa Rica) or CATIE, to work in collaboration with those farms to investigate innovative SPS adapted to the local context.

3.4. Large extensive farms

They are similar to the previous farm type expect that they dispose of very large extensions. This enables them to have diversified type of production and even counting with natural area in their land use. They have many opportunities to develop SPS, especially for timber plantation associated with grazing. They could use technical support and farmers meeting to help them developing their silvopastoral practices.

Table 24: SWOT analysis of SPS improvement of the cluster large extensive farms

Strengths	**Weaknesses**
• Good education level • Good access to capital • Diversified production (counting with agroforestry, timber plantation) • Interest in nature conservation (good knowledge on tree species diversity) • Can count with area of natural forest in the land use	• Farming is not the main activity (less involvement)
Opportunities	**Threats**
• Certification can represent an opportunity to value what is done on the farm related to nature conservation • Farmers meeting to exchange on their practices • SPS: LF,FB, timber/fruit plantation associated with grazing, TIP, SPSi	• Lack of technical support • Regulations too restrictive • Cost of external labour is too high

Additionally, certification for sustainable agriculture and environment conservation can be an interesting opportunity for them to value the natural potential they have at the farm scale, as well as guarantying the permanence of those natural areas. We can cite the example of the "Bandera Azul Ecológica" certification that was developed by the government of Costa Rica with the aim to involve the companies of the country into practices of conservation and protection of natural resources (BANDERA AZUL ECOLÓGICA, [n.d.]). "Rain Forest Alliance" certification can also be an option of certification in sustainable agriculture and protection of forest resources (RAINFOREST ALLIANCE, [n.d.]).It enables farmers to find a valorisation for their products in a market of exportation with high standards but it is quite costly and heavy process.

The strategy for this category should focus on valorisation of natural areas and communication on silvopastoral practices that benefit ecological connectivity adapted to farms with large extensions (such as timber plantation associated with grazing).

Photo 12: "Bandera Azul Ecológica" certification in a dairy farm

General Conclusion:

The objective of our study was to describe SPS that could be found in the CBVCT and identify determining factors for the adoption and management of those systems. Although our study was only conducted in 30 farms, we were able to show some results and deepen the knowledge on SPS implementation at the local scale of the CBVCT. Traditional SPS such as LF and TIP were the most represented in our study. There were also some farmers using FB of ligneous species to produce higher quantities of biomass to feed their animals on those resources. Although, farmers mentioned an important number of tree species, we observed that few species were really dominating in each SPS. The farmer valued them because they were adapted to their needs. Farmers perceived various uses and benefits from trees covering economic, environmental and social aspects. However, uses and services that provided economic benefits were the most mentioned: such as fodder, provision of shade for cattle and timber.

Farmers reported limitations to the SPS management such as difficulties to manage animal and young trees in the same plot, or problems in tree growth. They feared the reduction of grassland production due to the presence of trees or the high investment in labour and economic resources that would limit the adoption of SPS. Nonetheless, lack of technical support and sharing of information was an important limitation. This study tends to evidence the gap that exists between the research world and the reality of the farmers. To understand the determining factors in SPS implementation, we first needed to understand the objectives and the access to resources of farms investigated. We pretended to achieve this by establishing a classification of farm taking into account basic characteristics of the farm and farmer (size, type production, level of education, etc.). As well, we were looking at the silvopastoral practices and farmers ‘knowledge. From this data, we established another typology.

In our study, it appeared that small landowners were majority dairy farmers located in high lands of the CBVCT. The management could be qualified of intensive because of the high animal load and the use of feed concentrates. They were family based systems and were represented by organizations at the level of the community through producers associations. They were looking for efficiency as land access is the main limitation. That was why the implementation of multipurpose LF and FB seemed to be particularly adapted to their needs. Although, their knowledge on silvopastoral practices was quite limited, SPS might represent an interesting option to increase farm resiliency to climatic and economic threats. In opposition, meat farms with larger extensions were mainly located in lower lands of the CBVCT. They could be qualified of extensive because the animal load was quite low and they were using few inputs. Those models tended to be more entrepreneurial with farming activity being often considered as an additional source of income. We identified interesting diversity in silvopastoral practices showing that farmers of this group were experimenting new modalities to include tree in their farming system. For the ones disposing of very large extensions, SPS that improve ecological connectivity through the landscape appeared to be a valuable opportunity. For those farmers the lack of technical assistance would be the main limitation for SPS adoption.

Finally, we can say that SPS adoption and knowledge seemed linked to the farm and farmer characteristics. Additionally, access to information and technical support would play an important role in SPS adoption. Information sharing and personalized support would surely enable all types of cattle farmers to find adapted silvopastoral practices.

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Scientific name	Common name (in Spanish)	Family
Cedrela odorata	Cedro amargo	Meliaceae
Gmelina arborea	Melina	Verbenaceae
Tecoma stans	Candelillo	Bignoniaceae
Swietenia macrophylla	Caoba	Meliaceae
Platymiscium parviflorum	Cristobal	Fabaceae
Inga spectabilis	Guaba machete	Fabaceae
Cojoba arborea	Lorito	Fabaceae
Gliricidia sepium	Madero negro	Fabaceae.
Dipteryx panamensis	Almendro de montaña	Fabaceae
Vochysia Ferruginea	Botarrama	Vochysiaceae
Carapa guianensis	Caobilla	Meliaceae
Virola koschny	Fruta Dorada	Myrticaceae
Minquartia guianensis	Manu	Olacaceae
Hieronyma alchorneoides	Pilón	Phyllanthaceae
Tabebuia Rosea	Roble Sabana	Bignoniaceae
Cassia grandis	Carao	Fabaceae

Annex 2: Complete list of variables recollected during the interviews

Groups of variables	Typo of Variable	Variable	Variable ID	Unit	Unit categorical
Farmer and household	Category	gender	Fer_Gen		M/F
	Category	Education level	Fer_Edu		Value None -0 /primary-1/secondary-2/technic-3/university-4
	Quantitative	Number of family members involved in farming	Fam_Mem	number	
	Category	Relative importance of the farm as a main/additional resource of the household	Fam_Inc		Main -1/Additional-0
Farm characteristics	Quantitative	Altitude	Far_alt	meters	
	Qualitative	Locality	Far_loc		name
	Quantitative	Size of the farm	Farm_ha	ha	
	Category	Presence of other production	Farm_oth		yes=1, no=0
	Quantitative	Numbers of days of external labour/week	Farm_lab	Days/week	
	Quantitative	Years in cattle activity	Farm_catt_age	years	
	Qualitative	Ancient landuse	Farm_anc_land		cattle/coffee/agriculture/sugarcane/timber/forest
	Quantitative	area of natural forest	SPS_forest_ha	ha	
	Quantitative	area of timber plantation	SPS_timber_ha	ha	
Cattle activity	Quantitative	number of animals total	Cat_numb	number	
	Quantitative	Animal load	Cat_AU/ha	AU/ha	
	Category	Type of production	Far_typ_prod		dairy =4, weanlings=1, fattening=3, both weanlings and fattening=2
	Quantitative	Use of feed concentrates	Cat_conc	Kg/cow/week	
Grassland charactersitics	Quantitative	Size of grassland	Past_ha	Ha	
	Quantitative	Proportion of grassland in land use	Past_prop	%	
	Qualitative	Proportion of improved pastues	Past_prop_imp	%	
	Quantitative	Size of fodder bank	Past_FB	ha	
Evaluation of knowledge concerning SPS	Quantitative	Number of tree species cited durring the interview that are present on the farm	Knwl_nb_sp	number	
	Quantitative	Number of tree species cited in LF	Knwl_nb_LF	number	
	Quantitative	Number of tree species cited in TIP	Kwl_nb_TIP	number	
	Quantitative	Number of tree species cited in FB	Kwl_nb_FB	number	
	Quantitative	Number of tree species known of the module	Knwl_nb_mod	number	
	Quantitative	Total number of services and uses of trees recognized	Ben_nb	number	
	Quantitative	Total number of limitation of SPS mentioned	Lim_nb	number	

Annex 3: Interview guide for cattle farmer

Hello, thank you very much for receiving my and accepting this interview. My name is Lily and I am a master student in Agriculture in France. This study is for my thesis. The theme is referring to SPS or presence of trees in cattle farms of the CBVCT. We will start by talking about your farm in general and then we will focus on the cattle activity and the trees present on the farm. At the end, we will have a more opened discussion on what you think about SPS or presence of trees on farm. I approximately need one hour and half. After, if you wish we can walk around your farm. I would like to say that you should feel to answer or not my question and also to end this interview if you wish. The information collected will remain anonymous and you name won't be used, or related to any opinion. Does it bother you if I record this interview (Spanish is not my maternal language)? Can I also take pictures please?
Thank you very much!

1. **Characteristics of the farm and the household?**

- The farmer: Can you tell me about your history in this farm?
  How old are you? /What education did you receive?/When did you start to work in this farm?/ What are the origins of this farm?

- The household: Who lives with you? Who works with you on the farm? /What is the share of the farm in the income of the family? /Is it the main one?

- The farm: Can you describe the farm and its activities?
  What is the size of the farm?/Who is the owner ?/What is produced and on how much area?/Do you employ additional workers?

- The cattle activity: Can we talk about the cattle?
  How many animals do you have? / what do they produce? How much?/What is the area of the grassland?/What is the area of the fodder bank?/ Are you using feed concentrates?

- Additional: Did you receive any technical support or participated in trainings? From which institution? What was the theme?

2. Characteristics of trees on farm:

- <u>The type of SPS:</u> Do you the word “SPS”? Can you give me examples of SPS in you farm (lives fences, trees isolated in pastures, etc.)?
  Did you plant those trees? Where are they and why?

- <u>The species:</u> Can you give more information on the tree species present on you farm?
  What do you like about them/How do you use them?/What did they bring as a product?/ How do they benefit to your farm?

3. Determining factors for the adoption and management of trees:

- <u>Determining factors</u>: Would like to have more or less trees in your farm?
  Why and why not? Are you lacking something that would enable you to have more trees?

- <u>Opportunities for SPS adoption:</u> If you would have the potential to put more trees, where will you put them?
  Which species will you use? For which uses?

4. End of the interview:
- Do you farmers that could participate as well?
- Can you give a mail or a number so I can contact you to give you the results of this study?
- Do you have any questions, remarks?

Thank you very much!

Annex 4: Database used for quantitative analysis

code	ID	Ent01	Ent02	Ent03	Ent04	Ent05	Ent06	Ent07	Ent08	Ent09	Ent10	Ent11	Ent12	Ent13	Ent14	Ent15
Gender	Fer_Gen	M	M	M	F	M	M	M	M	M	M	M	M	F	F	M
Education	Fer_Edu	4	1	1	1	1	1	1	1	1	3	3	3	1	1	4
Family members involved in farming	Fam_Mem	0	2	2	1	1	1	0	1	2	0	4	2	0	1	0
importance of farm as source of income	Fam_Inc	0	1	0	1	1	1	0	0	1	0	0	1	1	1	0
Locality	Far_loc	Santa Teresita	El Sauce	El Sauce	El Sauce	El Sauce	El Sauce	El Sauce	El Sauce	La Pastora	Alto Vajas	Santa Cruz	Santa Cruz	Santa Cruz	Santa Cruz	Sitio Mata
Altitude	Far_alt	850	850	850	850	850	850	850	800	1700	800	2100	1500	2500	1500	950
size of farm (ha)	Farm_ha	18,00	4,00	5,50	1,00	2,25	2,50	1,00	5,00	17,50	20,00	2,10	3,00	12,00	3,00	2,80
other production presence	Farm_oth	0	1	0	0	0	0	1	0	0	0	1	1	0	1	0
additional labour (days/week)	Farm_lab	18	0	0	0	1,5	0	1,5	0	0	3	6	1	0,3	2,5	3,5
Since when cattle (years)	Farm_catt_age	6	13	10	12	10	10	8	18	10	27	5	41	46	36	12
ancient landuse	Farm_anc_land	coffee	coffee	forest plantation	coffee and agriculture	coffee	coffee	natural forest	coffee	cattle	coffee	cattle	cattle	cattle	cattle	coffee
Production	Far_typ_prod	dairy	dairy	dairy	dairy	dairy	dairy	dairy	fattening	dairy	fattening	dairy	dairy	dairy	dairy	fattening and weanlings
numbers of animals (total)	Cat_numb	60	13	19	10	14	9	10	15	52	50	16	13	30	20	17
Animal load (AU/ha)	Cat_AU/ha	3,2	2,5	3,4	7,2	5,3	3,5	4,5	2,8	2,5	2,2	11,8	5,5	2,1	6,7	6,4
feed concentrates (kg/animal/week)	Cat_conc	20,1	92,9	35,4	38,5	20,8	4	34,5	0	28	7	30	35	20,8	46	35
size of all pastures (ha)	Past_ha	15	4	5,5	1	2,25	2,5	1,75	5	16,8	19	1	2	12	2,5	2
Proportion of pasture in the landuse	Past_prop	83	100	100	100	100	100	175	100	96	95	48	67	100	83	71
Fodder bank (ha)	Past_FB	1,4	0,8	0,8	0,25	0	0,5	0,75	0	0,7	0	0	0,5	0	0,5	0,4
% of improved pasture	Past_prop_imp	1	1	1	1	1	1	0	1	0,75	1	1	1	1	1	1
SSP term	SPS_term	1	0	0	0	0	0	0	0	0	1	0	1	1	0	1
natural forest (ha)	SPS_forest_ha	0	0	0	0	0	0	0	0	31	0	1	0	30	0	0
timber plantation (ha)	SPS_timber_ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
number of tree species cited	Knwl_nb_sp	8	5	9	10	8	6	7	10	1	8	10	7	7	1	7
Number of species cited in LF	Knwl_nb_LF	4	3	1	2	2	5	0	5	4	3	1	2	2	0	4
Numbers of species in TIP	Kwl_nb_TIP	3	2	3	3	3	0	3	3	0	1	5	3	4	0	2
Numbers of species in FB	Kwl_nb_FB	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1
Number of the species on the module known	Knwl_nb_mod	14	7	11	8	8	11	12	16	16	16	12	15	5	16	15
Number of purposes cited	Ben_nb	7	3	3	5	4	5	5	6	1	6	3	4	1	1	5
Number of limitations cited	Lim_nb	7	3	4	4	1	4	2	2	3	4	0	2	1	2	3
farm cluster	f4 (var13) euc1	1	3	3	3	3	3	3	3	4	1	4	4	4	4	4
knwld cluster	Cluster kwldg3 (var7) e	1	2	2	2	2	1	2	2	2	1	2	2	2	2	2

code	ID	Ent16	Ent17	Ent18	Ent19	Ent20	Ent21	Ent22	Ent23	Ent24	Ent25	Ent26	Ent27	Ent28	Ent29	Ent30
Gender	Fer_Gen	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Education	Fer_Edu	4	1	1	4	3	1	4	4	3	4	4	2	4	1	3
Family members involved in farming	Fam_Mem	1	2	1	0	0	1	1,5	0	4	0	0	0	0	3	0
importance of farm as source of income	Fam_Inc	1	1	0	0	1	1	0	0	0	1	0	0	0	1	0
Locality	Far_loc	Santa Cruz (Las Virtudes)	Santa Cruz (Queserio)	Santa Cruz (calle Varjas)	Pacaytas	Mollejones	Mollejones	Pacaytas	Guayabo	El Colorado	Sitio Mata	Santa Rosa and Santa Cruz	Platanillo	Turrialba	Cien Manzanas	Turrialba
Altitude	Far_alt	1800	1800	1600	850	850	850	850	1100	700	1000	1300	850	650	850	600
size of farm (ha)	Farm_ha	3,85	12,00	55,00	16,00	100,00	22,00	190,00	6,00	35,00	22,00	3,40	9,00	37,00	4,00	6,00
other production presence	Farm_oth	0	1	1	1	1	0	1	1	0	0	0	0	1	0	0
additional labour (days/week)	Farm_lab	7	7	31	0,35	8,5	0	0	7	7	13	8	13	18	0	12
Since when cattle (years)	Farm_catt_age	27	26	50	3	50	30	48	43	5,5	5	33	8	7	10	32
ancient landuse	Farm_anc_land	cattle	cattle	cattle	cattle, coffee and agriculture	cattle	cattle	cattle	cattle	coffee	coffee and agriculture	cattle and coffee	sugarcane	n/a	sugarcane	forest plantation
Production	Far_typ_prod	dairy	dairy	weanlings	fattening and weanlings	weanlings	weanlings	fattening	dairy	dairy	weanlings	fattening	dairy	weanlings	dairy	dairy
numbers of animals (total)	Cat_numb	30	46	225	17	88	26	70	7	44	43	14	30	16	14	37
Animal load (AU/ha)	Cat_AU/ha	7,2	3,4	3,8	1,2	0,9	1,0	0,8	6,8	1,4	2,2	4,1	4,5	1,9	2,7	6,3
feed concentrates (kg/animal/week)	Cat_conc	45	16	1	0	0	0	0	0	25,9	0,0	7,0	21,0	0,0	23,0	37,9
size of all pastures (ha)	Past_ha	3	11	42	13	70	18,8	90	1,2	31	20	3,4	6,5	8,5	4,0	5,0
Proportion of pasture in the landuse	Past_prop	78	92	76	81	70	85	47	20	89	91	100	72	23	100	83
Fodder bank (ha)	Past_FB	0,85	1	3	0	0,05	0,5	0	0,9	1,25	0,5	0	2	0	0,15	0
% of improved pasture	Past_prop_imp	0,5	1	0,5	1	0,95	0,7	0,9	0	1	1	0,5	1	1	1	1
SSP term	SPS_term	1	0	0	1	1	1	0	1	1	1	0	0	1	0	0
natural forest (ha)	SPS_forest_ha	0,85	0	7	2	10	2,7	34	2,5	4	1,8	0	2	22	0	1
timber plantation (ha)	SPS_timber_ha	0	0	10	0	10	0	3	0	0	0	0	0	0	0	0
number of tree species cited	Knwl_nb_sp	13	9	30	6	15	9	22	7	6	14	12	14	11	10	10
Number of species cited in LF	Knwl_nb_LF	2	1	5	3	3	3	2	2	2	4	4	0	2	0	2
Numbers of species in TIP	Kwl_nb_TIP	4	4	3	1	4	5	13	0	5	5	3	2	10	1	2
Numbers of species in FB	Kwl_nb_FB	0	0	0	0	0	0	0	3	0	1	0	0	0	1	0
Number of the species on the module known	Knwl_nb_mod	15	11	13	16	16	10	15	16	8	15	13	15	12	12	12
Number of purposes cited	Ben_nb	8	5	6	5	6	7	4	6	4	9	6	4	4	4	3
Number of limitations cited	Lim_nb	5	2	6	5	6	2	2	1	3	4	5	3	5	2	3
farm cluster	f4 (var13) euc1	4	4	2	1	2	1	2	4	1	1	4	1	1	3	4
knwld cluster	Cluster kwldg3 (var7) e	1	2	1	1	1	1	3	2	2	1	1	2	3	2	2

Annex 5: Complete List of species mentioned during the interviews (identified thanks to PITTIER (1957))

Scientific name	Comon name (in Spanish)	Family	cited in LF	Cited in TIP	Cited in FB	Cited in total
Erythrina species	Poro	Fabaceae	19	13	1	36
Trichanthera gigantea	Nacedero	Acanthaceae	13	1	7	22
Gliciridia sepium	Madero negro	Fabaceae	16	2	0	19
Cedrela odorata	Cedro	Meliaceae	2	6	0	18
Cordia alliodora	Laurel	Boraginaceae	1	8	0	15
Cecropia sp	Guarumo	Moraceae	1	3	0	10
Inga species	Guaba	Fabaceae	0	3	0	10
Ficus species	Higueron	Moreaceae	0	6	0	9
Conostegia xalapensis	Lengua de vaca	Melastomaceae	1	3	0	8
Cupressus Benthami	Ciprés	Coniferae	0	3	0	7
Alnus acuminata	Jaul	Betulaceae	0	3	0	6
Eugenia sp.	Guayabillo	Myrtaceae	1	1	0	5
Acnistus arborescens	Guitite	Solanaceae	4	0	0	5
Pinus species	Pino	Coniferae	0	1	0	5
Pithecolobium species	Sotacabaillo	Mimosaceae	0	1	0	4
Yucca elephantipes	Itabo	Liliaceae	2	0	0	4
Citharexylum caudatum	Fruta paloma	Verbenaceae	0	0	0	4
Croton sp	Targua	Euphorbiaceae	0	1	0	4
Ceiba pentandra	Ceiba	Bombacaceae	0	2	0	4
Hieronyma alchorneoides	Pilon	Phyllanthaceae	0	1	0	4
Eucalipto species	Eucalipto	Myrtaceae	0	1	0	4
Lippia oxyphyllaria or Lippia Torresii	Caragra	Verbenaceae	1	1	0	3
Morus Species	Morera	Moraceae	1	0	1	3
Enterolobium cyclocarpum	Guanacaste	Mimosaceae	0	1	0	3
Guatteria oliviformis	Anonillo	Annonaceae	0	3	0	3
Vochysia Ferruginea	Chancho colorado	Vochysiaceae	0	0	0	3
Taetsia fructicosa	Cana de Indio	Liliaceae	2	0	0	2
Byrsonima crassifolia	Nance	Malpighiaceae	0	0	0	2
Bambusa vulgaris	Bambu	Gramineae	0	0	0	2
Annona muricata	Guanabana	Annonaceae	1	0	0	2
Phoebe species	Quizarras	Lauraceae	0	2	0	2
Hyptis verticillata	Canilla de mula	Verbenaceae	0	1	0	2
Tabeluia Rosa	Roble sabana	Bignoniaceae	0	1	0	2
Oreopanax species or Gilibertia arborea	Cacho de venado	Araliaceae	0	1	0	2
Visma guianensis	Achiotillo	Guttiferae	0	0	0	2
Heliocarpus species	Burio	Tiliaceae	0	0	0	2
Persea caerula, Phoebe mexicana, Phoebe Tonduzii	Aguacatillo	Lauraceae	0	0	0	1
Spondias purpurea	Jocote	Anacardiaceae	1	0	0	1
Brosimum costaricanum or terrabanum	Ojoche	Moraceae	0	0	0	1
Drimys Winteri	Quiebra muelas	Magnoliaceae	1	0	0	1
Reynosia latifolia	Albahaquilla	Celastraceae	0	1	0	1
Laplacea Brenesii	Yoro	Theaceae	0	1	0	1
Ocotea sp	Ira	Lauraceae	0	1	0	1
Psidium Guajava	Guyaba	Myrtaceae	0	1	0	1
Veronia stellaris/vernicosa/patens	Tuete	Compositae	0	1	0	1
Ochroma species	Balsa	Bombacaceae	0	1	0	1
Quercus species	Roble	Fagaceae	0	1	0	1
Achras Sapota o Manilkara spectabilis	Nispero	Sapotaceae	0	1	0	1
Cordia collococca	Niguito	Boraginaceae	0	1	0	1
Minquartia guianensis	Manu	Olacaceae	0	1	0	1
Dipteryx panamensis	Almendro de montana	Fabaceae	0	1	0	1
Zanthoxylum microcarpum	Lagartillo	Rutaceae	0	1	0	1
Croton xalapensis	Terré	Euphorbiaceae	0	1	0	1
Pithecolobium Saman	Cenicero	Mimosaceae	0	1	0	1
Hura crepitans	Jabillo	Euphorbiaceae	0	1	0	1
Virola koschny	Fruta dorada	Myrticaceae	0	0	0	1
Sambucus species	Sauco	Caprifoliaceae	0	0	0	1
Rapanea pellucido-punctata	Ratoncillo	Myrsinaceae	0	0	0	1
Ardisia species	Tucuico	Myrsinaceae	0	0	0	1
Cojoba arborea	Lorito	Fabaceae	0	0	0	1
Viburnum stellato-tomentosum	Sura	Caprifoliaceae	0	0	0	1
Albizia niopoides	Gallinazo	Fabaceae	0	0	0	1
Trema micrantha	Juco	Ulmaceae	0	0	0	1
Ruellia tetrastichantha	Corteza de venado	Acanthaceae	0	0	0	1
Tabeluia chrysantha	Corteza amarilla	Bignoniaceae	0	0	0	1
Socratea durissima	Palmito	Palmae	0	0	0	1
Carapa guianensis	Caobilla	Meliaceae	0	0	0	1
Citrus nobilis	Mandarina	Rutaceae	0	0	0	1
Magnolia sp.	Magnolia	Magnoliaceae	0	0	0	1

Annex 6: Interview with Roberto SOTO (28/06/16)

Researcher in the National Institute for Inovation and Agricultural Technogy transfer (INTA -Instituto Nacional de Innovación y Transferencia en Tecnología Agropecuaria), organismo público de investigación agrícola.

- Silvopastoral systems in the area:

The story of silvopastoral systems: In the beginning, the pastures were natural and the tree grew naturally thanks to natural regeneration. They brought many services like shade, wood resource and water.

Agricultural intensification brought the improved pastures with *Brachiaria species* for more production and in increase in animal loading. These are very aggressive respect to water competition. They also have deep and dense root system. This leads to very strong competitions with trees resulting in tree's collapse.

Planting living fences is not a good option in the area. Because it takes a lot of area and the trees are not adapted to the competition with *Brachiaria.* Although some species are more competitive like *Gliricidia sepium, "limones" and Inga trees, Iguito* (*Cordia collococca*) which monstrated high competition. It exists pasutres like *Ruffa and Cinodon* that are less aggressive for the tree.

It has been investigated that 15% of shade is the maximum that the pastures can take without decreasing biomass production.

- Farms in the area (Santa Cruz):

The farms are quite small with an average of 6 ha. They have SPS systems where they combine trees from natural regeneration with grasses like *pinecitu clandestine.*

They reached their maximum level of tree density and the farmers there would never plant a tree. "Jaoul" grows well there from natural regeneration and can be found close to the rivers.

The farms located in the area of Turrialba until the Atlantic coast, are using mostly *Brachiaria species* because they need to increase productivity without using more land. It is forbidden to deforest and once an area turned into a forest, it is not possible to go back to an agricultural use.

Table of appendices: