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TREE DIVERSITY IN AGROFORESTRY SYSTEMS: CASE STUDY FROM PERUVIAN AMAZON

DIPLOMA THESIS

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Title: Tree diversity in agroforestry systems: case study from Peruvian Amazon

Abstract: This diploma thesis studies tree diversity in cocoa agroforestry systems in Huayhuantillo village in Peruvian Amazon. Cocoa trees and shade trees have been measured within 15 study plots in agroforestry plantations in Huayhuantillo, Peru. Shade tree species were identified and tree diversity in cocoa plantation was evaluated. Within 15 study plots have been observed 195 individual trees belonging to 24 tree species both native and exotic to Amazon. Consequently results of tree diversity in Huayhuantillo cocoa agroforestry plantation were compared with tree diversity of forests from similar natural conditions in Peruvian Amazon and with European agroforestry system. Comparison of species diversity based on measurements has proved higher species diversity in forest reserve. Benefits of agroforestry systems for tree diversity conservation were also evaluated and compared with European agroforestry systems.

Keywords: agroforestry practice, cocoa plantations, shade trees, biodiversity conservation

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Názov: Diverzita stromov v agrolesníckych systémoch: príkladové štúdium z Peruánskej Amazónie

Abstrakt: Táto diplomová práca skúma diverzitu stromov v kakaových agrolesníckych systémoch v dedine Huayhuantillo v Peruánskej Amazónii. V rámci 15 výskumných plôch boli zamerané kakaové a tieniace stromy na agrolesníckych plantážiach v Huayhuantillo, Peru. Boli identifikované tieniace dreviny a bola vyhodnotená druhová diverzita stromov na kakaovej plantáži. V rámci 15 výskumných plôch bolo zaznamenaných 195 stromov patriacich do 24 druhov, a to ako pôvodných tak aj exotických druhov v Amazónii. Následne výsledky z druhovej diverzity stromov z kakaovej plantáže v Huayhuantillu boli porovnané s druhovou diverzitou stromov z lesov s podobnými prírodnými podmienkami v Peruánskej Amazónii a s Európskym agrolesníckym systémom. Porovnaním druhovej diverzity na základe meraní sa preukázala vyššia diverzita v sekundárnom lese. Výhody agrolesníckych systémov pre zachovanie druhovej diverzity stromov boli taktiež vyhodnotené a porovnané s Európskymi agrolesníckymi systémami.

Kľúčové slová: agrolesnícke postupy, kakaové plantáže, tieniace dreviny, zachovanie biodiverzity

CONTENT

1. INTRODUCTION 9

2. AIM OF WORK 10

3. LITERATURE REVIEW 11

3.1 Agroforestry - introduction 11

3.1.1 Classification of agroforestry systems 12

3.1.2 Historical context 14

3.1.3 Advantages and disadvantages of agroforestry 15

3.2 Agroforestry systems in South America 16

3.2.1. Lowland humid and subhumid tropics 18

3.2.2. Semiarid and arid tropics 19

3.2.3 Tropical highlands 19

3.3 Agroforestry systems in Europe 21

3.3.1 Intercropping under hardwood species 21

3.3.2 Livestock grazing in managed plantations 22

3.3.3 Windbreaks 23

3.4 Characteristics of cocoa tree, its origin and planting methods 24

3.4.1 Basic characteristics 24

3.4.2 Growing conditions for cocoa tree 25

3.4.3 Systems of planting cocoa 25

3.4.4 Role of cocoa agroforestry plantation in biodiversity conservation 28

4. MATERIALS AND METHODS 29

4.1 Description of the study area 29

4.1.1 Location of the agroforestry study area in Huayhuantillo 29

4.1.2 Location of the forest reserve study area in Tingo María 31

4.2 Sampling design 32

4.3 Materials 34
4.4 Data collection 34
4.5 Data analysis 35
5. RESULTS 37
5.1 Overview of cocoa agroforests and forest reserve 37
5.2 Main attributes of shade trees 40
5.2.1 Density of shade trees 40
5.2.2 Diameter classes 41
5.2.3 Important value index (IVI) 42
5.2.4 Comparison of tree species composition between the two study plots 44
6. DISCUSSION 48
7. CONCLUSION 52
8. SUMMARY 53
9. REFERENCES 54
10. LIST OF FIGURES, TABLES AND GRAPHS 63
a. List of figures 63
b. List of tables 63
c. List of graphs 64
11. ANNEXES 65

List of abbreviations

BRUNAS	Bosque Reservado de la Universidad Nacional Agraria de la Selva
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza
EURAF	European Agroforestry Federation
FAO	Food and Agricultural Organization of the United Nations
GPS	Global positioning system
ICRAF	International Council for Research in Agroforestry
IDRC	International Development Research Centre
IVI	Important Value Index
m. a. s. l.	Meters above sea level
NN	No name
n.r.	Not reported
RA	Relative Abundance
RD	Relative Dominance
RF	Relative Frequency
SIDA	Swedish International Development Authority
UNAS	Universidad Nacional Agraria de la Selva

1. INTRODUCTION

Today tropical rain forests are disappearing along with a growing human population. Their decline is due to expansion of commercial plantations of trees and crops, expansion of grazing cattle, human settlements, etc (Earth's ecosystems, 2017). The establishment of cocoa, especially monoculture plantations has affected ecosystems due to the extensive deforestation of tropical rainforests which regenerate slowly (ICCO, 1998).

Agroforestry is broadly used concept which is directly linked with sustainable agroecology, which aims to enhance social and environmental responsibility in agriculture (Discovery organics, 2017). Agroforestry system is a heterogenous and forest-like use of land which brings about many environmental and socio-economic benefits to its environment.

In the central part of Peru in high jungle, there is a village called Huayhuantillo, surrounded by secondary natural forests, where "chocolate forests" are one of the most important producers of cocoa crops in the region. 15 years ago, coca leave was the most common cultivated crop in region. Huayhuantillo is a nice example of transition from cultivation of cash crop *Erythroxylum coca* to *Theobroma cacao* using agroforestry practices. Nowadays small-scale producers from Huayhuantillo can benefit not only from cocoa crop but also from multipurpose shade tree species that are planted along with cocoa trees.

As natural habitat for *Theobroma cacao* is a humid tropical rainforest and it grows under the canopy of other tree species, it follows that cocoa is a shade loving plant growing in undergrowth. Therefore management of shade tree stands is an important element of agroforestry systems. As it is shown in figure 2, all components in agroforestry system are connected to each other, at the same time shade trees provide optimized light to crops, optimise soil fertility with leaf litter, and give refuge to many animals. And thus, contribute to biodiversity preservation.

Tree species diversity in agroforestry systems may also contribute to increase of fauna and flora diversity. The higher tree species diversity, the richer the biodiversity in a given area, as trees provide refuge for many birds, mammals, insects, etc. Hence, this study puts emphasis on tree species composition and diversity in agroforestry systems.

2. AIM OF WORK

The main objective of my diploma thesis is to evaluate the tree species composition in cocoa based agroforestry systems, to define the potential for biodiversity conservation. At the same time figuring out the benefits of cocoa agroforestry systems for tree diversity conservation based on measured data from cocoa plantations in the Peruvian Amazon.

The secondary objective is to compare shade tree diversity in cocoa plantations in Huayhuantillo, Peruvian Amazon with tree diversity of natural forests from similar natural conditions. To find out this study, data from forest reserve BRUNAS in Tingo María, Peruvian Amazon was used to compare with cocoa plantations.

The last purpose of this thesis is to make a comparison of tree species diversity in agroforestry systems among South America and Europe.

The main research questions are: What is the difference in tree diversity of cocoa agroforestry plantation and natural forest? Can agroforestry systems be used as a refuge of biodiversity in degraded areas? What is the difference between tree species diversity of agroforestry systems in South America and Europe?

3. LITERATURE REVIEW

This chapter gives an overview of agroforestry, its division, historical context and its benefits and drawbacks. Moreover, it provides information about agroforestry systems in South America and Europe. Furthermore it comes up with summary information about the cocoa tree, its origin, planting methods and how cocoa agroforestry plantations play an important role in biodiversity conservation.

3.1 Agroforestry - introduction

„*Agroforestry is the art and science of growing woody and non-woody plants together on the same unit of land for a range of benefits.*“ (Lundgren, 1982). The term agroforestry can also be described as the processes in which are grown actual agricultural crops (eventually concurrently with livestock) together with woody plants. While woody plants provide shade to crops (Ehrenbergerová et al., 2016).

According to the Food and Agricultural Organization (FAO, 2015) agroforestry is: „*A collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence.”* These systems are equally ecological and economical interactions among the various components. Whereas Young (1989) claim that „*An agroforestry practice is a distinctive arrangement of components in space and time. An agroforestry system is a specific local example of a practice, characterized by environment, plant species and arrangement, management, and social and economic functioning. ”*

Considering the wide range of definitions, all systems which are aspiring to become an agroforestry should relate to these basic attributes: the productivity - value creation (wood, crop, etc.), the sustainability - maintaining the potential of renewable resources (land) and the adaptability - the ability to adapt to changing conditions (Martiník, 2014).

Lundgren (1982) mentions that agroforestry commonly possesses the following features: multiple plant components (of which one have to be a woody perennial), a high level of interaction (economic and biophysical), multiple products (e.g., fuelwood, fodder), and for at least one service function (shade, shelter, etc.). Figure 1 demonstrates agroforestry practices which include the integration of three components, such as trees (and shrubs) with crop and/or livestock systems.

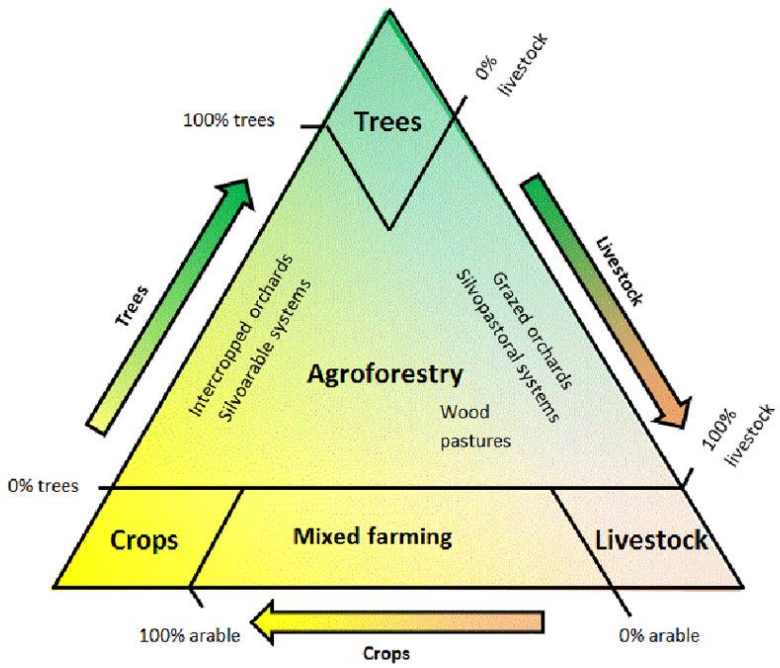

Figure 1 **Classification scheme of agroforestry (Den Herder, 2015)**

3.1.1 Classification of agroforestry systems

The main intention of classifying agroforestry systems is to give a practical framework and analysis of knowledge about existent systems and the advance of new favourable ones. The clearest criteria for classification of agroforestry systems are those components which are linked with spatial and temporal adjustment, the production targets and the social and economic aspects. Consequently, agroforestry systems can be classified in accordance with criteria set on structural, functional, socioeconomic and ecological basis (Nair, 1993).

Agroforestry contains various forms (called agroforestry practices or technologies) which can be assorted into various groups (Table 1) founded on their components in space and time and their production (either products or services). Services may include soil and water conservation, microclimate improvement, etc. Therefore we distinguish agrisilviculture (trees with crops), silvopastoral practices (trees with pasture and livestock), agrosilvopastoral practices (crops, pasture, animals and trees) and other practices such as multipurpose tree lots, apiculture with trees, etc (Huxley, 1999).

Table 1 Main agroforestry practices and their main characteristics (Nair, 1991)

Agroforestry practice + Brief description
Agrisilvicultural systems (crops + trees/shrubs)
(1) Improved fallow - woody species planted and left to grow during the 'fallow phase'
(2) Taungya - combined stand of woody and agricultural species during early stages of establishment of plantations
(3) Alley cropping - woody species in hedges
(4) Multilayer tree gardens - multilayer dense plant associations with no organized planting arrangements
(5) Multipurpose trees on crop lands - terraces or plot/field boundaries
(6) Plantation crop combinations - mixtures of plantation crops in alternate or other regular arrangement, shade trees for plantation crops; shade trees scattered
(7) Homegardens - Intimate, multi-storey combination of various trees and crops around homesteads
(8) Trees in soil conservation and reclamation - trees on bunds, terraces, raisers, etc.
(9) Shelterbelts and windbreaks, live hedges - trees around farmland/plots
(10) Fuelwood production - Interplanting firewood species on or around agricultural lands
Silvopastoral systems (trees + pasture and/or animals)
(11) Trees on rangeland or pastures - trees scattered irregularly or arranged according to some systematic pattern
(12) Protein banks - production of protein-rich tree fodder on farm/rangelands for cut-and-carry fodder production
(13) Plantation crops with pastures and animals - cattle under coconuts in south-east Asia and the south Pacific
Agrosilvopastoral systems (trees + crops + pasture/animals)
(14) Homegardens involving animals - multi-storey combination of various trees and crops, and animals, around homesteads
(15) Multipurpose woody hedgerows - woody hedges for browse, mulch, green manure, soil conservation, etc.
(16) Apiculture with trees - trees for honey production
(17) Aquaforestry - trees lining fish ponds, tree leaves being used as 'forage' for fish
(18) Multipurpose woodlots - for various purposes (wood, fodder, soil protection, soil reclamation, etc.)

3.1.2 Historical context

King (1968) has been said that *"Around the world, it has been common to cultivate tree species and agricultural crops in a close combination."* There are many examples. In Europe, it was a habit until the Middle Ages to clear forest, burn the area and cultivate food crops for various periods, and plant or seed trees before, simultaneously or after the seeding of crops. This system of farming is no longer being practised in Europe, however, until the end of the last century it was still extensively used in Finland and was used in a few areas in Germany (King, 1968).

Many societies throughout tropical America traditionally simulated forest conditions in their cultivate land for the purpose to obtain the benefits of forest structures. For example, land of farmers contained different species of plants corresponding to the laminated composition of mixed tropical forests: ground cover of plants with maize, a bush layer of cocoa or coffee, minor layer of citrus or bananas, and at last a layer of coconut or papaya (Wilken, 1977).

These examples show the wide geographical scope of the system and its early beginnings. They also point out to the fact that agroforestry was perceived as food production system where trees were a critical part of a farming system. In 1806, in the Tonze forests in Burma was set up a plantation of teak[1] by the method of the taungya[2] (Blanford, 1958). From these beginnings, the method turned out to be more and more popular. The taungya system expanded to other parts of Burma and was brought into South Africa in 1887 (Hailey, 1957) and was adopted from Burma to the Chittagong area in India in 1890 and to Bengal in 1896 (Raghavan, 1960).

At the beginning of the 1970s, agroforestry was adopted as a land management system that can be used in agricultural and forestry systems thanks to many factors and the gradual development. However serious doubts were being specified about the application of existing development policies and strategies. Amongst these factors were reviewed development policies of the World Bank and analysed policies relevant to forestry by the Food and Agricultural Organization of the United Nations (FAO). Project for the identification of tropical forestry research priorities was founded by the International Development Research Centre (IDRC) (McNamara, 1973). Accordingly

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[1] Teak is obviously not the only forest species which is being used in this agroforestry system. Indeed, the evidence proposes that if the system is adopted for the sole purpose of setting up forest plantations, that is only till the first closure of the forest canopy is obtained, then it may be utilized in the setting up of forest plantations of most species (King, 1968).

[2] Taungya is a Burmese word which exactly means hill cultivation (taung — hill, ya — cultivation).

change in policy, FAO prepared a paper "Forestry for Rural Development" (FAO, 1976), and together with Swedish International Development Authority (SIDA) organized seminars and workshops in all the tropical regions of the world.

The IDRC Project Report recommended the foundation of International Council for Research in Agroforestry (ICRAF), which plan and regulate investigation in linked land-management systems of agriculture and forestry (King and Chandler, 1978). Another organizations dealing with agroforestry is European Agroforestry Federation (EURAF) which operates with agroforestry systems in all parts of Europe (EURAF, 2017). In Central and South America it is Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) which is engaged in research and graduate education in agriculture and management, conservation and sustainable use of natural resources and agroforestry (CATIE, 2017).

3.1.3 Advantages and disadvantages of agroforestry

Besides the wide range of environmental benefits as basic **advantage** of agroforestry approaches can be considered product diversification (fruits, wood) and risk elimination (Martiník, 2014).

Protection of forests is another advantage as farmers can use wood from their plantations and so reduce the pressure on the surrounding forests (e.g. firewood). Many growers are focused only on cultivating one crop, and when price fluctuations occur they may get into financial trouble. Therefore, they can compensate these short-term fluctuations by selling timber, fruit and/or medicinal plants obtained from shade trees (Ehrenbergerová, 2014).

So that among agroforestry benefits also belong long-term production of fuel and timber and medium or long-term production of fruits. A further is protection and improvement of soil (particularly when legumes are included) and water sources and increase of efficiency in usage of land (Martin, 1998).

Agroforestry also reduces the incidence of certain diseases and insect infestation by allelopathic effect. The allelopathic substances repel pests and protect plants against diseases. Some other benefits are: reduction of wind speed and thereby reduction of erosion, improvement of soil aeration by the roots of trees which increase its porosity, increasing the amount of organic material in the soil and fixation of nitrogen and carbon dioxide (Ehrenbergerová, 2014).

Although agroforestry is a system of growing crops rather beneficial and positive, it also brings a number of negatives. Overall, the greatest **disadvantage** of agroforestry systems compared to traditional agriculture or forestry, is considered less use of mechanization and higher demand on human labour. (Sands 2005 in Martiník 2014).

Disadvantages in production indicators of agroforestry systems yet can be balanced by layer of other non-productive indicators, which are included under the sustainability and adaptability of systems (Nair 1993 in Martiník 2014).

More drawbacks of agroforestry systems are: damage to cultivated crops caused by falling trees and branches, reduction of wind speed and higher humidity under shading trees may cause fungal diseases and allelophatic activity of some woody plants can have negative effects on other plants, releasing chemicals into the environment (Ehrenbergerová, 2014).

3.2 Agroforestry systems in South America

There are many biomes in South America, but in this work the main emphasis is put on tropical biome and agroforestry in it. Tropical rainforest is a biome extended in the areas of humid climate of the intertropical zone on both sides of the equator. Majority of tropical rainforests are between 10 ° North and 10 ° South latitude. Average annual rainfall in this zone is between 2,000 and 3,000 mm and the average monthly and daily air temperature is above 25 ° C (Jeník and Pavliš, 2011). This biome has the longest continuity from all biomes. Its constant existence can be calculated from the Tertiary period, specifically from the Miocene period, when the continents were roughly at today's position (Prach et al., 2009).

South American tropical rainforest occupies a significant part of Amazon and Orinoco river-basin and zone along the Atlantic Ocean in Brazil (Jeník and Pavliš, 2011). South American region is characterized by largely represented families of Caesalpiniaceae, Mimosaceae, Myristicaceae, Sapotaceae, Lecythidaceae and Bromeliaceae. Among the most important economic trees coming from Amazonia belong rubber tree (*Hevea brasiliensis*) and cocoa (*Theobroma cacao*) (Prach et al., 2009).

Tree species composition of rainforest varies greatly among areas as well as the altitudinal gradient within one area (lowland rainforest versus montane rainforest). Species diversity is in average extremely high. Overall, it is said that this is a biome with the highest species diversity of all. The largest species richness of plants in rainforest is concentrated in the wood species, followed by lianas and epiphytes. About 400 tree species were identified on one hectare and trees create in average about 70% of all higher plant species. Generally, there is also high diversity of animals (Prach et al., 2009). In the vertebrate fauna they are represented as placental mammals as marsupials (Jeník and Pavliš, 2011).

World Agroforestry Centre (ICRAF 2000) determined agroforestry in tropics "*as a dynamic, ecologically based natural resource management practice that, through the integration of trees and other tall woody plants on farms and in the agricultural landscape, diversifies production for increased social, economic, and environmental benefits.*"

Important component in tropical agroforestry systems compose shade trees. Ehrenbergerová (2014) set up these major criteria for the selection of shade trees: compatibility with vegetation, strong and deep root system, the ability to endure extreme conditions, the ability of vegetative reproduction and quick growth, binding atmospheric nitrogen (*Fabaceae*), wide crown, and trunk and branches without thorns. Figure 2 underlines the significance of shade trees in tropical agroforestry system.

A general outlook of the most usual agroforestry systems in various parts of the American tropics is assumed in Table 2. Succeeding sections analyse this relation for the three major ecological regions in the tropics.

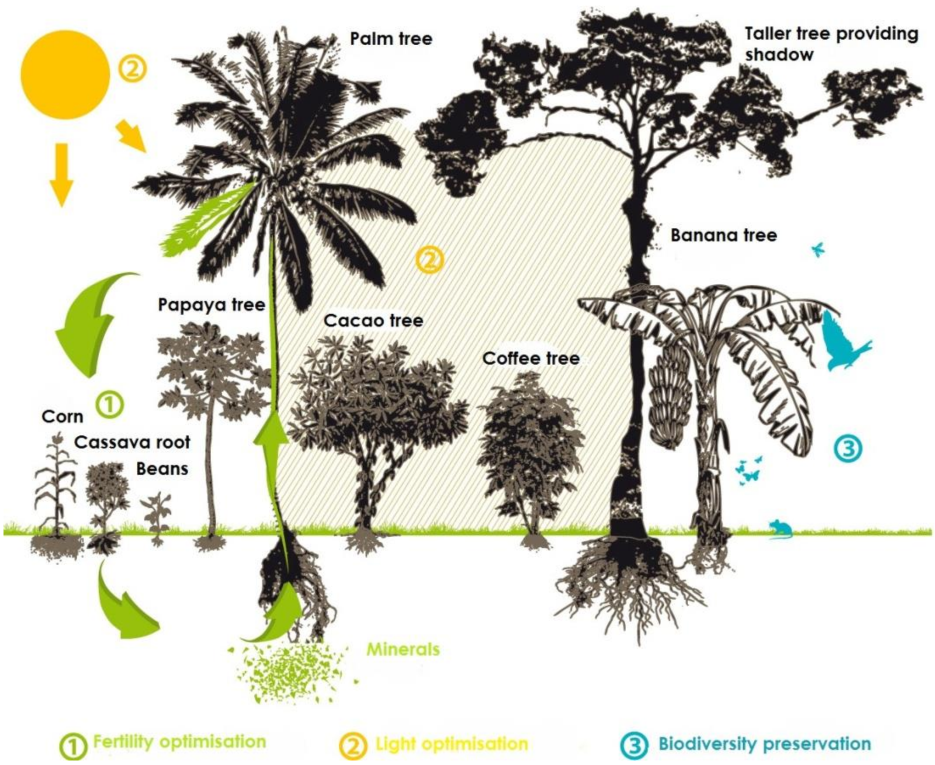


Figure 2 The cycle of shade trees in tropical agroforestry system. (Discovery organics, 2015)

Table 2 An overview of agroforestry systems in American tropics (Nair, 1989).

Subsystems and practices
AGRISILVICULTURAL SYSTEMS
(1) Improved fallow (in shifting cultivation areas) – several forms
(2) Taungya – several forms
(3) Tree gardens - e.g. Paraiso woodlots of Paraguay
(4) Hedgerow intercropping (alley cropping) - experimental
(5) Multipurpose trees and shrubs on farmlands - various forms in all ecological regions
(6) Plantation crop combinations – plantation crop mixtures; shade trees in commercial plantations; mixed systems in small-holdings; spice trees; babassu palm based systems
(7) Agroforestry fuelwood production - several forms in the dry regions
(8) Shelterbelts, windbreaks, soil conservation hedges - live-fences, windbreaks, especially in highlands
SILVOPASTORAL SYSTEMS
(9) Protein bank (cut-and-carry) fodder production - very common
(10) Live-fences of fodder trees and hedges - very common in highlands
(11) Trees and shrubs on pasture - common in humid as well as dry regions e.g. grazing under plantation crops in Brazil
AGROSILVOPASTORAL SYSTEMS
(12) Woody hedges for browse, mulch, green manure, soil conservation etc - especially in hilly regions
(13) Homegardens (involving a large number of herbaceous and woody plants and/or livestock) - very common in thickly populated areas
OTHER SYSTEMS
(14) Agrosilvo fishery (aquaforestry)
(15) Various forms of shifting cultivation – very common in all ecological regions
(16) Apiculture with trees

3.2.1. Lowland humid and subhumid tropics

This ecological region of lowland humid and subhumid tropics is defined by hot, humid climate all of the year with an evergreen or semi-evergreen vegetation. Considering climatic conditions that allow rapid growth of a huge number of plant species, different agroforestry plant associations are established in this area with big human population. In lowland humid tropics, depletion of natural rainforest is a common problem.

In such regions are common diverse forms of homegardens, plantation crop combinations, and multilayer tree gardens. The primary agroforestry systems in lowland of Latin America are trees on rangelands and pastures, improved fallow in shifting cultivation areas, and multipurpose tree woodlots. Thereby following agroforestry systems are most common in this zone: shifting cultivation, taungya, homegardens, plantation-crop combination, and diverse intercropping systems (Nair, 1993).

3.2.2. Semiarid and arid tropics

The semiarid and arid tropics are described by one or two wet seasons and for at least one long dry season. These climates tend to have minimal precipitation, so that drought is a hazard especially in the drier parts of the region.

The major agroforestry practices in this area are also affected by population, homegardens and multilayer tree gardens are rather established in the wetter zones with high population stress. In general the prevailing agroforestry practices in this zone are: diverse forms of silvopastoral systems, windbreaks and shelterbelts, and multipurpose trees on crop lands. The major land-use problems in this zone is fuelwood shortage (Nair, 1987), desertification and fodder shortage (Rocheleau et at., 1988).

3.2.3 Tropical highlands

Around 20% of the tropical lands are at elevations from 900 to 1800 metres. In South America, these areas comprise roughly half of the Andean highlands, parts of Venezuela and Brazil.

The highland tropics with important agroforestry potential are rather of humid or subhumid character, whilst areas with low potential have dry climate. There are similar land-use problems in the highlands to those in humid or dry low-lying regions consisting on the climate. In case of highlands, sloping lands and steep terrains cause also soil erosion.

The major agroforestry practices in tropical highlands are as follows: production systems including plantation crops such as coffee in commercial as well as smallholder systems, utilization of woody perennials in soil conservation and soil fertility maintenance, improved fallows, and silvopastoral systems (Nair, 1993).

Some examples of tropical agroforestry practices are provided at the end of this chapter. Figure 3 demonstrates silvopastoral agroforesty system in central part of Peru, consisting of combination of grazing cattle with cultivation of *Mauritia flexuosa* around homesteads. The following Figures 4 and 5 define agrisilvicultural systems of *Theobroma cacao* and *Coffea* spp in central Peru with shade trees for plantation crops.

Figure 3 Silvopastoral agroforestry system – cattle under „Aguaje“ *Mauritia flexuosa* in Tulumayo, central Peru. Photo: Author

Figure 4 Cocoa agroforestry plantation in Huayhuantillo. Photo: Author

Figure 5 Coffee agroforestry system in Villa Rica, Peru. Photo: Author

3.3 Agroforestry systems in Europe

Climate in Europe includes distinct warm and cold seasons. Precipitation and temperature vary throughout the year and therefore seasonality put here some unique agroforestry qualities. If we speak about agroforestry in Europe, we refer to temperate-zone agroforestry systems. In comparison with tropics where same crops are usually produced during the year, crops in the temperate zone are commonly restricted into one or two seasons (Nair, 1993).

Unlike the huge variety of systems and practices in the tropics, just a few agroforestry systems are used in temperate regions. As Nair (1993) has mentioned, the most common systems practiced in temperate zones are: agrisilvicultural (windbreaks and shelterbelts to prevent soil erosion in the plains), silvopastoral (livestock in many different woodland and range ecosystems), and agrisilvicultural combinations of fruit or nut or trees and herbaceous crops systems.

3.3.1 Intercropping under hardwood species

Gold and Hanover (1987) states there are two main types of hardwood intercropping systems which are fruit and nut-producing trees, and also high value timber. As Tejwani (1987) has been said in fruit orchards, cultivation of vegetable and other crops within the establishing phase decreases the need for vegetation management like mowing and herbicide application. Products from the orchards can be used for home consumption or market sale. When the trees grow bigger and shade the orchard floor, seasonal crops can be substituted by forage species. In this time the orchard may be opened to grazing as the trees are big enough to escape harm by animals.

Tree species of poplar (*Populus* spp) and their hybrids belongs to one of the most extensively intercropped group of trees. Traditionally these species were cultivated for short rotation fiber and fuel production. Poplar plantations in Europe have been interplanted with potatoes, corn, soybeans, and other cereals and tuber crops, in various temporal continuances, for the first three to six years after tree establishing (Gold and Hanover, 1987).

Another agroforestry system which was practiced across Europe over the centuries is **pollarding**. Read (2006) describes it as, "*a way of getting a regular product from the trees while also obtaining a crop from the land underneath them; a sustainable system of agro-forestry*." It is such a system of cutting branches from trees around three metres above ground level, to acquire fodder for nourishing livestock and/or get wood for fuel. In Europe, pollarding for fodder was especially common in northern Europe and mountain zones such as the Pyrenees, Alps and the high grazing lands of the Basque country (Read, 2006).

3.3.2 Livestock grazing in managed plantations

According to Byington (1990), the system of grazing livestock in plantations (silvopastoral system), has probably been more extensively applied than any other agroforestry practice in the temperate zone. This method uses not complicated management system where livestock are grazed freely in plantations set up fundamentally for timber production. Knowles (1991) assumes that following three different silvopastoral models have been developed: forest grazing, timberbelts, and trees on pasture. Among pre-eminent profitable species for agroforestry has proved to be *Pinus radiata*.

Some other agroforestry systems have been developed in particular regions of the temperate zone. **The dehesa oak woodlands** of Spain and Portugal have supplied acorns and forage for grazing animals and provided various wood products for local farmers (e.g. timber, charcoal, tannin, and cork). Pasture and crop cultivation are usual under the open oak canopy (e.g. *Quercus rotundifolia*, *Q. suber*, and *Q.* Faginea) of this agrosilvopastoral practice (Figure 6). The most common grazing animals are sheep, goats, cattle, or pigs and are also important components (Joffre et al., 1988).

Figure 6 Dehesa woodlands with grazing pigs in Spain (Pais de quercus, 2017).

Joffre et al. (1988) states there are more open woodlands in other Mediterranean countries utilized as silvopastoral practice, with dominant species of oaks or carob trees (*Ceratonia siliqua*).

3.3.3 Windbreaks

Wind erosion causes a serious problems as in the tropics as in many parts of the temperate zone. It has been a common agroforestry system to use windbreaks to protect agricultural fields and homesteads in this zone (Byington, 1990). There are several advantages of windbreaks in the temperate regions. In the protected zone, air temperatures are in general warmer throughout the day and cooler during the night than in unprotected areas. Also vertical transport of heat is decreased and humidity is augmented behind a windbreak, what normally reduces evapotranspiration (Jensen, 1983).

In many temperate countries have been set up small block plantings of multipurpose trees for production of biomass energy, fuelwood and fodder. Supplementary goals vary from creation of different wood products to soil conservation and water quality protection (Barrett and Hanover, 1991).

To sum up the agroforestry applications in temperate zones have often aimed at one or two high-value crops and comprise high levels of mechanization. Therefore these temperate-zone agroforestry practices are in contrast to those of tropical agroforestry systems, which are most commonly based on small individual farms or community lands (Nair, 1993).

3.4 Characteristics of cocoa tree, its origin and planting methods

3.4.1 Basic characteristics

Theobroma cacao, known as cocoa tree in the family Malvaceae (formerly Sterculiaceae) is an evergreen tropical tree which grows to a height of 6–10 meters (Mladá a Procházka 1987). In the natural environment can grow up to 15 m (Schumacher, 2002).

It grows naturally in the undergrowth of rainforest and is native to tropical regions of Central and South America. Already in the 5th century it was grown and used by native inhabitants of Central and South America (Valíček et al., 2002). Its cocoa beans (Figure 7) are used to prepare cocoa mass, cocoa butter, cocoa powder, confectionery, and chocolate (Pharmaxchange, 2013).

At present, the major part of production can be found in the following African countries: Cote D'Ivoire, Ghana, Nigeria and Cameroon, and in Latin American countries: Brazil, Ecuador, Peru and the Dominican Republic. The cocoa tree is also grown in Southeast Asia and Oceania in Malaysia, Indonesia, Papua New Guinea and Solomon Islands (Grulich, 2011).

Figure 7 Raw cocoa beans in a freshly cut cocoa. Photo: Author

3.4.2 Growing conditions for cocoa tree

Theobroma cocoa extends normally from the lowlands to about 500 m. a. s. l. with surrounding area around equator. Commonly is planted singly or in mixed plantings, and is most often grown on plantations (Nowak a Schulzová, 2002). Originally grows in the undergrowth of rainforest that provide a natural shade, so during commercial cultivation is necessary to use "artificial" shading (Mladá a Procházka, 1987).

Optimal temperatures for its good growth are around 21–32 ° C. Cocoa tree requires site with regular rainfall, amounts of rainfall per year should reach 1500–2500 mm and relative humidity of 77–96% (Grulich, 2011).

Cocoa needs fertile soils rich in humus and therefore farmers produce their own composts or organic based fertilizers. Composts are organic-mineral fertilizers of various formulas, eventually supplemented by imported fertilizer ingredients. Basic organic component are most often peel from the fruit of the cultivated crop (Ehrenbergerová et al., 2016).

The first harvest of cocoa tree under favourable conditions is coming in about 3-5 years. The harvest from the one tree is on average 20 to 30 fruits. Trees are often attacked by various pests and diseases (Krámský and Feitl, 2008).

3.4.3 Systems of planting cocoa

Agroforestry systems have long been practised in countries of Latin America and are less used in Africa (Schroth et al. 2011). Cocoa tree grows naturally in the undergrowth of rainforest, and therefore this system is an appropriate way of cultivation for cocoa. There are two ways of planting cocoa, either cocoa tree is planted in open forests under the crown of trees or valuable wood is removed from rainforest and consequently forest is burned out by farmers (Figure 8). On such modified sites are planted cocoa plants in lines and regular density and shade trees are planted between them (Ehrenbergerová et al., 2016).

Figure 8 Establishment of cocoa plantation by cutting down of trees and burning out the stand in Huayhuantillo. Photo: Author

Cocoa agroforestry systems contribute to the conservation of biological diversity that provides an environment for plant and animal species that are dependent on natural forests (Vebrova et al., 2014). Shade trees directly affect photosynthesis, growth and helps to control light regime (quality and quantity), the air temperature at the area, humidity, wind motion on the plantation (Somarriba, 2010).

There are more options of shade trees planting. Either such tree species are planted which produce shade to plantation during its entire lifetime or tree species of temporary shading are used, providing shade until the permanent shading trees grow up. To ensure temporary shadow, species of banana tree (*Musa*) are planted here (Figure 9). They are able to grow within one year, providing shade and fruits, and then they are removed (Ehrenbergerová et al., 2016).

Cocoa farms are often set up on cut-over areas of rainforest (South America, Asia) or in the forests, where there was performed thinning (Brazil, West Africa), or are planted as an intercrop with other tree species, such as coconut palm (*Cocos nucifera*), rubber (*Hevea brasiliensis*), oil palm (*Elaeis guineensis*) and other fruit tree species (Hebbar et al., 2011).

Figure 9 Banana tree planted in cocoa agroforestry system in Huayhuantillo. Photo: Author

Some other shade tree species used with cocoa trees are: kola nut (*Cola nitida*), mango (*Mangifera indica*), cashew tree (*Anacardium occidentale*), avocado (*Persea americana*), breadfruit (*Artocarpus communis)*, *Citrus* spp (Somarriba, 2010). These fruit and walnut tree species are often planted along with cocoa trees: areca palm (*Areca catechu*) from the family *Arecaceae*, brazil nut (*Bertholletia excelsa*) from the family *Lecythidaceae*, Guarana (*Paullinia cupana*) from the family *Sapindaceae*, peach-palm (*Bactris gasipaes)* from the family *Arecaceae* (Nair, 1993).

Sometimes cocoa trees are planted with *Swietenia spp.* or *Cedrela odorata*, which are used as timber-wood. Such wood harvested from cocoa plantations serves farmers as a source of income at a time when cocoa prices are low (Somarriba, 2010).

Shade trees can also be planted for different benefits to the ecosystem. Leguminous tree species as *Erythrina* spp, *Gliricidia* spp and *Inga* spp are generally used for their nitrogen fixation from atmospheric nitrogen (Anhar, 2005). In Peru, shade trees had good effect for the regeneration of cocoa agroforests where production stagnated after soil diminution (Kraus and Soberanis, 2001).

Monoculture cultivation is the agricultural practise where a single crop or plant is being grown in a field. The main goal of this farming system is maximized short-term productivity, yield and profit. Nowadays cocoa monoculture plantations are being practised the most in Cote d'Ivoire, Ghana, Malaysia and Indonesia (Andres, 2016).

Utilization of monoculture system has resulted in habitat destruction, loss of biodiversity and land degradation, however, many countries throughout the world use this farming system when growing cocoa (Schneider et al. 2014).

To set up monocultural land, natural vegetation is cut down and the area is then burned out. This leads to soil degradation, erosion and pollution. Monocultures also require large amounts of chemical fertilizers and pesticides, which also pollute the environment (Sabirin and Hamdan, 2000).

3.4.4 Role of cocoa agroforestry plantation in biodiversity conservation

Shade trees in cocoa agroforestry systems play an important role in biodiversity conservation, carbon stock, soil fertility, resistance against drought, and help the biological control of pests (ICCO, 2013). Agroforestry can also help to prevent water or wind erosion, improve food supply for animals and bees, increase the diversity of the landscape and enhance environmental quality (Nair, 1993).

On the other hand, establishment of cocoa plantations, especially monocultural plantations cause severe consequences of deforestation, destruction of biodiversity, changes climate and soil erosion. They require thousands of hectares and burning leads to the release of huge amounts of carbon dioxide. (Rainforestpartnership, 2015).

However, cocoa can be grown in agroforestry systems that are more environmentally friendly. Agroforestry systems have many advantages over monocultures systems. Monoculture systems are primarily used because of growing demand for cocoa beans, but this land management is not sustainable into the future. On the contrary, agroforestry plantations are more sustainable system in the future (ICCO, 1998).

4. MATERIALS AND METHODS

The focus of this section is on methodology of this work. All methods which were used to obtain the data are described in this chapter. It gives basic information about the study areas, sampling design, used materials, data collection and analysis. First part of this chapter has descriptive character whereas second part is focused on analysis of results.

4.1 Description of the study area

4.1.1 Location of the agroforestry study area in Huayhuantillo

The agroforestry study area is located in the central part of Peru in the Huánuco region, Leoncito Prado province (see Figure 10). The geographic coordinates of the area are 9° 15' 38" S and 75° 50' 59" W. Huayhuantillo is a village of 100 hectares with elevation from 500 to 800 m. a. s. l. located in the foothills of the Peruvian Andes (Ehrenbergerová et al., 2014). The village is mainly inhabited by smallholder cocoa farming communities. In annexes, more detailed geographical representation of study plots in Huayhuantillo can be seen.

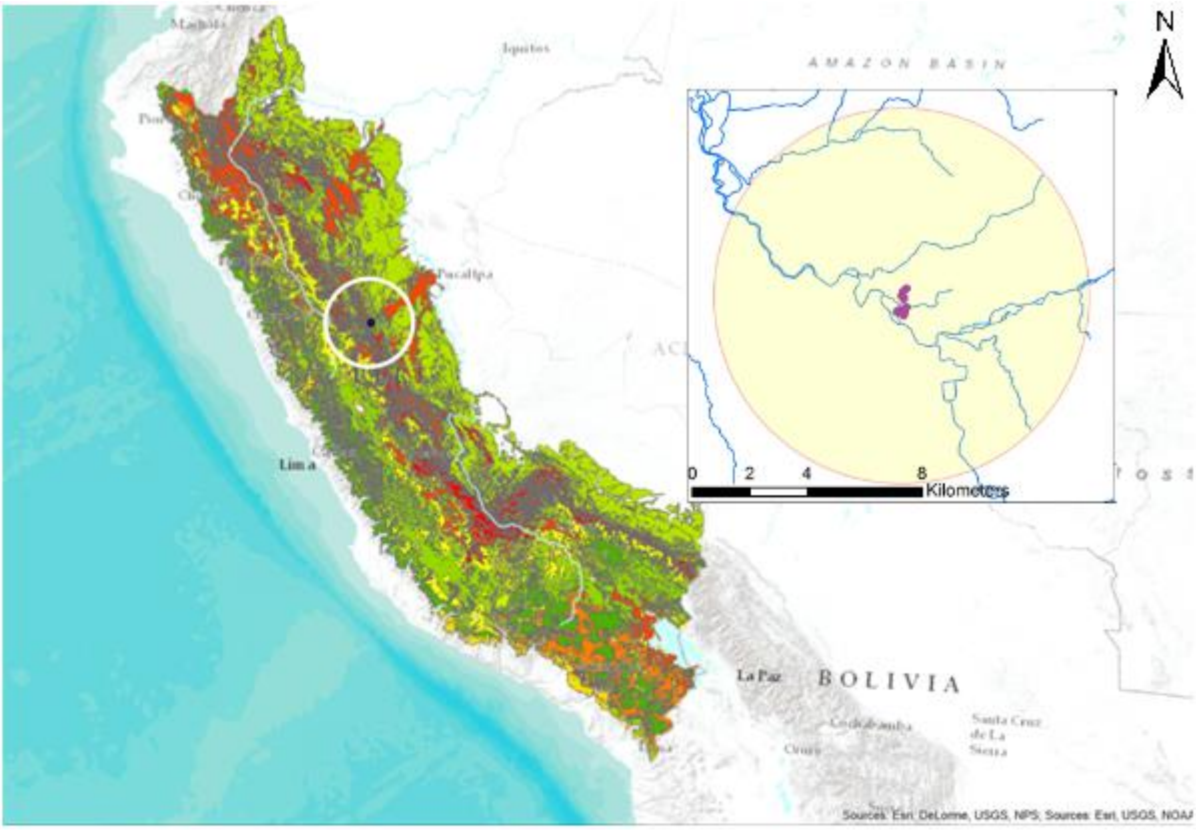


Figure 10 **Map of the location of study area in Huayhuantillo, Central Peru**

Climatic conditions are suitable for cultivation of cocoa, coffee, corn, yucca, papaya and rice. Nowadays *Theobroma cacao* is the most economically important crop in Leoncio Prado province. There are more than 3,800 hectares of cocoa plantations with different ages and varieties. However, plantations of *Erythroxylum coca* created the majority of Huayhantillo's production from the 70´s to the 80´ (in years 60 and 70 was cultivated *coffea* spp) (Ministerio de Agricultura, 2014).

About fifteen years ago, there were several projects in South America that promoted the transition of farmers from cultivating coca to cocoa. One of them is called Desarrollo Alternativo - Integral and Sustainable Alternative Development, or another is DEVIDA - The National Commission for Development and Life without Drugs.

As part of this aid have been holding seminars about the process for establishing plantations and cultivation of cocoa, distribution of seedlings, including shade trees. Currently local farmers are doing their production under Organic certification[3] within the frame of Cooperativa Agraria Industrial Naranjillo (Ehrenbergerová et al., 2016).

Density of plantation spacing of cocoa in agroforestry plantations in Huayhuantillo is as follows: 3x3 triangle (1283 plants per ha), 3x3 square (1111 plants per ha), 2x2.5 square (850 plants per ha), 5x5 square (450 plants per ha).

Varieties of cocoa used in Huayhuantillo are following: CCN–51, ICS–95, ICS–6, ICS–39, ICS–1, TSH–565. Cocoa trees in agroforestry farm in Huayhuantillo give crops every half an year, one tree gives approximately 30 fruits, from which about 50% is decayed and 50% is worthy. Local farmers claim that many cocoas are infested by serious pest *Carmenta theobromae*. Cocoa tree starts to produce crops two years after planting. Fertilization is carried out every four months (twice a year). Chemical and organic fertilization is combined in Huayhuantillo.

The most common shade tree species in cocoa agroforestry system in Huayhuantillo is native fruit tree *Inga edulis* (see figure in annexes), in English has been called "ice-cream beans" while in Spanish commonly known as „guaba" (World agroforestry, 2009). In the first year around 240 shade trees are planted per hectare in cocoa plantation. They create permanent shade for cocoa trees. After five years shade trees are gradually cut down until approximately 25 trees remain in one hectare. It is because as cocoa tree gets older it does not need much shadow. Local farmers from

[3] In Peru is very popular cultivation of cocoa in the context of Organic certification (also known as organic farming). Entry to this certification, however, brings the farmers a series of complications because they can not use some substances in the spraying to combat the disease.

Huayhuantillo state that a lot of shade can create humidity and this can lead to occurrence of many diseases. They also claim that trees from family *Inga* are very compatible with cocoa and are capable to fix nitrogen from the air and so that improving degradated soil. This pioneer tree species is very popular among agroforestry systems due to its fast growth, edible fruits, tolerance to acid soils, erosion control, and open crown providing shade (World agroforestry, 2009). Other important shade trees found in plantations in Huayhuantillo are these: *Cedrela odorata*, *Mangifera indica*, *Schizolobium parahyba*, *Brunellia dulcis*, *Vitex seudolia*, *Colubrina glandulosa*, *Parahancornia peruviana*, *Persea Americana* and *Schizolobium amazonicum*.

4.1.2 Location of the forest reserve study area in Tingo María

Tingo María (see Figure 11) is the capital of Leoncio Prado Province in the Huánuco Region in central Peru. The city is located 37 km from the village Huayhuantillo. The city lies on the transition of the Andes and the Amazon lowland on the Huallaga River of 650 m.a.s.l. Forest Reserve´s geographical coordinates are 9° 18' 58" S and 75° 59' 31" W.

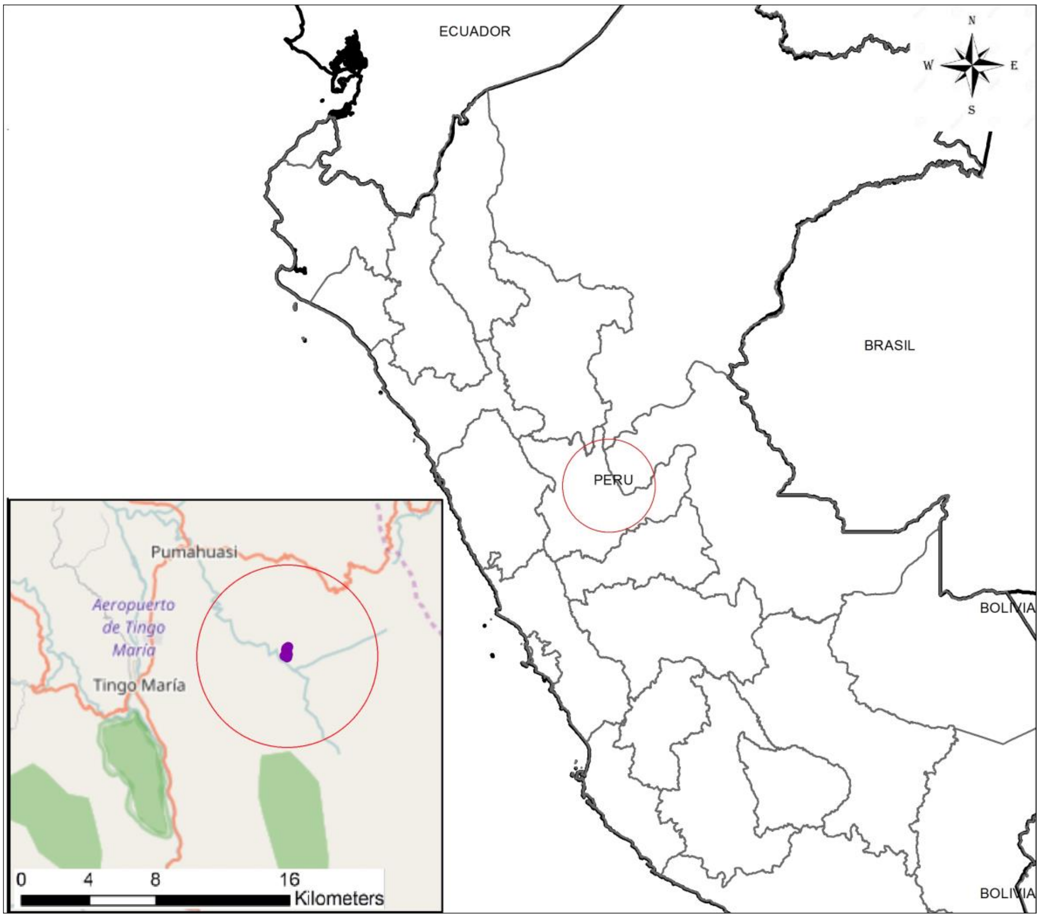


Figure 11 **Map of the location of study area in Tingo María, Central Peru**

The forest reserve of Universidad Nacional Agraria de la Selva in Tingo María (BRUNAS) is an area with forest cover of high jungle and represents wooded areas with a little intervention in Leoncio Prado province. It was created in 1971 as an intangible area in order to conserve the natural resources like flora, fauna, soils, water and biological diversity existing in this forest. Many trees of *Cedrelinga cateniformis* (oldest specimen in South America) and *Swietenia macrophylla* have been planted in forest reserve in 1950 (Burgos, 1955 in Puerta, 2012).

Regarding climate conditions of the study area, high rainfall are present with an average annual precipitation of 3428.8 mm. The highest rainfall occurs between September and April. Relative humidity is 87 % and an average annual temperature is 24 ° C. Altitudinal range of the area is located from 667 to 1 092 m.a.s.l. (Puerta, 2012).

Tree composition in the interior of forest reserve are: huangana caspi (*Senefeldera inclinata*), shiringa (*Hevea brasiliensis*), cicotria (*Psychotria caerulea*), huamansamana (*Jacaranda copaia*) caimito (*Pouteria caimito*), cetico (*Cecropia sciadophylla*), cumala (*Virola pavonis*), apuleya (*Apuleia leiocarpa*), moena (*Nectandra magnoliifolia*), quina (*Cinchona officinalis*), paliperro (*Vitex pseudolea*), machimango (*Couratori macrosperma*), carahuasca (*Guatteria modesta*), cumala (*Iryanthera tricornis*), moena (*Persea grandis*), tornillo (*Cedrelinga cateniformis*), and others (Rodriguez, 2000 in Puerta, 2012).

Table 3 Overview of two study sites (Climate-data, 2017)

Study area	**Latitude**	**Longitude**	**Altitude (m.a.s.l)**	**Rainfall (mm)**	**Temperature (°C)**
Cocoa Agroforests in Huayhuantillo	9° 15' 38'' S	75° 50' 59'' W	702–792	3400	24.5
Forest Reserve in Tingo María	9° 18' 58'' S	75° 59' 31'' W	720–760	3042	24.4

4.2 Sampling design

Fieldwork in cocoa agroforests was done by following practices. 15 selected study plots (see Figure 12) of radius 25 meters were localized with a differential GPS in October 2016. Research plots were placed randomly on transect every 200–400 meters in cocoa agroforests. In the field we focused on two circular plots - external and internal. The inner surface had radius of 10 meters, and there were measured all the cocoa trees and shade trees. The outer surface had radius of 25 meters and there were measured only shade trees (see Figure 13). The volume of each circle plot was 1963 m² and its circumference was 157 metres. All together were measured 15 circle plots (2.95 hectares).

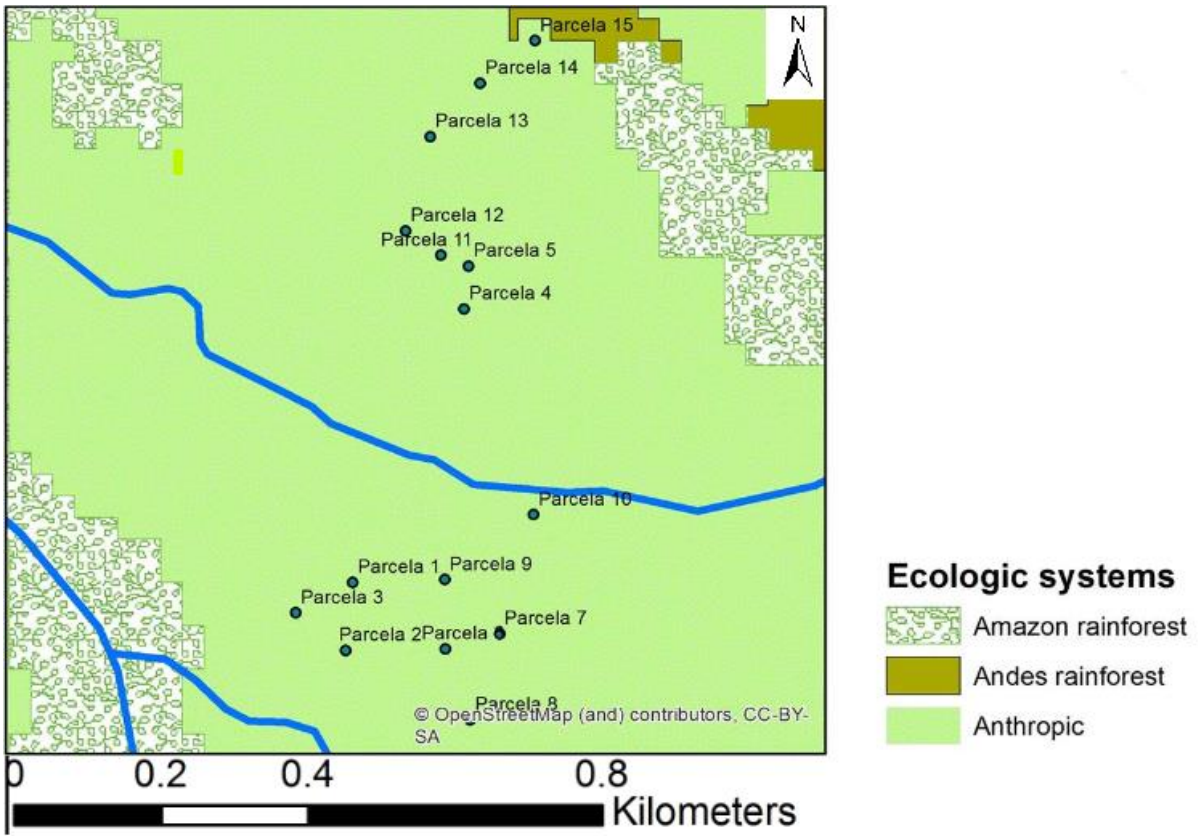


Figure 12 Overview of 15 study plots in cocoa agroforests in Huayhuantillo

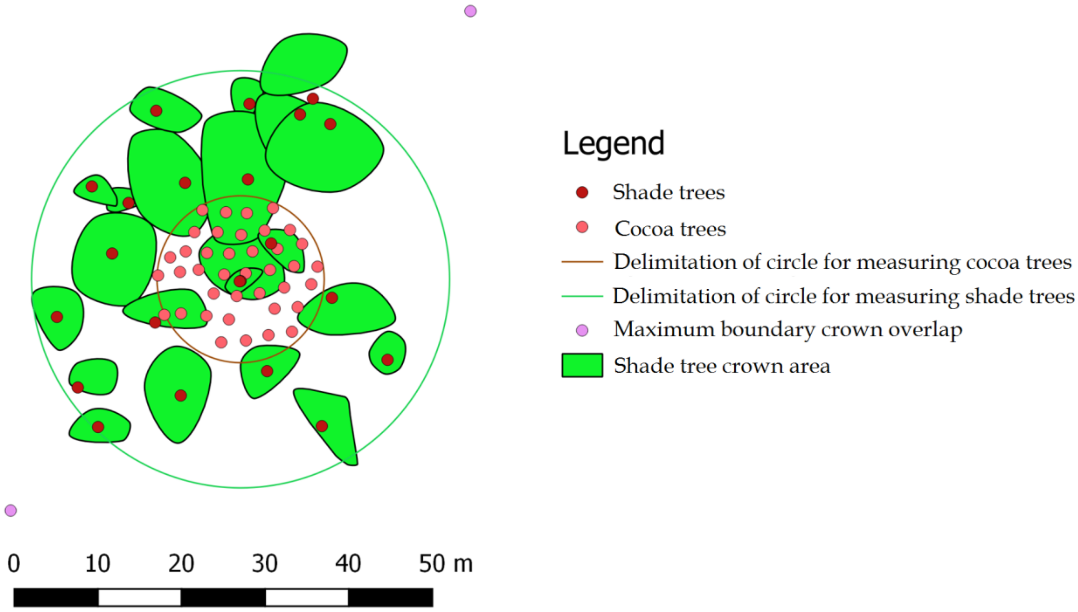


Figure 13 Scheme of sample design of study area no. 6 demonstrating methods of measurement in Huayhuantillo (Mervartová,2017)

To compare cocoa agoroforests with the secondary forest of similar natural conditions in Peruvian Amazon, forest reserve in Tingo María was chosen. Data from 5 study plots of size 20x100 m² (one ha) were collected in 2012. The size of one plot in both study areas are similar (1963 m² in Huayhuantillo and 2000 m² in Tingo María). Consequently, species richness and other variables were evaluated on the basis of one hectare from forest reserve and cocoa agroforests in next chapter. To illustrate graphically the maps of study plots, QGIS desktop 2.18.5 was used.

4.3 Materials

Since the data collection in both study sites was carried out with Field-Map technology, this subchapter is devoted to brief description of it. IFER (Field-Map, 2017) gives a clear description of what is dealing with this technology. *„Field-Map is a system for computer aided field data collection with primary emphasis to forestry. Currently it is the only software and hardware solution that is being used in numerous national forest inventories (NFIs).”*

Field-Map has its users worldwide since it has a very flexible system. Field-Map software package is classified into two major parts, Project Manager and Data Collector. Field-Map Project Manager determines a structure of a database (project) founded on a single methodology. Many different layers with many various attributes can be assigned inside one project. Field-Map Data Collector directly supports such field measurement devices as GPS, electronic compass, laser rangefinder, electronic inclinometer, and electronic calliper and thus gives the opportunity to map and measure in the field of study. Measurement devices such as GPS, map or local co-ordinate system are used to get user position and dimensions of trees. (Field-Map, 2017)

During the measurement in cocoa agroforests these Fielp-Map devices were used: ARMOR field computer, tripod, laser trupulse 200, support bracket, connection cables, monopod and reflectors.

4.4 Data collection

Evaluation of tree species diversity in agroforestry systems in Peruvian Amazon was developed on the basis of results from fieldwork made by author in cocoa plantation in Huayhuantillo. Students of bachelor's degree programs: Dita Mervartová, Pavel Horák and Kelly Ayala were helping during the fieldwork. Data from forest reserve were obtained from Universidad Nacional Agraria de la Selva in Tingo María (UNAS).

Shade trees and cocoa trees were measured with Field-Map technology in cocoa agroforests in Huayhuantillo. Technology Field-Map was borrowed from the UNAS and students of the same University helped us with the research.

Geographical position of cocoa trees was determined within circular sample plot of 10 meters radius. Tree parameters as average DBH and average height were measured and age and variety of cocoa was determined.

During measurement of shade trees we measured following tree parameters: diameter at breast height (DBH) which was measured with diameter tape (D-tape), height of trees, which was measured with laser borrowed from the UNAS, crown projection area of shade trees (in m^2), which was determined using the Field-Map technology with at least four points perpendicular to each other, and tree species were determined with the help of local farmers. Shade trees were localized within circular sample plots of 50 meters in diameter. In both study sites, were evaluated only trees with diameter ≥ 10 cm.

4.5 Data analysis

So far, data have been analyzed in an attempt to determine species diversity rates in both cocoa agroforests and forest reserve. The data can be used to compare them with another agroforests or forests from similar natural conditions. Tree variables as density of shade trees, tree thickness, important value index (IVI), area of crown projection, basal area, average height, Shannon and Simpson diversity indexes, and species richness (R) were calculated per study plots.

To illustrate all graphs, Excel format was used. Moreover, tree diameter classes of both study areas (per ha) were made with following DBH classes: class 10: 10-19.9, class 20: 20-29.9, class 30: 30-39.9, class 40: 40-49.9, class 50: 50-59.9, class 60: 60-69.9, class 70: 70-79.9, and class 80≥.

At the end of the result section, all tree species found during survey in cocoa agroforests and forest reserve are listed in tables with basic information about their taxonomy, use, and abundance. The origin and main use of all tree species were defined by means of internet sources, mainly according to http://tropical.theferns.info/.

To get value of IVI sum average of relative abundance, relative dominance and relative frequency was calculated. Geobotany (2017) interprets these terms subsequently: Relative abundance (RA) is the number of individuals of given species divided by the absolute number of individuals of all species (in percentage), relative dominance (RD) is the absolute basal area of a species divided by the sum of basal area for all species (in percentage), and relative frequency (RF) is the absolute frequency of given species divided by the sum of the total frequencies for all species (in percentage).

Equation for calculation of IVI is following:

$$IVI\ (\%) = (RA + RD + RF) / 3$$

Different indices of diversity (e.g. Shannon, Simpson and species richness) were calculated to analyse species distribution in both study sites. The difference between them is whether they place more emphasis on richness or evenness.

Simpson index belongs to best-known index group called the indices based on dominance. It is strongly dependent on the most numerous species and less sensitive to rare species. Its values vary from zero to one. The index value correlates strongly negative with evenness, with its rising value increases dominance and decreases evenness of community, thus often is used its reciprocal form or reduction of one (May, 1975). Therefore its inverse form was used in this work, since the value is higher and is better to compare it with similar works.

Assumption of Shannon index is a random selection of individuals from a theoretically unlimited amount and presence of all species of communities in the sample. Usually ranges from 1.5 to 4.5. It uses natural logarithms (Pielou, 1975).

Species richness (R) expresses the number of species found in a designated area. Indexes and species richness were calculated using RStudio.

5. RESULTS

This chapter deals with processing and interpreting of results in both study areas. Comparative and statistical methods were used when processing and describing graphs and species diversity indexes. At the end of this section, there is a list of all tree species surveyed in both study areas.

5.1 Overview of cocoa agroforests and forest reserve

In cocoa agroforests (Figure 14), total number of surveyed individuals (DBH ≥ 10 cm) was 195, pertaining to 24 species and 18 families in total area of 29,445 m² (2.95 ha), that means 66.1 individual shade trees per hectare. The tree family with the highest representation was Fabaceae (5 species/134 individuals) what makes 68.7 % out of all individuals. Number of cocoa trees per ha was 1234 individuals.

Regarding distribution of shade trees, the most common tree species found in cocoa agroforests was *Inga edulis* (Fabaceae), leguminous tree native to the American humid tropics with 121 individuals. Other most abundant shade tree species were *Cedrela odorata* (Meliaceae), *Vitex seudolia* (Lamiaceae), *Schizolobium amazonicum* (Fabaceae), *Piper auritum* (Piperaceae), *and Persea Americana* (Lauraceae).

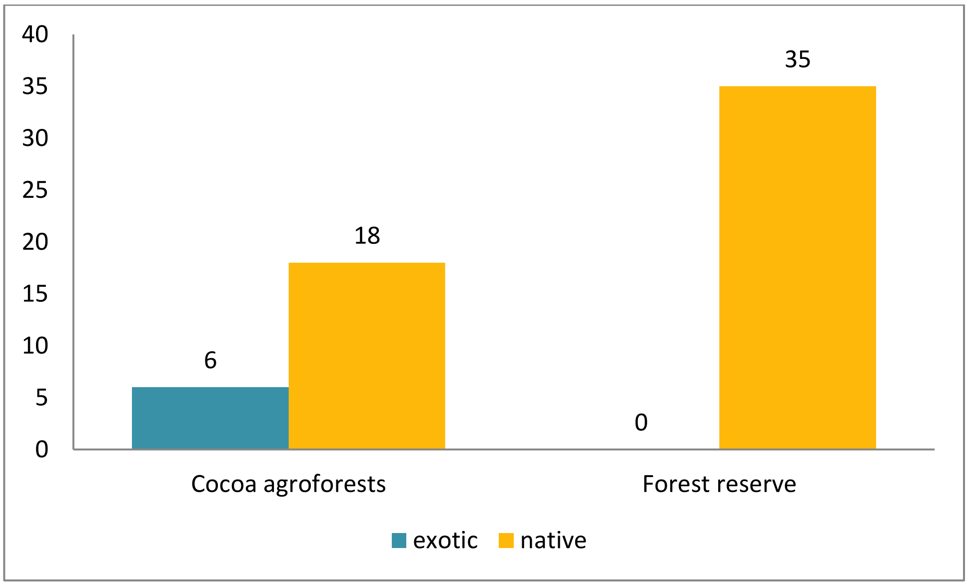
Total number of tree individuals (DBH ≥ 10 cm) per hectare (10,000 m²) in forest reserve was 595, pertaining to 36 species and 18 families, as it was in case of cocoa agroforests. This occurred because total area (2.95 ha) surveyed in agroforestry systems was bigger than total area (1 ha) in forest reserve. Tree families with the largest number of individuals were Fabaceae (5 species/113 individuals) with total distribution of 19 %, further family Urticaceae (2 species/113 individuals), and Myristicaceae (2 species/93 individuals).

Among most abundant tree species belong *Pourouma bicolour* with no. of individuals 85 (Urticaceae), *Virola elongate* with 78 individuals (Myristicaceae), *Schefflera morototoni* with total individuals of 52 (Araliaceae), *Inga pezizifera* with 51 individuals (Fabaceae), *and Parkia igneiflora* with 46 trees individuals (Fabaceae).

In comparison to cocoa agroforests, forest reserve significantly proves higher number of individual trees per hectare. The difference is huge because the abundance of trees in tropical forests is very high.

Figure 14 **Cocoa agroforestry system of the study area in Huayhuantillo. Photo: Author**

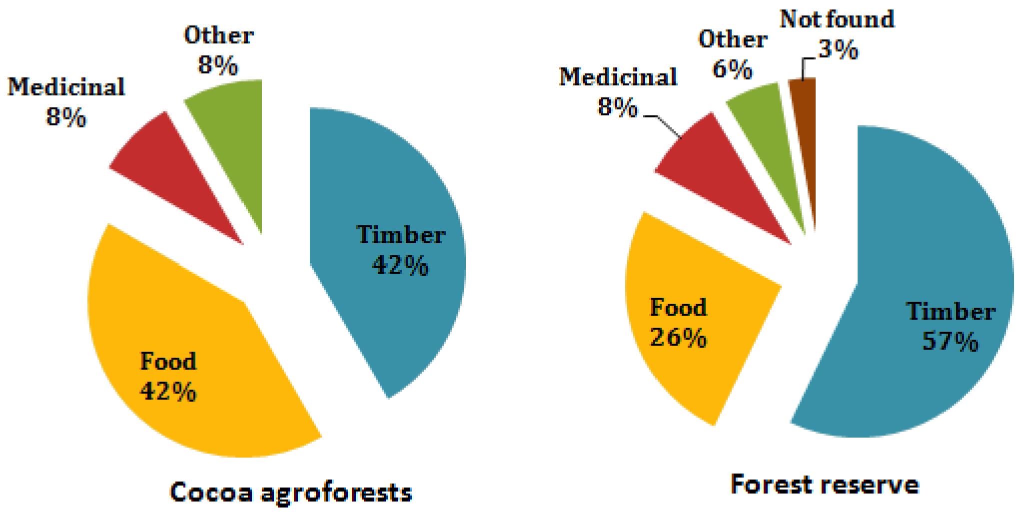
Concerning to origin of tree species in forest reserve in Tingo María, all 35 species which were measured are native to the Amazon (Graph 1). While in cocoa agroforests, 6 out of 24 were exotic to Peru. Within introduced species in Huayhuantillo belonged *Acacia* spp, *Piper auritum, Mangifera indica, Euphorbia tirucalli, Persea americana, and Syzygium malaccense.* Exotic tree species have been used in agroforestry systems long time ago.



Graph 1 Rate of native and exotic tree species in both study areas

In humid tropical areas, it has been traditional practice of small farmers to plant species like avocado (*Persea americana)* and mango (*Mangifera indica*) within the cropping area. Therefore species such as *Mangifera indica*, *Persea americana*, and *Syzygium malaccense* are usually found in agroforestry plantations. The majority of these introduced species are multipurpose trees which bring along benefits like atmospheric nitrogen fixation, shading the cocoa trees, and fast growth timber. Small-scale producers in Huayhuantillo benefit also from exotic species for their fast-growing timber or from their fruit production, since many introduced species are fruit trees. There is a certain risk of invasiveness when introducing exotic species to different habitat, since they can replace native species.

The range of application of tropical tree species was distinguished according to their timber value, food (fruit), medicinal properties and other uses. In cocoa agroforests (Graph 2 – left), 42 % of all species are used for their timber and fruit, while remaining 8 % are used for medicinal and other purposes like firewood, fodder or herbalism. Local farmers in Huayhuantillo uses mainly fruit trees to get food and simultaneously are using them for timber. The main characteristics for some tropical tree species is that they have multiple use, so that at one time they can provide fruit, fuelwood, and also medicinal value, as it is in case of *Inga edulis* or *Spondias mombin.* High value timber trees in Huayhuantillo are *Cedrela odorata*, *Cedrelinga cateniformis*, or *Colubrina glandulosa*. Comparing to forest reserve (Graph 2 – right) the use of tree species do not differ significantly. The major use of tree species is dedicated to timber (57 %) and food (26 %), and then medicine (8 %) and other purposes (3 %). For further reading, the list of use of all species surveyed in both study areas is found at the end of this chapter.



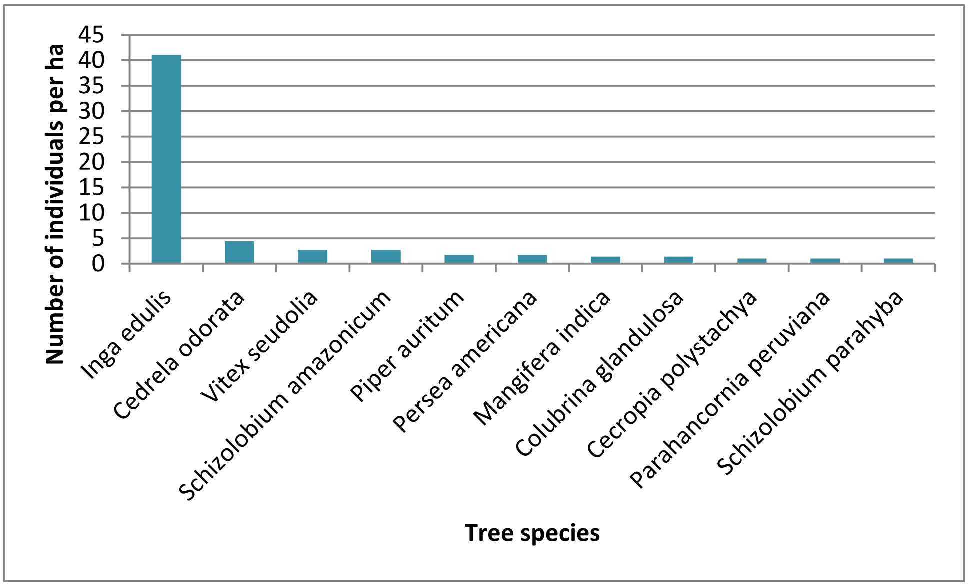
Graph 2 Main use of wood species in both study areas

5.2 Main attributes of shade trees

This subchapter comprise main parameters such as density of most abundant shade tree species, diameter classes and important value index (IVI).

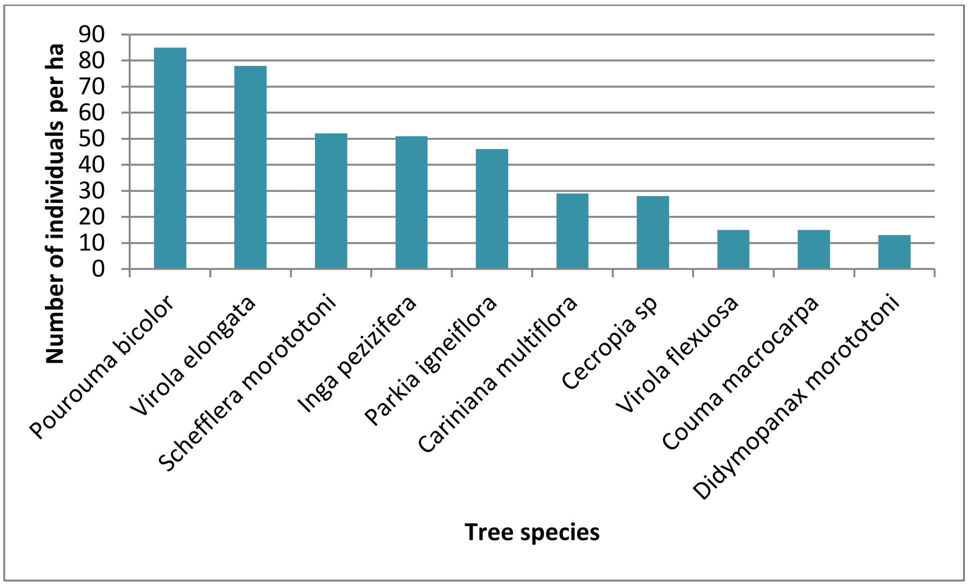
5.2.1 Density of shade trees

Average tree density in cocoa agroforests was 66 individuals per hectare with 24 recognized species. As Graph 3 has shown that the most prevailing shade tree species in cocoa agroforests is *Inga edulis* (41 individuals/ha) which makes 62 %. Remaining species *Cedrela odorata*, *Vitex seudolia*, *Schizolobium amazonicum*, etc. showed very low density. This big drop in abundance between species *Inga* and other species is due to preference of small-scale cocoa producers to plant shade trees of this species.



Graph 3 Density of 11 most abundant shade tree species in cocoa agroforests

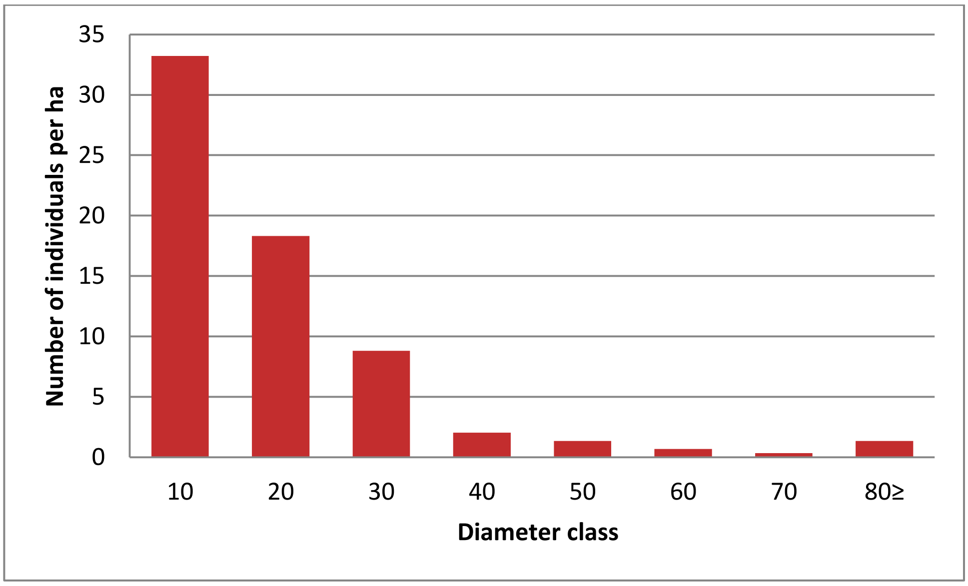
In comparison with forest reserve (Graph 4), where 595 individual trees per hectare were observed with total number of 35 species (per ha), the main difference between these two land systems is not only in number of individuals (per ha) but also in abundance of tree species. While representation of most abundant tree species in cocoa agroforests is uneven with dominance of only one tree species, in case of forest reserve the representation of most abundant tree species is more equal. The most common tree species in forest reserve were *Pourouma bicolour* (14.3 %), *Virola elongata* (13.1 %), *Schefflera morototoni* (8.7 %), *Inga pezizifera* (8.6 %), *Parkia igneiflora* (7.7 %), *Cariniana multiflora* (4.9 %), *Cecropia* sp (4.7 %), *Virola flexuosa* (2.5 %), *Couma macrocarpa* (2.5 %), and *Didymopanax morototoni* (2.2 %).



Graph 4 Density of 10 most abundant tree species in forest reserve

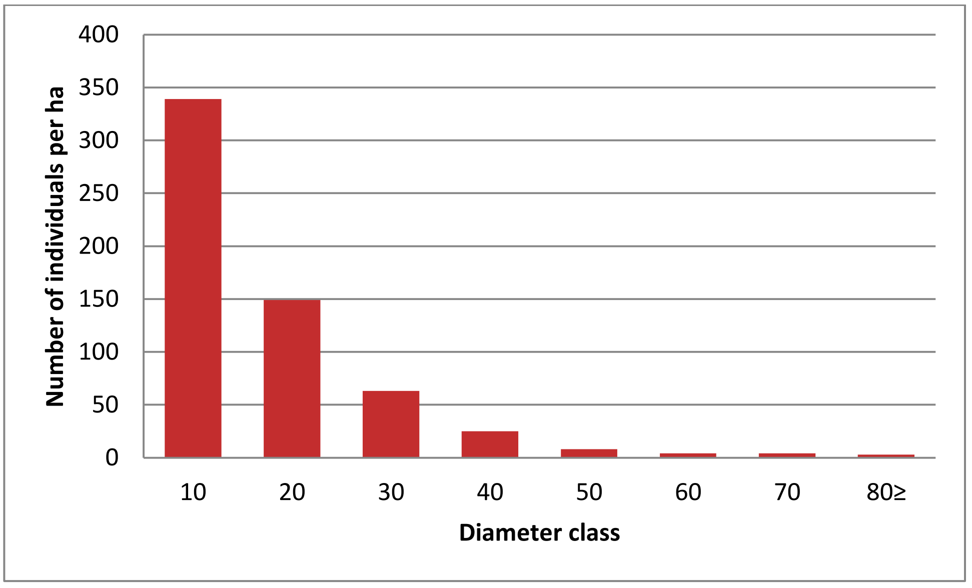
5.2.2 Diameter classes

Graph 5 shows the number of trees by diameter class per hectare in study area cocoa agroforests. 50 % of individuals belonged to class with diameter between 10 and 19.9 cm, the second most abundant diameter class was between 20 and 29.9 cm with 27.3 %, following classes had lower percent occurrence: 30-39.9 with 13.6 %, 40-49.9 with 3 %, 50-59.9 with 1.5 %, 60-69.9 with 1.5 %, 70-79.9 with 0 %, and last class 80≥ with 1.5 %.



Graph 5 Diameter size-class distribution in Cocoa Agroforests

Graph 6 shows the distribution of trees by diameter class per hectare in study area in forest reserve. Overall, 57 % of individuals belonged to class 10-19.9, 25 % of trees had diameter in class 20-29.9, 10.6 % of individuals had diameter in class 30-39.9, only 4.2 % of trees had diameter about 40-49.9, and remaining classes 50-59.9 with 1.3 %, class 60-69.9 with 0.7 %, class 70-79.9 with 0.7 %, and last class 80≥ only with 0.5 %. Distribution of trees by diameter size classes is similar for both study areas, there is not considerable deviation. In both cases, prevailing classes are 10 and 20 and remaining classes are less frequent. Again, the most significant difference is in number of individuals.



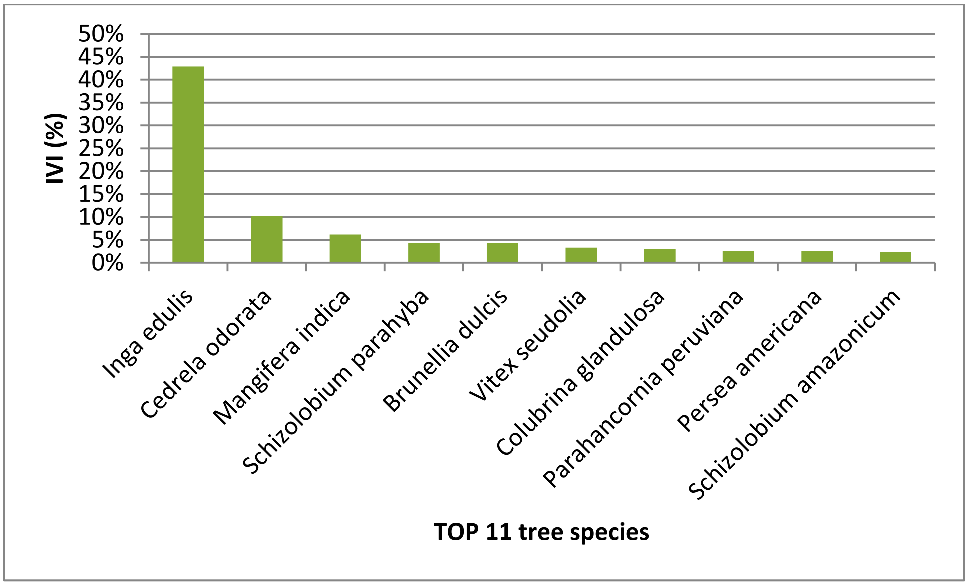
Graph 6 Diameter size-class distribution in Forest Reserve

5.2.3 Important value index (IVI)

As was mentioned above, IVI gives us a value of most dominant species in a given area. To calculate important value for each tree species, firstly diameter of all trees was measured and then converted to basal area (cross-sectional area of stem). As a sum of relative abundance, relative dominance, and relative frequency gives us overview of relative dominance expressed in percentage.

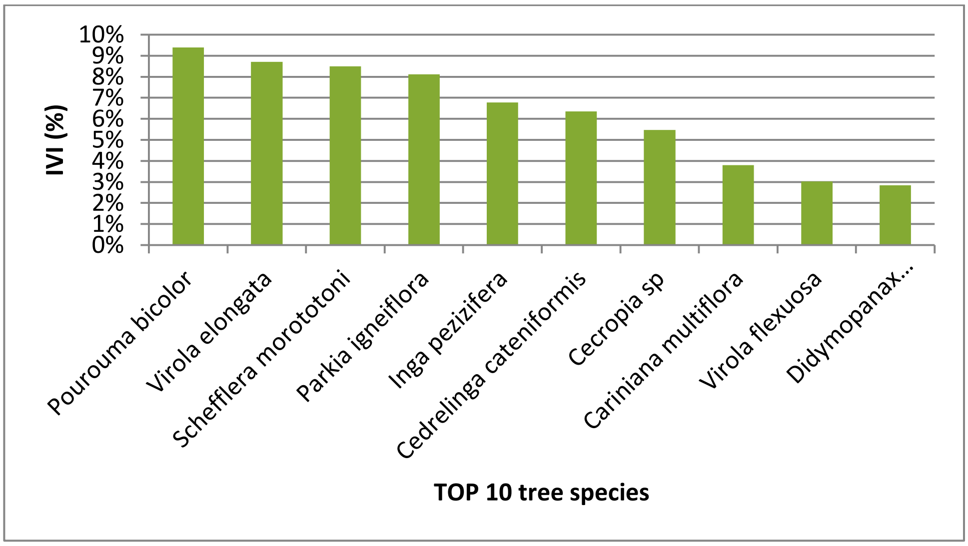
Therefore from Graph 7 results that the most important shade tree species in cocoa agroforests is *Inga edulis*, with the highest value of IVI = 43 %, highest value of relative dominance (IVI = 39 %), so as with the highest numbers of relative frequency (IVI = 27 %), and relative abundance (IVI = 62 %). Following by shade tree species with lower important values, *Cedrela odorata* (IVI = 10 %), *Mangifera indica* (IVI = 6 %), *Schizolobium parahyba* (IVI = 4 %), *Brunellia dulcis* (IVI = 4 %), *Vitex seudolia*

(IVI = 3 %), *Colubrina glandulosa* (IVI = 3 %), *Parahancornia peruviana* (IVI = 3 %), *Persea Americana* (IVI = 3 %), and *Schizolobium amazonicum* (IVI = 2 %).



Graph 7 Importance value index (IVI) in percentage in cocoa agroforests

Percentage results of important value indexes in forest reserve are more equal one to each other. Hence the most dominant tree species in forest reserve are *Pourouma bicolour* (IVI = 9 %) with 14 % of rel. abundance, 10 % rel. dominance and rel. frequency of 4 %, and *Virola elongata* (IVI = 9 %) with rel. abundance, dominance and frequency of 13 % 9 % and 4 %. Succeeding dominant trees are *Schefflera morototoni* (IVI = 8 %), *Parkia igneiflora* (IVI = 8 %), *Inga pezizifera* (IVI = 7 %), *Cedrelinga cateniformis* (IVI = 6 %), *Cecropia sp* (IVI = 5 %), *Cariniana multiflora* (IVI = 4 %), *Virola flexuosa* (IVI = 3 %), and *Didymopanax morototoni* (IVI = 3 %).



Graph 8 Importance value index (IVI) in percentage in forest reserve

5.2.4 Comparison of tree species composition between the two study plots

Overall, in both land use systems, were found together 58 tree species, 30 families and in total were observed 790 individual trees. 35 tree species were found in forest reserve and 24 in cocoa agroforests. In total, 43 individuals were unidentified, out of which 41 belonged to forest reserve and remaining 2 were recorded in cocoa agroforests. All 35 tree species observed in forest reserve were native to Amazon, while 6 out of 24 tree species found in cocoa agroforests were exotic, what makes one quarter of total shade tree species.

There was only one tree species which was found in both study areas, and that is *Cedrelinga cateniformis* (Tornillo tree). In forest reserve, there were surveyed 12 individuals with IVI=6 %, however, in cocoa agroforests only one individual tree was found with IVI=1 %.

However, several common genera were found in both land use types, for example genus *Inga* sp., *Cecropia* sp., and *Pouteria* sp. Tree species of *Inga edulis, Cecropia polystachya*, and *Pouteria caimito* were surveyed in cocoa agroforests. While species of *Inga pezizifera* and *Pouteria guianensis* were found only in forest reserve. All of them are native to Amazon and fruit tree species.

The most abundant and frequent family in this land use systems was family Fabaceae, with total number of individuals 247 and 9 tree species.

Table 4 compares tree parameters and tree diversity in two land use systems. To compare tree diversity, these indexes of species diversity were used: species richness (R), Simpson's reciprocal and Shannon indexes. When comparing species richness between forest reserve (R = 2.7) and cocoa agroforests (R = 0.9), forest reserve has higher ($p \leq 0.05$) value, while the difference remains relatively low.

Both Shannon and Inverse Simpson indexes have shown higher ($p \leq 0.05$) values in case of forest reserve. Shannon index usually ranges from 1.5−3.5, the higher the value the greater the species evenness. Value 2.74 in forest reserve shows that tree species have more similar relative abundance than agroforestry systems, where value 0.89 shows low evenness among tree species.

Simpson's reciprocal index was applied in comparison of these land use systems. This index was considerably higher ($p \leq 0.05$) in forest reserve (11.97) than in cocoa agroforests (2.27), what has shown greater tree species diversity in forest reserve. Mean values for height and basal area (per ha) were lower in cocoa agroforests in comparison to forest reserve.

When comparing the index values in forest reserve and cocoa agroforests, it has shown that between the areas is statistically significant difference in all indexes. The comparison was performed by one-way ANOVA.

Table 4 Characteristics of study plots and tree species in cocoa agroforests and forest reserve

Variables	**Cocoa Agroforests**	**Forest Reserve**
Surveyed area (ha)	2.95	1
No. of sample plots	15	5
Size of sample plot (m²)	1,962	2,000
Tree abundance (Total no. of trees)	195	595
Total species observed	24	35
No. of cocoa trees (per ha)	1234	n.r.
Average species richness (R)	0.9[a]	2.7[b]
Inverse Simpson diversity index	2.27[a]	11.97[b]
Shannon index of species diversity	0.89[a]	2.74[b]
Tree density (per ha)	66	595
Average height (m)	11.58 ± 5.05	16.28 ± 5.72
Basal area (m² per ha)	0.022 ± 0.022	0.048 ± 0.033
Crown projection area (m² per ha)	21.36 ± 19.59	n.r.

± *(standard deviation)*

Mean indexes followed by different letters across rows were significantly different according to independent samples t-test ($p \leq 0.05$).

In Tables 6 and 7 below can be found all tree species surveyed in land use systems with their taxonomy, main use, and abundance within the scope of their occurrence.

Table 5 Tree species found within survey of 15 plots (2.95 ha) in cocoa agroforests in Huayhuantillo, Peru, their use and abundance

Scientific name	Family	Common name	Utilization	Abundance
Acacia spp	*Fabaceae*	Acacea	Fuelwood	1
Bixa orellana	*Bixaceae*	Achiote	Dye, food additive	1
Brunellia dulcis	*Brunelliaceae*	Cedrillo	Timber	1
Brunellia inermis	*Brunelliaceae*	Cedrillo de montaña	Timber	1
Cecropia polystachya	*Cecropiaceae*	Cetico	Food, firewood	3
Cedrela odorata	*Meliaceae*	Cedro	Timber, medicinal	13
Cedrelinga cateniformis	*Fabaceae*	Tornillo	Timber	1
Colubrina glandulosa	*Rhamnaceae*	Shaina	Timber, medicinal	4
Euphorbia tirucalli	*Euphorbiaceae*	Palo lapiz	Medicinal	1
Guazuma crinita	*Sterculiaceae*	Bolaina blanca	Timber	1
Inga edulis C. Martius	*Fabaceae*	Guaba	Fruit, timber, med.	121
Mangifera indica	*Anacardiaceae*	Mango	Fruit	4
Matisia cordata	*Malvaceae*	Sapote	Fruit	2
NN	NN	NN	n.r.	2
Parahancornia peruviana	*Apocynaceae*	Naranjo podrido	Fruit	3
Persea americana	*Lauraceae*	Palta	Fruit	5
Piper auritum	*Piperaceae*	Hierba santa	Food, herbalism	5
Piptocoma discolor	*Asteraceae*	Ocuera	Timber	1
Pouteria caimito	*Sapotaceae*	Caimito	Fruit	2
Rollinia mucosa	*Annonaceae*	Anona	Fruit	1
Schizolobium amazonicum	*Fabaceae*	Pino chuncho	Other	8
Schizolobium parahyba	*Fabaceae*	Pashaco	Timber	3
Spondias mombin	*Anacardiaceae*	Tapisho	Fruit, medicinal	1
Syzygium malaccense	*Myrtaceae*	Pomarrosa	Fruit	2
Vitex seudolia	*Lamiaceae*	Paliperro	Other	8
Total individuals				**195**
Total species				**24**

Table 6 Tree species found in Forest Reserve (1 ha) in Tingo María, Peru and their use and abundance

Scientific name	Family	Common name	Utilization	Abundance
Aniba amazonica	*Lauraceae*	Moena amarilla	Other	10
Aniba perutilis	*Lauraceae*	Moena negra	Timber	9
Aniba sp	*Lauraceae*	Ishma moena	Timber	1
Apeiba membranacea	*Malvaceae*	Maquisapa ñapcha	Timber	2
Bellucia pentamera	*Melastomataceae*	Manzanita tropical	Fruit	4
Brosimum alicastrum	*Moraceae*	Manchinga	Food	1
Brosimum rubescens	*Moraceae*	Palisangre	Timber	9
Cariniana multiflora	*Lecythidaceae*	Cachimbo	Timber	29
Cecropia sp	*Urticaceae*	Cetico	Food, firewood	28
Cedrelinga cateniformis	*Fabaceae*	Tornillo	Timber	12
Ceiba pentandra	*Malvaceae*	Huimba	Timber	1
Cinchona sp	*Rubiaceae*	Cascarilla	Medicinal	10
Clarisia racemosa	*Moraceae*	Mashonaste	Timber	2
Couma macrocarpa	*Apocynaceae*	Leche Caspi	Food	15
Didymopanax morototoni	*Araliaceae*	Anonilla	Timber	13
Diplotropis martiusii	*Fabaceae*	Chontaquiro	Timber	3
Guatteria elata	*Annonaceae*	Carahuasca	Timber	1
Hevea brasiliensis	*Euphorbiaceae*	Shiringa	Food, medicine	1
Chimarrhis sp	*Rubiaceae*	Papelillo caspi	Timber	1
Inga pezizifera	*Fabaceae*	Shimbillo	Food, medicine	51
Jacaranda copaia	*Bignoniaceae*	Huamansamana	Timber, medicine	2
Miconia poeppigii	*Melastomataceae*	Rifari	Timber	7
NN	NN	NN	n.r.	41
Ormosia amazonica	*Fabaceae*	Huayruro	Timber	1
Parkia igneiflora	*Fabaceae*	Pashaco blanco	n.r.	46
Pourouma bicolor	*Urticaceae*	Uvilla	Timber	85
Pouteria guianensis	*Sapotaceae*	Caimitillo	Fruit, timber	8
Protium plagiocarpium	*Burseraceae*	Copal	Timber	6
Pseudolmedia laevigata	*Moraceae*	Chimicua	Medicine, timber	11
Rinorea lindeniana	*Violaceae*	Café de monte	Other	8
Schefflera morototoni	*Araliaceae*	Aceite Caspi	Timber, medicine	52
Sterculia sp	*Malvaceae*	Huangana	Food	10
Symphonia globulifera	*Clusiaceae*	Palo azufre	Medicinal	12
Theobroma subincanum	*Malvaceae*	Cacahuillo	Fruit, medicine	10
Virola elongata	*Myristicaceae*	Cumala blanca	Timber, medicine	78
Virola flexuosa	*Myristicaceae*	Cumala	Timber	15
Total individuals				**595**
Total species				**35**

6. DISCUSSION

Tree composition and diversity of cocoa agroforestry plantation

It was revealed that the majority of shade trees used in cocoa agroforestry plantations in Huayhuantillo are multipurpose wood species, used mainly for their edible fruits, valuable timber, and/or medicinal purposes. Besides these values, shade tree species also bring environmental benefits to agroforestry systems like shadow, improvement of soils, etc. Small-scale producers in Huayhuantillo are also more self-sufficient thanks to multipurpose shade tree species.

In the study from coffee agroforestry systems in Southern India, Dhanya (2014) has shown that native trees also provide multiple benefits (up to four different uses) whereas exotic species provide up to two or three uses mostly. The most common use of shade trees in this study was for timber, then fuelwood and fruits, and for medicinal purposes.

Inga edulis, known as guaba is very common shade tree species in agroforestry throughout whole Latin America. In Huayhuantillo, it was most abundant tree species (41 individuals/ha) with the highest important value (IVI = 43 %). *I. edulis* is very popular among local farmers for its fast growth, atmospheric nitrogen fixation, soil improvements, fruits, timber, etc. The same occurred in the study in cocoa agroforests in San Alejandro in Peru, where *I. edulis* had the highest density (62 individuals/ha) and also the highest IVI = 153.7 % (Vebrova et al., 2014). In the study of Vebrova (2014) and also in this study, comparing to secondary forest, *I. edulis* was found only in cocoa agroforests. Except of its good compatibility with cocoas trees, the reason why local farmers in Huayhuantillo preferably plant *I. edulis* is to improve initially degraded soils after coca plantations. In this case *I. edulis* has not only important ecological but also socio-economic role. Therefore agroforestry systems may be used as a refuge for biodiversity in degraded areas, in this case after coca degraded plantations.

Cedrela odorata also called cedro was the second most abundant tree species, even though with much lower density than *I. edulis*. *C. odorata* is often planted in agroforestry plantations for its valuable timber, however, for its overexploitation it is found in red list of threatened species.

Comparing diversity of shade tree species found in both, cocoa agroforests in San Alejandro and Huayhuantillo, these trees were found in both study areas: *Cedrela* *odorata*, *Cecropia polystachya*, *Rollinia mucosa*, *Matisia cordata,* and *Persea americana*.

Among exotic fruit tree species found in Huayhuanatillo were *Mangifera indica*, *Persea americana* and *Syzygium malaccense*. In case of *Persea americana* it can be misleading whether it is native or exotic tree species to Peru, since it has been cultivated in tropical regions since long, but still, it originates from Central America – Mexico. It is very common also for different parts of Latin America to introduce exotic trees species in agroforestry, especially for their edible fruits.

It has been found in many cocoa regions around the world that usual shade cover in agroforestry systems is dense (>60%), what can contribute to tree species diversity (Bos et al., 2007; Faria et al., 2007; Sonwa et al., 2007). On the contrary, local farmers in Huayhuantillo remove considerable part of shade trees, what depends on selected shade tree management of each producer.

In addition to shade trees removing in cocoa agroforests in Huayhuantillo, local farmers commonly remove shade trees gradually as cocoa trees reach the mature stage, from initial number 240 shade trees, remain only approximately 25 trees per one hectare. From the initial density, shade trees are thinned to 10.4 %. Similar shade method removal was found in cabruca cocoa system of Bahia in Brasil, where trees and shrubs were thinned to 10 % of their original density (Alves, 1990). In other study in old growth cocoa agroforests in Cameroon, tree species diversity of plantation with remaining age decreased to number 11 tree species (Vidal, 2008).

As has been proved during the fieldwork, the plot with the highest density of shade trees is the plot with the youngest cocoa trees, and vice versa. Small-scale producers in Huayhuantillo are often based on their own knowledge or experiences when it comes to management of shade trees. With shade removal they also try to avoid occurrence of many pests and diseases, as overshadow can lead to their outburst.

On the contrary from producers, Piasentin et al. (2014) in their study say "*if (you) take away the shade, it (the cocoa tree) resents it... without shade, the strong sun will kill a large part... cocoa shrivels and even dies, the leaves dry out... it's like when we go to the (drought-ridden) barrens*".

Comparison of cocoa agroforestry plantation with forest reserve and other agroforests

Cocoa agroforestry plantations have shown lower tree density and species diversity (66 individuals per ha; 24 tree species) than the secondary forest reserve (595 individuals per ha; 35 tree species). Even though tree density in present study is low, tree species diversity is relatively comparable. The forest reserve has shown higher values in species richness (R), Shannon and Simpson species diversity indexes than cocoa agroforests.

On the other hand, Oke and Odebiyi (2007) have surveyed only 23 shade tree species per hectare in cocoa agroforests, and 276 tree species per hectare in natural forest in Ondo State, Nigeria. The majority of shade tree species surveyed in cocoa agroforests were edible fruit trees. However, it is not possible to compare Shannon diversity index due to different survey methodologies. These results even are lower than that of present study, but still they are relatively comparable. Oliveira et al. (2013) has surveyed cocoa farms in Ghana, Africa, and the results shows that majority of farms have less than 9 species per ha. Species richness >12 species per ha has shown only 25% of the farms.

In addition, other study in cocoa agroforests in Cameroon, West Africa has observed similar mean tree density, which was 89 individual trees per hectare with 43 tree species for total area surveyed (Daghela et al., 2013).

Comparing to coffee agroforestry system in Uganda, where 116 trees per ha were found, CAF still prove low tree density (Negawo, 2016). Probable reason of low tree abundance in this study could be the fact that in coffee agroforests they use different shade tree management.

Tree species diversity and agroforestry systems in Europe and South America

What is the difference between tree species diversity of agroforestry systems in South America and Europe? To answer this research question, it can be a little bit misleading as we are comparing tree species diversity in two such a different world biomes.

In comparing these two different biomes we have to take into the account their climate conditions, geography, vegetation and animals adaptations. The tropical rainforest has the richest biodiversity in the world.

Earth's ecosystems (2017) state that the world record in tree diversity of 300 species per ha was recorded near Iquitos in Peru. Of course there are big differences in diversity within the different types of tropical rainforest and the different geographical areas.

To compare the diversity of tropical rainforests and temperate forests there is a statistics from the Malaysian peninsula, where there grows about 8,000 plant species belonging to the genera 1,400 (about 28 endemic). On double area of Great Britain were found 1,430 native plants belonging to 620 genera (no endemic) (Earth's ecosystems, 2017).

Obviously tree species diversity in tropical rainforest shows higher tree species diversity comparing to that of temperate forests. Tropical rainforests are evergreen forests with two main seasons, whereas temperate forests are deciduous and coniferous forests with four distinct seasons.

Agroforestry systems have been practiced in South America longer time than in Europe. As was mentioned before Tanguya, the first agroforestry system which comprises crop cultivation with wood species (teak) was developed in tropical region in Barma. In Europe, the oldest common agroforestry practice was pollarding, a system of getting a product from trees whilst acquiring a crop (Read, 2006).

According to Martiník (2017) these are the most common tree species used in Europe followed by different agroforestry practices: silvoarable practices (*Quercus* spp., *Juglans* spp., *Populus* spp., *Primus* spp., *Castanea sativa*), silvopasture (*Quercus* spp., *Castanea* spp., *Pinus* spp.), riparian buffer strips (*Alnus* spp., *Populus* spp., *Fraxinus* spp.), forest farming (*Fagus* spp., *Quercus* spp., *Abies* spp.), multipurpose trees (*Robinia*, *Quercus* spp., *Fraxinus* spp., *Betula* spp., *Castanea sativa*), improved fallow (*Ulex europaeus*, *Cytisus stratus*).

In tropical rainforest of South America, these tree species are planted within different agroforestry systems: tanguya (*Cordia alliodora, Swietenia macrophylla, Carapa quianensis,* and *Cedrela odorata),* living fences and windbreaks (exotic *Eucalyptus globulus* and *Prosopis* sp.), fruit trees associated with crops (*Citrus* spp., *Carica papaya, Mangifera indica, Persea americana, Manilkara zapote, Crysophylum caimito, Byrsonima erassifolia* and *Anacardium occidentale).* Other shade species used are: *Erythrina* spp., *Gliricidia sepium, Cassia* spp., *Schinus peruviana, Hevea quianensis, Caryocar* sp, *Vitex Pseudolea, Jacaranda copaia,* etc. (FAO, 2017).

In Europe, agroforestry is concerned mainly on one or two crop cultivation or monoculture cultivation (e.g. Paulownia monoculture), and high level of mechanization is common. On the contrary in Latin America, the combination of more crops with shade tree species is common (e.g. cocoa, coffee), however, agroforestry practice is being managed mainly by small-scale producers. Even though agroforestry systems in Europe are not as diverse as in the tropics, both agroforestry systems increase biodiversity and have other benefits such as soil protection against erosion, increase of production potential, etc.

7. CONCLUSION

This study was aimed at tree species composition and diversity in cocoa agroforestry system, and the results were compared to secondary forest with similar natural conditions. The results have shown that species richness was higher in case of secondary forest reserve and that about 66.6 %. Indexes of species diversity (Shannon, Simpson's reciprocal) have shown, that forest reserve verifies higher species diversity and also evenness of that species in sample plots than cocoa agroforests. The mean tree height and basal area (m^2 per ha) of individual trees was also higher in forest reserve. Average tree diameter of trees per hectare was comparable, with the prevailing representation of tree diameter classes 10 and 20 in both cases.

Study demonstrated that far the highest importance value index (IVI) in cocoa agroforests, had native tree *Inga edulis* which was very well represented due to its high average density, frequency and dominance compared to other shade tree species in the same area. In case of forest reserve representation of IVI was more even among the tree species. The highest values obtained *Pourouma bicolour* and *Virola elongata*. The only tree species found in both study plots was *Cedrelinga cateniformis*, very popular native tree for its valuable timber.

All species found in forest reserve were native to Amazon, while one quarter of trees surveyed in cocoa farms were of exotic origin. The productive value of majority of these introduced species in cocoa agroforests is edible fruit. It was proved in both study areas that many native tree species to Amazon are multi-use tree species (up to three uses were found). They are preferably used for their timber, fuelwood, food and medicinal purposes, while exotic tree species indicated mainly one (up to two) productive values.

This study also confirmed that the composition and tree species richness depends not only on natural conditions, but also on the knowledge and approaches of small-scale producers. Shade tree management takes an important place in decision making. It was found in previous studies that optimal shade for cocoa trees is >60 %, but local farmers in cocoa agroforests remove trees till shade gets to 10.4 %. The farmers could consider more, whether such thinning of shade trees is necessary in mature cocoa trees stands, and thus preserve tree biodiversity. Contrary to one or two crop cultivation used in agroforestry systems in Europe, application of a wide range of shade tree species which are intercropped with other crop species is commonly practiced in South America.

8. SUMMARY

Hlavným cieľom tejto diplomovej práce bolo zhodnotiť drevinovú skladbu na príklade kakaovej agrolesníckej plantáže v Huayhuantillu, a tým určiť jej potenciál pre zachovanie biodiverzity. Zároveň táto práca popisuje výhody kakaových agrolesníckych systémov pre zachovávanie druhovej diverzity. Výsledky vychádzajú z výskumu z kakaových plantáží v peruánskej Amazónii, ktorý sa uskutočnil v októbri 2016. Vďaka technológii Field-Map, ktorú sme mali zapožičanú z UNAS, sme zamerali tieniace dreviny a kakaovníky v 15 výskumných plochách o veľkosti 2.95 hektárov.

Sekundárnym cieľom tohto výskumu bolo porovnať druhovú rozmanitosť tieniacich drevín v kakaových agrolesníckych systémoch v Huayhuantillu, s druhovou rozmanitosťou prirodzených lesov z podobných prírodných podmienok. Na porovnanie sa osvedčili dáta z 5 výskumných plôch o veľkosti 1 hektára zo sekundárneho lesa BRUNAS v Tingo María. Posledným cieľom tohto výskumu bolo zakomponovanie Európy do tejto práce, a porovnať tak druhovú diverzitu v agrolesníckych systémoch medzi Južnou Amerikou a Európou.

V súčasnej dobe môžu mať malovýrobcovia z Huayhuantilla úžitok nielen z kakaovej plodiny, ale aj z viacúčelových tieniacich drevín, ktoré sú vo veľa prípadoch sadené spolu s kakaovníkmi ako medziplodina pre ich významnú produktívnu hodnotu (drevo, ovocie, krmivo, liečivé účely, atď.).

Výsledky ukázali, že druhová bohatosť bola vyššia v prípade sekundárneho lesa, a to o 66.6 %. Indexy druhovej diverzity (Shannon a recipročný Simpson) ukázali, že sekundárny les preukazuje vyššiu diverzitu stromov a tiež druhovú rovnomernosť než kakaové plantáže.

Hodnoty priemernej výšky stromov a bazálnej plochy (m^2/ha) boli menšie u kakaovej plantáži. Výsledky priemerov (diameter) jednotlivých stromov boli porovnateľné. Hrúbkové triedy s najväčším zastúpením boli pre obidve výskumný plochy: 10-19.9 a 20-20.9.

Štúdie taktiež ukázali, že najdôležitejší strom (IVI) na kakaových plantážiach je pôvodný strom *Inga edulis*, ktorý bol zastúpený na každej výskumnej ploche. Čo sa týka sekundárneho lesa, bolo IVI viac vyrovnané spomedzi drevinami, s najvyššími hodnotami *Pourouma bicolour* a *Virola elongata*. *Cedrelinga cateniformis* bola jediná drevina, ktorá sa nachádzala ako v sekundárnom lese, tak aj v kakaových plantážiach.

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10. LIST OF FIGURES, TABLES AND GRAPHS

a. List of figures

Figure 1 Classification scheme of agroforestry (Den Herder, 2015) 12
Figure 2 The cycle of shade trees in tropical agroforestry system. (Discovery organics, 2015) 18
Figure 3 Silvopastoral agroforestry system – cattle under „Aguaje“ *Mauritia flexuosa* in Tulumayo, central Peru. Photo: Author 20
Figure 4 Cocoa agroforestry plantation in Huayhuantillo. Photo: Author 20
Figure 5 Coffee agroforestry system in Villa Rica, Peru. Photo: Author 21
Figure 6 Dehesa woodlands with grazing pigs in Spain (Pais de quercus, 2017). 23
Figure 7 Raw cocoa beans in a freshly cut cocoa. Photo: Author 24
Figure 8 Establishment of cocoa plantation by cutting down of trees and burning out the stand in Huayhuantillo. Photo: Author 26
Figure 9 Banana tree planted in cocoa agroforestry system in Huayhuantillo. Photo: Author 27
Figure 10 Map of the location of study area in Huayhuantillo, Central Peru 29
Figure 11 Map of the location of study area in Tingo María, Central Peru 31
Figure 12 Overview of 15 study plots in cocoa agroforests in Huayhuantillo 33
Figure 13 Scheme of sample design of study area no. 6 demonstrating methods of measurement in Huayhuantillo (Mervartová, 2017) 33
Figure 14 Cocoa agroforestry system of the study area in Huayhuantillo. Photo: Author 38

b. List of tables

Table 1 Main agroforestry practices and their main characteristics (Nair, 1991) 13
Table 2 An overview of agroforestry systems in American tropics (Nair, 1989). 18
Table 3 Overview of two study sites (Climate-data, 2017) 32
Table 4 Characteristics of study plots and tree species in cocoa agroforests and forest reserve 45
Table 6 Tree species found within survey of 15 plots (2,95 ha) in cocoa agroforests in Huayhuantillo, Peru, their use and abundance 46
Table 7 Tree species found in Forest Reserve (1 ha) in Tingo María, Peru and their use and abundance.. 47

c. List of graphs

Graph 1 Rate of native and exotic tree species in both study areas 38

Graph 2 Main use of wood species in both study areas 39

Graph 3 Density of 11 most abundant shade tree species in cocoa agroforests 40

Graph 4 Density of 10 most abundant tree species in forest reserve 41

Graph 5 Diameter size-class distribution in Cocoa Agroforests 41

Graph 6 Diameter size-class distribution in Forest Reserve 42

Graph 7 Importance value index (IVI) in percentage in cocoa agroforests 43

Graph 8 Importance value index (IVI) in percentage in forest reserve 43

11. ANNEXES

A - Map of 15 study plots in cocoa agroforests in Huayhuantillo

B - Photos

50 years old cocoa trees in Huayhuantillo

Example of young cocoa plantation in Huayhuantillo

Students of Mendel University during fieldwork in cocoa agroforests in Huayhuantillo

Marking of study plots in Huayhuantillo

Fruit of *Inga edulis,* the most common shade tree used in Huayhuantillo

Preparing Field-Map technology for measurements, Huayhuantillo

During fieldwork with students of UNAS in the forest reserve, Tingo María

Tornillo tree, *Cedrelinga cateniformis* in forest reserve, Tingo María