MENDEL UNIVERSITY IN BRNO
Faculty of Forestry and Wood Technology
Department of Forest Botany, Dendrology and Geobiocenology

Shade effect on the *Coffea canephora* diameter increment in the Mondulkiri province, Cambodia

Bachelor Thesis

2018/2019 **Yessika Alejandra Garcia Cano**

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Yessika Garcia

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Title of the bachelor's thesis: Shade effect on the *Coffea canephora* diameter increment in the Mondulkiri province, Cambodia

Abstract: Agroforestry systems with Coffee are very frequent, and, ecological benefits for the soil, water conservation, biodiversity, and quality have been well documented. It was hypothesized that shade practices might have influence on growth of *C. canephora*, therefore the increment of coffee shrubs and its relationship with environmental conditions like air humidity, temperature and soil moisture were studied. Three different Coffee plots in the province of Mondulkiri were selected. From the results, the statistical significance of the differences between the two main conditions, shade and full-sun was not clear, however it was assumed that other conditions besides microclimatic can have influence, like phenological stages of the coffee plant and source-sink relationships. Soil moisture remained higher under shaded conditions.

Keywords: agroforestry, Robusta Coffee, soil moisture, microclimate, growth, physiology

Jméno posluchače: Yessika Alejandra Garcia Cano

Název práce: Vliv zástinu na tloušťkový přírůst *Coffea canephora* v provincii Mondulkiri, Kambodža

Abstrakt: Agrolesnické systémy s kávovníky (*Coffea* sp.) jsou po celém světě velmi rozšířené a jejich ekologické přínosy pro půdu, ochranu vod, biologickou rozmanitost a kvalitu produkce jsou dobře zdokumentovány. V této studii bylo předpokládáno, že by mohl mít stín vliv na růst a vývoj *Coffea canephora,* a proto byly měřeny přírůsty kmenů kávovníků a jejich vztah k podmínkám prostředí jako je teplota, vlhkost vzduchu a půdní vlhkost. Byly vybrány tři různé kávovníkové plantáže v provincii Mondulkiri. Z celkových výsledků nebylo možné dokázat statistickou významnost rozdílů v přírůstech kávovníků mezi stínem a plným sluncem. Nicméně předpokládalo se, že kromě mikroklimatických podmínek mohou mít na přírůst kávovníků i podmínky jiné, jako například fenologické fáze kávovníků a vztah mezi zdrojem a příjemcem. Půdní vlhkost byla vyšší v zástinu.

Klíčová slova: agrolesnictví, kávovník statný, pudní vlhkost, mikroklima, růst, fyziologie

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1 Introduction

One of the world's most important beverage is Coffee. Around 165.18 million bags of coffee were consumed between years 2018/19 according to the ICO's market report from December 2018 (ICO, 2018). When we think about coffee from the consumer point of view, is easy to say that the only thing that matters is the flavor and the feeling of satisfaction, but from a scientific point of view, everything changes. The need of research about the whole process required for bringing one cup of coffee to the table is one of the aims of science, from a starting point, the growth of the plant till the end, the beverage.

The Kingdom of Cambodia has 16,449,519 of inhabitants, around 85 % of its population live in rural areas and most of them base their livelihood in agriculture. The main agricultural product in Cambodia is rice with about 80 % of the total production. (World Bank et al. 2013). Although rice is predominant, the agriculture of Cambodia has been diversified into a wide range of crops such as maize, cassava, mung bean, sweet potato, peanut, soy bean, rubber, coffee, among many others (Tong Yves, 2011).

Robusta's coffee (C*offea canephora* Pierre ex A. Froehner) (hereinafter coffee) is the main species of coffee cultivated in Cambodia, mainly cultivated in the northeastern highlands of Ratanak Kiri and Mondulkiri provinces, where the altitudes not often surpass the 800 m (Three Corner Coffee Roasters, 2012). Native Robusta coffee grows naturally under shade in the inferior levels of the Guinea/Congo forests (Wintgens, 2012). According to this information I decided to study coffee in Cambodia and its relationship to the environment, ecological factors, and requirements. The Cambodian climate is monsoonal, with separate wet and dry seasons (Kem, 2017).

The purpose of this document is to study the effect of shade and full-sun exposure on the Robusta's coffee stem diameter increment in plantations placed at the Mondulkiri's province in the kingdom of Cambodia.

Coffee production is rarely mentioned in the agriculture crops reports of Cambodia; it seems that the influence it has on the country's economy is very low. The coffee industry according to the ministry of agriculture of Cambodia, is growing even though, is a small part of the agricultural crops in the country. The unstable price of coffee and the impact of climate change as droughts and high temperatures are some of the causes for the slow progress of Cambodia for entering in the international coffee market. Despite the above, the massive growth of the global coffee industry appears to be a great opportunity for Cambodia to be included in this expansion (Cheng, 2016).

In order to help fulfill the great challenges that Cambodia must face to accomplish its purpose in the following years of improve and increase coffee production and achieve a position in the international market, coffee physiology and coffee yield must be factors to study. Until the year 2014 Cambodia harvested an area of coffee of 435 ha with a yield of 919,5 Mg/ha (FAO, 2015b), this yield is still too low to compete with the largest producers in the market (see chapter 3.2. Coffee is one of the export commodities in Cambodia (22000 US$ in 2017), however, the country is not part of the world's top coffee exporting countries, occupying the position 138th in the rank with a share of 0,0001 % of the world total production (Workman, 2019).

This document begins with a literary review from the state of the art of research on the influence of shade in the *Coffea canephora* diameter increment in the Mondulkiri's province of the Cambodian kingdom. Following is a detailed explanation of the methodology created in order to respond to the problem presented through the objectives. From there follows a presentation of the results obtained and then a discussion arises, explaining the reasons that will lead to the conclusion of the document as a final chapter.

2 Thesis objective

The main aim of the study is to compare stem diameter increment of coffee shrubs under full-sun exposure and under shade during one year in three plantations located in the Mondulkiri's province in the Kingdom of Cambodia.

2.1 Partial objectives

- Research about coffee growing in agroforestry systems in Cambodia.
- Research about the influence of shade on microclimatic characteristics in coffee plantations.
- Create a usable methodology for observing and measuring the diameter increment in coffee plants.
- Compare the changes in the coffee diameter increment with soil moisture.
- Compare coffee stem diameter increments with respect to the period (dry and rain).
- Understand the influence of shade on microclimate characteristics in order to find out the difference between coffee diameter increments in shaded and non-shaded parts of the plantations.

3 Current state of the issue in question

3.1 Coffee

The coffee plant is a tropical evergreen shrub of African origin (Maurin et al. 2007). It has been said that coffee was originated in the Ethiopian highlands for *Coffea arabica* L. and in the forests of west and central Africa for *Coffea canephora*. There are records about the first use of coffee as a beverage of coffee in Yemen in the 14th century (Waller et al. 2007).

Coffea canephora is a flowering plant (angiosperm) in the form of a bush or small tree. It belongs to the Rubiaceae family, Gentianales order and to the *Coffea* genus. There are around 125 species under the genus Coffea (Stevens, 2001). The best-known species for production and consumption are *Coffea arabica*, believed to be the first species of coffee to be cultivated and *Coffea canephora* with the 65 % and 35 %, respectively, of the total production around the world (Kilili, 2015). *Coffea canephora* is cultivated from widely dispersed tropical areas in altitudes below 1000 m a.s.l. (Wintgens, 2012).

3.2 Coffee in Cambodia

Although is almost unknown the history of coffee production in Cambodia, it has been said coffee was introduced by French colonies in the middle of the 19th century to the country at almost the same period as Laos and Vietnam (Robequain, 1939). The coffee grown in Cambodia is primarily Robusta coffee (*Coffea canephora*). Tong (2011) in his report about the agricultural productivity and diversification of Cambodia, reported 231 ha of coffee in Cambodia until the year 2009. According to the Food Agriculture Organization (FAO), until the year 2014 Cambodia harvested an area of coffee of 435 ha with a yield of 0, 9195 Mg/ha. A difference in the yield is relevant compared to the highest coffee producers countries in the world such as Brazil that harvested an area of 2 085 522 ha with a yield of 1.4215 Mg/ha and Vietnam that harvested an area of 584 600 ha with a yield of 2.4991 Mg/ha (FAO, 2015b).

Coffee is mainly cultivated in the northeastern highlands of Ratanak Kiri and Mondulkiri's provinces of Cambodia, where the predominant red soil is suitable for a huge variety of crops including rubber, several tropical fruits, black pepper, cassava, cashews, and of course coffee. Coffee growers in these lands mostly belong to indigenous tribes (Three Corner Coffee Roasters, 2012). Since the 1980s, China trade volumes have expanded and caused Southeast Asia's demand for agricultural and natural resource products to raise, making increase the production of crops such as oil palm, rubber, coffee, and sugar cane (Hughes and Un 2011).

3.3 Agroforestry[1]

As long as times are moving, coffee growers are looking to maintain economic and ecological balance that allows them to reduce the negative effects of monocultures and climate change. Therefore, systems like agroforestry are being implemented in tropical countries with special interest in systems with perennial species such as coffee, cocoa, rubber, among others, that are sensitive and respond physiologically to specific levels of luminosity.

The term Agroforestry has been used since the mid-twentieth century but the practices that it defines are very ancient (Montagnini, 2017). The concept of agroforestry comprises a long list of practices. Some of them are crop diversification, long rotation systems for soil conservation, homegardens, boundary plantings, perennial crops and hedgerow intercropping. Agroforestry systems have ecological benefits as soil conservation by preventing erosion and increasing fertility and economic like timber, fodder and fuelwood. In these days the potential of agroforestry for the ecological benefits is in general accepted (Nair, 1993).

Among other things, it has been said that agroforestry has certain advantages for mitigating and adapting to the negatives impacts of climate change (Verchot et al. 2007).

[1] *"Agroforestry can be defined as a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (...)*". (FAO 2015a)

3.3.1 *C. canephora* in the agroforestry systems

Robusta coffee (*Coffea canephora*) is indigenously grown in the lower levels of the forest (Wintgens, 2012). It seems that since the beginning the coffee plant was established in agroforestry systems that weren't known and named officially until the last centuries. The productive approach of coffee in agroforestry is, to a certain extent, a response of the small coffee farmer to his environment. By not having enough economical resources to install a rigorous intensive production system, manage irrigation , the synthetic incorporation of nutrients and modern agricultural techniques, the farmers limited themselves to take advantage of the natural fertility of the soil and the environmental services provided by the forest as well as: lateral uptake of water, permanent renewal of the agricultural soil layer and permanent recycling of nutrients (Torres et al. 2008).

The use of agroforestry with coffee consists of forest trees planted in between the coffee plantation in alternate rows to the shade trees. Forest tree species are appropriate because require less maintenance, and offer less competition for soil, water, and nutrients than fruit tree species (Wintgens, 2012). Coffee grown under shade is the most commonly used coffee farming system in the tropics. It represents 60 % to 80 % of the total world production. The practice involves more than 20 million people, most of them are smallholder producers (Russell et al. 2005). In Latin America, the coffee was grown in agroforestry systems called "shade-grown coffee" till the end of the 40s. By 1950 and following the coffee production began to modernize and it was there when the coffee production changed to be produced in systems caller "sun-grown coffee" (Montagnini, 2017).

One of the most mentioned negative consequences of coffee growing in agroforestry systems has been the decrease in the yield and production of Coffee. In countries like Brazil where coffee production is mainly from unshaded monocultures, researches have been shown a negative relationship between Robusta's coffee grown in agroforestry systems associated with Australian Cedar (*Toona ciliata*), Ferreira Sales et al. (2013) concluded that the higher the growth rate of shade trees, the lower the coffee production. Vasconcellos et al. (2016) reported also losses in coffee Robusta yield because of Rubber trees shade and its formation. Alike, Salgado et al. (2004) found that arabica's coffee grown in agroforestry systems associated with the Inga tree and Southern silky oak, obtain superior yields than coffee growing at full-sun. Meylan et al. (2017) in Costa Rica, didn't found a significant effect of shade in coffee arabica production. On the other hand, Van

Long et al. (2015) in their work in Vietnam reported no differences in fruit set between shaded and unshaded sites, even though informed that the first drop of the beans for coffee under shade was less in quantity than coffee under full-sun. And more directly related to the region studied in this work, Klimková (2018), concluded that shade has no negative effect on coffee Robusta yield.

Although the investigations are a little discouraging, not everything is lost, the most of the investigations that have shown that there are losses under shade in terms of coffee yield and production as well as negative changes in microclimatic conditions, have also shown great benefits for conservation, maintenance of biodiversity, control of diseases and pests as well as, economic benefits from the other associated crops and trees providing shade (Baliza et al. 2012).

3.3.2 Shade influence in *C. canephora* with agroforestry systems

Shaded coffee is gaining each day more and more attention because of its relation to the native environment. Coffee needs between 25-50 % of light for optimum production of the fruits (Martini et al. 2017). The shaded coffee permits to the small coffee growers diversify their crops and provide livelihood to their families when the prices of the coffee are not enough for their subsistence (Wintgens, 2012). However, the income from timber cannot fully compensate for losses caused by fluctuations in coffee prices (Ehrenbergerová, 2017) . The shade system may contain species like fruit species, timber species, spice species, etc. Following tree species are commonly planted in coffee agroforestry systems in Cambodia:

In the southern Asia Durian (*Durio zibethinus*) is one of the most extensively grown fruit species, especially in Cambodia is an economically and culturally important crop that has been cultivated at the village level, usually grown in mixed plantations (Drenth and Guest 2004).

Senna siamea commonly known as *Cassia siamea* or cassia tree in Cambodia, is a popular forestry and ornamental tree, native to South-East Asia and probably adjacent countries. According to farmers some of the advantages of this tree growing with coffee are the compatibility of the tree with coffee and the amount of organic matter that tree provides (Albertin and Nair 2004).

The Lychee (*Litchi chinensis* subsp. *Chinensis*) is a fruit tree native to southern China, northern Vietnam and Cambodia. This is the only commercialized Lychee species. It is an evergreen tree that usually grows to a height between 4-20 meters. In Cambodia, the fruit is called "*kuleen*" in the Khmer language. Farmers plant Lychee among plantations in association with other crops as Coffee, Banana, Durian, among others. Occasionally is grown to provide shade (Fern, 2018).

Although the Avocado (*Persea americana*) have never played a big role in the traditional food of Cambodia, lately its production has been increased in there. The main regions where this tree has been cultivated are the Mondulkiri and Ratanak Kiri provinces (Vichea, 2017). *Persea americana* is an evergreen tree native from tropical America. It's known besides its fruit because provide shade to other crops. The height of this tree reaches to 30 (Wolstenholme and Whiley 1999). Usually is grown in monoculture, but in Cambodia and other tropical countries may be cultivated in association with other crops.

Fruit trees as Banana (*Musa spp*) are known in agroforestry like shade trees planted in association with coffee around the world. The *Musa* species are native to the Indo-Malesian, Asian and Australian tropics. Pisang Awak "Chek Namva" is the most grown banana species in Cambodia. It is a cross between *Musa acuminata* and *Musa balbisiana* cultivar belonging to the AABB banana cultivar group. These plants are better able to compete in a shaded agroforestry scenery (Scot et al. 2006).

3.4 Ecophysiology of *C. canephora*

There are six main environmental factors that are suitable for coffee cultivation in order to understand and ensure the best results of the coffee quality and production. The optimal annual temperatures are between 22 and 28 °C (Wintgens, 2012).

The water availability recommended for this plant includes the rainfall and atmospheric humidity. *Rainfall* must include a few months with little or no rain, normally 2 or 3 because the coffee plant needs this period to stimulate flowering. The annual rainfall for Robusta's coffee must be between 2000-2500 mm and the *atmospheric humidity* level is 70-75 %, this could vary between the interior and the border of the coffee plantation (Wintgens, 2012).

The sunlight and shading: originally the coffee plant was planted under natural shaded conditions, forests, due to some issues like the extremes high and low temperatures and erosion the coffee plant mostly requires shade. On the other hand, exposure to the sunlight should reach approximately 60 % of the potential during the rainy season and 60-75 % during the dry season, in conclusion, coffee requires an average of 2200-2400 hours of sunlight (Wintgens, 2012).

Wind: this factor is correlated to the geographical and topographical location of the plantation, because in areas where may occur cyclones, tornadoes and trade winds will cause damage to the coffee plant, to manage this factor may be used windbreaks like shade trees. The soil characteristics for coffee cultivation present types of soil like alluvial and colluvial with a favorable texture. The soil depth should be at least 2 m to allow tap root system development. In dryer areas the soil depth should be deeper, the Robusta's coffee is most productive in lateritic soils. The physical properties of the topsoil are more important to the coffee plant than those of the deeper subsoil. The percentage of soil porosity recommended for the Coffee might be 50-60 % (water + air), 45 % (mineral content) and 2-5 % (organic content); the ideal soil type should be slightly acid (Wintgens, 2012).

The Topography favorable for the coffee cultivation may be flatlands or slightly rolling hills as well are steep slopes even though the cultivation could be more costly farming (Wintgens, 2012). In the appendix A are shown the environmental factors suitable for Robusta Coffee.

3.5 Climate change and phenology of Coffee in Cambodia

Climate change is an alteration in the statistical distribution of weather patterns when that change persists for an extended period (i.e., decades to millions of years). The negative impacts of climate change have become one of the most serious risks for humanity. One of the areas that have been most affected by these changes has been Southeast Asia, with a significant impact on economic development and natural resources. Climate projections have shown that one of the implications of climate change in Cambodia would be that rainfall to get higher in the provinces of higher elevation during the wet season, but will get drier during the dry season, which could hamper the production of coffee and rubber (National Climate Change Committee, 2013), (see Appendix B). In the areas where coffee is cultivated in Cambodia, the annual rainfall and temperatures will increase, which will cause a reduction in the suitability of Robusta coffee (ICEM, 2013).

Knowledge of the phenology of crops is important for the proper planning of certain cultural practices such as harvesting, application of fertilizers and the control of pests, diseases, and weeds, among others. Also, for the selection of the appropriate times in which, such practices must be carried out (Arcila et al 2007). During its life cycle, the coffee plant spends a part of it to the formation of non-reproductive structures such as roots, branches, nodes, and leaves. This stage is called vegetative development. The stage when the formation and development of reproduction structures such as flowers and fruits occur is called reproductive development (Arcila et al. 2007). In the reproductive stage is possible to follow the phenological development stages of the plant that describe and divide its growth. In the case of coffee plant, these growth stages are defined by its BBCH-scale (Meier, 1997). The stages defined are:

1. Leaf development,
2. Formation of side shoots, tillering,
3. Stem elongation or rosette growth, shoot development,
4. Development of harvestable vegetative plant parts, bolting,
5. Inflorescence emergence, heading,
6. Flowering,
7. Development of fruit,
8. Ripening or maturity of fruit and seed,
9. Senescence, beginning of dormancy.

After several years of activity, the plant ages and starts a deterioration process that is called, the senescence or biological aging stage (Meier, 1997).

According to information collected from coffee growers, in the Mondulkiri's province of Cambodia, the coffee flowering period is around March, normally at the end of the dry season, and the harvest take place in November, just at the beginning of dry season.

4 Methods

4.1 Location

To be familiar with the context of the present study it is necessary to know about the country where the measurements were carried out, Cambodia. The kingdom of Cambodia is located on mainland Southeast Asia between Thailand, Laos and Vietnam. The country has an area total of 181,035 km^2 of which 176,515 $km^2$are land area and 4,520 km^2 water. Cambodia has a population of about 16.5 million inhabitants. The capital city is Phnom Penh. Spoken language is predominantly (96.3 %) Khmer, other languages are less common (3.7 %) (CIA, 2019).

The country is characterized by a tropical climate. Temperature and rainfall patterns are regulated by monsoons and characterized by two major wet and dry seasons: rainy monsoon season (May to November) and dry season (December to April). The annual average temperature is 28 °C, with an average maximum temperature of 38 °C in April and an average minimum temperature of 17 °C in January (Thoeun, 2015). In Cambodia, the land use is based on 32.1 % of agricultural land (*arable land 22.7 %, permanent crops 0.9 %, permanent pasture 8.5 %*), 56.5 % of forest land and 11.4 % corresponding to other types of land use (CIA, 2019). The country remains one of the most heavily forested countries in the region, although deforestation continues at an alarming rate (World Bank et al. 2013).

The study plots are located in Mondulkiri, which is the largest and most sparsely populated province in Cambodia with an area of 14,288 km^2 and elevations ranging from 190 to 1000 m. Mondulkiri lies in the south-east part of the country and shares borders with Vietnam, see Figure 1. Sen Monorom is its provincial capital. Its population derives their livelihoods from agriculture, rice cropping, fruit trees, rubber, coffee, variety of vegetables, among others, (KAFDOC, 2018).

There are three major ecosystems in Mondulkiri's province. In the south-eastern part, near Sen Monorom, there is a plateau located at an altitude of 600-900 m a.s.l.. The ecosystem is savanna with islands of evergreen forests. With average temperatures between 15-20 °C during the cold season and between 25-30 °C from February to June, this part of Mondulkiri is one of the coldest areas of Cambodia. In the south of the province, at altitudes of 300-600 m a.s.l., the foothills are characterized by high forest stand and include different forest types. There are evergreen forests, seasonal forests, deciduous dipterocarp forests, and bamboo forests. In the northern part, there are lowlands lying at altitudes of 100 to 300 m. These lowlands are very similar to the central Cambodian plain (Maurice, 1993).

4.1.1 Environmental conditions

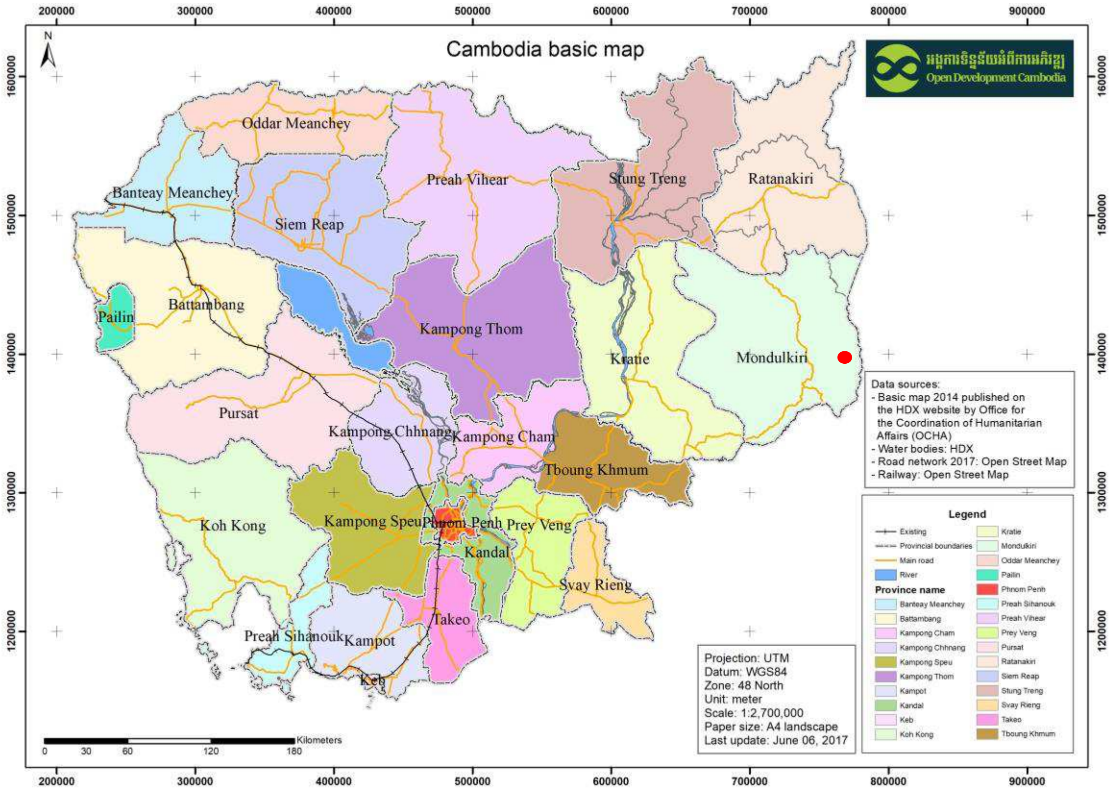


Figure 1 Location of study plots in Mondulkiri (ODC, 2014)

Sen Monorom has a tropical climate (see Figure 2). This location is cataloged as Aw[2] by Köppen and Geiger. The typical temperature in Sen Monorom is 22.9 °C. The usual annual rainfall is 2203 mm. In January is presented the less amount of rain with an average of 3 mm. The highest amount of rainfall occurs in August when the average is about 370 mm. The highest temperatures are observed in April, with an average around 25.0 °C. The lower temperatures occur in January, the average is around 20.9 °C. The

[2] Tropical wet and dry climate (Beck et al. 2018)

difference in precipitation between the wettest and driest months is 367 mm. Variation in temperatures all over the year is 4.1 °C (Climate-Data.org, 2018).

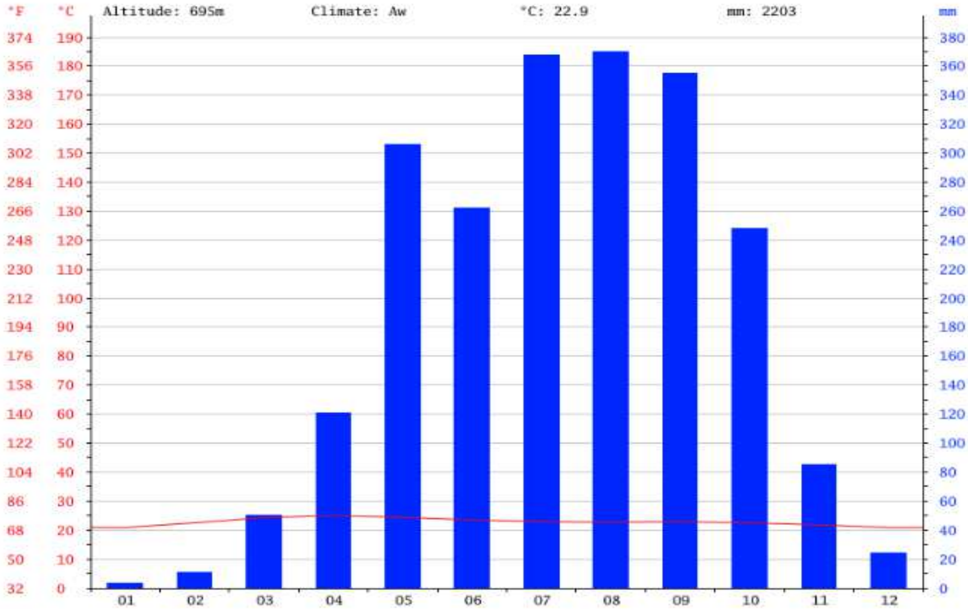


Figure 2 Climograph of Sen Monorom, Cambodia (Climate-Data.org, 2018)

The soils of Cambodia are diverse across its 19 provinces. The soil type found in the area of study Mondulkiri are Latosols, more exactly according to the classification system used in Cambodia, the soil group is called Labansiek Soil, see Table 1. This soil group occurs on the sides of hills or mountains with a red colored and a clayey textured surface soil. Soils are in pluvial lands and do not occur in flooded valleys. The soils developed from the underlying basaltic rock. It has a uniform deep profile and a characteristic red color. The soil is very sticky and slippery when wet (White et al. 1997).

Table 1 Profile description of Labansiek soil in Cambodia (White et al. 1997).

Characteristic		Layer	
		Upper	Subsoil
Depth		20-30 cm	
Texture		Clayey	Clay
Color	Dry	red; sometimes brown	red to brown
	Moist	most often dark red, sometimes brown	dark red to brown
Mottles		None	None
Consistency	Dry	Hard	Hard
	Moist	Loose	loose
Structure		Crumb	Crumb

4.2 Study Plots

The Study was carried out in three coffee study plots in the province of Mondulkiri, Cambodia, near to the Sen Monorom municipality. The dominant soil type in all research areas is Latosol.

4.2.1 Study plot 1. Owner Chay Mao

Figure 3 Study plot 1.

This coffee plantation is located 7.2 km northeast municipality of Sen Monorom (12°29' North and 107°13' East). Coffee in this study plot is grown in an area of 3 ha. The distance between coffee plants is 3x3 m. The average altitude of the plantation is 720 m a.s.l.. The slope on which the coffee plants are grown is 5 %. Slope exposure to sunshine is southwest. No cuttings or chemical fertilizers or sprays are used. Occasionally, the coffee is missing in sunny places, or only the trunk is left behind. The main shade trees in the plantation are Lychee (*Litchi chinensis*), Durian (*Durio zibethinus*) and Avocado (*Persea americana*).

4.2.2 Study plot 2. Owner Om Pheap (Chamkar Cafe' & Restaurant)

Figure 4 Study plot 2.

This coffee plantation is located 3.5 km northeast municipality of Sen Monorom (12°28' North and 107°12' East). This study plot is the largest plantation of this study and is known in the region because of tourism.

The plantations have more coffee stands of different age, there are in total approx. 9 hectares. The distance between coffee plants is 3x3 m. The average altitude of the plantation is 697 m a.s.l. and the slope on which the coffee plants are grown is 6 %. Slope exposure to sunshine is southwest. The main shade species in the plantation are Banana (*Musa* spp.), Durian (*Durio zibethinus*) and Avocado (*Persea americana*).

The final download of meteorological data on 23 November 2018 was not possible in this study plot, because of the loss of the data from dendrometers on coffee plants and Tomst datalogger.

4.2.3 Study plot 3. Owner Nget Chan Raksmey

Figure 5 Study plot 3.

This coffee plantation is located 3.9 km northeast of municipality of Sen Monorom (12°27' North and 107°12' East).

Coffee in this study plot is grown in an area of 6.3 ha. The distance between plants is 3x3 m. The average altitude of the plantation is 693 m a.s.l.. The slope on which the coffee plants are grown is 5 %. Slope exposure to sunshine is southwest. No cuttings or chemical fertilizers or sprays are used. The main shade trees in the plantation are *Senna siamea* (*Cassia siamea*) and Durian (*Durio zibethinus*). One of the micro dendrometers installed on one of the coffee plants under shade got lost and the data could not be extracted.

4.3 Data collection

Field research and data collection took place for one year, from November 27th of 2017 to November 23rd of 2018, on three study plots around Sen Monorom, Mondulkiri (described above). The students of the Faculty of Forest Sciences of the Royal University of Agriculture in Cambodia collaborated to the author with the installation of the measuring instruments and with downloading data.

After one field visit to the area of research a form that gathered the basic information of the possible plantations and their owners was filled out, see Appendix C. Twelve (12) coffee plants were set up for monitoring the changes in stem diameter. In each study plot, two (2) coffee shrubs under shade and two (2) coffee shrubs under full-sun exposure, where selected and equipped with one (1) stem diameter sensor PDS40 SDI (EMS Brno, CR). In each study plot, two (2) soil moisture sensors TMS-3 dataloggers (TOMST s.r.o., Praha, CZ) were installed at a depth of 0.5 m. Additionally, one (1) dendrometer DRL26C (EMS Brno, CR), in one (1) of the shade trees in each study plot was installed. After 1 day of measurement, the functionality of all instruments was double checked. In the study plot 3 was located the meteorological station with one rain gauge (Pronamic, Ringkøbing, DK), and one air humidity and temperature datalogger Minikin THI (EMS Brno, CZ).

In the study areas, from 2017 to 2018 various research methods were used to identify the response of coffee plants to the change in the water regime under different regimes of luminosity. The specification of these methods is given in the following paragraphs.

4.3.1 Rainfall measurement

Cambodia’s climate is determined by monsoons and divided into two major periods wet and dry. From mid-May to early October are presented heavy rains and high humidity and from early November to mid-March, humidity and winds are lower (Thoeun, 2015). Distribution of the rainfall is observed in Figure 6, were the region VI represents the area where this experiment was carried out.

The rainfall was continuously measured at an open plot, in the study plot 3 by a rain gauge [Rain-O-Matic Professional (mm), (Pronamic, Ringkøbing, DK)]. For this study according to the data measured and based on the temperature and rainfall patterns of climate in the literature studied, the two main periods were determined as follows:

- dry season from 27th November 2017 to 16th March 2018.
- rainy season from 17th March 2018 to 23rd November 2018.

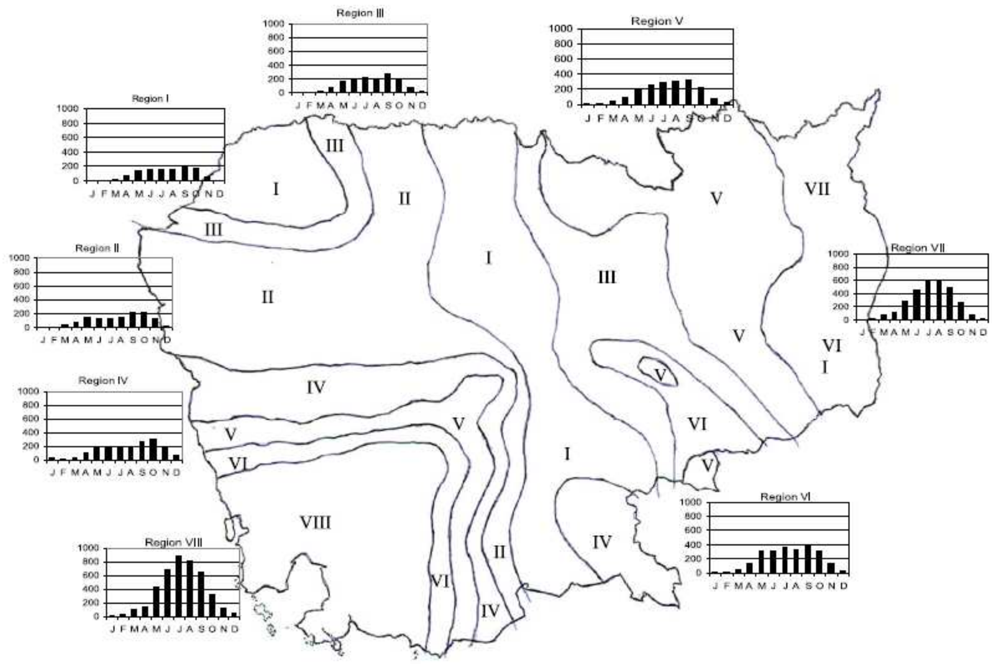


Figure 6 Rainfall patterns of Cambodia (Thoeun, 2015)

4.3.2 Air temperature and humidity measurement

Meteorological conditions like air temperature (°C) and relative air humidity (%) [Minikin THI (EMS Brno, CZ)], were continuously monitored at an open plot, in the study plot 3. The interval of measurements was one (1) hour.

4.3.3 Soil moisture measurement

Soil moisture is the water stored in the soil, specifically is the water held in the spaces between soil particles. Soil moisture is altered by precipitation, temperature, soil characteristics, and other factors (Kar, 2016). With the objective of measuring soil humidity in the areas of study, two TMS datalogger were installed in each study plot, one (1) near of the coffee plants under shade and one (1) near to the coffee plants under full-sun exposure. The depth for installation was 0.5 m. The data logger measured an interval of 15 minutes.

4.3.4 Diameter increment measurement

Dendrometers allow tracking the daily dynamics of the changes in the stem diameter of the plant which is caused by the hydration and dehydration of the tissues, such as the periodic growth of the thickness of the plant produced by the action of the vascular cambium and the cork cambium (phellogen). Measured data may indicate drought stress because stressed plants show higher daily dynamics of diameter as well as the increase of the thickness of the vascular cambium under the influence of water stress is limited (Šen-feldr et al. 2017).

The measurements were taken in coffee plants with synchronized phenology stage. Coffee plants were selected according to the following procedure:

- The thickness of the stem must not be less than 4 mm and greater than 40 mm.
- Plant height must be between 1,5 m and 3 m.
- The coffee plant must be in a vigorous state.
- The plants have optimum nutritional conditions and don't have evidence of pest and diseases.

The increment on the coffee stem diameters was monitored using stem diameter sensor [PDS40 SDI, (EMS Brno, CR)], which were noninvasively fixed to the coffee shrubs at a height of approximately 1.5 m, see figure 7. The measured values were referenced to the initial diameter and reported in millimeters (mm). The measurements were taken at an hourly interval. There were measured the diameter changes of one selected shade tree in each study plot with a dendrometer DRL26C (EMS Brno, CR), which measures increments with a resolution of 1 μm. The shade trees selected were: in study plot 1 Durian tree, in study plot 2 Durian tree and, in the study plot 3 Cassia tree.

Figure 7 Illustration of micro dendrometer PDS40 SDI, front and back side.

4.3.5 Shade estimation

Shade or its inverse, the amount of radiation a plant receives, determine factors such as photosynthesis, growth, development, the demand of nutrients and water, pest and diseases and eventually the production and quality of the main crop (Somarriba, 2002). Each of the study plots had part with shade-grown coffee and parts with full-sun grown coffee. Coffee plants chosen in the shaded part of each study plot were located at 2 m from the shade tree. The levels of shade were determined by visual estimation and defined by the following ranges:

A. Full-Sun (0-5 %)
B. Minimal (5-30 %)
C. Regular (30-60 %)
D. Shaded (60-90 %)
E. Full Shaded (90-100 %)

There were selected study plots in which shade areas ranged between (60-90 %) of shade, further called “under shade” or “shaded”, and areas with full-sun exposure further called as “under full-sun exposure” or “non-shaded”.

4.4 Data processing

4.4.1 Rainfall measurement

Data with the information of rainfall was downloaded with the EMS Mini32 software (EMS Brno, CR) and exported to an excel file. After a monthly sum was made and graphed.

4.4.2 Air temperature and humidity measurement

Data with the information of air temperature and humidity was downloaded with the EMS Mini32 software (EMS Brno, CR) and exported to an excel file. After monthly means were calculated and graphed.

4.4.3 Soil moisture measurement

To download the data, Tomst company offers the Lolly manager software (TOMST s.r.o., Praha, CZ). Data was exported to an excel file. The instrument gives a raw moisture signal. To convert data into volumetric soil moisture, the Conversion tool, TMS Calibr utility was used.

Daily averages of soil moisture were calculated for each instrument. After that, a comparison was made in search of the differences between the water content of the plants growing under shade and plants growing under full-sun exposure. In study plot 2, was not possible to make this comparison for all the period of study because the loss of data.

4.4.4 Stem diameter increment measurement

Data were downloaded in two terms. The first term was during 30- 31 May 2018 and the second and final during 23-24 November 2018. The data was downloaded from dataloggers with the EMS Mini32 software (EMS, Brno, CZ). After downloading, data was exported and processed by Microsoft Excel software. For purposes of distinction, coffee plant individuals and shade trees were named with following codes:

Study plot 1, coffee shrub under shade No 1:	**P1SH1**
Study plot 1, coffee shrub under full-sun No 1:	**P1SN1**
Study plot 1, coffee shrub under shade No 2:	**P1SH2**
Study plot 1, coffee shrub under full-sun No 2:	**P1SN2**
Study plot 1, shade tree (Durian):	**P1SHTREE**
Study plot 2, coffee shrub under shade No 1:	**P2SH1**
Study plot 2, coffee shrub under full-sun No 1:	**P2SN1**
Study plot 2, coffee shrub under shade No 2:	**P2SH2**
Study plot 2, coffee shrub under full-sun No 2:	**P2SN2**
Study plot 2, shade tree (Durian):	**P2SHTREE**
Study plot 3, coffee shrub under shade No 1:	**P3SH1**
Study plot 3, coffee shrub under full-sun No 1:	**P3SN1**
Study plot 3, coffee shrub under full-sun No 2:	**P3SN2**
Study plot 3, shade tree (Cassia):	**P3SHTREE**

Following the chapter 4.3.1, for purposes of this experiment, the period for the dry season was from 27 November 2018 00:00 to 16 March 2018 00:00, and for rainy season from 17 March 2018 01:00 to 23 November 2018 until 00:00. To clearly identify differences between the dry period and the rainy period, two representative months were chosen in each of the seasons (December and May). The hourly mean for the 31 days of each month were calculated and graphed.

Statistical analysis was performing using JASP 0.9.2 software [JASP Team (2018). JASP (Version 0.9.2) [Computer software]]. Statistical tests were done under 95 % of confidence level. The significance of the model was tested by ANOVA (α= 0.05). If the calculated P-value was less than α the model was considered significant. The analysis of varianza (ANOVA) was divided in two, rainy and dry season because the measurements of the study plot 2 during the rainy season weren't complete. A t-test was used to test the significant differences between coffee plants growing under shade and under full-sun exposure during the seasons.

5 Results

5.1 Rainfall

The total rainfall in the study plot during the period of measurements was 2427 mm. The highest rainfall amount recorded over a calendar month at the site was 553 mm on May 2018 with a peak of highest daily rainfall of 125 mm on May 11. The lowest rainfall amount recorded over a calendar month was 0.6 mm in February 2018. Additionally, the total amount of days in the year with ≥ 1 mm of precipitation were 143 days. The distribution of precipitation during the year can be seen in the Figure 8.

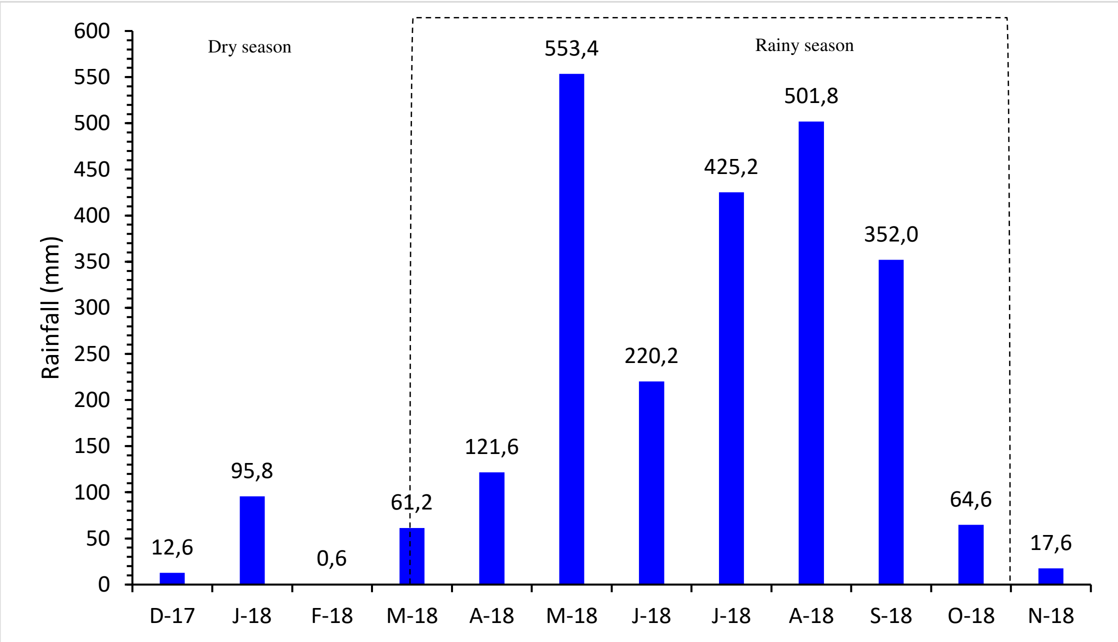


Figure 8 Rainfall from Nov 2017 till Nov 2018 in study plot 1.

5.2 Air Temperature and Humidity

Figure 9 shows the daily mean air temperature in the study plot 3 at a place in full-sun exposure during the whole year. The annual average was 22.9 °C. The lowest temperatures were observed during the dry period. The minimum temperature was 15 °C on December 27, 2017. In the other hand, the higher temperature was observed at the beginning of the rainy season, on April 12, 2018, with a daily mean of 26.7 °C. There was one day of high extreme temperatures in the area of study (Hot Day: one day above 35 °C), on April 14, 2018, at 14:00 and at 15:00 pm the values reached 35°C and 36 °C respectively.

Regarding air humidity, the annual average was 87.2 %. The humidity curves shown in Figure 9 indicate that the months from December till March are relatively drier with air humidity values between 65 to 75 %. During the rest of the year, especially from June to September humidity is excessively higher with more than 90 %.

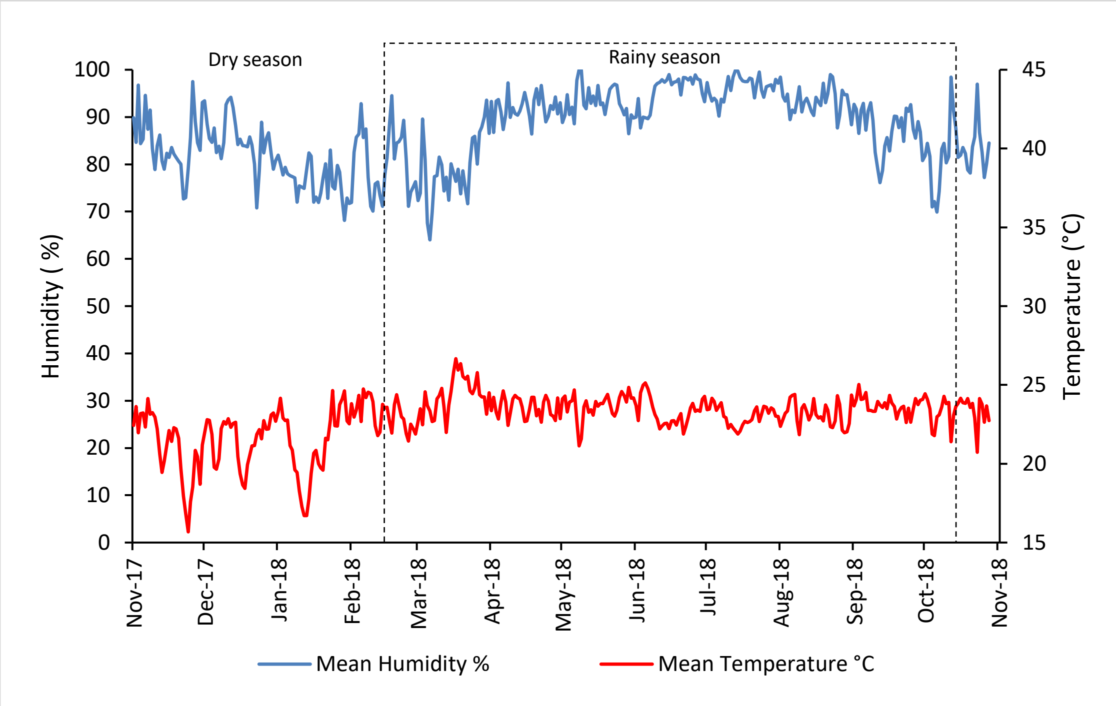


Figure 9 Daily average of air temperature and humidity in study plot 3.

5.3 Soil moisture

The results of daily average soil moisture during the whole year in the study plot 1 are shown in Figure 10. The soil moisture during the whole year for shaded site ranged from 33.9 % to 53.8 %. For site under full-sun exposure oscillated between 31 % and 50.5 %. The soil moisture was higher in the shaded for almost whole measurement. During the dry period, soil moisture averages at shaded site ranged from 33 % to 43 % and at the non-shaded site from 45 % to 33 %. During the rainy period, the soil moisture at shaded site averaged ranges from 40 % to 53 % and at non-shaded site averaged from 33 % to 50 %.

The results of daily average soil moisture at a shaded site throughout the half year for the study plot 2 are shown in Figure 11. The soil moisture ranged from 28.9 % to 41.3 %. This result belongs only to samples located under shaded conditions and till May 2018. Sensor located under full-sun exposure got damaged and some data was wasted.

The results of daily average soil moisture during the whole period of measurements for study plot 3 at the shaded site and at the non-shaded site are shown in Figure 12. The soil moisture for shaded site ranged from 28.3 % to 51.3 %. For site under full-sun exposure ranged between 21.2 % and 44.8 %. During the whole year, the soil moisture had a similar pattern in both sites, although the averages were lower at the site under full-sun exposure.

5.4 Stem diameter increment

5.4.1 Coffee stem diameter increment by study plot during a year

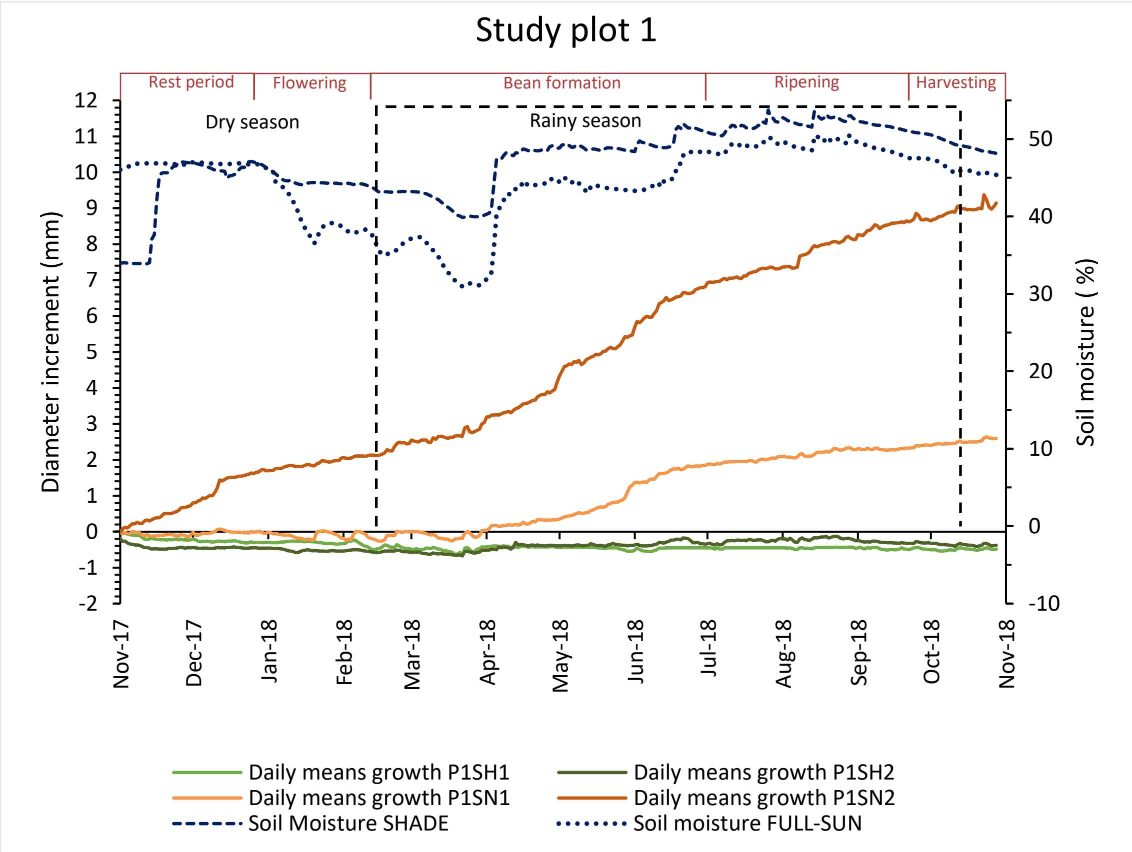


Figure 10 Daily average of diameter increment of coffee shrubs and soil moisture in study plot 1

According to Figure 10, during the dry season, a minimal positive increment for coffee plants under full-sun exposure (P1SN1, P1SN2) and negative for coffee plants under shade (P2SH1, P1SH2) was observed. During the rainy season, increment was observed in both types of shading. For the coffee shrubs under shade although their stem expanded during the rainy season, their diameters were smaller than they were before the dry season began. It looks like these plants remained in a dehydrated condition even with the presence of rains.

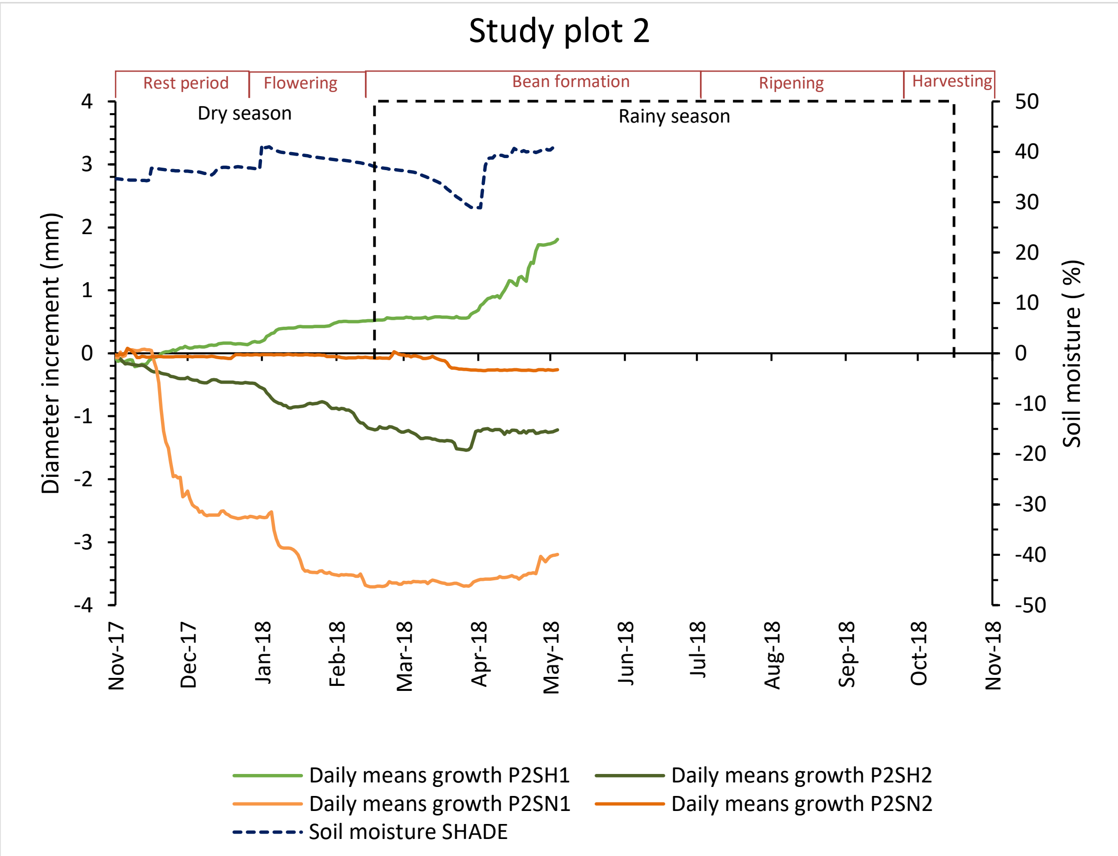


Figure 11 Daily average of diameter increment of coffee shrubs and soil moisture in study plot 2

In Figure 11, coffee plants stem growth response was different in comparison with the study plot 1. With respect to the dry season, coffee shrubs under full-sun exposure P2SN1 and P2SN2 showed negative growth, as well as one of the coffee plants under shade P2SH1. In the other hand the other coffee plant under shade P2SH2, presented increment of the diameter. Information about the rest of the rainy season is not shown because of the loss of the data from micro dendrometers.

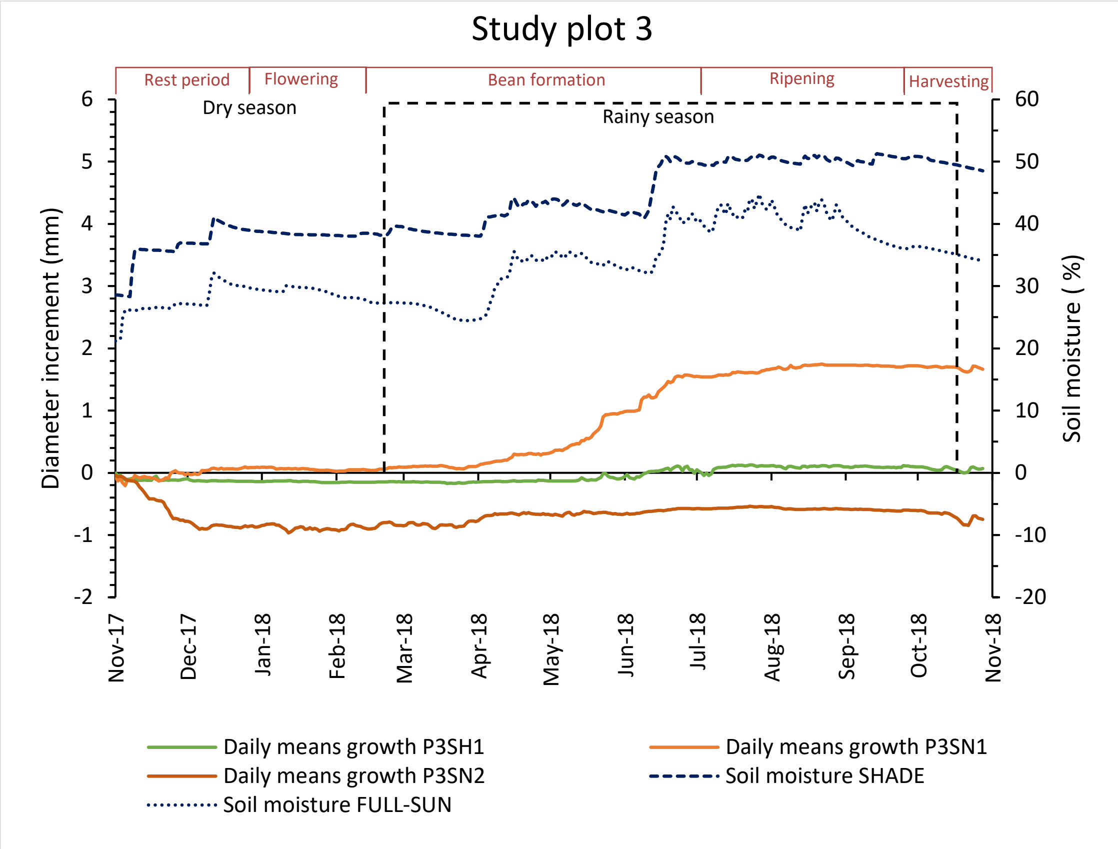


Figure 12 Daily average of diameter increment of coffee shrubs and soil moisture in study plot 3

In Figure 12, for samples under full-sun exposure, a decrease was shown at the beginning of the dry season. After almost one month, the coffee plant (P3SN1) expanded its stem gradually until the end of measurements period. The other coffee plant under full-sun exposure (P3SN2), after the decrease at the beginning of the dry period remained without any apparent increase until the end of the rainy season.

The coffee plant under shade (P2SH1) showed a decrease at the beginning of the dry season until half of the rainy season when it presented a minimal increase in the stem diameter.

The statistical analysis didn't show significant differences of the influence of shade in coffee shrubs, because, in order to make this type of determination, it is necessary to include a greater amount of data, see chapter 5.4.2.

5.4.2 ANOVA – Analysis of variance

Table 2 shows the results for the analysis of variance of the effect of shade on coffee stem diameter during the dry season in three study plots. From the results obtained until the end of the dry season at 109 days, it was not possible to deduce whether a significant statistical difference does exist. It could have two main reasons. First, the amount of data was insufficient. Second, there is not any apparent difference between the coffee shrubs. The results are described graphically in the Figure 13.

Table 2 Analysis of variance of the effect of shade on the coffee diameter increment (dry season).

ANOVA - Dry season					
Cases	**Sum of Squares**	**df**	**Mean Square**	**F**	**p**
PLOT	4.043	2	2.022	1.008	0.412
TYPE	1.991	1	1.991	0.993	0.352
Residual	14.036	7	2.005		
Note. Type III Sum of Squares					

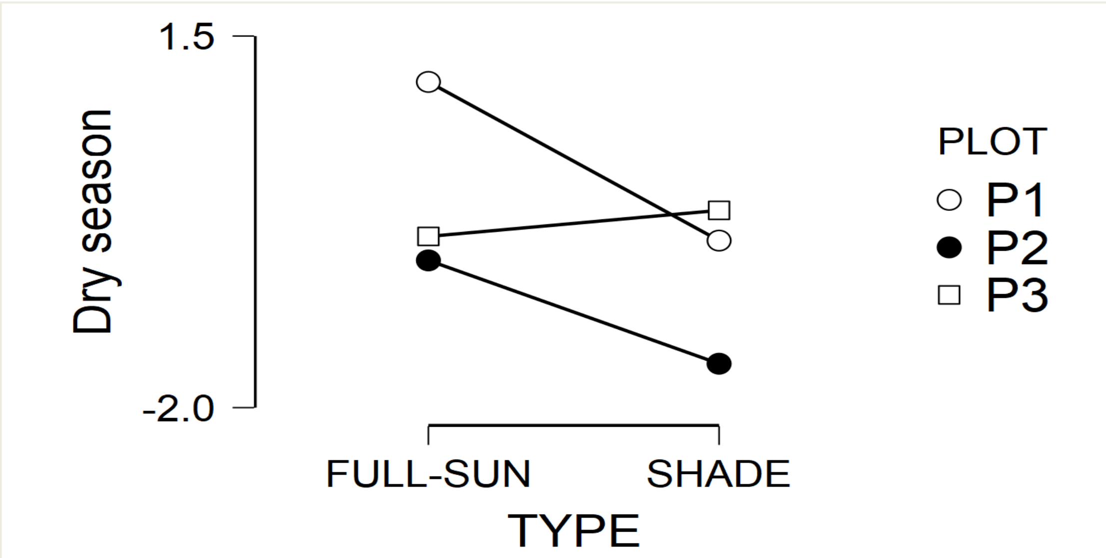


Figure 13 Descriptive plot of ANOVA during dry season

Table 3, shows the results for the analysis of variance of the effect of shade on coffee plant diameter in two study plots during the rainy season. From the results obtained until the end of the season at 251 days, was not possible to determine whether a significant statistical difference does exist. It could have two main reasons. First, the amount of data isn't enough. Second, there is not any difference between the coffee shrubs growing under full-sun exposure and these under shade. See the graphic description in Figure 14.

Table 3 Analysis of variance of the effect of shade on the coffee diameter increment (rainy season).

ANOVA - Rainy season

Cases	Sum of Squares	df	Mean Square	F	p
PLOT	8.651	1	8.651	2.074	0.223
TYPE	16.207	1	16.207	3.886	0.120
Residual	16.682	4	4.171		

Note. Type III Sum of Squares

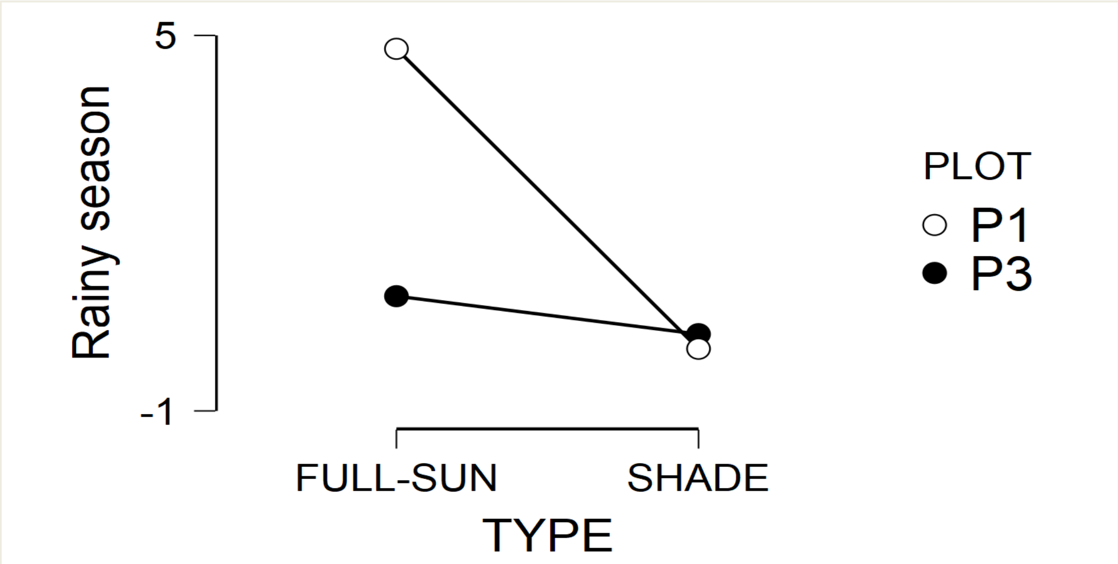


Figure 14 Descriptive plot of ANOVA during rainy season

A significant difference between the diameter increment of the coffee shrubs under shade and under full-sun exposure among seasons, was found [p =0,0021], see Table 4. Figure 15 shows a summary of the results obtained from the t-test.

Table 4 Paired Samples T-Test of monthly increment of diameter among seasons

			t	df	p	Mean Difference	SE Difference	95 % CI for Mean Difference Lower	95 % CI for Mean Difference Upper	Cohen's d	95 % CI for Cohen's d Lower	95 % CI for Cohen's d Upper
Dry season	-	Rainy season	-3.100	6	0.021	-0.187	0.060	-0.334	-0.039	-1.172	-2.129	-0.162

Note. Student's t-test.

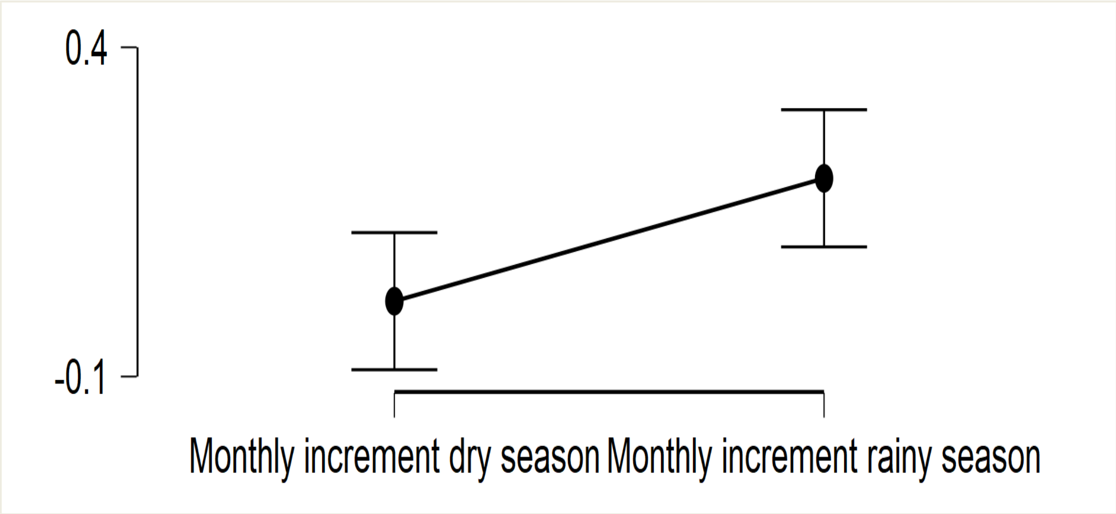
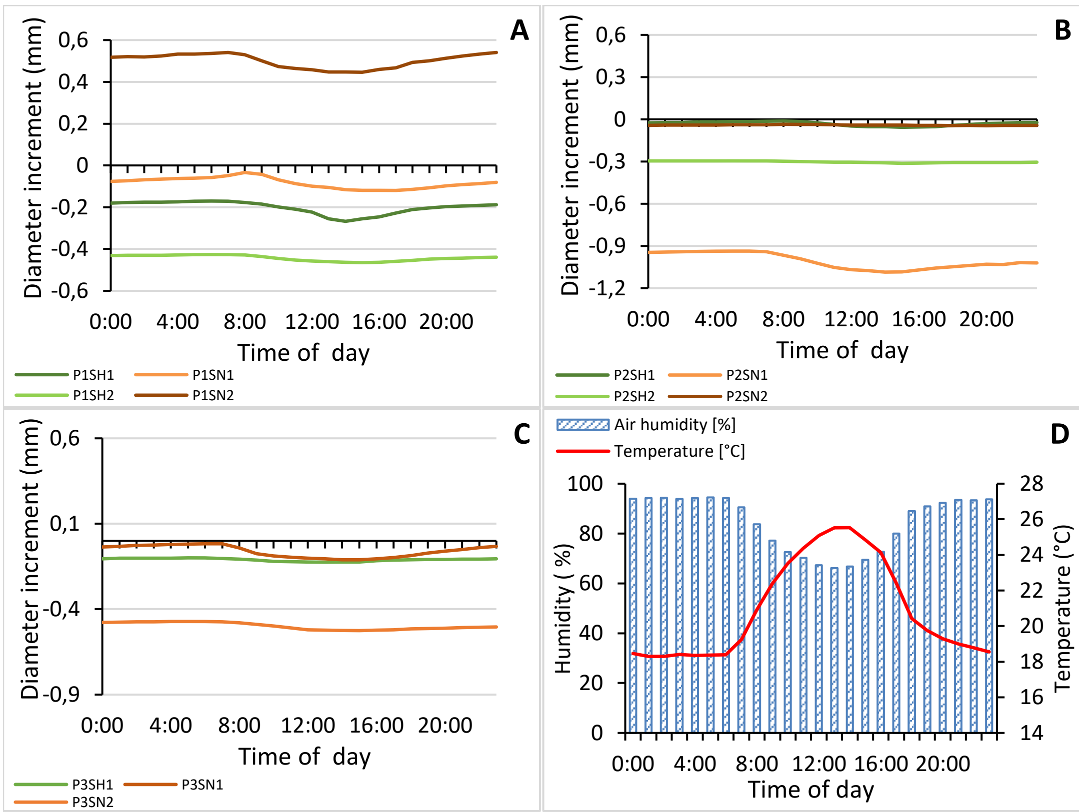


Figure 15 Descriptive plot of the monthly diameter increment during seasons.

5.4.3 Diurnal variations of coffee shrubs stem diameter by study plot between seasons



A Hourly average increment of coffee diameter in the Study plot 1
B Hourly average increment of coffee diameter in the Study plot 2
C Hourly average increment of coffee diameter in the Study plot 3
D Hourly average of air temperature and humidity in the study site

Figure 16 Diurnal pattern of the stem diameter variations of coffee shrubs during one dry month (Dec 2017) in three plantations in the Mondulkiri's province, Cambodia

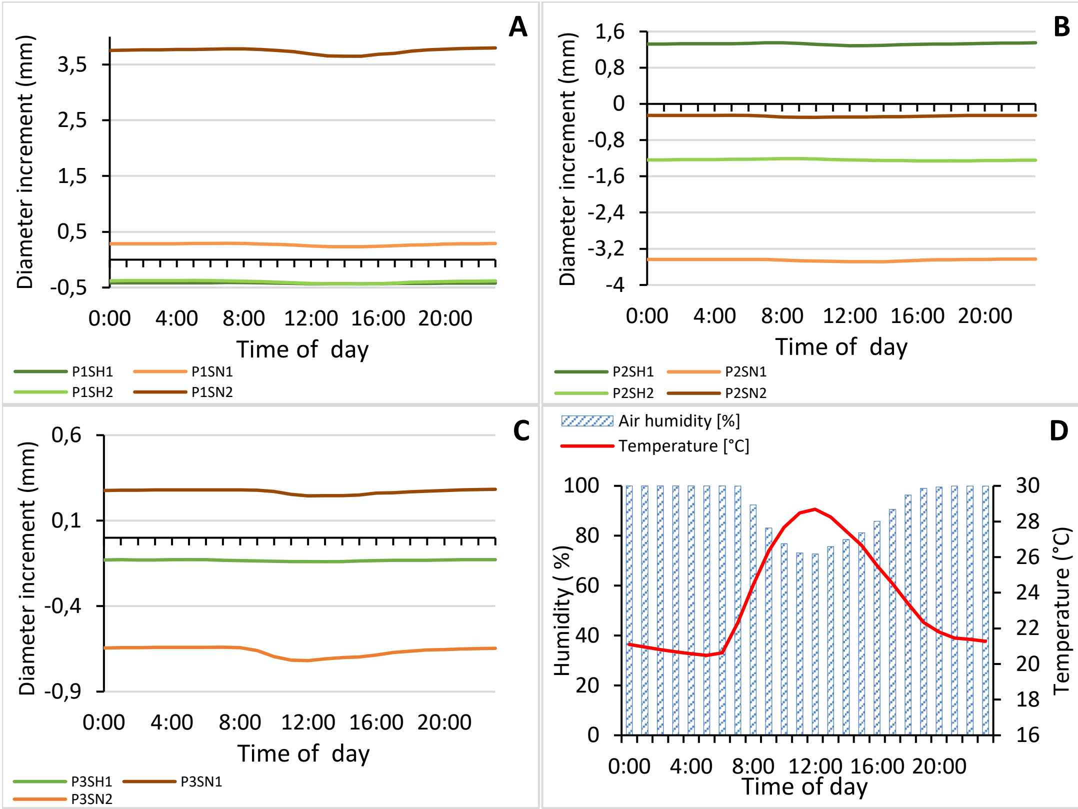
Figure 16 shows the diurnal stem diameter variation of coffee shrubs under shade and under full-sun exposure, as well as, the diurnal pattern of air humidity and temperature, in one month in the middle of the dry season, in three study plots.

In Figure 16A, daily changes in stem diameter of coffee shrubs under shade and full-sun exposure, in the study plot 1 are illustrated. For both categories of coffee plants, a slightest expand in the stem diameter was observed during the early morning. For coffee plants under full-exposure P1SN1 and P1SN2 a maximum in diameter stem was presented at 7:00 am and 8:00 am respectively. A minimum stem diameter was identified at 15:00 pm. For coffee shrubs under shade P1SH1 and P1SH2, the maximum value in diameter was at 6:00 am and the minimum at 15:00 pm. After that period, the shrubs stem swelled.

In Figure 16B the daily increments of coffee shrubs in the study plot 2 are presented. For coffee plants under full-sun exposure and under shade, the maximum stem diameter was presented at 7:00 am and 8:00 am, respectively. The minimum at 14:00 pm and at 15:00 pm correspondingly. Through the night the coffee shrubs stem began to increase again.

The daily increments of coffee shrubs in the study plot 3 are described in Figure 16C. For both types of coffee plants selected, a very small expansion in the stem diameter was observed, early in the morning, with a maximum value at 6:00 am. The minimum stem diameter value for plants P3SN1 and P3SN2 was at 15:00 pm and the coffee plant under shade P3SH1 at 13:00 pm. After that hours the stem diameter started to increase again.

In Figure 16D, is illustrated the diurnal variation of air humidity and temperature in full-sun site in the study plot 3. In the case of temperature, after 6:00 am, the increase of temperature was showed and continued increasing until 14:00 pm when it presented the maximum daily average (25.5 °C), after that, the temperature dropped gradually. Conversely, air humidity showed a decrease from 7:00 am till 14:00 pm when the minimum average (66.1 %) was presented, following by a progressively increase throughout the late afternoon till night.



A Hourly average increment of coffee diameter in the Study plot 1
B Hourly average increment of coffee diameter in the Study plot 2
C Hourly average increment of coffee diameter in the Study plot 3
D Hourly average of air temperature and humidity in the study site

Figure 18 Diurnal pattern of the stem diameter variations of coffee shrubs during one rainy month (May 2018) in three plantations in the Mondulkiri's province, Cambodia.

In Figure 17, the diurnal stem diameter variation of coffee shrubs under shade and under full-sun exposure are shown, as well as, the diurnal pattern of air humidity and temperature, in three study plots, in May 2018. During this period the coffee plants under full-sun exposure showed a net stem diameter growth from 21:00 to 23:00 pm. It means the diameter of the shrubs were bigger than they were at the morning time.

In Figure 17A, the hourly average of coffee shrubs in the study plot 1 are shown. Plants P1SN1, P1SN2 presented the maximum stem diameter at 7:00. For the coffee shrub under shade P1SH1, the maximum value of diameter stem was at 08:00 and for P1SH2 at 5:00 am. The minimum value in all coffee shrubs was at 15:00 pm.

The coffee plants at study plot 2 are shown in Figure 17B. For coffee plants under full-exposure P2SN1, P2SN2 the maximum in diameter stem was observed at 5:00 am, and the minimum at 14:00 pm. For coffee plants P2SH1, P2SH2 the maximum stem diameter value was at 8:00 am and the minimum at 12:00 m.

In Figure 17C, the coffee plants under full-exposure P3SN1 and P3SN2 presented at 7:00 am, the maximum in diameter stem and P3SH1 at 5:00 am. The minimum stem diameter was between 12:00 m to 13:00 for all the coffee plants.

In Figure 17D, the diurnal variation of air humidity and temperature for the area of study is depicted. In the case of temperature, after 6:00 am it gradually increased until 12:00 pm when it presented the maximum average (28.6 °C), after that, the temperature values declined rapidly. On the contrary, air humidity showed a slowly decrease from 7:00 am till 12:00 pm, when the minimum average (72.8 %) was presented, after that time, it increased again.

5.4.4 Shade trees stem diameter increment

Figure 18 shows the results for the stem diameter increment of three (3) shade trees in each of the study plots. During the dry season, it was shown a decrease in the trunk diameter for the shade tree P3SHTREE and a notable increase for the trees P1SHTREE and P2SHTREE. With the beginning of rainy season, it was a notable faster increment in the trunk diameter of P1SHTREE and P3SHTREE. In the other hand, P2SHTREE, did not present much increase, in almost the whole period it remained at a constant diameter value and at the end of the period from mid-September showed a small increase.

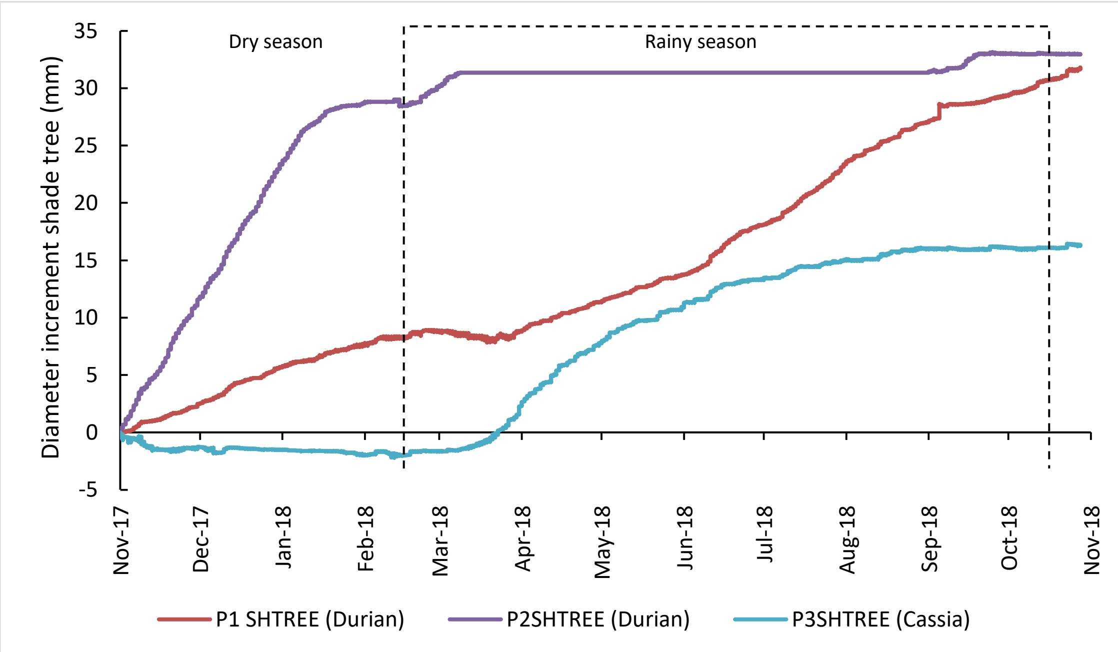


Figure 19 Stem diameter increment of shade trees in the three study plots

6 Discussion

6.1 Rainfall, air temperature, and humidity

The rainfall pattern measured during a year in the study area, showed two marked different seasons, rainy and dry. These results were similar to the results presented by Thoeun (2015), who reported a wet season from May to September with heavy rain and a dry season from the beginning of November till mid-March for Cambodia. Nesbitt (1998) identified two peaks of rainfall during the rainy season in Cambodia, what coincides with the measurements of this study. By the year 1995 the peaks were in May and September as well as was in this study in the year 2018. The rainfall calculated in this study was within the optimum necessary average of rainfall for ideal growth of *Coffea canephora*, described by Nair (2010).

The air temperatures measured during the year 2018 by this investigation in the Mondulkiri's province showed an unusual lower annual average, that as well as the maximum and minimum temperatures varied with respect to the defined patterns of the climate of Cambodia presented by Thoeun (2015). The same author also estimated possible changes in the annual average temperature, as well as maximum and minimum temperature, in a period of 90 years (2008-2098). PPCR (2014) mentioned that the usual number of Hot Days (HD) in the Mondulkiri's province was 7 and presuppose an increase) of about +7 expected for 2018, in the present experiment there was presented only one HD. These differences are explained also by PPCR (2014), for whom variations in maximum temperatures are related to elevation and especially for the region of Mondulkiri, where the elevations are higher, the maximum value does not reach above 35 °C often. Regarding the environmental requirements of temperature for suitable coffee growing, the range of temperatures presented during the whole year did not report contrasting between wet and dry seasons, which demonstrate that this condition was within the optimum range (24-30 °C) necessary for optimal *Coffea canephora* cultivation described by Nair (2010). Although it was a measurement at a region scale this does not represent the optimal values at microclimate levels.

Respecting to air humidity, the maximum value measured in this work was presented in September and the minimum in March, which was corroborated with the information presented by PPCR (2014) and Nesbitt (1998), who reported a range of humidity from 60 to 85 % in the region, same range presented in this experiment.

6.2 Soil moisture

Soil moisture within the plant-soil-water relation system depends on the soil texture and structure as well as on the plant's root system characteristics (Hillel and Hatfield, 2005). It was demonstrated by Peasley and Rolfe (2003) that coffee shrubs obtain between 70 % and 93 % of their water necessities from the upper 30 cm depth of soil. In this experiment, the soil humidity showed higher values in sites where coffee was growing under shade and lower values in sites without shade, what could be attributed to the fact that natural cover, maintained soil conditions and that shade trees have deeper roots than coffee, therefore, they can take their necessary water from deeper areas. These results were similar to those presented by Súarez de Castro et al. (1961), who established that the soil where coffee was growing under shade had higher soil moisture. In the same way Morais et al. (2006) in their study in Brazil, presented high soil moisture in sites where coffee was growing in agroforestry, and this was attributed to the addition of organic matter obtained from pruning and falling of the leaves and branches of the shade plants and coffee.

On the contrary, the authors Prijono and Bana (2015) and Neves et al. (2007), described different patterns of soil humidity in their investigations, in the case of the sites with full-sun exposure soil moisture was higher and for the coffee growing in agroforestry array, it was lower. They assumed that it may be presented a competition for water, nutrients and sunlight between the plants in the agroforestry system.

According to the above paragraph, it is pertinent to mention that the water management for coffee cultivation, include the guarantee of adequate soil moisture, which should encourage the root development of the plant as well as the optimal physiologic processes for growth and this can have a direct relationship with the maintenance of microclimate. Vasconcellos et al. (2016) presented in their work in Brazil, that microclimatic conditions for Robusta coffee grown in intercropping were directly influenced by shading. In comparison with this, in the area of this study, the trees used as a shade to the coffee seemed to have incidence in the maintenance of soil humidity.

6.3 Stem diameter increment

Regarding observations made in this study, it was noted that some of the coffee shrubs ended with an annual negative growth. First of all, researches showed that this does not indicate human measurements error, but it can be due physiological and physical processes of the plant (Martinez et al. 2007). In this case Kozlowski and Pallardy (1997), explained the shrinkage changes of stem woody plants as a factor influenced by pathogens, plant genetical information, soil humidity, leaf area, nutrition supply and environmental conditions, because these aspects can affect the transpiration and the water-conducting vessels.

In coffee bushes, vegetative growth, for example, the formation of nodes and leaves, and the generation of new roots, the increase in stem thickness among others occur during the whole life of the plant and in most of the time, it is interspersed with the reproductive growth (Arcila et al. 2007). Coffee plants under shade (P1SH1, P1SH2) and one of the coffee plants under full-sun exposure (P3SN2), presented at the end of the year smaller stem diameters compared to the beginning of the measurements. Diaz et al. (2015) mentioned in their research, that water stress could be an indicator of the stem diameter fluctuation in perennial trees. In the area of this experiment, the drought period was longer than that optimal for coffee, plant that requires about one to two dry months, so the stress induced by less water in the plant system will help to induce flowering and with these a production is a guarantee (Nair, 2010). During the rainy period although was expected that coffee trees recharged and rehydrated and consequently their stem expanded, it didn't happen. It should be noted that in this period the fruits gain dry matter and this process attracts more than seventy percent of photosynthesates fabricated by the shrubs (Cannell, 1985). Amaral et al. (2006) in their experiment about the seasonal vegetative growth of arabica coffee and its relationship with fruiting, reported that coffee plants that had full fruit load showed a lower shoot growth, similar results were reported in *Coffea arabica* by Cannell (1971).

One of the most important microclimatic conditions that have incidence in the decrease of stem diameter of coffee plants is temperature (Barros et al. 1997). Even though the annual average in the area of study was within the optimal range suitable for coffee cultivation, (see chapter 3.4), during the dry period temperatures lowered till 15 °C, this data are similar to those reported by Partelli et al. (2013), who found in their research that the stem diameter of the *C. canephora* reduced when temperatures lowered 19 °C. Although, the same author found that some of the coffee shrubs presented higher diameter increment in the same conditions and related that to the mechanisms of tolerance of the specie, specifically the efficiency of xanthophyll cycle, the increase of antioxidants enzymes and the postponement of dehydration to maintain photosynthesis (Fortunato et al. 2010).

About the microclimatic conditions that influence the growth of the stem diameter of the coffee plant Waller et al. (2007) and Righi et al. (2007), described the differences between microclimate of coffee shaded and non-shaded and how it affects its growth. They found that decreasing light intensity cause the coffee shrubs may extend their productive life and prevent problems with dieback, reproductive development, bearing, photosynthesis parameters, among others. Solórzano and Querales (2010) reported how the season influenced the arabica's coffee stem diameter increment under shade, the higher increment was presented during the rainy season what was similar to the results of this experiment.

The growth of plants is generally the consequence of the production of dry matter through photosynthesis and, therefore, can be highly dependent on the intensity of light (Nunes et al. 1968). Some of the coffee plants in studied plots 1 and 3, presented higher stem diameter increment under full-sun conditions than under shade. Baliza et al. (2012) reported a better photosynthetic performance during the rainy season of arabica's coffee under low shade levels, he concluded that coffee planted under 35 % of shade seemed to have the ideal percentage of shade for optimal stem growth. The author assumed that the less percent of shade the better growth of the plants. However, the author also reported that coffee plants in conditions under full sunlight presented higher incidence of pathogens. In terms of this, the control and reduction of pathogens in coffee plants can be managing by agroforestry systems, as has been reported by Waller et al. (2007), who presented as one of the major effects of shade, that pest and diseases were less damaging.

According to the diurnal patterns of variations in coffee shrubs stem diameter represented in this experiment, Dixon and Johnson (1993) labeled that plants habitually undergo water stress that develops when transpiration exceeds water absorption by the roots, plants equilibrate with bulk soil water during rehydration that occurs nightly. As was represented in Figure 16, during a day in a dry month the stem diameter of coffee plants presented fluctuations that didn't conclude in an increase of the stem diameter, but the diurnal pattern of the stem presented early, maximum and late contractions of the stem, same as was observed by De la Rosa et al. (2014), who related early contraction of trunk diameter with water stress. In the other hand during the rainy month by the end of the day, it was presented an increment on the stem diameter of coffee plants. It was similar to the results presented by Barros et al. (1997), who reported that the active phase growth of coffee in Brazil was during the rainy period and the restrained growth was during the dry period. According to Barros et al. (1997) in the rainy period in the morning (08:00-09:00 a.m.) stomatal conductance was relatively high and decreased gradually. During the inactive growth phase, stomata were closed for most of the diurnal period.

The light intensity on coffee shrubs declines under shade and that depends on the shade tree species. In studies like the presented by Van Long et al. (2015), was shown that in coffee agroforestry systems, trees as *Senna siamea* reduced the light intensity in an average of 58 % and trees as Durian (*Durio zibethinus)* 50 %, these results were measured in comparation with an open space in the southern Asia, as was measured in this study. According to (Hariyono, 2018) in his measurements made from May till October, in Indonesia, in the generative phase some species of Durian were characterized by the nonappearance of growth in stem diameter, what in comparison with this work does not apply, because of the durian trees growth during whole year. *Senna siamea* is used in the study area to establish windbreaks and to provide shade to coffee plantations and grow faster in the rainy period as was mentioned also by Rocas (2004), who described the plant as a fast-growing evergreen.

7 Conclusion

In the province of Mondulkiri, Cambodia coffee farmers tend to cultivate coffee in agroforestry systems with tree species as *Senna siamea*, Avocado, Durian, among others, as well as in mixed intercropping with crops as banana, lychee, rambutan, pineapple, among others suitable to the climatic conditions of the region. Agroforestry practices provide several benefits in terms of natural resource conservation, support resilience to climate change, and land equivalent ratio, among others.

While in one of the study plots (1), coffee shrubs growing under full-sun exposure tended to grow more quickly and effectively than coffee plants growing under shade during both of seasons, in the others study plots (2,3), was not possible to determine these differences. Thus, because in the study plot 2, the measurements couldn't be made during the rainy season and in the study plot 3, coffee plants under full-sun exposure differed in performance between them. For coffee plants under shade, one of the sensors got lost and the remaining coffee tree presented small growth during the rainy season, even though it was significant. In addition, a difference in the growth of coffee between the rainy and dry season was observed, the coffee stem diameter increases more during the rainy season. During the study period, relatively normal patterns of rainfall, air temperature and humidity were shown, thus, in comparison with the predicted for the region by other authors. The soil moisture was higher at sites under shade than those sites unshaded.

Because of the loss of data, the number of experiments carried out was insufficient to confirm if there is influence of the shade on the *C. canephora* diameter increment. It was statistically and graphically concluded that there is influence of the season on the growth of the stem of the coffee trees in Cambodia.

For future research in Cambodia, it is recommended to assure the proactive participation of communities in order to get the maximum amount of data as possible, and to generate a sense of care and property over the instruments, that in order to avoid any unexpected situation. Additionally, some important additional variables such as type of nutrition, liming and chemical conditions of soil, must be included in further studies related to physiology of *Coffea canephora*.

8 Shrnutí

V provincii Mondulkiri mají kambodžští pěstitelé tendenci pěstovat kávu v agrolesnických systémech zastíněných například avokádem (*Persea americana*), *Senna siamea* nebo durianem (*Durio zibethinus*), a dále také ve smíšených porostech s plodinami jako jsou banán, liči, rambutan, ananas apod.

V průběhu tohoto výzkumu byly ukázány relativně běžné úhrny srážek, průměrné teploty a normální vlhkost vzduchu. Půdní vlhkost byla vyšší na zastíněných místech než na těch, které byly na přímém slunci. Byl patrný rozdíl v růstu kávovníků v suchém a dešťovém obdobím, přičemž průměr kmene se během období dešťů značně zvětšoval. Některé kávovníky vykazovaly během celého období smršťování kmene a nevrátily se k původní hodnotě. V několika vědeckých studiích bylo prokázáno, že smršťovaní kmene u dřevin je běžná záležitost a může souviset s fenologickými fázemi, nízkou teplotou prostředí a genetickými vlastnostmi. Např. při dozrávání plodů kávovníku se více než 70 % asimilátů vyrobených fotosyntézou spotřebuje na jejich tvorbu.

Zatímco na jedné z pokusných ploch (č. 1) kávovníky na plném slunečním světle rostly rychleji než kávovníky rostoucí ve stínu během obou sezón, na ploše č. 2 byly údaje získány pouze z období sucha a pak byla data ztracena. Na pokusné ploše č. 3, bylo u kávovníků v plném slunečním světle zjištěno jiné chovaní v růstu. Jeden z kávovníků ve stínu vykazoval stejný růst jako na ploše č. 1, z druhého kávovníku se ztratily výsledky.

Kvůli ztrátě dat byl počet provedených experimentů nedostatečný, aby se statisticky potvrdilo, zda má stín vliv na tloušťkový přírůst *Coffea canephora*. Pro budoucí výzkum v Kambodži se doporučuje zajistit proaktivní účast komunit, s cílem získat co největší množství dat z přístrojů o které bude dobře postaráno, aby se zabránilo neočekávaným situacím.

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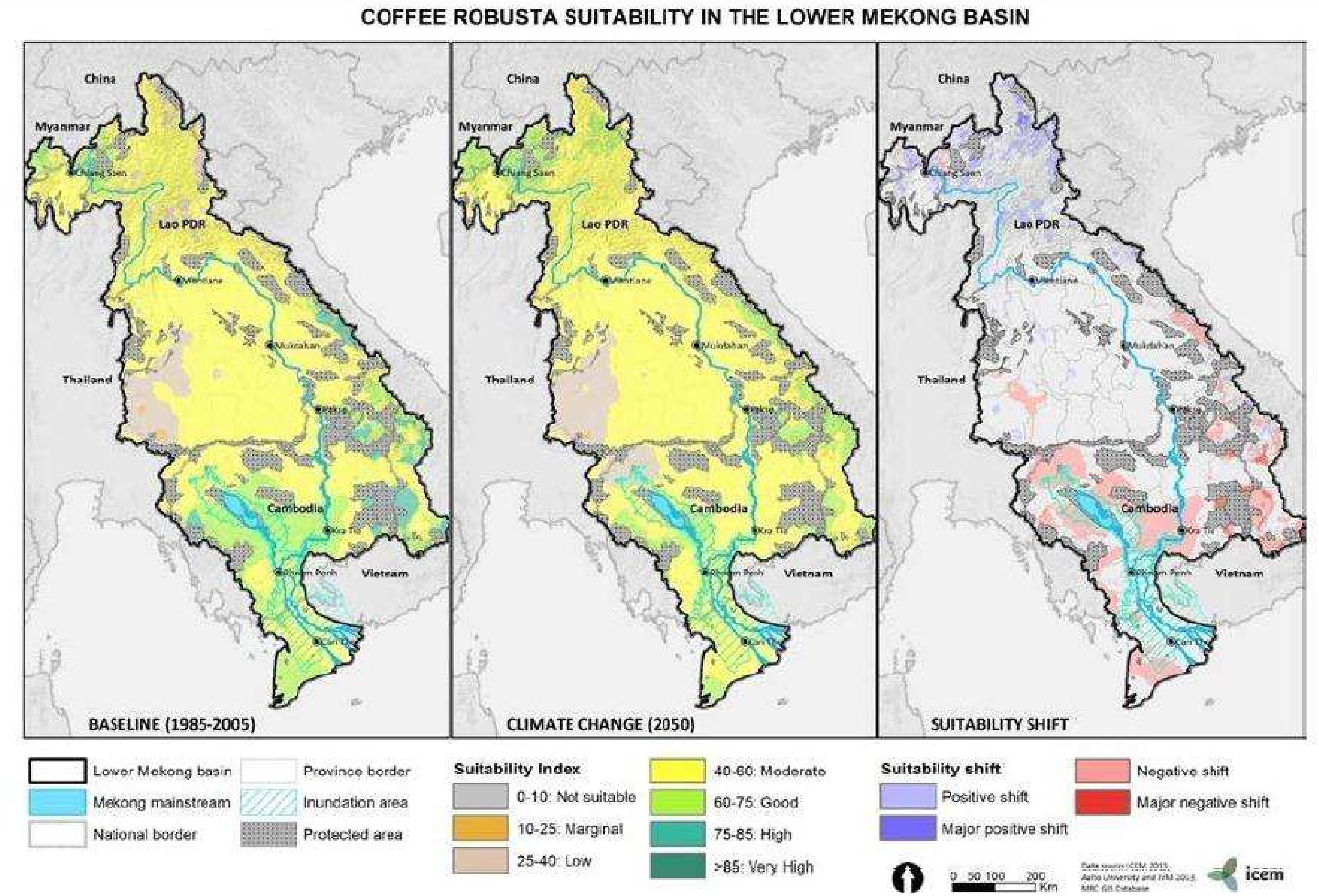
11 Appendixes

A.Environmental factor suitable for Robusta Coffee

Levels of suitability			S1	S2	S3	N1	N2
Degree of limitation		**0**	**1**	**2**	**3**	**4**	**4**
Climatic characteristics							
Temperatures (°C)	mean annual	22-28	22-25	20-22	18-20		<18
	mean maximal annual	>29	27-29	24-27	22-24		>22
	mean daily minimal	>20	18-20	16-18	14-16		<14
Rainfall (mm)	annual length of dry season	2000-2500	1600-2000	1400-1600	1200-1400		<200
	(months)	2-2,5	2,5-3	3-3,5	3,5-4		>4
Relative humidity (%)	mean RH of driest month	70-75	75-80	80-90	>90		
		60-65	45-60	35-45	30-35		<30
Soil characteristics							
Slope (%)	without irrigation	0-4	4-8	8-16	16-30	30-50	>50
	with irrigation	0-2	2-4	4-8	8-16		>16
Hydrous Conditions	drainage	good	good	moderate	imperfect	Imperfect, but drainable frequent	Imperfect, but not drainable frequent
	submersion	none	none	none	occasional		
Physical characteristics of the soil	depth of soil (cm)	>200	150-200	100-150	50-100		>50
	texture	clay,clayey-silty, silty-clayey	loam silty-clayey-sand	silty-sandy	sandy-silty	sand	sand
Chemical characteristics of the soil	% of coarse elements >2mm	0-3	3-15	15-35	35-55		>55
	pH (H_2O)	5.5-5.0	5.3-5.5	5.0-5.3	4.5-5.0	<4.5	
	apparent CEC (meq/100 g clay)	>16	<16+	<16-			
	saturation in cations of layer 0-15 cm (%)	>35	20-35	<20			
	organic carbon of layer 0-15 cm (%)	>1.5	0.8-1.5	<0.8			

S1 = Best suited units with very few (three or four) slight restrictive factors or none. **S2** =Average units with more than three or four slight restrictive factors and/or no more than two or three moderately restrictive factors. **S3** = Marginally suitable units with more than two or three moderately restrictive factors and/or no more than one serious restrictive factor provided it does not totally exclude farming.
N1 = Unsuitable units with one or more serious restrictive factor and no more than one serious restrictive factor which totally excludes farming. Potentially suitable if improvements were implemented. **N2** =Totally and potentially unsuitable units.
Source (Wintgens 2012)

B. Robusta Coffee suitability in the lower Mekong Basin



C.Initiation form

Jméno majitele/kontakt:

Den návštěvy:

Název plantáže:

Rozloha:

Poloha (souřadnice GPS – jde si stáhnout do telefonu, případně půjčím GPS sebou):

Sklon:

Expozice:

Stáří plantáže:

Vedení řádků: pokud jsou vysázeny stromy v řadách tak zapsat v jakém směru (sever-jih; východ-západ), to stejné pro kávovník
Zástin: ano/ne případně v jakém poměru

Variety kávovníku: jaké variety kávovníku pěstuje a pokud bude schopen říci v jakém poměru
Vyskytující se onemocnění:

Režim ORGANIC: Ano / Ne

Používaná hnojiva a postřiky: zapsat název

Je součástí družstva? Pokud ano – název:

Foto číslo:

Majitel nechá dělat měření na svých plochách – jen měření kávovníku a stromů: Ano / Ne

Majitel nechá nainstalovat přístroje na svých plochách: Ano / Ne

Majitel nechá odebírat vzorky půdy na svých plochách: Ano / Ne

Majitel nechá odebrat sklizeň z některých kávovníků, dojde k jejich odkoupení: Ano / Ne

Popis: