YIELD AND MANAGEMENT OF *COFFEA ARABICA* L. IN AGROFORESTRY SYSTEM IN DOI TUNG DEVELOPMENT PROJECT UNDER ROYAL INITIATIVE, CHIANGRAI PROVINCE, THAILAND

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ABSTRACT

Coffea arabica L. is the crop which the Thai government supports to plant instead of opium. The objective of this research was to find the most appropriate *C. arabica* L. plantation management system for the Doi Tung Development Project, under Royal Initiative, and to benefit the environmental, economic and social sustainability of the region.

180 sample plots of *C. arabica* in the agroforestry system were planted under shade trees of 3 different types : *Pinus kesiya* Royle ex Gordon plantation (AP), secondary forest trees (AS), and other crop plants (AC) plantations. The plantation of these agroforestry systems were compared with the monoculture system (AM) and the results indicated that the crown was shaded by trees and were highly covered the most by AP (83.17%±9.86), then AS (74.83%±14.18), and then AC (52.36%±21.42), while AM plantation had no shade trees in the system. The results further indicated that *C. arabica* L. planted under other crop plants (*Litchi chinensis* Sonn., *Macadamia* sp. F. Muell. and *Camellia sinensis var. assamica* (Mast.), etc.) had the highest yield average, which was 1.90±1.40 kg/m^2 ($p < 0.05$). Although the nutritional values in potassium and phosphorus for AP and AM were very different, the nutrition was sufficient enough for the coffee trees to grow within all systems. Comparing the economic benefits, the net present value (NPV) results for fresh fruits and dry fruits of coffee were AP > AM > AS > AC. Benefit/Cost ratio (B/C ratio) of fresh fruits and dry fruits in AP were 3.05, and 2.73, respectively.

To conclude, the AP and AS plantations in the agroforestry management system were the most appropriate for planting *C. arabica* L. in the Doi Tung Development Project because these plantations provided the highest coffee yields, highest benefits in economic income, and also the best natural products which will provide benefits and advantages to the environment, economic and social development.

KEY WORDS: YIELD / MANAGEMENT / *COFFEA ARABICA* L. / AGROFORESTRY SYSTEM

74 pages

ผลผลิตและการจัดการกาแฟอาราบิก้า (*COFFEA ARABICA* L.) ในระบบวนเกษตรในพื้นที่โครงการพัฒนาดอยตุง (พื้นที่ทรงงาน) อันเนื่องมาจากพระราชดำริ จังหวัดเชียงราย ประเทศไทย

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บทคัดย่อ

กาแฟอาราบิก้าเป็นพืชเศรษฐกิจที่มีการส่งเสริมให้เกษตรกรชาวเขาปลูกทดแทนฝิ่น ดังนั้นวัตถุประสงค์ของการศึกษา เพื่อให้ทราบรูปแบบการจัดการการปลูกกาแฟอาราบิก้าที่เหมาะสมกับสภาพพื้นที่โครงการพัฒนาดอยตุง (พื้นที่ทรงงาน) อันเนื่องมาจากพระราชดำริ และสนับสนุนให้เกิดประโยชน์ในด้านสิ่งแวดล้อม เศรษฐกิจ และสังคม อย่างยั่งยืน

จากการศึกษาแปลงตัวอย่างจำนวน 180 แปลง แบ่งเป็นรูปแบบการปลูกกาแฟอาราบิก้าในระบบวนเกษตร 3 รูปแบบ ได้แก่ การปลูกกาแฟอาราบิก้าร่วมกับสวนป่าสนสามใบ (AP) ป่ารุ่นสอง (AS) และพืชเกษตร (AC) เทียบกับการปลูกแบบเชิงเดี่ยว (AM) พบว่า พื้นที่ปลูกกาแฟร่วมกับสนสามใบ พรรณไม้ป่ารุ่นสอง และพืชเกษตรอื่น เป็นระบบการปลูกที่มีไม้บังร่ม แปลงปลูกกาแฟภายใต้สนสามใบมีการปกคลุมของเรือนยอดสูง (83.17%±9.86) พรรณไม้ป่ารุ่นสอง (74.83%±14.18) และพืชเกษตรอื่น (52.36%±21.42) ตามลำดับ แต่การปลูกกาแฟอาราบิก้าในระบบเชิงเดี่ยวไม่มีไม้บังร่มในระบบ กาแฟอาราบิก้าที่ปลูกร่วมกับพืชเกษตร (*Litchi chinensis* Sonn., *Macadamia* sp. F. Muell. And *Camellia sinensis var. assamica* (Mast.), etc.) มีปริมาณผลผลิตเฉลี่ยมากที่สุด 1.90±1.40 กก./ตร.ม. ($p < 0.05$) ปริมาณฟอสฟอรัส และโพแทสเซียมในดินมีความแตกต่างกันอย่างมีนัยสำคัญในพื้นที่ปลูกกาแฟอาราบิก้าร่วมกับสวนป่าสนสามใบ และปลูกกาแฟอาราบิก้าเชิงเดี่ยว ธาตุอาหารหลักและธาตุอาหารรองมีปริมาณเพียงพอกับการเติบโตของต้นกาแฟ เมื่อเปรียบเทียบผลตอบแทนทางเศรษฐกิจ โดยวิเคราะห์มูลค่าปัจจุบันสุทธิ (Net present value; NPV) จากการจำหน่ายในรูปผลสด และผลแห้ง พบว่า AP > AM > AS > AC ตามลำดับ อัตรามูลค่าต่อต้นทุน (Benefit/Cost ratio; B/C ratio) จากการจำหน่ายในรูปผลสด และผลแห้งเท่ากับ 3.05 และ 2.73

รูปแบบการปลูกระบบ AP และAS เป็นแนวทางการจัดการการปลูกกาแฟอาราบิก้าในระบบวนเกษตรที่เหมาะสมในพื้นที่ ทั้งสองรูปแบบให้ปริมาณผลผลิตกาแฟอาราบิก้า ผลตอบแทนทางเศรษฐกิจ และผลผลิตจากทรัพยากรธรรมชาติในระบบสูง เป็นประโยชน์ต่อการพัฒนาในด้านทรัพยากรธรรมชาติ และสิ่งแวดล้อม ทางด้านเศรษฐกิจ และสังคม ควบคู่กันไป

74 หน้า

CONTENTS

CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

Table **Page**

LIST OF FIGURES

LIST OF FIGURES (cont.)

ACRONYMS AND ABBREVIATIONS

Units

g	gram
kg	kilogram
mg	milligram
ml	milliliter
dS	decisemen
cmol	centimole
mm	millimeter
cm	centimeter
m	meter
m^2	square meter
m^3	cubic meter
°C	Degree Celsius

Parameters

D	Density
Do	Dominance
DBH	Diameter breast height

Others

yr	year
MSL	middle sea level

CHAPTER I
INTRODUCTION

1.1 Statement of problem

Doi Tung Development Project under Royal Initiative area was used to be a fertile forest. When hill tribes was in migrated in this area there were manage the place such as shifting cultivation and cultivated around Thai-Myanmar border. All the forest areas were directed, only 0.32 km^2 of hill evergreen forest now natural forest were leive at Wat Phrathat Doi Tung (1).

Doi Tung Development Project under Royal Initiative in Mae Fah Luang and Mae Sai district, Chiang Rai province were established to conserve and restore the natural habitat and environment in Doi Tung after most of the forest was by shifting cultivated destroyed and opium plantation. Fertile soil and was forest was protected from illisal logging to protected the water source. New forest was plantation in the clear to be an economic forest for the local people and changed them from the destroyer to be the protector and conservator and learn how to conserve the forest to be a good system and sustainable (2).

Doi Tung Development Project under Royal Initiative had been developed agricultural technique and trans forest local people. The Opium were replaced by the economic plants. to for cultivated in the *Coffea arabica* L. is one of the shitible crop plant that was well appropriated for cultivated in the area. The plantation of trees with crop plants was a way to rehabilitate and conserve the balance of ecosystem environment and agricultural in the area and to promote the income to the local communities. There activities will ensure the long term improvement of welter, economic, social and environment for the local people in the area and benefit of human and forest in the area. (3)

1.2 Objectives

1.2.1 To study the pattern of *C. arabica* L. plantation in Doi Tung Development Project area.

1.2.2 To study the effects of the environmental factors on *C. arabica* L. yield in Doi Tung Development Project area.

1.2.3 To study the appropriate pattern of *C. arabica* L. cultivation in the area for sustainable development of economic, social and environment.

1.3 Hypothesis

Management of *C. arabica* L. in different agroforestry plantation with macro, micro nutrient, crown cover elevation, and slop were effected the yield of *C. arabica* L. and economic refund.

1.4 Scope of work

This research were conducted in Doi Tung Development Project under Royal Initiative area, Chiang Rai province. *C. arabica* L. was cultivated in different agroforestry pattern. Yield and environmental factors such as elevation, slope, dominant tree species, density of trees, density of *C. arabica* L., crown cover, soil reaction, conductivity of soil, capacity cation exchange, soil humidity, organic matter, macro nutrient and micro nutrient such as nitrogen, phosphorus, potassium, calcium and magnesium in 180 of *C. arabica* L. study plots.

1.5 Expected results

1.4.1 Understand the *C. arabica* L. plantation pattern in Doi Tung Development Project area.

1.4.2 Understand the effects of environmental factors on *C. arabica* L. yields in Doi Tung Development Project area.

1.4.3 Understand the appropriate management of *C. arabica* L. plantation that advantage in economic, social, natural resource and environment in Doi Tung Development Project area.

1.4.4 This research will be use to improve the *C. arabica* L. plantation in Doi Tung Development Project area and other areas.

CHAPTER II
LITERATURE REVIEW

2.1 Coffee

Coffee is dicotyledonae in Rubiaceae family, genus coffea. It have more than 100 species (4). Fifty species are plantation around the world. Arabica and Robusta are favorite in Thailand most of them cultivated in northern and southern on Thailand, respectively (5).

The scientific name of Arabica is *Coffea arabica* L. The allotetraploid is 2n = 44 (6). The origin of *C. arabica* L. is Ethiopia. It is small shrub and may be higher than 5 meters. It is the evergreen plant (7).

2.1.1 Botanical Characteristics

1) Root

Tap root of *C. arabica* L. is short and fat, normally do not longer than 45 cm. and have 4-8 branch roots that sprout from tap root (Figure 2.2). Tap root is 2-3 m. depth. Branch roots have 1-2 m. long fibrous roots that lei parallel with ground and seek for food. Coffees are well growing in moisture soil rather than the cool roots that run deeper can keep coffee resist to arid. Normally, coffee root are not resistant to flood and Cray are growing well rich nutrition and well drainage soil (6).

Figure 2.1 **Characteristic of *C. arabica* L. (1) primary branch (2) dormatia under leaf (3-4) star flower (5) normal flower in vertical section (6) fruit that gown on node of branch (7) coffee fruit (8) coffee fruit goes out some meat (9) stipule (10).**

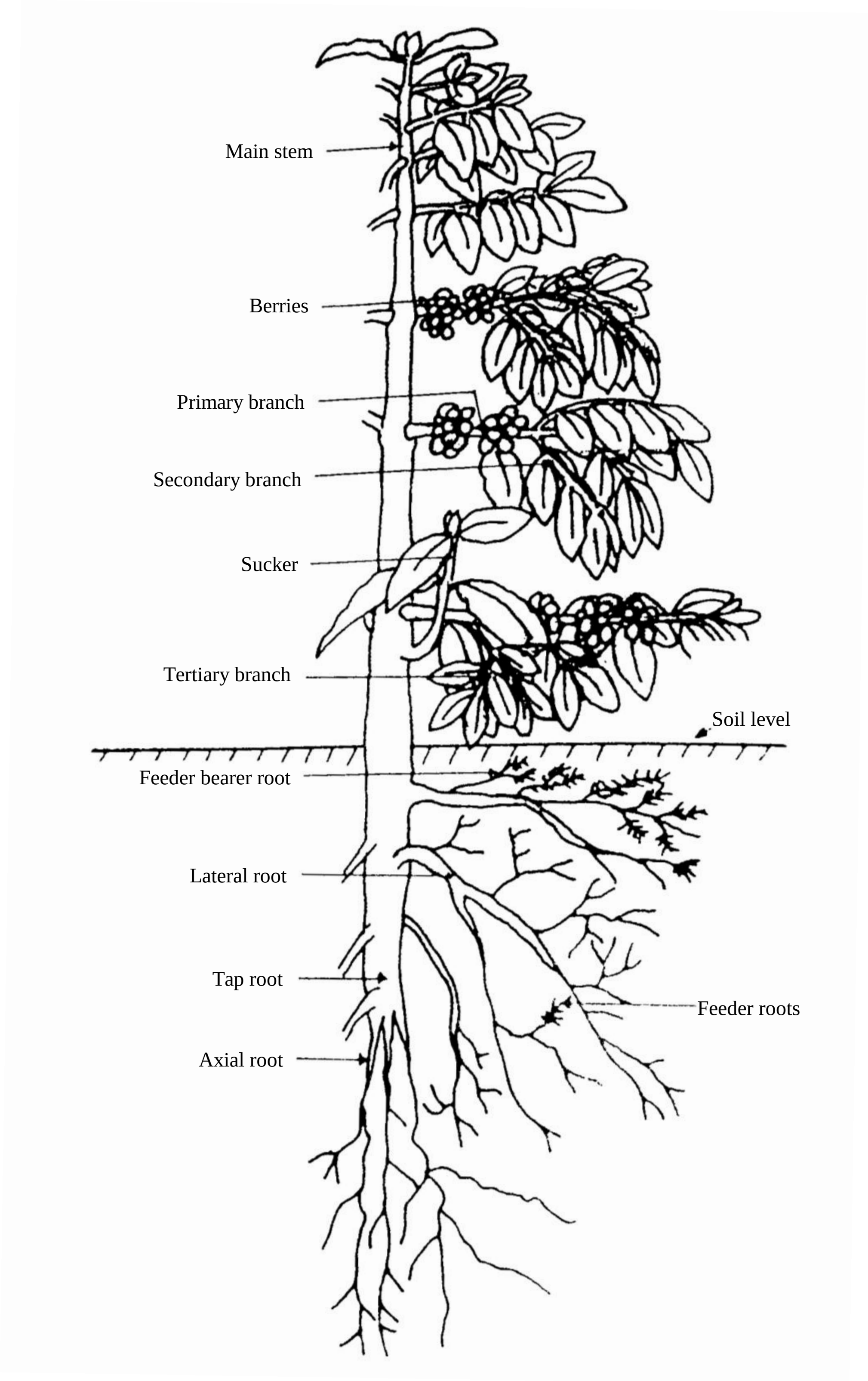


Figure 2.2 Structure of coffee and root system (8).

2) Stem

Stem of coffee is like other dicotyledonae. Stem is short or long depend on the variation of coffee species. Two main stem are orthotropic and branch. Orthotropic is the branch that stands upright, include main stem. Both orthotropic and branch are very important to coffee tree (Figure 2.3).

Main stem or stem which connect to tap root have leaf on node and fall later. When coffee grow, they will have bud on node call serial bud and extra-axillary. Serial buds find before flowering and fruiting. This bud can develop in each matere branch. Branch cannot be orthotropic but branch can develop from orthotropic. The first stem or secondary orthotropic call primary fruiting branch. Primary branch cound develop secondary fruiting branch and secondary branch could develop tertiary or fourth branch (9).

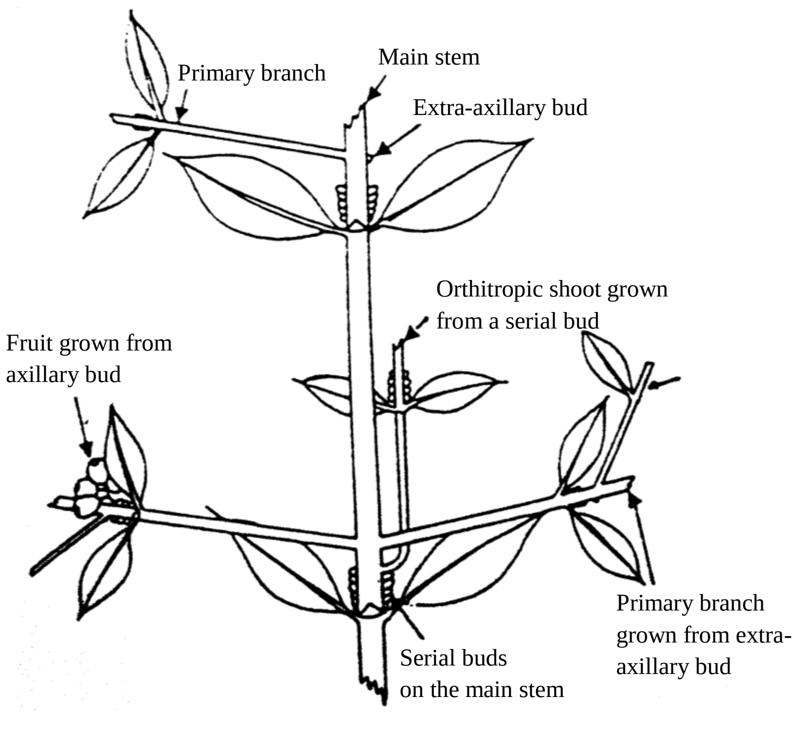


Figure 2.3 Structure of bud that be orthotropic and branch (9).

3) Leave

Leave are opposite (Figure 2.4). The upper side of leave are bright or dark green. The young leave are red or green in color call coffee red or green apical that have advantage to separate kind of *C. arabica* L. The hybrid coffee may find red or green apical together. Leaf apex, petiole is short, about 1 cm. long (6), lamina is 6.5-7.7×14-14.7 cm. (7), undulate has lateral vein about 7-12 pairs. The food production is depend on the longevity of leave (6).

Figure 2.4 Leave of *C. arabica* L.

4) Flowers

Flowers are group, each group have 6 flower buds. The first bud is located closest to the branch (Figure 2.5). Third and fourth bud will be flowering. Every inflorescence has 4 flowers. Flowers are which in color and located in each node. Coffee flower smell like Jasmine. Inflorescence from each group of each node has about 2-20 flowers that found in primary or secondary branch. Flower bud has 4-5 mm. long. In this state, coffee is loss of water, when the rain fall down they will flowered (6).

Figure 2.5 Flowers of *C. arabica* L.

A flower has 5 petal and 5 stamen, ovary separate in 2 rooms each has 1 ovule most of the fruits have 2 seeds (10). In height temperature, the flowers are abnormal such as succulent petal and green stigma with and stick may be green stigma came out do incomplete stamen call star flowers there flower are not develop the fruit. Coffee flowers are bloom between 8 and 12 days after having the water. The longevity of blooming days is depended on temperature. Normally, coffee flowers are bloom between 1 and 2 days then petal are fall down. Only ovary are left and develop to coffee seed (6).

5) Pollination

Coffee is self pollination. About 7-9 % are pollination by wind or insect. Pollen is meture while flower is blossom and stigma is ready to receive them. In cloudy day or low light, flowers are not bloom but pollen may be released (6).

6) Fruits

From blossom stage to ripe has 7-8 months long depend on elevation, at the elevation of 1,500 m. Coffee fruit has long time to ripe if culture in the fruit are ripe longer than at 1,000 m. Only 40 % of flowers are ready to harvest, 60 % are not developing to fruit. Even grow in the same elevation, they are ripe in the same time (6).

Ripe fruits are 1.5 cm. long with oval elliptic shape, short stalk (Figure 2.6). Young fruits are green the become yellow, orange or red to maroon depend on geneliese variation species. Coffee fruit have 3 parts; (1) exocarp, (2) sarcocarp, (3) parchment are thin but hard for cover seed (6).

Figure 2.6 Characteristic of *C. arabica* L. fruit.

7) Seed

Seed are oval shape, 8.5-12.5 cm. long. Each fruit have two seeds, attach each other. Endosperm has thin layer call silver skin cover endosperm. Embryo is attached at the base of seed. Embryo can have more than one embryo. After mill thin layer off, the coffee seed or bean or part of endosperm can roast and blend to make a cup call fresh coffee or produce to instant coffee. Five to 6 kg. of fresh coffee fruit will be 1 kg. of coffee bean depend on variety of coffee (6).

2.1.2 Varieties of *C. arabica* L.

C. arabica L. is self fertile. Stamens and pistil are fertilizing in the same flower or same tree. Germination by seed are significant different species characteristic. However, the mutations are occurring such as Typica, Bourbon, Blue Mountain, Caturra, Kona, Kent and Catimor (7).

2.1.3 Physiology of Coffee

Growth rate are depend on amount of water, moisture, temperature, light and long period of day time. Lack water can cause the effect of growth rate. In the long dry season, coffee need water to protect them self, but when the water are too much, it will affect the growth rate (11).

Temperature is the main effect on seed growing. The result shown that coffee seed and grow in 3 weeks at 30 $^{\circ}$C, while the temperature are dropped to 17 $^{\circ}$C, axil bud near stem are not developed to be orthotropic branch or die by temperature. Flowers are developed at the deferent of temperature between day and night at 10 $^{\circ}$C. In high temperature or hot day, flowers are not developing fruit, will only left sepal that it will star flowers (11).

Concentration of light are affected the growth rate, height, leaf branch and stem size of coffee. Growth rate will be increase in high concentrate of light or day long. Thus, growth rate of seedling are well develop under shade (12).

Short and long period of day time are part of the growth rate, height, number of node and distance between nodes. Growth rate are increased when increased day time. Coffee is short-day plant if cultivated in 13 hours day time, only lateral branch will be developing. (12).

2.1.4 Appropriate Environment for *C. arabica* L. Cultivation

Appropriate environment for Arabica coffee cultivation are depend on environmental base. The directed factors effect of cultivation and production of Arabica in Northern Thailand are precipitation, temperature, moisture, shade, wind and win direction. The indiracted effects are elevation and aspect (13). There are related and impact each other.

1) Rainfall; The suitable precipitation are 1,500-2,300 mm./yr. for about 8-9 mouth. In cloudy place and rainfall less than 1,500 mm./yr., coffee can cultivated in the soil that cover with cover retired to prevent evaporation (5). In rainy place, the water drainage is very important especially in heavy rain with poor drainages soil. In dry season coffee need 2-3 months between November and February to develop their fruit to be ripped. Harvest and preservation of coffee bean are taken at this time. Wood and blossom branches are developed to be flowering letter. In the area that has rain for whole year, coffee can produce flowers and fruits throughout the year. The fruits are not ready to harvest at the same time. Insects and disease out bralte will be occurring in the area (6).

2) Temperature; Coffee trees are not resisted to hot and cold. The appropriate temperature is 15-25 $^{\circ}$C (14). The temperature is varied depend on many factors, such as altitude, direction, moist, and sunlight especially average day temperature are 26 $^{\circ}$C and 20 $^{\circ}$C at night. The quality of coffee in high elevation are that cold on highland have to better than low elevation. The photosynthesis is decreased at 30 $^{\circ}$C. Leave become yellow and finally fall. In high temperature at time and cooler at night time, the leave may in yellow and growth rate are decrease especially in dry season or late winter (6). Growth rate of coffee are increase in shade. Planted coffee under the trees is preventing them from the temperature damage (5).

3) Moisture; Moisture is important to coffee except in flower and fruit phase. In this phase, moisture is not important to reduce the flowers and ripped the fruits (5). Straw or dry grasses are appropriation to keep moisture in the soil and also prevent the soil erosion from rain. Decomposed straw or dry grass can increase soil organic matter (5).

4) Soil; One and a half maters top soils are appropriate for coffee. Loam or sandy loam with red color are rich potassium that for develop fruits (14). Good drainage will high organic matters, moist are pH between 4.5 and 5.5 or less acidity are appropriations for coffee (6).

5) Shade; Shade is important for coffee. Under shade, low concentration of light demitity is high produce. In the open clear area coffee will produce more fruit, but they will die out at for the limitation of other physical factors (5).

6) Wind; Coffee is damage by wind. Root will be break, the growth rate will be decrease. The evaporation will be increase, the leave margin will be brown, and then whole leave will be yellow and finally effect the growth rate (6).

7) Elevation; Coffee is well developing in elevation between 1,200 and 1,500 m. MSL At than 1,500 m. MSL, Arabica coffee will have problem with frost in winter and finally have damage product and input to the yield (6).

8) Slope; Slop is a limit factor of land use. Coffee plantations are limited with slope because of the risk of soil erosion and conservation of water (6).

9) Aspect; North aspect is the most suitable for cultivated coffee. Sunlight is not then aspects are not receiving sunlight for all day. The East and North-East are better than South and West because of the conantation coffee will of sunlight during the day. In South and West aspect, coffee need shade to protect them from the sunlight (6).

2.2 Agroforestry system

Bene et al. (15) agroforestry is a sustainable land management system to increase the productivity of crop plants, trees and forest, this domestic animal at the same time or in the rotation system. Agroforestry are expanded, the appropriate concept are develop and apply in each area.

The International Council for Research on Agroforestry (ICRAF) decide formal define in 1987 by B. LundgrenJ and B. Raintree, agroforestry is similar word, it means systems to use land with perennial plant technology (like tree undergrowth, bamboo, palm, coconut, Toddy palm, etc.) live unity with crop manage and animal husbandry at the same time or do rotate in the same area. Other functions in agroforestry is relate nor environment or economic. (16). In conclusion agro forestry be applying real estate system that have growing plant or look after the tree goes together with agricultural plant and domesticating animals which might grow the tree goes together with agricultural plant is in a hurry same area at the same time or grow alternate a person vacates the time all right (17).

Agroforestry system is a sterztegies tools, or management patterns the activity of forest management, or feel the domesticating in the same area at the same time or the activities to produce the sustainable yield. It is an integrated science to use the existing energy and resource to produce the efficiently products under the balance of ecosystem to support the requirement and skill of the human society in the area (18).

Agroforestry is a system that is has a main propose to restorable the environment with optimum ecosystem to produce the crop yields (3).

Agroforestry is art and science to cultivated plant by using trees is the domidant species the system. There plant will be supported each others to produce the maximum yield such as income, food or energy with minimum west (19).

Agroforestry system or agriculture forest system is the system that growing the crop plant in the forest (20).

Agroforestry is a sustainable system (21) for economic social natural resource and environment. In the productive area, crop production with forest trees can produce more productivity of crop and trees than monoculture system (16). Agroforestry can improve the local society and standard of living. Health and nutrition of local community are increase because of the income on employee. The variety of food species and increased the security of food in the community. Shifting cultivation and cutting down the forest trees are decreased. The environment are rehabilitated by growing the crop plant under the shade of forest trees. In the shade system, humidity are high under the optimum ecosystem and protected the environment from the degradation (22). The different level of trees can panitrate the sunlight and increase the efficiency of nutrient cycling. The root system of the trees can reduce the surface runoff and increased the soil infiltration (19). There the technique can protect in soil from erosion and nutrition loss (23). Soil moisture and temperature are increase by increasing the interception of roots and plant litter, evaporation rate are decreased under the shade. There litter are increased the nutrition and decomposition (16). Agroforestry system is agriculture practices for forest balancing the environment by improve the agriculture with rehabilitation. It is a sustainable utilization of lead to produce the yield while conserving the resonse in the system (24; 25).

The mean compositions of agroforestry systems are trees and others agriculture activities. Trees in agroforestry are hard woods or perennial plants. Other agriculture is crop plants these two compositions are related in the system and effective in both ecology and economic interaction (17, 26).

2.2.4 Group of agroforestry

Agroforestry has 3 major groups.

1) *Agrosilvicultural systems* that have tree with crop plant

2) *Sylvopastoral systems* that have product from pets such as cow, buffalo, goat and tree produce (leaf, flower and fruit) for to pet food.

3) *Agrosyvopastoral systems* that have product from agriculture plant, tree product such as fruit wood leaf and flower for pet food and pastoral product (17; 27).

2.3 *C. arabica* L. in agroforestry system

In the past, *C. arabica* L. are to cultivated under shade of trees in the habitat of animals and other living things. At present coffee are cultivated in the rolls with a few trees or in the open areas. This technique is use to ripped the coffee fruits. Campanha et al. (28) in Brazil, the growth rate of coffee in the monoculture are better than in the agroforestry 2,443 kg/ha and 515 kg/ha, respectively.

Kind and fertilizer use rate that appropriate with Arabica coffee in difference shade highland research and development center Kun Chang Kian found that the growth rate of diameter, height, number of fruits per node and fruits per tree in open area are higher than shade plantation. The ripe phase of shade coffee are lower them in the open area, but number of seeds and quality of coffee are higher under the shade. Shade coffees are friendly with the environment and high diversity of other organisms. More fertilizers and insecticide are needed to apply in the monocrop plantation. These may cause the impact to environment auch as forest distraction, contamination of insecticide, wildlife habitat loss, reduce of soil and water quality, imbalance of environment, direct and indirect imparts to other organisms (29).

The promotion of agroforestry technique or agroforestry system in coffee production are inproved the standard of living of the hill tribes, natural resource, and environment. The effective of the agriculture forest on *C. arabica* L. plantation are increased the quantity and production coffee longivity of coffee, better, control of soil erosion, and forest utilization in the system (30). A research on the coffee plantation under the trees showed that, this system is not effect to the highland environment even the yield of this system are lest than other system, but the yields are sustained and increase the forest area and sustained yield (31).

2.4 Study area

This project conducted at Doi Tung Development Project under Royal Initiative between Mae Fah Luang and Mae Sai district, Chiang Rai province (Figure. 2.7) the total area 149.624 km^2 (2).

2.4.1 Topography

Doi Tung Development Project under Royal Initiative is located in the mountainous area with high elevation and steep rain. The areas are the top of the valley 400 and 1,509 m. above sea level (2).

2.4.2 Land use

In 1988, 44.81 % of the total areas are forest, 38.70 % are agriculture area (2).

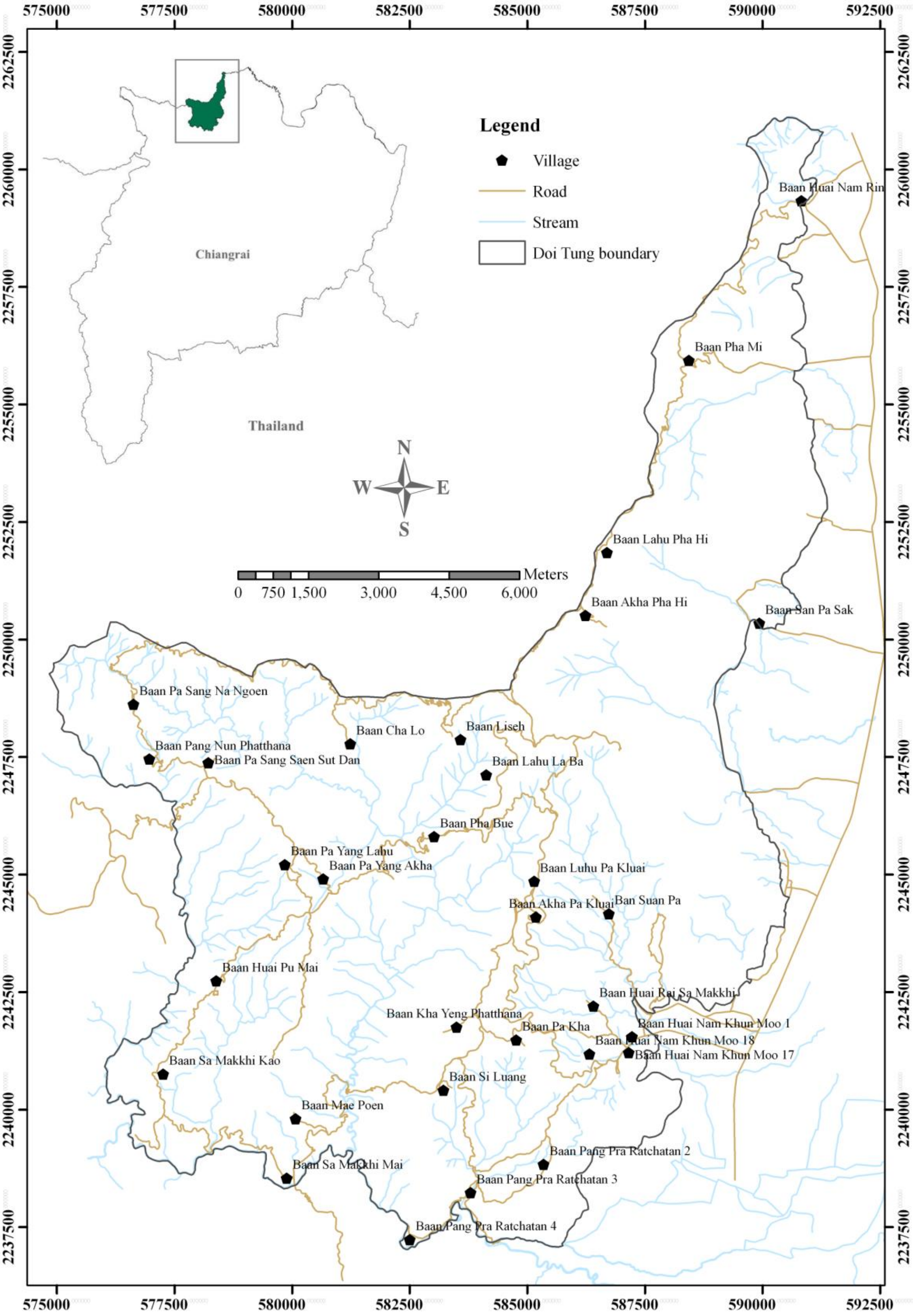


Figure 2.7 The study area at Doi Tung Development Project under Royal Initiative.

2.4.3 Climate

1) Season

The weather is Tropical Monsoon climate that have rainfall all year. The rain season May to October, winter is November to February and summer is February to May (2).

2) Temperature

The data between 2000 and 2009 collected by Doi Tung Weather Station at 750 m. Average annual showed that the temperature is 22.9 °C. The highest temperature between March and May are 30-31 °C. The coldest between December and January are 14 °C (Table A1.1).

3) Rainfall

Average rainfall between 1992 and 2009 (Table A1.1) was 2,075.2 mm./yr. and average humidity was 80.9 %.

2.4.4 Social and economic

1) Population

Doi Tung development project have 27 villages. Population between 2003 and 2005 was 10,741 people. (Akha, Lahu, Haw, Shan and Lawa (Lau)) (2).

2) Occupation and income

Most of the population and labor, and farmer, merchant, and craftsman. Income are increased from 30,732 baht between 2003 and 2004 to 32,159 baht between 2004 and 2005 (2).

3) *C. arabica* L. plantation

Over million coffee trees had been planted in the 6.65 km^2 (400 trees per rai) (Table A1.2). Between 2007/2008 and 2008/2009, more than 1,034,505 and 787,457 kg. of coffee were produce at Doi Tung Development Project under Royal Initiative, respectively (Table A1.3).

CHAPTER III
MATERIALS AND METHODS

3.1 Materials

3.1.1 Field study

- Map of Doi Tung development project in Mae Fah Luang and Mae Sai district, Chiang Rai province, 1:10,000 scale
- Geographical Position System (GPS)
- Fifty meters tapes
- Diameter tapes

3.1.2 Laboratory

- Cabinet bakes (Oven)
- Conductivity meter (EUTECH Instruments, PC 650)
- pH meter (EUTECH Instruments, PC 650)
- Spectrophotometer
- Atomic Absorption Spectrophotometer
- Centrifuge
- erlenmeyer flask size 50, 125 and 250 ml.
- Kjeldahl tube size 100 ml.
- Filter paper number 5 and 42
- and other laboratory meterials

3.1.3 Statistical Analysis

Microsoft office Excel 2007, SPSS Statistics version 17.0 and Arc GIS 9 were employed to analyze the data.

3.2 Methods

3.2.1 Distribution of *C. arabica* L. plantation

3.3.1.1 Satellite imaged and field surveyed were conducted and plantation systems in Doi Tung development projects to identify the positions of coffee plantation. The data were used to produce a distribution map of coffee in the area.

3.3.1.2 One hundred and eighty study plots were stratified sampling random in 4 different management system such as *C. arabica* L. plantation under *Pinus kesiya* Royle ex Gordon plantation, secondary forest, fruit trees and monoculture.

3.2.2 Environmental Factors in *C. arabica* L. plantation

Elevation, slope, trees, were recorded in each diameter at breast height (DBH), height and crown cover. The specimens of trees were collect and identify in the laboratory. The specimens are preserved as follows.

- Specimens were dry at 60-70 $^{\circ}$C for 2 days.
- Dry specimens were put in the mixture of mercuric chloride 250 ml., Phenol 50 ml. and alcohol 90 % 10 l. (32). These specimens were air dry.
- Reference specimens were used to compare with unknown species.

The density (D) and Dominance (Do) were measured as follows:

$$\text{Density (D)} = \frac{\text{number of species}}{\text{sampling area}}$$

$$\text{Dominance (Do)} = \frac{\text{basal area (BA) of species}}{\text{basal area (BA) of all species}}$$

3.2.3 Firewood

Measured diameter (DBH) and length of the fire woods were to estimate the volume and in each study plots.

3.2.4 Soil nutrition content

Three sample points diagonal line in each sample plots, 20-30 cm. in depth in 10×10 m. plot of *C. arabica* L. were obtained to evaluate the nutrition content in the laboratory (33) (Figure 3.1).

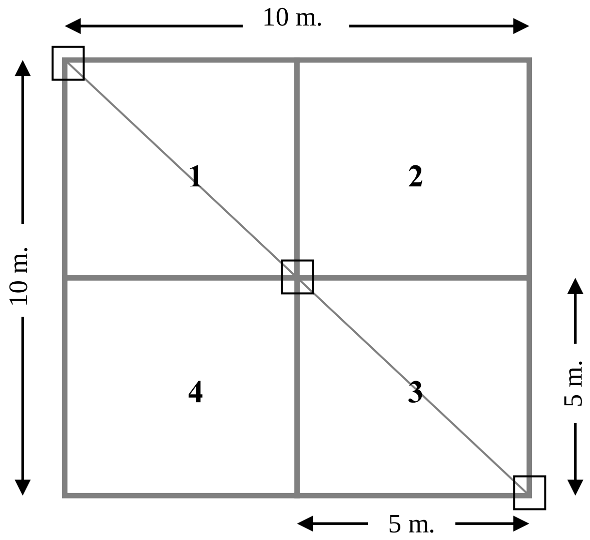


Figure 3.1 There systematic soil sample points in diagonal line in each plots was obtained to evaluate the nutrition content.

Soil analysis

1. Soil Reaction; pH

- Soil reaction (pH) was measured by 1:1 soil water solution (34) pH meter (EUTECH Instruments, PC 650) was used to measure pH.

2. Electrical Conductivity; EC

- Electrical conductivity (EC) was measured by 1:5 soil water solution Conductivity meter (EUTECH Instruments, PC 650) was used to measure EC.

3. Cation Exchange Capacity; CEC

- Cation exchange capacity (CEC) was measured by Ammonium acetate (NH4OAc) 1 N at pH 7.0 by Buchner funnel filtration (35).

4. Soil water content

- Soil water content was calculated as follow (36).

$$\% \text{ soil moisture by weight} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

5. Organic Matter; OM

- Organic matter (OM) was titrated follow Walkley and Black (37).

6. Total Nitrogen; N

- Kjeldahl was obtained to estivated the Total Nitrogen (N) (38).

7. Available Phosphorus; Avail. P

- The way Bray II was obtained to estivated of the Available Phosphorus (Avail. P) (39).

8. Exchangeable Potassium; Exch. K

- Ammonium acetate (NH_4OAc) 1 N at pH 7 was used to estivated the Exchang Potassium (Exch. K) (40).

9. Exchangeable Calcium; Exch. Ca

- Ammonium acetate (NH_4OAc) 1 N at pH 7 was used to estivated the Exchang Calcium (Exch. Ca) (41).

10. Exchangeable Magnesium; Exch. Mg

- Ammonium acetate (NH_4OAc) 1 N at pH 7 was used to estivated the Magnesium (Exch. Mg) (41).

Soil nutrition analysis was conducted by Soil Science laboratory, Faculty of agricultural, Kasetsat University, Kampangsan campus.

3.2.5 Yields of *C. arabica* L. in different plantation systems

- One hundred square meters plot with four 5 × 5 m. subplots were random by selected (33) (Figure 3.2).

- Growing space, numbers, diameter at ground levels, height, crown cover and species of trees in the sample plots were measured.

- Each sample plot was divided in to 4 subplots. Small-size, medium-size and large-size of coffee trees and branches (Figure 3.2).

- The fruit of coffees in three branches at below the top branch, middle of the coffee tree, and the branch next to the lowest branch in the same direction in each selected coffee tree were measure (Figure 3.3).

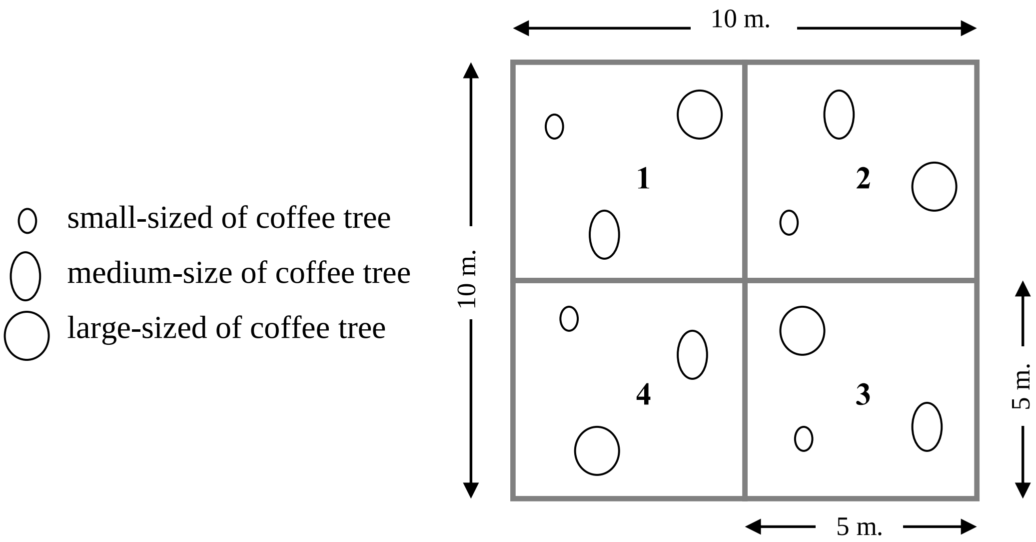


Figure 3.2 Number of *C. arabica* L. fruits was measured in 4 subplots (5 × 5 m.) in each sample plots.

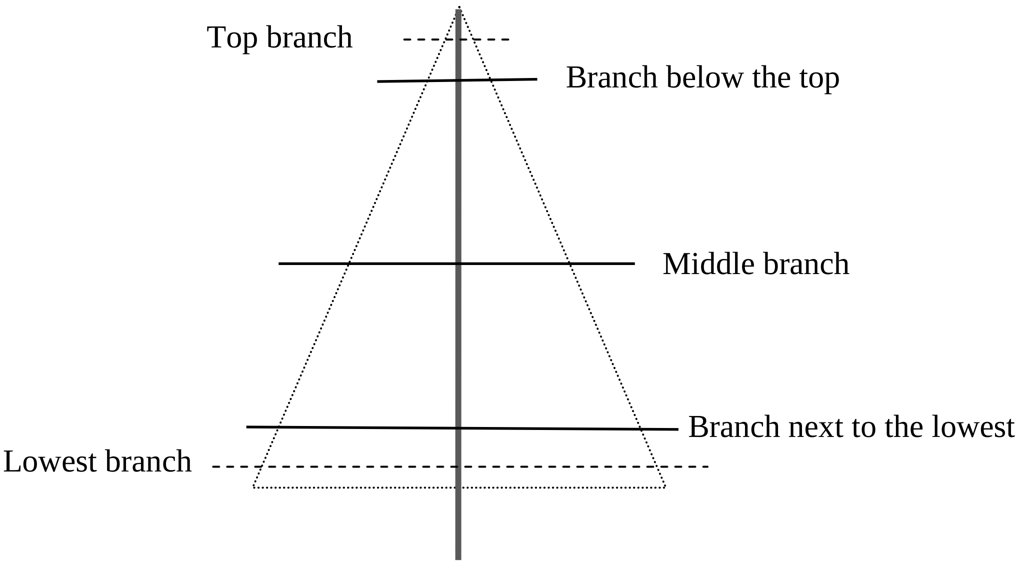


Figure 3.3 A systematic sampling of coffee yield in each selected tree.

3.2.6 Economic

The information of economic data were obtain from the field studied and the data from Doi Tung Development Project. The ratio between benefit coffee yield and other products and cost (seedling, labor and fertilizer) were used to estivate the income in each plantation systems.

The total cost (TC) (19), Net present value (NPV) and Benefit-Cost ratio (B/C ratio) were analyze to suger the appropriated coffee plantation systems the local communities.

$$NPV = \sum_{i=1}^{n} [\,B_t / (1+r)^t\,] - \sum_{i=1}^{n} [\,C_t / (1+r)^t\,]$$

$$B/C = \frac{\sum_{i=1}^{n} [\,B_t / (1+r)^t\,]}{\sum_{i=1}^{n} [\,C_t / (1+r)^t\,]}$$

When; B_t = benefit at year t

C_t = cost at year t

r = interest rate

t = time (year 1, 2,3,…,n)

3.2.7 Management

Coffee yields and the benefit in each resource in plantation systems were used to identify the appropriated coffee plantation system in Doi Tung Development Project to ensure the sustainable management and better environment for the local community in the area.

3.2.8 Data Analysis

The SPSS version 17.0 was used to analyze the percentage, average (Mean), ANOVA and T-test significance levels 0.05.

CHAPTER IV
RESULTS

4.1 Distribution of *Coffea arabica* L. plantations

The distribution of *C. arabica* L. plantations in Doi Tung Development Project were show in Figure 4.1. The *C. arabica* L. plantations were closed to the village between 0 and 3.25 km^2. Most of them were closed to the village between 250-500 m., then 500 and 750 m., and 0 and 250 m., respectively ($t=3.20$, $p<0.05$) (Table 4.1 and Figure 4.2). They were appropriated to travel and take care of coffee.

Tables 4.1 The relationship between distance from the village and number of coffee plantations in Doi Tung Development Project.

Distance (m.)	Number of coffee plantation
0-250	191
250-500	321
500-750	209
750-1,000	167
1,000-1,250	123
1,250-1,500	59
1,500-1,750	48
1,750-2,000	37
2,000-2,250	18
2,250-2,500	8
2,500-2,750	1
2,750-3,000	0
3,000-3,250	1
Total	**1,183**

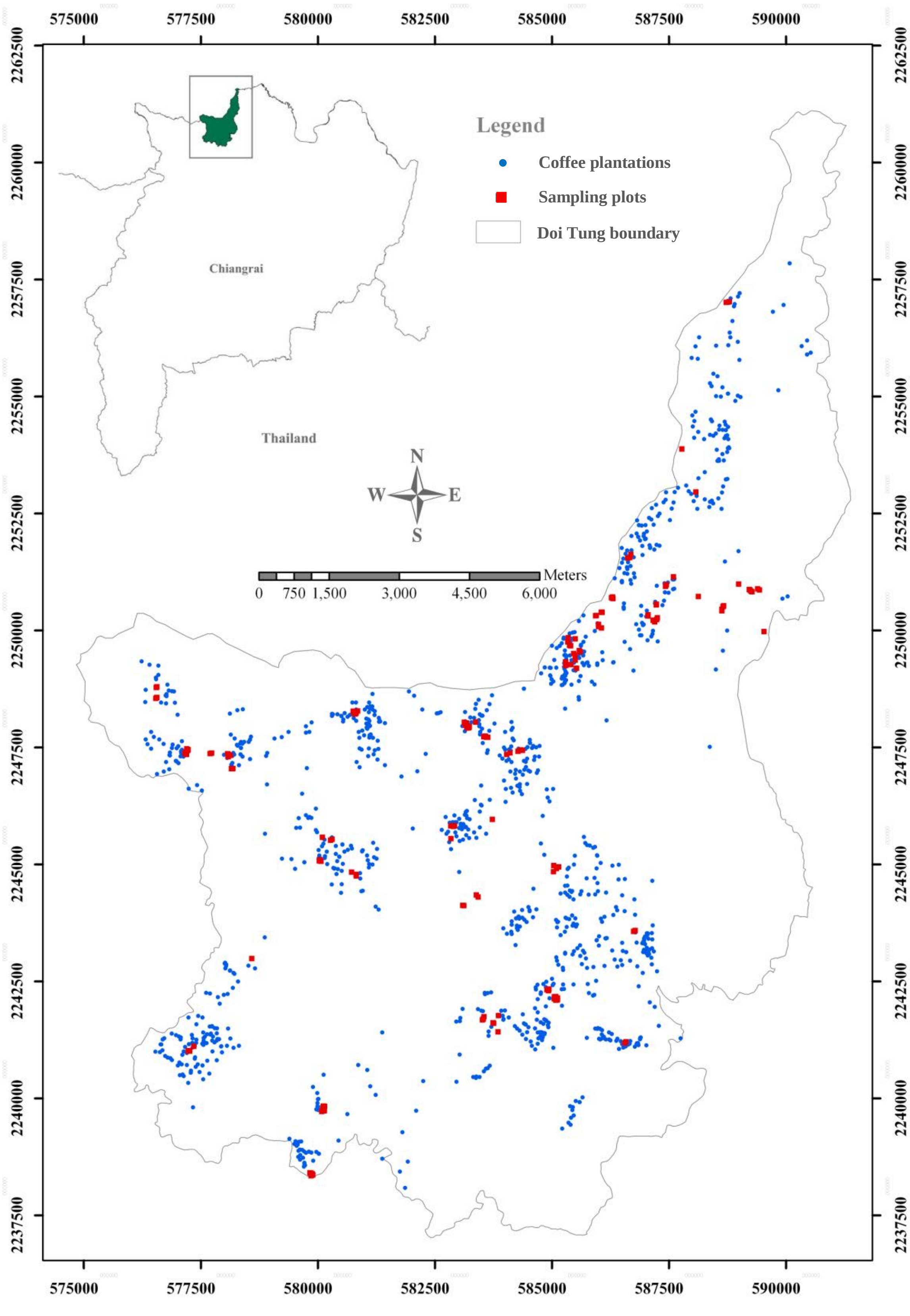


Figure 4.1 Coffee plantation and sample plot in Doi Tung Development Project.

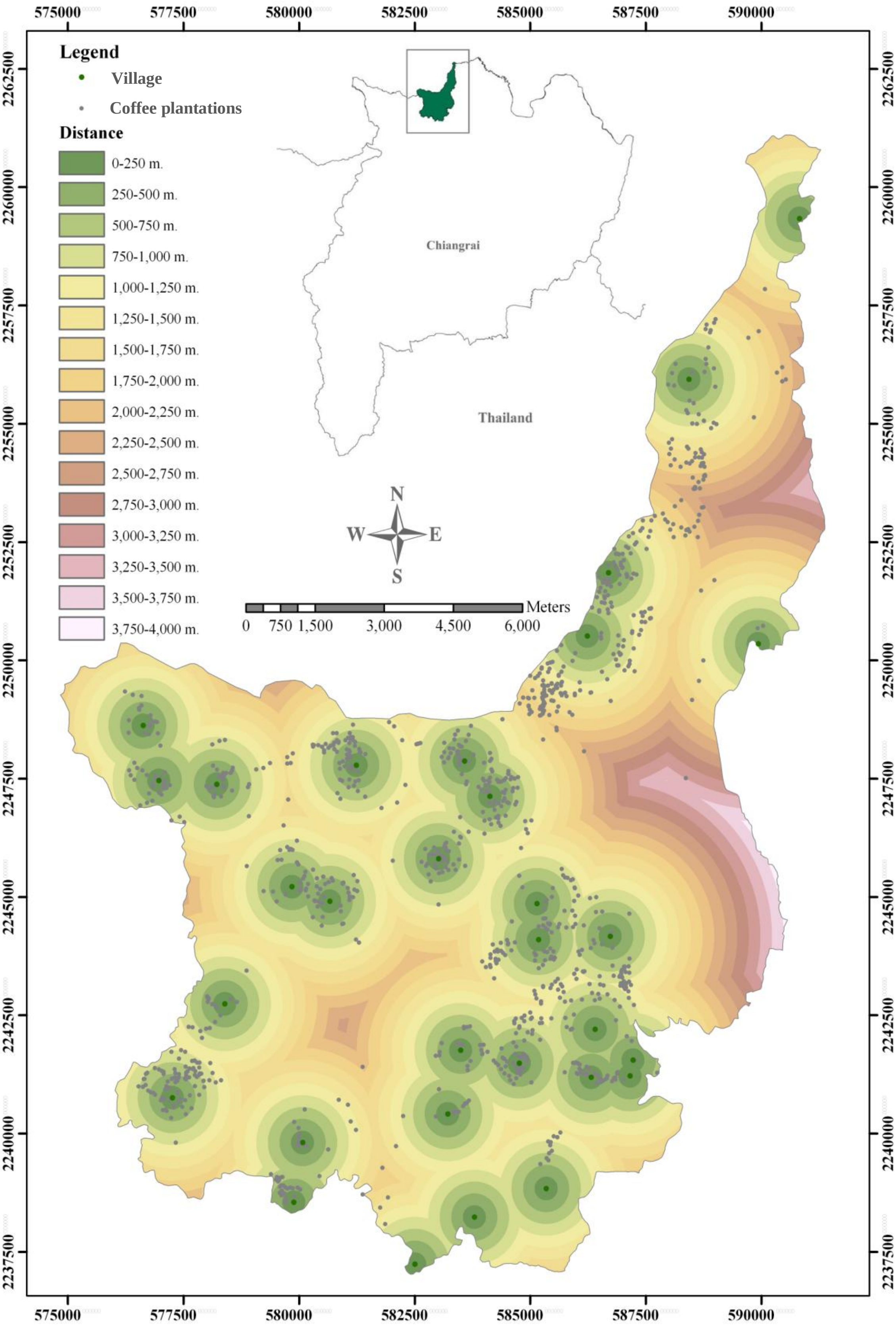


Figure 4.2 Distribution of coffee plantations and the distance from the villages.

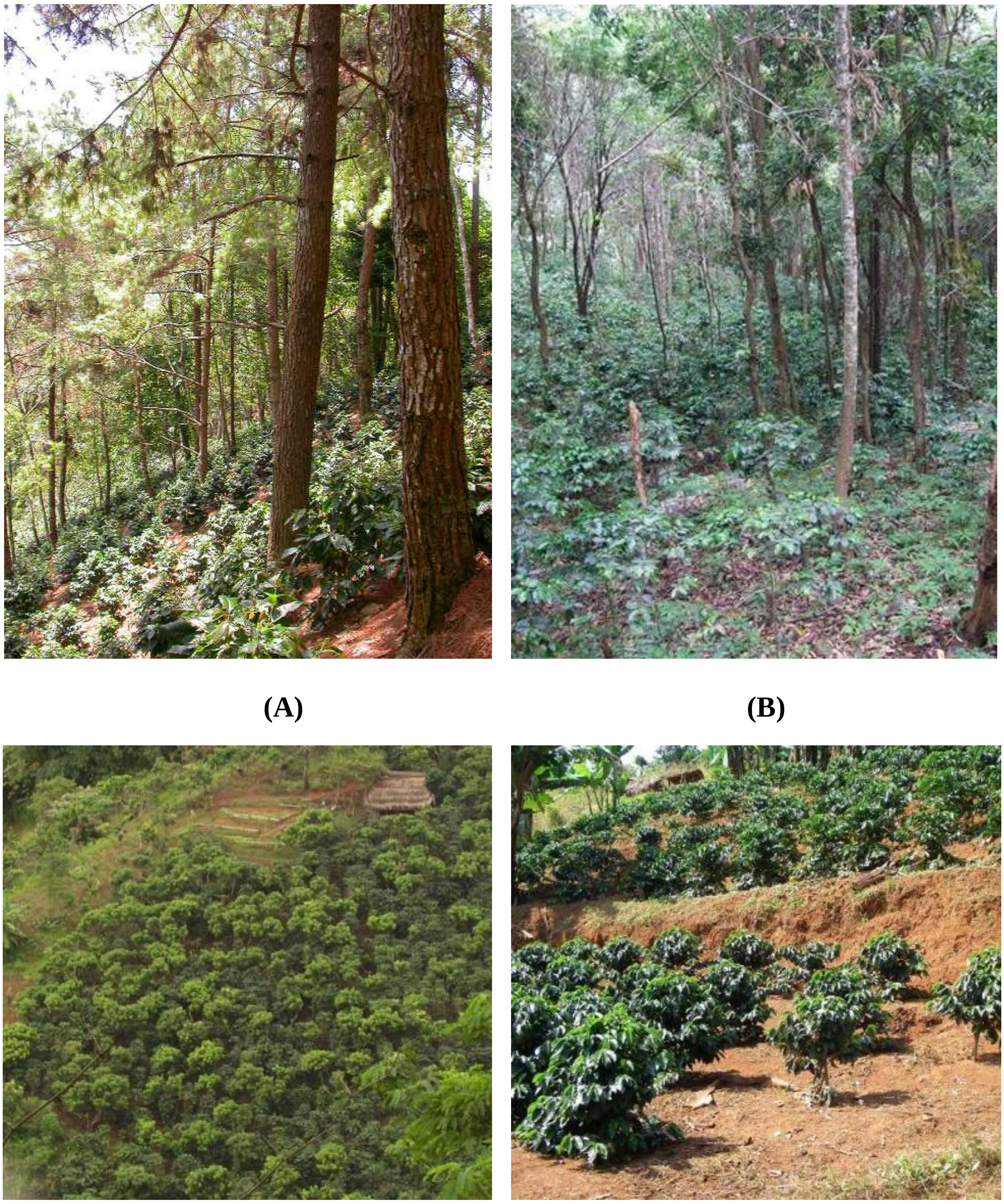
C. arabica L. plantations in Doi Tung Development Project were classified in to 4 systems (Figure 4.3).

1. *C. arabica* L. under *Pinus kesiya* Royle ex Gordon forest plantation (AP). The *C. arabica* L. were grow under 20 year olds *P. kesiya* Royle ex Gordon plantation with space between trees were 4×4 m. *C. arabica* L. were planted between the space of *P. kesiya* Royle ex Gordon. Spacing of coffee were 2×2 m. and sometimes found the natural trees were ground between the pines.

2. *C. arabica* L. under secondary forest trees (AS). The *C. arabica* L. were grow under secondary forest trees that have several species diversity of trees, ages, stem sizes and heights that were recovered after rehabilitation. The spacing of *C. arabica* L. were varied depend on the species of secondary forest trees in the area. In the steep areas *C. arabica* L. were grow along the row at the same elevation with uniform species.

3. Cultivation *C. arabica* L. under crop plants (AC). Lichee, macadamia and orange, etc. were main crop plant in the area. In some areas these crop plants mixed with natural trees. In some areas, *C. arabica* L. were grow under the crop plants or grow crop plant after *C. arabica* L. The spacing of this system was 1.2×1.2 m. in most areas. The density of *C. arabica* L. in this system has denser when compare to other systems.

4. Cultivation *C. arabica* L. in monoculture (AM). This system were grow *C. arabica* L. in the same paces (2×2 m) or difference spacing in both flat and high steep area.



(A) **(B)**

(C) **(D)**

Figure 4.3 ***C. arabica* L. plantation systems in Doi Tung Development Project area (A) *C. arabica* L. under *P. kesiya* Royle ex Gordon forest (B) *C. arabica* L. under secondary forest trees (C) *C. arabica* L. under crop plants and (D) *C. arabica* L. in monoculture.**

4.2 Environmental factors in *C. arabica* L. plantations

4.2.1 Elevation

Doi Tung Development Project was located between 400-1,509 m. MSL. While *C. arabica* L. plantations were distributed between 444 and 1,400 m.MSL. Most of them were located between 800 and 1,000 m. MSL., 600 and 800 m. (Table 4.2 and Figure 4.4).

Table 4.2 Distribution of *C. arabica* plantation along the elevation in Doi Tung Development Project.

Elevation (m.MSL.)	Number of coffee plantation
< 400	3
400-600	182
600-800	302
800-1,000	424
1,000-1,200	164
1,200-1,400	103
> 1,400	5
Total	**1,183**

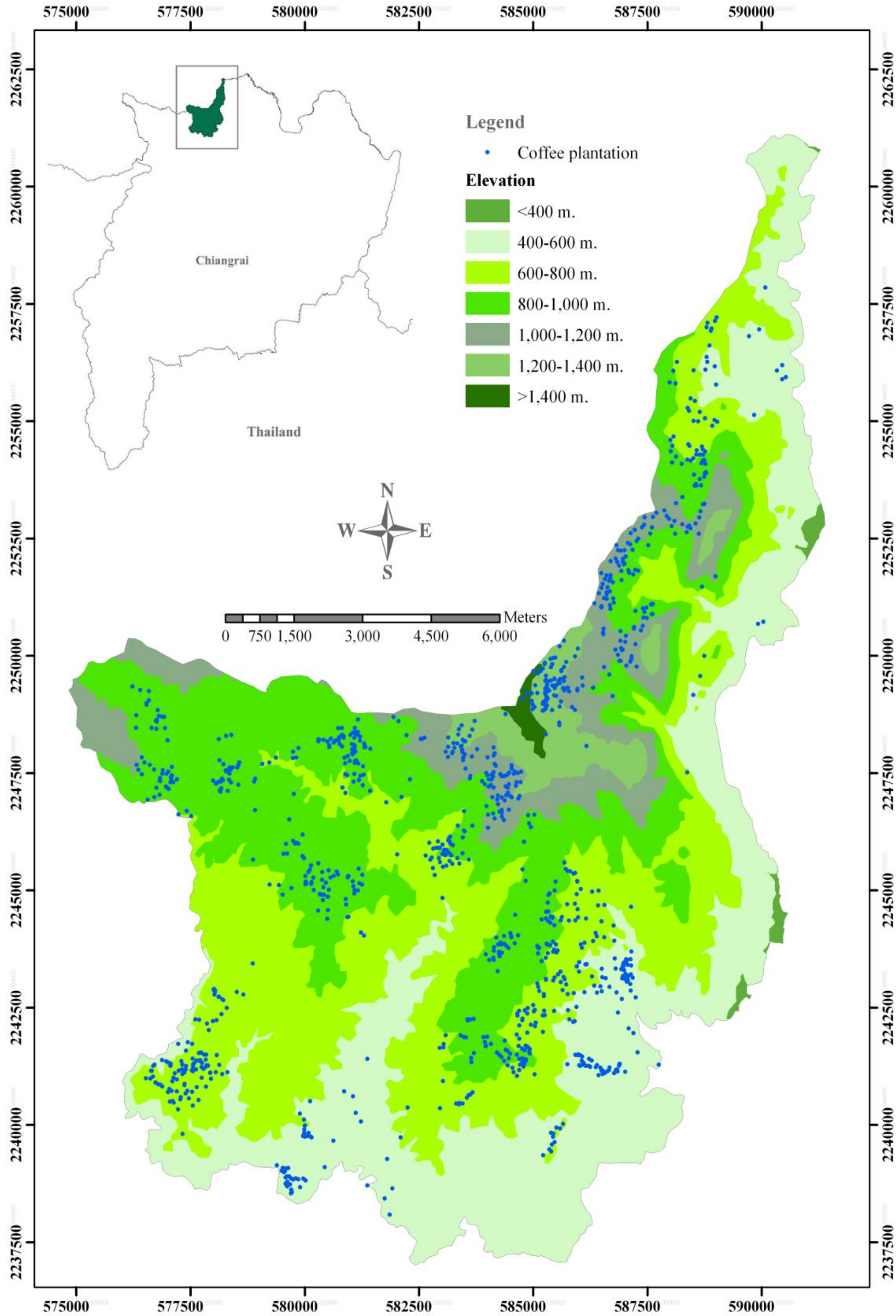


Figure 4.4 Distribution of *C. arabica* L. plantations different elevation in Doi Tung Development Project.

The plantation system of *C. arabica* L. were related to the elevation. AP mostly found between 1,200 and 1,400 m. MSL., AS and AC were mostly found between 800 and 1,000 m. MSL., while, AM was mostly found between 1,000 and 1,200 m. MSL. (Table 4.3).

Table 4.3 Number of *C. arabica* L. plantations along the elevation in Doi Tung Development Project.

Different	Elevation (m. MSL)						
plantation	**400-600**	**600-800**	**800-1000**	**1,000-1,200**	**1,200-1,400**	**1,400-1,600**	**Total**
AP	0	4	4	6	10	0	24
AS	11	7	30	10	4	0	62
AC	8	7	21	11	6	0	53
AM	7	5	11	13	5	0	41
Total	**26**	**23**	**66**	**40**	**25**	**0**	**180**

Remark : AP = *C. arabica* L. under *P. kesiya* Royle ex Gordon
AS = *C. arabica* L. under secondary forest trees
AC = *C. arabica* L. under crop plants
AM = *C. arabica* L. in monoculture system

4.2.2 Slope

Doi Tung Development Project was located in the mountain area with slope between 0 % and 80 %. Most of them were AP between 31 % and 40 %, 41 % and 50 %, respectively. AS were located between 31 % and 40 %. AC were located between 41 % and 50 %, 0 % and 10 %, respectively. AM were locate between 51 % and 60 % (Table 4.4 and Figure 4.5).

Table 4.4 Number of *C. arabica* L. plantations along the slope in Doi Tung Development Project.

Different	Slope (%)								
plantation	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	Total
AP	1	3	2	8	7	3	0	0	24
AS	9	7	10	20	13	3	0	0	62
AC	12	7	5	9	14	6	0	0	53
AM	3	2	7	10	6	12	0	1	41
Total	**25**	**19**	**24**	**47**	**40**	**24**	**0**	**1**	**180**

Remark : AP = *C. arabica* L. under *P. kesiya* Royle ex Gordon
AS = *C. arabica* L. under secondary forest trees
AC = *C. arabica* L. under crop plants
AM = *C. arabica* L. in monoculture system

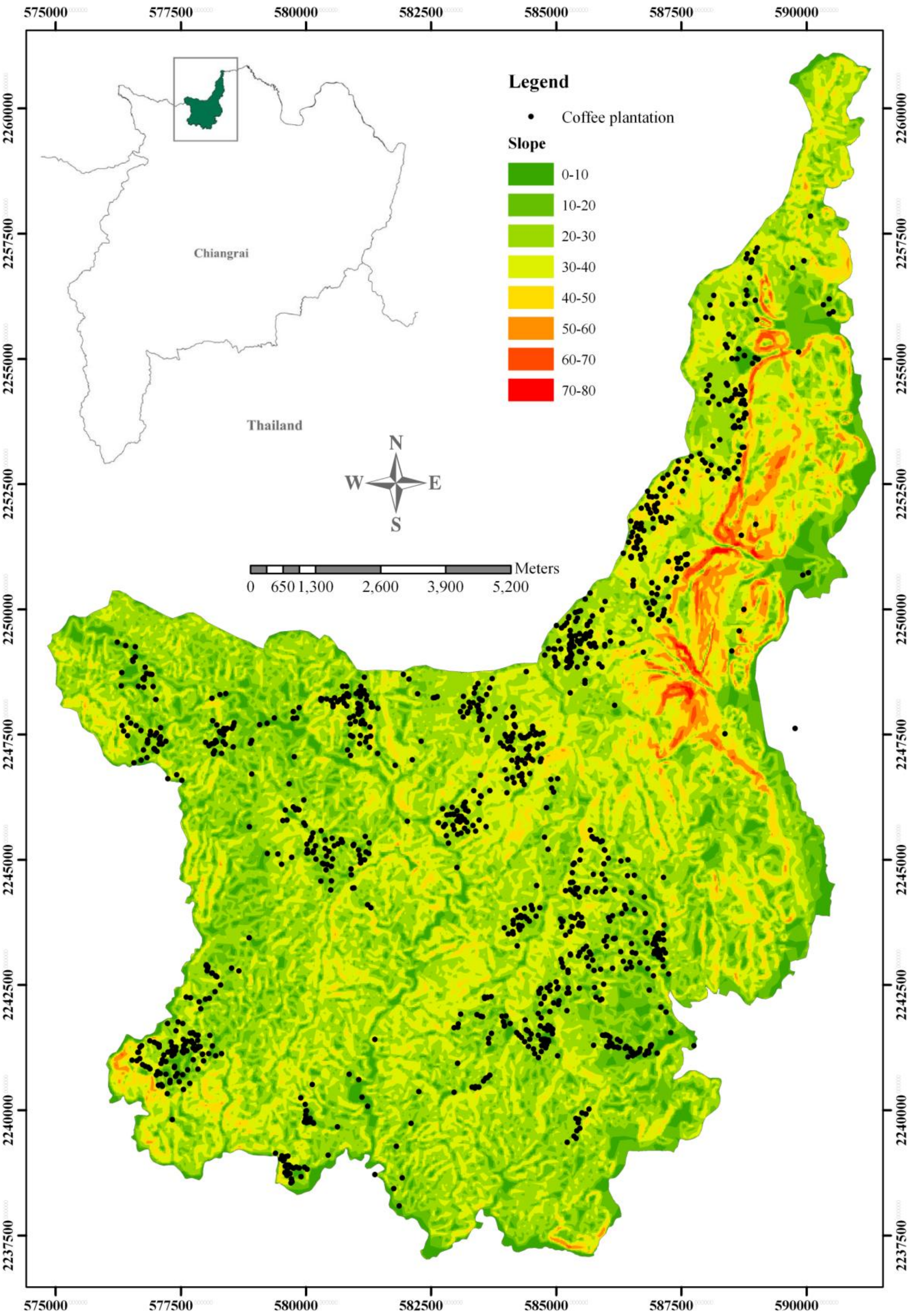


Figure 4.5 Distribution of *C. arabica* L. plantation at different slope in Doi Tung Development Project.

4.2.3 Shade trees

4.2.3.1 Diameter breast height; DBH

C arabica L. were growed under shade except in AM. The DBH of shade trees were highest in AS coverage diameter (28.30±15.56 cm.), (*p<0.05*) (Table 4.5), such as *Albizia chinensis* (Osbeck) Merr., *Aporusa villosa* (Wall. ex Lindl.) Baill and *Schima wallichii* (DC.) Korth., etc. (Table A1.5). The average diameter of AP shade trees was 27.87±13.46 cm., such as *P. kesiya* Royle ex Gordon, *Ficus semicordata* Buch.-Ham. ex Sm., *Litsea monopetala* (Roxb.) Pers. and *Prunus cerasoides* D.Don, etc. (Table A1.4) The crop plants in AC were *Litchi chinensis* Sonn., *Macadamia* sp. F. Muell., *Tamarindus indica* L., and *Camellia sinensis* (L.) Kuntze var. assamica (Mast.) Kitam., etc. and natural trees such as *Erythrina subumbrans* (Hassk.) Merr., *Paramichelia baillonii* (Pierre) Hu and *Fernandoa adenophylla* (Wall. ex G.Don) Steenis with the average diameter at 12.12±10.40 cm. (Table A1.6).

4.2.3.2 Height of shade trees

The height of trees were highest in AP (13.26±4.94 m., then AS (11.33±4.93 m.) and AC (3.76±3.05 m.), respectively (*p<0.05*) (Table 4.5).

4.2.3.3 Basal area (BA)

The basal area of shade trees were effected to dominate and density of *C. arabica* L. in the area, but the result showed that *C. arabica* L. in 4 different plantation systems were not significance different (*p>0.05*). AS had 44 pecies of shade trees with average 45.28±6.48 cm^2 BA, such as *Parkia sumatrana* Miq. ssp. streptocarpa (Hance)) Hopkins, *A. chinensis* (Osbeck) Merr., *A. villosa* (Wall. ex Lindl.) Baill, *Lagerstroemia venusta* Wall., and *S. wallichii* (DC.) Korth. (Table A1.5). AP had 13 species while average 23.75±8.00 cm^2 BA, such as *P. khasya* Royle, *F. semicordata* Buch.-Ham. ex Sm., *L. monopetala* (Roxb.) Pers., *Dillenia ovata* Wall. ex Hook. f. & Thomson and *Phyllanthus emblica* L. (Table A1.4). AC had 14 species with average 24.93±8.63 cm^2 BA, such as *E. subumbrans* (Hassk.) Merr., *P. baillonii* (Pierre) Hu, *L. chinensis* Sonn., *T. indica* L., *Macadamia* sp. F. Muell., *Citrus* sp., and *Artocarpus heterophyllus* Lam. (Table A1.6).

Tables 4.5 Vegetation characteristics in different plantation system in Doi Tung development project (Mean±SD)

Plantation system	Shade tree						Firewood			
	Number of Species	Diameter breast height (cm.)	High (m.)	Basal area (cm^2)	Density ($tree/m^2$)	Crown cover (%)	Number	Diameter (cm.)	Long (m.)	Volume (m^3)
AP	13	27.68±13.37^{a}	13.23±4.88^{a}	23.75±8.00^{ns}	0.01±0.01^{b}	83.17±9.86^{a}	3.54±0.76^{a}	5.43±1.11^{ns}	2.09±0.33^{a}	115.38±63.26^{ns}
AS	44	27.58±15.79^{b}	11.07±5.06^{a}	45.28±6.48^{ns}	0.02±0.01^{a}	74.83±14.18^{a}	6.74±0.88^{ab}	4.17±0.42^{ns}	1.30±0.12^{b}	97.31±40.44^{ns}
AC	14	11.83±10.11^{a}	3.66±2.86^{b}	24.93±8.63^{ns}	0.02±0.02^{a}	52.36±21.42^{b}	5.70±1.31^{b}	4.45±0.46^{ns}	1.43±0.16^{bc}	59.91±22.55^{ns}
AM	0	-	-	-	-	-	1.44±0.44^{ac}	3.75±0.52^{ns}	1.29±0.18^{bd}	18.48±4.70^{ns}

Remark : Data with different latter in the same column indicated a significant difference at 95 % level according to LSD test.

AP = *C. arabica* L. under *P. kesiya* Royle ex Gordon

AS = *C. arabica* L. under secondary forest trees

AC = *C. arabica* L. under crop plants

AM = *C. arabica* L. in monoculture system

4.2.3.4 Density

Density of tree in AS and AC were 0.02±0.01 and 0.02±0.02 trees/m^2, respectively (Table 4.5). AP was 0.01±0.01 trees/m^2 ($p<0.05$).

4.2.3.5 Crown cover

Crown cover of shade trees were effected to light intensity in the *C. arabica* L. plantation average crown cover in AP was 83.17%±9.86 (Table 4.5), AS was 74.83%±14.18 and AC was 52.36%±21.42 ($p<0.05$). These 3 systems were much lower in light intensity when compared to AM that had no shade trees.

4.2.4 Firewood

Shade trees in the *C. arabica* L. plantations were shade and decrease sun light for *C. arabica* L. The branches of them were used as firewood by the villages. In the 100 m^2 plots of AS had firewood 6.74±0.88 pieces. The average volume was 97.31±40.44 m^2/piece. AC had 5.70±1.31 pieces/plot (59.91±22.55 m^3/pieces). In this system, the fire woods were pruned after harvested. AP had .54±0.76 pieces/plot (115.38±63.26 m^3/pieces). The volume in this system was highest when compared to other systems because most of them were larger and longer than other. AM had 1.44±0.44 pieces/plot (18.48±4.70 m^3/pieces) (Table 4.5).

4.3 Soil nutrition content

4.3.1 Soil Reaction; pH

Soils in C. arabica L. plantations were little acid (Table 4.6). Soil pH in AS were lowest (4.57±0.67) and highest in AP (4.99±0.49) ($p<0.05$) while, AM and AC were 4.60±0.70 and 4.75±0.84, respectively.

4.3.2 Electrical Conductivity; EC

Electrical conductivity value in all coffee plantation systems were not significant different. AS was highest 385.76±173.06 dS/m, while AM, AP and AC were 350.01±174.94, 339.14±156.35 and 302.70±150.57 dS/m, respectively (Table 4.6).

Tables 4.6 Characteristic of soil characteristics in different *C. arabica* L. plantation systems (Mean±SD)

Plantation system	pH	EC (dS/m)	CEC (cmol/kg)	Soil water (%)	OM (%)	Total N (%)	Avail. P (mg/kg)	Exch. K (mg/kg)	Exch. Ca (mg/kg)	Exch. Mg (mg/kg)
AP	4.99 ± 0.49^{a}	339.14 ± 156.35^{ab}	23.75 ± 11.10^{a}	35.32 ± 8.85^{a}	2.72 ± 0.68^{ns}	0.21 ± 0.04^{ns}	110.20 ± 94.73^{a}	283.36 ± 149.32^{a}	$1,383.95 \pm 1,091.96^{ns}$	396.27 ± 274.73^{ns}
AS	4.57 ± 0.67^{b}	385.76 ± 173.06^{ab}	13.12 ± 2.98^{b}	30.30 ± 6.71^{b}	2.48 ± 0.68^{ns}	0.21 ± 0.09^{ns}	10.64 ± 1.89^{b}	236.16 ± 58.82^{ab}	977.33 ± 100.10^{ns}	243.48 ± 16.01^{ns}
AC	4.75 ± 0.84^{ab}	302.70 ± 150.57^{ac}	22.94 ± 0.21^{a}	31.28 ± 6.65^{bc}	1.92 ± 0.85^{ns}	0.26 ± 0.06^{ns}	57.48 ± 8.76^{ab}	291.43 ± 41.35^{a}	$1,200.27 \pm 110.00^{ns}$	404.00 ± 24.21^{ns}
AM	4.60 ± 0.70^{ab}	350.01 ± 174.94^{a}	12.09 ± 1.34^{b}	34.13 ± 7.59^{ac}	0.81 ± 0.62^{ns}	0.19 ± 0.03^{ns}	14.18 ± 3.45^{bc}	116.52 ± 10.75^{bc}	$1,359.79 \pm 446.97^{ns}$	153.79 ± 72.94^{ns}

Remark : Data with different latter in the same column indicated a significant difference at 95 % level according to LSD test.

AP = *C. arabica* L. under *P. kesiya* Royle ex Gordon

AS = *C. arabica* L. under secondary forest trees

AC = *C. arabica* L. under crop plants

AM = *C. arabica* L. in monoculture system

4.3.3 Cation Exchange Capacity; CEC

The cation exchange capacity in all plantation systems were high (Table 4.6). CEC in AP was 23.75±11.10 cmol/kg, while AC was (22.94±0.21 cmol/kg), AS and AM were 13.12±2.98 and 12.09±1.34 cmol/kg, respectively.

4.3.4 Soil water content

Soil water content was in AP (35.32%±8.85), while AM, AC and AS were to 34.13±7.59%, 31.28±6.65% and 30.30±6.71%, respectively (Table 4.6).

4.3.5 Organic Matter; OM

The variation in organic matter was high. The highest was AP (2.72%±0.68), while AS and AC were 2.48%±0.68 and 1.92%±0.85, respectively. The lower was matter in lowest level average be (0.81%±0.62) (Table 4.6).

4.3.6 Total Nitrogen; N

Total nitrogen was high in each plantation systems. The highest total was AC (0.26%±0.06), while AP, AS, and AM were 0.21%±0.04, 0.21%±0.09, and 0.19%±0.03, respectively (Table 4.6).

4.3.7 Available Phosphorus; Avail. P

Available phosphorus was higher in AP (110.20±94.73 mg/kg). AP was significant different with AS ($p<0.05$) (10.64±1.89 mg/kg), while AC and AM were 57.48±8.76 mg/kg and 14.18±3.45 mg/kg (Table 4.6).

4.3.8 Exchangeable Potassium; Exch. K

Exchangeable potassium in all plantation system were high (Table 4.6) which AC was 291.43±41.35 mg/kg, while AP, AS and AM were 283.36±149.32, 236.16±58.82, and 116.52±10.75 mg/kg, respectively.

4.3.9 Exchangeable Calcium; Exch. Ca

Exchangeable calcium was highest in AP (1,383.95±1,091.96 mg/kg), while AM, AC, and AS were 1,359.79±446.97, 1,200.27±110.00, and 977.33±100.10 mg/kg, respectively (Table 4.6).

4.3.10 Exchangeable Magnesium; Exch. Mg

Exchangeable magnesium was not significant different in all plantation systems. The highest was AC (404.00±24.21 mg/kg), while AP, AS, and AM were 396.27±274.73, 243.48±16.01, and 153.79±72.94 mg/kg, respectively (Table 4.6).

4.4 Yields of *C. arabica* L. in different plantation systems

Four *C. arabica* L. plantation systems age between 1 - 25 year olds were significant different in yields ($p < 0.05$). The highest was AC (1.90±1.40 kg/m^2 or 3,040.68±2,246.26 kg/rai), while AM, AS and AP were 3,006.15±2,426.73, 1,697.17±1,103.36 and 1,587.76±1,381.25 kg/rai, respectively (Table 4.7). The limiting factors that affected the quantity of coffee yields were diameter, height, growing space, density and number branches of coffee trees. In AC, the diameter of coffee trees were 5.68±1.60 cm, while the height were not significant different 1.88±0.46 cm., spacing and density of coffee trees were not significant different, 1.70±0.07 m. and 0.46±0.15 $tree/m^2$, respectively ($p > 0.05$). Number of branches were highest in AM (38.26±13.89 branches), while AC, AS, and AP were 37.62±19.33, 30.01±12.21, and 25.74±8.89, respectively.

The study showed that *C. arabica* L. yields were correlated $p < 0.05$ with DBH (AC >AM > AS > AP), Nitrogen (AC > AP,AS > AM), while the soil moisture content was highest in AP (Table 4.6) *C. arabica* L. was not prefix the high moisture content in the soil. This factor was affected to the coffee yields. The crown cover of the shade trees were highest in AP > AS > AC and no shade trees in AM (Table 4.5). The shade was affect to the growth rate of *C. arabica* L. that reduced the productivity of coffee fruits. Thus 50-60% of crown cover was suitable for growth and yields of *C. arabica* L.

Table 4.7 The relationship between characteristic of *C. arabica* L. trees and yields in different plantation systems (Mean±SD).

Plantation system	No. sample plot	Density of coffee ($tree/m^2$)	DBH (cm.)	High (m.)	Number of coffee branch	Yields (kg/m^2)	Yields (kg/rai)
AP	24	0.45±0.09 [ns]	3.58±0.82 [c]	1.75±0.43 [ns]	25.74±8.89	0.99±0.86 [b]	1,587.76±1,381.25 [b]
AS	62	0.47±0.16 [ns]	4.68±1.42 [b]	1.83±0.34 [ns]	30.01±12.21	1.06±0.69 [b]	1,697.17±1,103.36 [b]
AC	53	0.47±0.18 [ns]	5.68±1.60 [a]	1.86±0.32 [ns]	37.62±19.33	1.90±1.40 [a]	3,040.68±2,246.26 [a]
AM	41	0.41±0.11 [ns]	5.41±1.71 [ab]	2.06±0.69 [ns]	38.26±13.89	1.87±1.52 [a]	3,006.15±2,426.73 [a]

Remark : Data with different latter in the same column indicated a significant difference at 95 % level according to LSD test.

AP = *C. arabica* L. under *P. kesiya* Royle ex Gordon

AS = *C. arabica* L. under secondary forest trees

AC = *C. arabica* L. under crop plants

AM = *C. arabica* L. in monoculture system

4.5 Economic

4.5.1 Costs

From analyzed secondary data *C. arabica* L. plantation in Doi Tung Development Project, showed that *C. arabica* L. was grained yields in the third years. The costs of growing *C. arabica* L. was analyzed between first and third years. The cost of planting *C. arabica* L. was separated into seedling, preparation, fertilizer and labor that compose of clear and plantations, weeding and harvesting. Weeding was applied in the first year, while applied in the third years.

The cost of lead and seedling preparation was high in the first and third years, respectively due to the cost in the first year and labor harvesting in the third years (Table 4.8). The most expenses were seedling preparation and fertilizer were highest cost in *C. arabica* L. plantation. The cost of *C. arabica* L. plantation was highest in AP (12,360.38±1,487.98 baht/rai) then, AM, AS, and AC (8,442.31±975.57, 6,963.24±1,412.02 and 6,376.78±1,176.53 baht/rai, respectively).

4.5.2 Benefits

The Benefits of *C. arabica* L. plantation included coffee yields and other plant production such as lichee, tea tree, firewood, bark, etc. *C. arabica* L. was sale fresh fruits and dry fruits. The price of dry fruits was higher than fresh fruits. The income of fresh fruits and dry fruits were highest in AP 28,744.08±1,695.40 baht/rai in dry fruits and 25,177.06±14,535.98 baht/rai in fresh fruits, Table 4.9. When AM was 12,087.23±6,978.57 baht/rai in dry fruits and 7,263.73±4,193.71 baht/rai in fresh fruits. While, AS was 10,616.84±6,129.64 baht/rai in dry fruits and 6,358.64±3,671.16 baht/rai in fresh fruits. AC was 8,563.71±4,944.26 baht/rai in dry fruits and 5,397.44±3,116.21 baht/rai in fresh fruits.

The filtration sells coffee yields in which form that has Opportunity Cost was highest benefits will be receive from sale coffee yields in other form. In AP sale fresh fruits and dry fruits, if agriculturist chooses to sell in fresh fruits they has opportunity cost 28,744.08 baht/rai, but choose sell dry fruits they has opportunity cost 25,177.06 baht/rai. Therefore if want high benefits should choose has least opportunity cost, in this case was sale coffee yields in dry fruits.

Table 4.8 Cost of *C. arabica* L. plantation systems between 1and 3 years (Mean±SD).

Plantation systems	Cost (Baht/rai)						
	Years	Seedling	Fertilizer	Labor			Total Cost
				Clear and Planting	Weeding	Harvesting process	
AP	1	2,844.26±219.79	1,469.47±158.86	403.67±145.85	403.67±145.85	0.00±0.00	5,121.07±458.14
	2	347.49±73.97	1,659.08±179.36	0.00±0.00	403.67±145.85	0.00±0.00	2,410.24±254.40
	3	171.34±51.62	3,167.22±1,249.40	0.00±0.00	403.67±145.85	1,086.83±281.92	4,829.07±1,204.50
	Total	**3,363.09±1,494.96**	**6,295.77±930.30**	**403.67±233.06**	**1,211.01±0.00**	**1,086.83±627.48**	**12,360.38±1,487.98**
AS	1	2,934.00±436.87	579.80±93.23	205.76±85.76	205.76±85.76	0.00±0.00	3,925.33±508.25
	2	191.29±55.58	869.70±139.85	0.00±0.00	205.76±85.76	0.00±0.00	1,266.76±197.43
	3	11.97±3.42	1,210.17±189.39	0.00±0.00	205.76±85.76	343.26±182.79	1,771.16±336.80
	Total	**3,137.26±1,637.73**	**2,659.66±315.52**	**205.76±118.80**	**617.29±3.48**	**343.26±198.18**	**6,963.24±1,412.02**
AC	1	2,349.59±292.87	611.66±75.90	206.30±72.08	206.30±72.08	0.00±0.00	3,373.84±323.43
	2	137.59±48.19	693.21±86.02	0.00±0.00	206.30±72.08	0.00±0.00	1,037.10±112.80
	3	52.63±18.88	1,020.55±170.05	0.00±0.00	206.30±72.08	686.36±224.77	1,965.83±332.90
	Total	**2,539.81±1,302.32**	**2,325.42±216.41**	**206.30±119.11**	**618.89±0.00**	**686.36±396.27**	**6,376.78±1,176.53**
AM	1	2,168.00±234.39	1,119.92±144.73	154.58±89.56	154.58±89.56	0.00±0.00	3,597.07±465.75
	2	297.40±70.30	1,269.24±164.03	0.00±0.00	154.58±89.56	0.00±0.00	1,721.22±251.88
	3	67.69±31.98	1,312.93±135.09	0.00±0.00	154.58±89.56	1,588.83±909.62	3,124.02±989.89
	Total	**2,533.09±1,152.04**	**3,702.08±101.21**	**154.58±89.25**	**463.74±0.00**	**1,588.83±917.31**	**8,442.31±975.57**

Table 4.9 Benefit of *C. arabica* L. plantation systems between 1and 3 years (Mean±SD).

Plantation systems	Years	Benefit (Baht/rai)				
		Fresh fruits	Dry fruits	Other plants	Fresh & others	Dry & others
AP	1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	2	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	3	25,177.06±10,904.36	28,744.08±13,950.36	0.00±0.00	0.00±0.00	0.00±0.00
	Total	**25,177.06±14,535.98**	**28,744.08±1,695.40**	**0.00±0.00**	**0.00±0.00**	**0.00±0.00**
AS	1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	2	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	3	6,238.64±1,194.30	10,496.84±2,009.88	120.00±120.00	6,358.64±1,171.85	10,616.84±1,984.99
	Total	**6,238.64±3,601.88**	**10,496.84±6,060.35**	**1,800.00±1,039.23**	**6,358.64±3,671.16**	**10,616.84±6,129.64**
AC	1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	2	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	3	4,799.91±621.88	7,966.19±1,099.32	597.53±274.46	5,397.44±760.88	8,563.71±1,212.53
	Total	**4799.91±2,771.23**	**7,966.19±4,599.18**	**1,643.19±948.70**	**5,397.44±3,116.21**	**8,563.71±4,944.26**
AM	1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	2	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	3	7,263.73±1,258.58	12,087.23±2,188.01	0.00±0.00	0.00±0.00	0.00±0.00
	Total	**7,263.73±4,193.71**	**12,087.23±6,978.57**	**0.00±0.00**	**0.00±0.00**	**0.00±0.00**

4.5.3 Economic Cost-Benefit

Economic cost-benefit analysis was use to compare the investment of 4 *C. arabica* L. plantations by use Net present value (NPV) the making profit, and Cost-benefit ratio (B/C ratio) to analyze of the production efficiency in berry fruits and dry fruits (Table 4.10).

The Net Present Value (NPV) of fresh fruits were 10,108.26±10,026.54 in AP, -1,449.57±595.29 in AM, -978.00±1,139.23 in AS, and -1,224.65±700.76 in AC, while dry fruits were 13,103.20±12,066.08 in AP, 2,600.34±833.77 in AM, 2,596.46±1,694.72 in AS and 1,433.82±945.48 in AC. Benefit-Cost ratio (B/C ratio) of fresh fruits were 3.05±1.61 in AP, 0.84±0.08 in AM, 0.95±0.21 in AS, and 0.85±0.14 in AC, while dry fruits were 2.73±1.61 in AP, 1.37±0.13 in AM, 1.59±0.35 in AS, and 1.32±0.20 in AC.

The profit of *C. arabica* L. plantation was highest in AP, AM, AS, AC, respectively. Even the cost of AP was highest in the first years. Opportunity cost for choose to grow *C. arabica* L. in each different plantations by consider from NPV of *C. arabica* L. in dry fruits. If choose AP that has opportunity cost 2,600.34, choose AS has opportunity cost 13,103.20, choose AC has opportunity cost 13,103.20 and choose AM has opportunity cost 13,103.20. Therefore should choose invest AP because, has least opportunity cost.

4.6 Management

C. arabica L. plantations in Doi Tung Development Project were not only improved the quality of the local communities, but they also evaluated the cost and benefit of developed *C. arabica* L. plantation systems on natural resources and environment in area. Managing the coffee plantations had been concerned on the environmental factors, natural resources, environmental conservation, and the impacts on the local communities. Organizations more important to develop the economic and socials.

Table 4.10 Net present value and Benefit-Cost ratio of *C. arabica* L. plantations between 1 and 3 years (Mean±SD).

Plantation Systems	Years	PV of Cost	PV of Benefit		NPV		B/C ratio	
			Berry	Dry	Berry	Dry	Berry	Dry
AP	1	4,831.20±432.21	0.00±0.00	0.00±0.00	**10,108.26±10,026.54**	**13,103.20±12,066.08**	**3.05±1.61**	**2.73±1.61**
	2	2,145.11±226.42	0.00±0.00	0.00±0.00				
	3	4,054.58±1,011.32	21,139.15±9,155.51	24,134.08±11,712.99				
	Total	**11,030.89±1,189.07**	**21,139.15±12,204.69**	**24,134.08±13,933.82**				
AS	1	3,703.14±479.48	0.00±0.00	0.00±0.00	**-978.00±1,139.23**	**2,596.46±1,694.72**	**0.95±0.21**	**1.59±0.35**
	2	1,127.41±175.72	0.00±0.00	0.00±0.00				
	3	1,487.10±282.78	5,338.84±983.91	8,914.10±1,666.64				
	Total	**6,317.64±792.31**	**5,338.84±3,082.38**	**8,914.10±5,146.56**				
AC	1	3,182.87±305.12	0.00±0.00	0.00±0.00	**-1,224.65±700.76**	**1,433.82±945.48**	**0.85±0.14**	**1.32±0.20**
	2	923.02±100.39	0.00±0.00	0.00±0.00				
	3	1,650.55±279.51	4,531.79±638.85	7,190.26±1,018.06				
	Total	**5,756.44±512.56**	**4,531.79±2,616.43**	**7,190.26±4,151.30**				
AM	1	3,393.47±439.38	0.00±0.00	0.00±0.00	**-1,449.57±595.29**	**2,600.34±833.77**	**0.84±0.08**	**1.37±0.13**
	2	1,531.88±224.17	0.00±0.00	0.00±0.00				
	3	2,622.98±831.13	6,098.76±1,056.73	10,148.67±1,837.10				
	Total	**7,548.33±1,354.20**	**6,098.76±3,521.12**	**10,148.67±5,859.34**				

The environmental factors such as elevation, slope, pH, EC, CEC, MC, OM, N, P, K, Ca and Mg. Species of shade trees, measured DBH of shade trees, height, and crown cover (Figure 4.6) were to evaluate the appropriated plantation system restoration and improved the natural resources and environment with economics retuned. Coffee yields direct value on coffee miner forest products such as food plants and fire woods, etc. were added in economic value to identify the most appropriated management of coffee in Doi Tung Development Project.

C arabica L. plantations in Doi Tung Development Project were not significant different in management straeg. In high slope, *C arabica* L. plantations were applied on the row along the same elevation. This system was suitable to conservation of soils and waters. Managed and harvested of the coffee trees and yields were suitable by growed in this system. Keep shade trees in the plantations were increased the growth rate of coffee under shade. This system was also decreased the pesticides and fertilizers application had been applied in the area.

All *C. arabica* L. plantation systems had grain and loss on environment, economics, and socials, which different problems. AC had highest yields but could not restore the natural resources and environment. Planted *C. arabica* L. in the agroforestry system were affective, while natural resource and land use in the area. AP and AS already applied appropriated to use in the project area to improve the economics and standard of living.

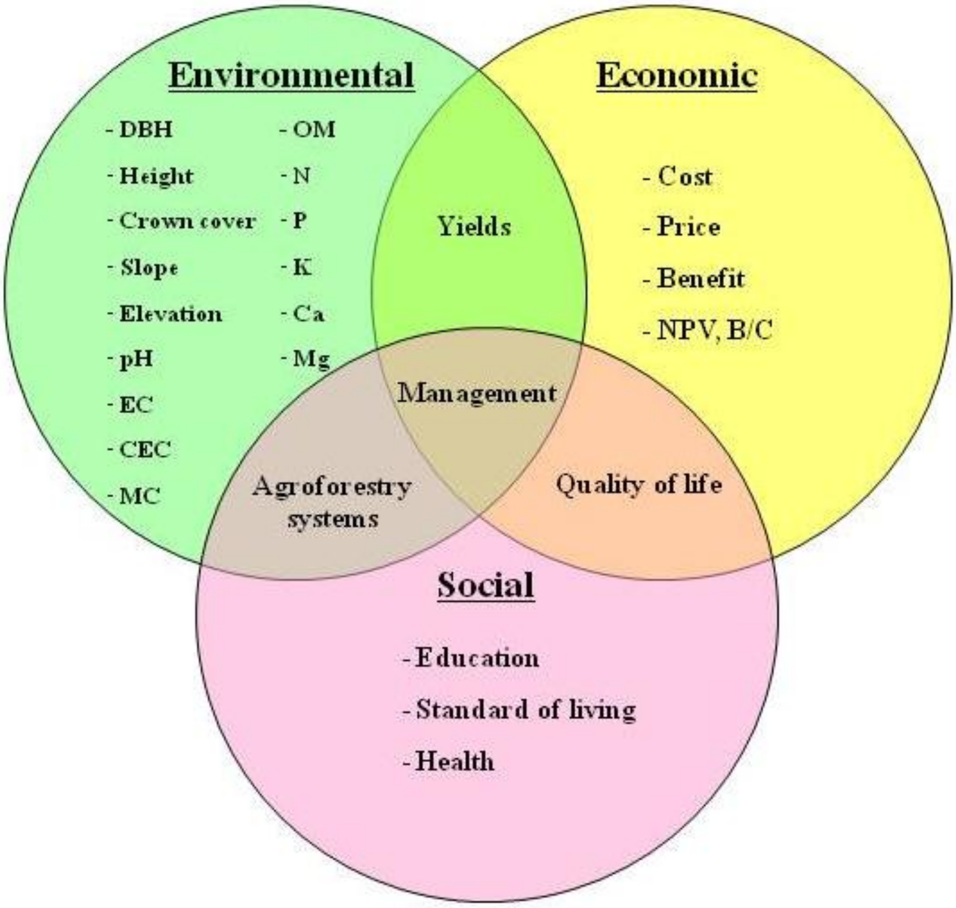


Figure 4.6 Integrated environment, economics and social in management plan of *C. arabica* L. plantation in Doi Tung Development Project.

CHAPTER V
DISCUSSION

5.1 Distribution of *Coffea arabica* L. plantations

Coffee plantation in Doi Tung Development Project were classified into 4 systems; 1) *C. arabica* L. under *Pinus kesiya* Royle ex Gordon forest plantation (AP); 2) *C. arabica* L. under secondary forest trees (AS); 3) Cultivation *C. arabica* L. under crop plants (AC); and 4) *C. arabica* L. in monoculture (AM). This studied was similar to studied of Theeradaj et al. (42) which classified into 2 systems, 1) monoculture, and 2) multicultural. The multicultural could divides into several systems such as coffee with forest trees, coffee with tea trees and forest trees, and coffee with crop plants.

5.2 Environmental factors in *C. arabica* L. plantations

Doi Tung Development Project was located in the elevation between 400 and 1,509 m MSL average precipitation was 2,075.2 mm./yr., average humidity was 80.9%, Temperature was 22.9 $^{\circ}$C. These environmental factors were suitable for *C. arabica* L. (5, 6 and 14). The slope was range between 0% and 80%. The water and soil erosion controls were important protected the coffee plantations (6).

Shade trees were important to decrease the light concentration. AP had highest in crown cover of shade trees, even lower in number of trees species, basal area, density than AP, twenty year olds *P. kesiya* Royle ex Gordon plantation was cultivated systematically. Three trees had same height (15.22±4.04 m.), and wide range and dent canopy with natural trees. The concentration of light under the canopy were low. While average tree height in AS was lower than AP. Species diversity was high in AS, but range branches were not wide and asymmetry. The gap between natural trees high. The light density in AS was higher than AP, but lower than other systems. This result was similar to studies of Perfecto et al. (43) found that forest trees could reduced the light 71-100%, while multiple crop plants with different layers were 31-70%, and monoculture do not have shade.

5.3 Soil nutrition content

All plantation systems were suitable for cultivate *C. arabica* L. which in the range between 4.5 and 5.5 (6). AP has higher moisture content than other systems, because most of them were located in the high elevation and humidity.

Total Nitrogen; N

Total Nitrogen in the soils (N) in all *C. arabica* L. plantations were high, between 0.19±0.03% and 0.26±0.06%, especially in AC because the villager had been applied the fertilizer to their crop plants. These N had been remeaned in the soils. *C. arabica* L. could take advantaged on these fertilizers. In AP and AS, the N was dramatical high. These N was decomposed from the leaves litter of shade trees. *C. arabica* L. in shade trees required low N because the growth rate was low. This was cause the effect to the quantity of coffee yield growed under shade trees even the N was high. In AM, the growth rate and coffee yields of *C. arabica* L. was higher than other systems. In this system, coffee may require much more N. The villager had to apply the high volume of N to prevent the lack of nutrition and die back (6).

Available Phosphorus; Avail. P

Available Phosphorus was moderate to high concentration in soil in all systems. There amount enough for *C. arabica* L. to grow because *C. arabica* L.was require the small amount of P (6).

Exchangeable Potassium; Exch. K

Exchangeable potassium concentration soil was high to very high, especially in AC. Potassium was limited fertilizer. In the *C. arabica* L. plantation will require much more K applied to the coffee trees. Potassium requirement depends on age of coffee. Young *C. arabica* L. plantations were required less K, while required much more N. The lack of K will be appearing when the growth rate and coffee yields were high. High K concentration will affect to exchangeable Mg. While high Mg concentration will affect to K concentration. These two elements had chemical reaction to each other (6).

Exchangeable Calcium; Exch. Ca

Exchangeable calcium in soil were inverse to pH the AP contained highest in the soils and had low acidity. The lowest Ca was found in AS with high acidity. *C. arabica* L. required small amount of Ca. In Doi Tung Development Project, Ca concentration was enough for coffee to develop. If Ca are to high it will be affect to the exchangeable K and Mg in the soils (6).

5.4 Yields of *C. arabica* L. in different plantation systems

Coffee yields in Doi Tung Development Project were higher in AC and AM. Than other systems Campanha et al. (28) reported that Arabica coffee in monoculture system higher yields and growth better than agroforestry system. While Perfecto et al. (44) reported that the percentage of shade cover was related to species density and shade tree richness which opposite with coffee yields. If percentages of shade cover or shade tree richness, coffee yields will low. Lagemann and Heuveldop (45) report that high shade cover was gave the negative affect to coffee yields. The coffee outside the shade could gave the higher yields than beneath the shade system. However coffee yields were not depended on only one factor, because every factors were related.

5.5 Economic

C. arabica L. plantation in Doi Tung development project area was owned by the hill tribes in the small area. This was a factor that affected the development of *C. arabica* L. plantation to increase yields and profits. Profit mean positive turn over (turn over=output-input) which, depend on varied factors such as capital, size of plantation area, labor cost, transportation, market, policy and extension service (6).

AP had lowest yield, but highest in profit. The villager who grow coffee in AP was increased their profit by sold dry coffee fruits that had higher price than sold in fresh fruits. These villagers were work as a more 11.10±7.11 rai per person in AP has cooperative society to transfer the knowledge on cultivation management, production, preservation and marketing. While AC was lest profit because of management practices, soil nutrition, quality of coffee yields and the affect of crop plants.

5.6 Management

Arabica coffee plantation in AP and AS are appropriate to be apply in the Doi Tung Development Project. These result similar to the *C. arabica* L. growth beneath the 4 species of shades trees such as *P. kesiya* Royle ex Gordon, *Prunus mume* Siebold & Zucc., and wild apple. Coffee yields were highest under pine trees because pine tree root had several *Mycorrhiza* spp. These fungus could increased soil moisture content.

Pine trees were evergreen trees leaves were green for all year round, when other shade their leave in dry season. The quality of *C. arabica* L. under shade trees was mature and harvest longer than outside the shade and had higher quality (6). The long term benefit of grow coffee under shade trees could increase the forest area in the future, especially in the multilayer trees. These systems could increase the humidity, fertility, and soil nutrition for coffee production. Vaast et al. (46) suggested that shade was a key factor on sustainable coffee production and quality. The effect of shade could include the growth rate, carbon exchange, disease and insect resistant of coffee, when compete with shade trees (47). Shade was an important factor for coffee plantation in the agroforestry system. Bosselmann et al. (48) reported that, high elevation and shade were affected or taste and quality of coffee. Low elevation was decreased the immature fruits and caused the effect to the coffee yields.

Alvarado et al. (33) reported that high diversity species which have many cover level gave lower yields than in the monoculture system, but they were high in organic matter and related to total nitrogen in soil. Future more agroforestry was decreased soil erosion (49). Roose and Ndayizigiye (23) reported that agroforestry system could protect the soil erosion and losses of soil nutrition. Beer et al. (50) suggested that coffee in agroforestry system could protect soil erosion in the short and long term. Sanchez, P.A. (51) reported that agroforestry system can decrease soil erosion in short and long term. The covers of humus could decrease soil erosion in to 95% when compared to the open area. Thus soil cover was important to apply the soil erosion control technology in agroforestry systems.

Young (24) suggest that, the agroforestry was an advantage system to increase the income, food, and energy with minimized environment effect while, Oijen et al. (52) found that, coffee in agroforestry or shade tree system was gave the high yields of coffee, consuming and product to sell. High other benefits from agroforestry system were firewood and timbers. When decreases the density of shade tree in the system, coffee yields will be increase but the wood and the nature will be disappear (53). Kajomulo-Tikaijuka (54) reported that wood products under shade tree had low capital with high value of fruit, trunk, branch, and firewood. In this study, the result showed that planted *C. arabica* L. in agroforestry system (AP and AS) could improved the environment system when compare to the higher coffee yields in the unshade system (Figure 5.1)

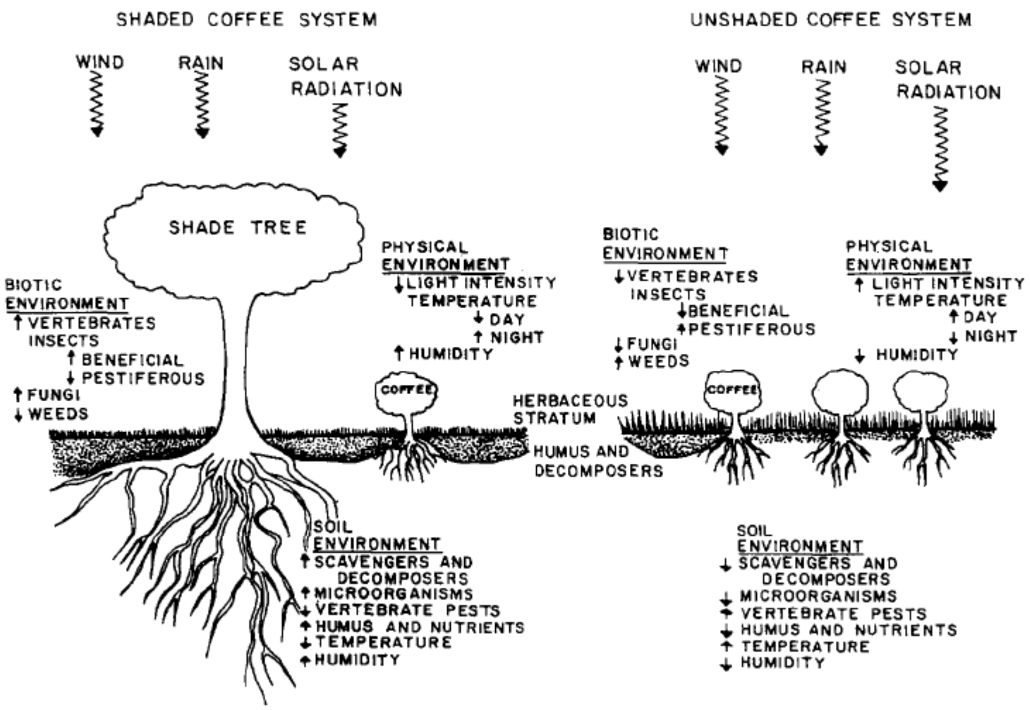


Figure 5.1 Biotic and abiotic environments in shaded and/or unshaded coffee ecosystems. ↑ enhanced or increased; ↓ inhibited and/or reduced (55).

The applying the agroforestry system with *C. arabica* L. was ensure the conservation could cause the balance of the environment and sustainable of the crop production and ecosystem services. Plucknet (56) reported that, the success of resource management for human utilization was to conserve the quality of environment and the natural resources at the same time. Natural resources management must give balance ecology. The principle environment manages for sustainable must have analysis system for assess status of ecology and framework defensive and develop by consider efficiency of ecology have work correspond be ecology works normal there is balance, ecology system no affect to environment and human. Environment management is relationship in system can work (57), be applying sustainable advantage must consider to natural resources and environment, economic and social can proceed go together get then will sustainability (58).

Limitation of agroforestry system was suggested by Huijun and Padoch (59) that agroforestry system development could not supported rapid growth of people, market, and the agricultural policies. However agroforestry system not changes just in some area that has managed with this system only, but agroforestry system develops and change generally area. There for, the development of agroforestry system in Doi Tung Development project could increase the forest development but effect to the growth rate of coffee for this problem. Craswell et al. (60) suggest that in the highland or steep area, the sustainable of the agriculture system had to be balance with the indirect value of soil and water conservation.

CHAPTER VI
CONCLUSION

6.1 Distribution of *Coffea arabica* plantations

Coffee plantation from village most distances during 250-500 m., next be 500-750 m. and 0-250 meters, respectively. AP system meet very at altitude during 1,200-1,400 m., AS system meet very at 800-1,000 m. levels like AC system and AM system meet very at 1,000-1,200 m.

6.2 Environmental factors

Shade tree cover

AP system have crown cover most be average 83.17±9.86 %, next be AS system (74.83±14.18 %), AC system (52.36±21.42 %) and AM system have not shade tree cover.

Firewood

In area 100 square meter AS system there is firewood average most 6.74±0.88 pieces, next be AC system have firewood 5.70±1.31 pieces, AP system have firewood 3.54±0.76 pieces and AM system have firewood 1.44±0.44 pieces.

6.3 Soil nutrition content

Soil Reaction; pH

Soil in AS system be acid most pH value 4.57±0.67, next soil in AM and AC system have pH value average 4.60±0.70 and 4.75±0.84, respectively. Soil in AP system is acid little more than other systems have pH value 4.99±0.49.

Electrical Conductivity; EC

Soil in AS system have electrical conductivity most average 385.76±173.06 dS/m, next be AM, AP and AC systems has EC average value 350.01±174.94, 339.14±156.35 and 302.70±150.57 dS/m, respectively.

Cation Exchange Capacity; CEC

Soil in AP system cation exchange capacity most have average value 23.75±11.10 cmol/kg, next be AC system have CEC average value 22.94±0.21 cmol/kg, AS and AM system has CEC average value 13.12±2.98 and 12.09±1.34 cmol/kg, respectively.

Soil water content

AP system there is soil moistness most average 35.32±8.85 %, next be AM, AC and AS system has soil moistness average 34.13±7.59 %, 31.28±6.65 % and 30.30±6.71 %, respectively.

Organic Matter; OM

AP system there is organic matter in soil most average 2.72±0.68 % next be AS and AC system there are organic matter average 2.48±0.68 % and 1.92±0.85 %, respectively. AM system have organic matter in low level average 0.81±0.62 %.

Total Nitrogen; N

Soil in AC system there is total nitrogen highest 0.26±0.06 % which in very high-level, next be AP, AS and AM systems there are total nitrogen average 0.21±0.04 %, 0.21±0.09 % and 0.19±0.03 %, respectively.

Availlable Phosphorus; Avail. P

Soil in AP system there is available phosphorus very high average 110.20±94.73 mg/kg, next be AC system have avail. P average 57.48±8.76 mg/kg, AM systems have avail. P average 14.18±3.45 mg/kg, and soil in AS system there is avail. P least average 10.64±1.89 mg/kg.

Exchangeable Potassium;Exch. K

Soil in AC system there is exchangeable potassium highest average 291.43±41.35 mg/kg, next be AP and AS systems there are exch. K average 283.36±149.32 and 236.16±58.82 mg/kg, respectively. Soil in AM system has exch. K least average 116.52±10.75 mg/kg.

Exchangeable Calcium; Exch. Ca

Soil in AP system there is high exchangeable calcium average 1,383.95±1,091.96 mg/kg, next be AM, AC and AS systems there are exch. Ca average 1,359.79±446.97, 1,200.27±110.00 and 977.33±100.10 mg/kg, respectively.

Exchangeable Magnesium; Exch. Mg

Soil in AC system there is exchangeable magnesium highest average 404.00±24.21 mg/kg, next be AP, AS and AM systems there are exch. Mg average 396.27±274.73, 243.48±16.01 and 153.79±72.94 mg/kg, respectively.

6.4 Yields

AC system have highest coffee yields average 1.90±1.40 kg/m^2 or 3,040.68±2,246.26 kg/rai, next be AM, AS and AP systems there are coffee yields 3,006.15±2,426.73, 1,697.17±1,103.36 and 1,587.76±1,381.25 kg/rai, respectively.

6.5 Economic

Cost

The cost of *C. arabica* L. plantations between 1 and 3 years found that, AP > AM > AS > AC, respectively. 12,360.38±1,487.98 baht/rai in AP, 8,442.31±975.57 baht/rai in AM, 6,963.24±1,412.02 baht/rai in AS, and 6,376.78±1,176.53 baht/rai in AC.

Benefits

The benefits of sale fresh fruits and dry fruits in different *C. arabica* L. plantation systems found that AP > AM > AS > AC, respectively.

Economic Cost-Benefit analysis

The Net Present Value (NPV) and Benefit-Cost ratio (B/C ratio) of *C. arabica* L. plantation systems found that AP > AM > AS > AC, respectively.

6.6 Management

C. arabica L. cooperate with *P. kesiya* Royle ex Gordon forest system (AP) has suitability for consider to coffee plantation management in area, second be *C. arabica* L. cooperate with secondary forest trees system (AS) because 2 systems gives many coffee yields, besides condition factors that affect coffee yields for example crown covers affects to shade and sunlight quantity. In two coffee plantation system have many tree, large size and height, soil macro nutrient and micro nutrient include moistness and organic matter in soil rather high.

Unless Arabica coffee that get wood from tree in system to firewood which two systems has many amount and capacity firewood, many economical benefits Thus two coffee plantation systems coffee yields, economical benefits and shade tree and natural resources produce in systems, and advantage to agriculture development goes to forest area expansion together, which be advantage management for development in natural resources, environment, economy and social be sustainable management in long time.

Suggestions for *C. arabica* L. plantation management in Doi Tung Development Project under Royal Initiative.

1. Study area state for planting *C. arabica* L., the planting areas character must have factor provides to growth of coffee, such as landform, soil nutrient, slope, rainfall, and shade trees, etc.

2. From result, some slope areas has management. If encourage and give the management knowledge, such as doing step, trail lets off the water, or growing cover plants, etc. Would to help decrease erosion of ground surface, let off the water, protect coffee tree damage from erosion, convenience in maintenance, and harvest coffee produce.

3. *C. arabica* L. plantation should has shade trees for decreases light quantity that shines to ground, but if has shade too much, might affect to coffee produce. Thus should have shade covers about 50-60 %. If has densely shade trees makes to high crown cover should slitting decorates some branch for light can shine to ground of *C. arabica* L. plantation.

4. Study soil nutrient affects to preservation, fertilizer to coffee tree. If has high necessity nutrient for growth of coffee, such as N, P, K, Ca, and Mg, do not have to apply fertilizer to soil again, will make to high cost of production go up.

5. *C. arabica* L. in monoculture can manage to sgroforestry system, by grow other trees inside plot, such as local forest tree or other crop plants. *C. arabica* L. plantation management to agroforestry system has variety of produce more than monoculture and give indirect advantage to environment, community, and social.

6. *C. arabica* L. in agroforestry is grow system then social and agriculturist should allocate the resource in production too much go up, in *C. arabica* L. in agroforestry that system should emphasize to give the agriculturist has freedom in filtration does production are appropriate readiness state of production factor in local area, should perform in arrangement seeks news information, fund, and marketing gives to agriculturist.

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APPENDIX

Table A1.1 Climate data between 1992 and 2008 from Doi Tung Weather Station at 750 m. MSL.

Year	Air Temperature (°C)			Humidity	Rainfall
	Max	Min	$\overline{X}$	(%)	(mm.)
1992	26.4	19.1	22.8	73.3	1,536.9
1993	26.8	19.6	23.2	77.9	1,683.7
1994	27.1	19.7	23.4	79.2	2,517.1
1995	27.3	19.1	23.2	82.6	2,440.5
1996	26.6	19.1	22.9	81.9	2,807.3
1997	27.2	16.6	21.9	78.9	1,871.6
1998	30.9	16.0	23.4	78.4	1,827.4
1999	26.7	15.4	21.0	83.5	2,289.3
2000	26.6	16.3	21.4	85.0	1,844.3
2001	26.9	17.3	22.1	85.0	2,022.6
2002	26.8	17.9	22.4	86.1	2,388.3
2003	27.6	18.5	23.1	84.0	1,887.1
2004	27.5	17.8	22.6	82.0	2,434.4
2005	26.6	17.6	22.1	81.6	1,694.5
2006	26.5	16.5	21.5	83.0	2,161.2
2007	26.2	17.7	21.9	79.8	2,253.8
2008	43.2	18.4	30.8	83.3	1,618.0
AV	**28.1**	**17.8**	**22.9**	**81.5**	**2,075.2**

Source: Doi Tung Development Project (2009)

Table A1.2 *C. arabica* L. plantation in Doi Tung development project in 2006.

	Village/Site	No. farmer	No. of coffee tree	Areas (rai)	Areas (m^2)
1	Baan Huai Nam Khun	6	6,900	18	28,800
2	Baan Huai Rai Sa Makkhi	3	4,370	11	17,600
3	Baan Pa Kha	21	69,570	174	278,400
4	Baan Si Luang	4	2,450	7	11,200
5	Baan Kha Yeng Phatthana	40	36,950	93	148,800
6	Baan Luhu Pa Kluai	16	46,500	116	185,600
7	Baan Akha Pa Kluai	73	378,394	946	1,513,600
8	Baan Lahu La Ba	28	85,880	215	344,000
9	Baan Cha Lo	30	49,640	124	198,400
10	Baan Sa Makkhi Kao	10	28,380	71	113,600
11	Baan Pa Sang Na Ngoen	27	27,365	69	110,400
12	Baan Sa Makkhi Mai	13	6,150	16	25,600
13	Ban Suan Pa	19	92,105	231	369,600
14	Baan Huai Pu Mai	11	7,050	10	16,000
15	Baan Pa Sang Saen Sut Dan	26	30,950	78	124,800
16	Baan Pa Yang Lahu	24	36,200	91	145,600
17	Baan Pa Yang Akha	28	41,710	105	168,000
18	Baan Pang Nun Phatthana	19	29,184	73	116,800
19	Baan Pha Bue	21	73,800	185	296,000
20	Baan Huai Nam Rin	3	2,080	6	9,600
21	Baan Lahu Pha Hi	22	86,900	218	348,800
22	Baan San Pa Sak	22	62,650	157	251,200
23	Baan Pang Pra Ratchatan	1	1,100	3	4,800
24	Navuti Site 1	11	48,504	110	176,000
25	Navuti Site 2	35	97,357	533	852,800
26	Navuti Site 3	9	16,820	104	166,400
27	Navuti Site 4	22	42,744	258	412,800
28	Navuti Site 6	12	55,750	136	217,600
	Total	**556**	**1,467,453**	**4,158**	**6,652,800**

Remark : Average 400 coffee trees in 1 rai (2×2 m.)

Source: Navuti Co. Ltd. (2009)

Table A1.3 *C. arabica* L. yields in Doi Tung Development Project between 2007 and 2008.

Village / site		*C. arabica* L. Yields (kg.)	
		2007	**2008**
1	Baan Huai Nam Khun	787	901
2	Baan Pa Kha	3,029	3,946
3	Baan Si Luang	266	235
4	Baan Kha Yeng Phatthana	8,830	7,179
5	Baan Luhu Pa Kluai	26,218	20,503
6	Baan Akha Pa Kluai	234,508	241,697
7	Baan Lahu La Ba	38,691	30,751
8	Baan Cha Lo	14,237	8,381
9	Baan Pa Sang Na Ngoen	18,142	15,157
10	Baan Sa Makkhi Kao	5,036	5,797
11	Baan Pa Yang Akha	18,321	25,014
12	Baan Pa Yang Lahu	8,502	9,024
13	Baan Pha Bue	32,943	11,226
14	Baan Huai Pu Mai	712	1,221
15	Baan Pa Sang Saen Sut Dan	24,575	18,801
16	Baan Pang Nun Phatthana	34,082	25,812
17	Ban Suan Pa	8,499	6,105
18	Baan Lahu Pha Hi	113,577	20,671
19	Baan San Pa Sak	20,711	11,736
20	Navuti Site 1	48,622	42,972
21	Navuti Site 2	154,379	125,244
22	Navuti Site 3	25,654	32,129
23	Navuti Site 4	85,198	64,203
24	Navuti Site 6	80,581	32,590
Total		**1,034,505**	**787,457**

Source: Doi Tung Development Project (2009)

Table A1.4 Natural and plantation trees in *C. arabica* L. mixed with *Pinus kesiya* Royle ex Gordon plantation (AP) (Mean±SD).

	Scientific name	Family	DBH (cm.)	High (m.)	Density (tree/m^2)	Dominance	Basal area (cm^2)
1	*Cyathocalyx martabanicus* Hook.f. & Thomson	ANNONACEAE	11.46±0.00	6.00±0.00	0.01±0.00	4.13±0.00	413.11±0.00
2	*Oroxylum indicum* (L.) Kurz	BIGNONIACEAE	10.19±0.00	6.00±0.00	0.01±0.00	3.26±0.00	326.41±0.00
3	*Dillenia ovata* Wall. ex Hook. f. & Thomson	DILLENIACEAE	20.86±14.05	12.75±4.99	0.01±0.01	24.44±29.51	2,444.26±2,951.03
4	*Aporusa villosa* (Wall. ex Lindl.) Baill	EUPHORBIACEAE	15.61±0.00	7.00±0.00	0.01±0.00	7.65±0.00	765.35±0.00
5	*Phyllanthus emblica* L.	EUPHORBIACEAE	25.75±8.42	17.50±3.54	0.01±0.00	21.16±13.37	2,115.99±1,336.98
6	*Litsea monopetala* (Roxb.) Pers.	LAURACEAE	35.19±32.20	13.00±1.41	0.01±0.00	55.22±71.23	5,521.74±7,123.26
7	*Aphanamixis polystachya* (Wall.) R.Parker	MELIACEAE	4.12±2.38	5.67±4.59	0.02±0.02	1.36±1.09	136.46±108.73
8	*Chukrasia tabularis* A. Juss.	MELIACEAE	12.74±0.00	6.00±0.00	0.01±0.00	5.10±0.00	510.02±0.00
9	*Ficus semicordata* Buch.-Ham. ex Sm.	MORACEAE	29.56±9.05	9.67±1.75	0.02±0.02	59.23±29.77	5,923.33±2,977.38
10	*Pinus kesiya* Royle ex Gordon	PINACEAE	32.94±10.65	15.22±4.04	0.03±0.01	95.72±58.94	9,571.78±5,894.31
11	*Prunus cerasoides* D.Don	ROSACEAE	16.92±3.97	10.75±0.96	0.02±0.00	18.74±8.26	1,873.60±825.51
12	*Canthium parvifolium* Roxb.	RUBIACEAE	15.61±0.00	10.00±0.00	0.01±0.00	7.65±0.00	765.35±0.00
13	*Mischocarpus pentapetalus* (Roxb.) Radlk.	SAPINDACEAE	12.74±0.00	6.00±0.00	0.01±0.00	5.10±0.00	510.02±0.00

Table A1.5 Natural and plantation trees in *C. arabica* L. mixed with secondary forest (AS) (Mean±SD).

	Scientific name	Family	DBH (cm.)	High (m.)	Density (tree/m^2)	Dominance	Basal area (cm^2)
1	*Mangifera caloneura* Kurz	ANACARDIACEAE	51.27±0.00	16.00±0.00	0.01±0.00	82.63±0.00	8,262.61±0.00
2	*Alstonia rostrata* C.E.C. Fisch.	APOCYNACEAE	46.66±33.55	7.75±8.84	0.01±0.00	86.11±98.40	8,610.53±9,840.21
3	*Trevesia palmata* (Roxb. ex Lindl.) Vis.	ARALIACEAE	9.19±0.29	2.00±0.00	0.02±0.00	5.31±0.00	530.89±0.00
4	*Betula alnoides* Buch.-Ham. ex G.Don	BETULACEAE	22.97±7.09	10.33±3.61	0.03±0.01	53.71±44.35	5,371.40±4,434.81
5	*Fernandoa adenophylla* (Wall. ex G.Don) Steenis	BIGNONIACEAE	7.96±0.00	4.00±0.00	0.01±0.00	1.99±0.00	199.23±0.00
6	*Millingtonia hortensis* L.f.	BIGNONIACEAE	14.33±0.00	13.00±0.00	0.01±0.00	6.45±0.00	645.49±0.00
7	*Protium serratum* (Wall. ex Cobbr.) Engl.	BURSERACEAE	20.06±0.00	12.00±0.00	0.01±0.00	12.65±0.00	1,265.16±0.00
8	*Cassia javanica* L.	CAESALPINIOIDEAE	23.09±12.54	11.38±2.38	0.03±0.01	51.77±17.01	5,176.88±1,700.69
9	*Dillenia indica* L.	DILLENIACEAE	14.70±12.09	16.00±1.41	0.01±0.00	9.09±11.17	908.71±1,117.19
10	*Dipterocarpus alatus* Roxb. ex G.Don	DIPTEROCARPACEAE	38.22±0.00	15.00±0.00	0.01±0.00	45.90±0.00	4,590.16±0.00
11	*Aporusa villosa* (Wall. ex Lindl.) Baill	EUPHORBIACEAE	57.96±0.00	12.00±0.00	0.01±0.00	105.59±0.00	10,558.64±0.00
12	*Macaranga kurzii* Pax ex Hoffm.	EUPHORBIACEAE	28.34±0.00	13.00±0.00	0.01±0.00	25.25±0.00	2,524.91±0.00
13	*Ostodes paniculata* Blume	EUPHORBIACEAE	21.26±10.92	6.50±0.71	0.01±0.00	16.08±14.59	1,607.71±1,459.40
14	*Phyllanthus emblica* L.	EUPHORBIACEAE	11.43±9.87	3.75±1.66	0.02±0.00	12.81±16.22	1,280.60±1,622.33
15	*Castanopsis tribuloides* (Sm.) A. DC.	FAGACEAE	35.99±0.00	18.00±0.00	0.01±0.00	40.70±0.00	4,070.26±0.00

Table A1.5 (Continue)

	Scientific name	Family	DBH (cm.)	High (m.)	Density (tree/m^2)	Dominance	Basal area (cm^2)
16	*Quercus semiserrata* Roxb.	FAGACEAE	54.14±0.00	15.00±0.00	0.01±0.00	92.12±0.00	9,212.20±0.00
17	*Cratoxylum cochinchinense* (Lour.) Blume	GUTTIFERAE	17.91±6.45	10.50±3.63	0.02±0.01	22.51±12.29	2,250.85±1,229.05
18	*Callicarpa arborea* Roxb.	LABIATAE	37.26±0.00	10.00±0.00	0.01±0.00	43.64±0.00	4,363.52±0.00
19	*Vitex canescens* Kurz	LABIATAE	39.17±21.17	15.00±1.41	0.01±0.00	55.27±52.12	5,526.68±5,212.11
20	*Vitex peduncularis* Wall. Ex Schauer	LABIATAE	13.38±0.00	7.00±0.00	0.01±0.00	5.62±0.00	562.29±0.00
21	*Vitex pinnata* L.	LABIATAE	29.41±0.00	15.00±0.00	0.01±0.00	26.69±0.00	2,668.75±0.00
22	*Vitex quinata* (Lour.) F.N.Williams	LABIATAE	18.97±3.31	11.11±3.10	0.05±0.02	52.25±11.03	5,225.13±1,103.10
23	*Cinnamomum iners* Reinw. ex Blume	LAURACEAE	7.64±0.00	3.50±0.00	0.01±0.00	1.84±0.00	183.61±0.00
24	*Litsea monopetala* (Roxb.) Pers.	LAURACEAE	40.18±17.79	15.67±0.58	0.01±0.00	57.37±46.39	5,737.30±4,638.63
25	*Parkia sumatrana* Miq. ssp. Streptocarpa (Hance) Hopkins	LEGUMINOSAE	43.55±21.47	20.33±10.79	0.03±0.00	207.77±0.00	20,777.25±0.00
26	*Bauhinia saccocalyx* Pierre	LEGUMINOSAE	27.19±11.39	12.50±5.26	0.02±0.01	52.59±69.75	5,258.80±6,975.45
27	*Erythrina subumbrans* (Hassk.) Merr.	LEGUMINOSAE	29.99±14.91	10.67±4.51	0.01±0.00	32.92±27.76	3,292.30±2,775.96
28	*Lagerstroemia venusta* Wall.	LYTHRACEAE	38.38±13.83	13.44±2.53	0.02±0.01	103.94±78.46	10,394.50±7,845.95
29	*Kydia calycina* Roxb.	MALVACEAE	24.36±5.18	8.00±2.83	0.01±0.00	19.08±7.93	1,907.63±793.18
30	*Chukrasia tabularis* A. Juss.	MELIACEAE	8.92±0.00	4.00±0.00	0.01±0.00	2.50±0.00	249.91±0.00

Table A1.4 Natural and plantation trees in *C. arabica* L. mixed with *Pinus kesiya* Royle ex Gordon plantation (AP) (Mean±SD).

	Scientific name	Family	DBH (cm.)	High (m.)	Density (tree/m^2)	Dominance	Basal area (cm^2)
1	*Cyathocalyx martabanicus* Hook.f. & Thomson	ANNONACEAE	11.46±0.00	6.00±0.00	0.01±0.00	4.13±0.00	413.11±0.00
2	*Oroxylum indicum* (L.) Kurz	BIGNONIACEAE	10.19±0.00	6.00±0.00	0.01±0.00	3.26±0.00	326.41±0.00
3	*Dillenia ovata* Wall. ex Hook. f. & Thomson	DILLENIACEAE	20.86±14.05	12.75±4.99	0.01±0.01	24.44±29.51	2,444.26±2,951.03
4	*Aporusa villosa* (Wall. ex Lindl.) Baill	EUPHORBIACEAE	15.61±0.00	7.00±0.00	0.01±0.00	7.65±0.00	765.35±0.00
5	*Phyllanthus emblica* L.	EUPHORBIACEAE	25.75±8.42	17.50±3.54	0.01±0.00	21.16±13.37	2,115.99±1,336.98
6	*Litsea monopetala* (Roxb.) Pers.	LAURACEAE	35.19±32.20	13.00±1.41	0.01±0.00	55.22±71.23	5,521.74±7,123.26
7	*Aphanamixis polystachya* (Wall.) R.Parker	MELIACEAE	4.12±2.38	5.67±4.59	0.02±0.02	1.36±1.09	136.46±108.73
8	*Chukrasia tabularis* A. Juss.	MELIACEAE	12.74±0.00	6.00±0.00	0.01±0.00	5.10±0.00	510.02±0.00
9	*Ficus semicordata* Buch.-Ham. ex Sm.	MORACEAE	29.56±9.05	9.67±1.75	0.02±0.02	59.23±29.77	5,923.33±2,977.38
10	*Pinus kesiya* Royle ex Gordon	PINACEAE	32.94±10.65	15.22±4.04	0.03±0.01	95.72±58.94	9,571.78±5,894.31
11	*Prunus cerasoides* D.Don	ROSACEAE	16.92±3.97	10.75±0.96	0.02±0.00	18.74±8.26	1,873.60±825.51
12	*Canthium parvifolium* Roxb.	RUBIACEAE	15.61±0.00	10.00±0.00	0.01±0.00	7.65±0.00	765.35±0.00
13	*Mischocarpus pentapetalus* (Roxb.) Radlk.	SAPINDACEAE	12.74±0.00	6.00±0.00	0.01±0.00	5.10±0.00	510.02±0.00

Table A1.5 Natural and plantation trees in *C. arabica* L. mixed with secondary forest (AS) (Mean±SD).

	Scientific name	Family	DBH (cm.)	High (m.)	Density (tree/m^2)	Dominance	Basal area (cm^2)
1	*Mangifera caloneura* Kurz	ANACARDIACEAE	51.27±0.00	16.00±0.00	0.01±0.00	82.63±0.00	8,262.61±0.00
2	*Alstonia rostrata* C.E.C. Fisch.	APOCYNACEAE	46.66±33.55	7.75±8.84	0.01±0.00	86.11±98.40	8,610.53±9,840.21
3	*Trevesia palmata* (Roxb. ex Lindl.) Vis.	ARALIACEAE	9.19±0.29	2.00±0.00	0.02±0.00	5.31±0.00	530.89±0.00
4	*Betula alnoides* Buch.-Ham. ex G.Don	BETULACEAE	22.97±7.09	10.33±3.61	0.03±0.01	53.71±44.35	5,371.40±4,434.81
5	*Fernandoa adenophylla* (Wall. ex G.Don) Steenis	BIGNONIACEAE	7.96±0.00	4.00±0.00	0.01±0.00	1.99±0.00	199.23±0.00
6	*Millingtonia hortensis* L.f.	BIGNONIACEAE	14.33±0.00	13.00±0.00	0.01±0.00	6.45±0.00	645.49±0.00
7	*Protium serratum* (Wall. ex Cobbr.) Engl.	BURSERACEAE	20.06±0.00	12.00±0.00	0.01±0.00	12.65±0.00	1,265.16±0.00
8	*Cassia javanica* L.	CAESALPINIOIDEAE	23.09±12.54	11.38±2.38	0.03±0.01	51.77±17.01	5,176.88±1,700.69
9	*Dillenia indica* L.	DILLENIACEAE	14.70±12.09	16.00±1.41	0.01±0.00	9.09±11.17	908.71±1,117.19
10	*Dipterocarpus alatus* Roxb. ex G.Don	DIPTEROCARPACEAE	38.22±0.00	15.00±0.00	0.01±0.00	45.90±0.00	4,590.16±0.00
11	*Aporusa villosa* (Wall. ex Lindl.) Baill	EUPHORBIACEAE	57.96±0.00	12.00±0.00	0.01±0.00	105.59±0.00	10,558.64±0.00
12	*Macaranga kurzii* Pax ex Hoffm.	EUPHORBIACEAE	28.34±0.00	13.00±0.00	0.01±0.00	25.25±0.00	2,524.91±0.00
13	*Ostodes paniculata* Blume	EUPHORBIACEAE	21.26±10.92	6.50±0.71	0.01±0.00	16.08±14.59	1,607.71±1,459.40
14	*Phyllanthus emblica* L.	EUPHORBIACEAE	11.43±9.87	3.75±1.66	0.02±0.00	12.81±16.22	1,280.60±1,622.33
15	*Castanopsis tribuloides* (Sm.) A. DC.	FAGACEAE	35.99±0.00	18.00±0.00	0.01±0.00	40.70±0.00	4,070.26±0.00

Table A1.5 (Continue)

	Scientific name	Family	DBH (cm.)	High (m.)	Density (tree/m^2)	Dominance	Basal area (cm^2)
16	*Quercus semiserrata* Roxb.	FAGACEAE	54.14±0.00	15.00±0.00	0.01±0.00	92.12±0.00	9,212.20±0.00
17	*Cratoxylum cochinchinense* (Lour.) Blume	GUTTIFERAE	17.91±6.45	10.50±3.63	0.02±0.01	22.51±12.29	2,250.85±1,229.05
18	*Callicarpa arborea* Roxb.	LABIATAE	37.26±0.00	10.00±0.00	0.01±0.00	43.64±0.00	4,363.52±0.00
19	*Vitex canescens* Kurz	LABIATAE	39.17±21.17	15.00±1.41	0.01±0.00	55.27±52.12	5,526.68±5,212.11
20	*Vitex peduncularis* Wall. Ex Schauer	LABIATAE	13.38±0.00	7.00±0.00	0.01±0.00	5.62±0.00	562.29±0.00
21	*Vitex pinnata* L.	LABIATAE	29.41±0.00	15.00±0.00	0.01±0.00	26.69±0.00	2,668.75±0.00
22	*Vitex quinata* (Lour.) F.N.Williams	LABIATAE	18.97±3.31	11.11±3.10	0.05±0.02	52.25±11.03	5,225.13±1,103.10
23	*Cinnamomum iners* Reinw. ex Blume	LAURACEAE	7.64±0.00	3.50±0.00	0.01±0.00	1.84±0.00	183.61±0.00
24	*Litsea monopetala* (Roxb.) Pers.	LAURACEAE	40.18±17.79	15.67±0.58	0.01±0.00	57.37±46.39	5,737.30±4,638.63
25	*Parkia sumatrana* Miq. ssp. Streptocarpa (Hance) Hopkins	LEGUMINOSAE	43.55±21.47	20.33±10.79	0.03±0.00	207.77±0.00	20,777.25±0.00
26	*Bauhinia saccocalyx* Pierre	LEGUMINOSAE	27.19±11.39	12.50±5.26	0.02±0.01	52.59±69.75	5,258.80±6,975.45
27	*Erythrina subumbrans* (Hassk.) Merr.	LEGUMINOSAE	29.99±14.91	10.67±4.51	0.01±0.00	32.92±27.76	3,292.30±2,775.96
28	*Lagerstroemia venusta* Wall.	LYTHRACEAE	38.38±13.83	13.44±2.53	0.02±0.01	103.94±78.46	10,394.50±7,845.95
29	*Kydia calycina* Roxb.	MALVACEAE	24.36±5.18	8.00±2.83	0.01±0.00	19.08±7.93	1,907.63±793.18
30	*Chukrasia tabularis* A. Juss.	MELIACEAE	8.92±0.00	4.00±0.00	0.01±0.00	2.50±0.00	249.91±0.00

Table A1.5 (Continue)

	Scientific name	Family	DBH (cm.)	High (m.)	Density (tree/m^2)	Dominance	Basal area (cm^2)
31	*Albizia chinensis* (Osbeck) Merr.	MIMOSOIDEAE	60.83±43.46	17.00±1.41	0.01±0.00	145.97±166.18	14,597.11±16,617.70
32	*Artocarpus chaplasha* Roxb.	MORACEAE	50.96±0.00	15.00±0.00	0.01±0.00	81.60±0.00	8,160.28±0.00
33	*Broussonetia papyrifera* (L.) Vent.	MORACEAE	15.92±0.00	4.00±0.00	0.01±0.00	7.97±0.00	796.90±0.00
34	*Ficus oligodon* Miq.	MORACEAE	27.36±8.78	9.20±2.59	0.01±0.00	25.46±16.02	2,545.74±1,602.20
35	*Ficus semicordata* Buch.-Ham. ex Sm.	MORACEAE	23.54±9.78	10.00±2.72	0.03±0.04	56.60±55.35	5,660.24±5,535.13
36	*Dalbergia glomeriflora* Kurz	PAPILIONOIDEAE	20.45±7.31	11.40±4.67	0.02±0.01	24.13±27.86	2,413.34±2,786.45
37	*Prunus cerasoides* D.Don	ROSACEAE	18.33±3.18	10.83±2.71	0.02±0.00	21.65±6.87	2,164.60±686.83
38	*Prunus persica* (L.) Batsch	ROSACEAE	6.39±0.00	5.00±0.00	0.01±0.00	1.28±0.00	128.14±0.00
39	*Turpinia pomifera* (Roxb.) DC.	STAPHYLEACEAE	13.38±1.35	5.00±0.00	0.02±0.00	11.30±0.00	1,130.33±0.00
40	*Schima wallichii* (DC.) Korth.	THEACEAE	46.02±6.05	17.78±6.28	0.02±0.01	101.37±54.31	10,136.88±5,431.50
41	*Grewia eriocarpa* Juss.	TILIACEAE	20.86±0.00	3.50±0.00	0.01±0.00	13.68±0.00	1,367.56±0.00
42	*Microcos paniculata* L.	TILIACEAE	35.24±12.11	8.04±2.05	0.01±0.00	42.71±28.08	4,270.53±2,807.57
43	*Debregeasia velutina* Gaudich	URTICACEAE	35.03±0.00	10.00±0.00	0.01±0.00	38.57±0.00	3,857.01±0.00
44	*Xanthophyllum virens* Roxb.	XANTHOPHYLLACEAE	52.87±0.00	14.00±0.00	0.01±0.00	87.84±0.00	8,783.78±0.00

Table A1.6 Natural and plantation trees in *C. arabica* L. mixed with crop plants (AC) (Mean±SD).

	Scientific name	Family	DBH (cm.)	High (m.)	Density (tree/m^2)	Dominance	Basal area (cm^2)
1	*Mangifera indica* L.	ANACARDIACEAE	12.78±1.36	4.46±1.36	0.02±0.02	9.08±6.72	907.59±671.65
2	*Fernandoa adenophylla* (Wall. ex G.Don) Steenis	BIGNONIACEAE	11.21±0.00	4.00±0.00	0.01±0.00	3.95±0.00	394.96±0.00
3	*Tamarindus indica* L.	LEGUMINOSAE	30.10±7.88	8.25±0.35	0.01±0.00	29.44±14.91	2,944.24±1,491.01
4	*Erythrina subumbrans* (Hassk.) Merr.	LEGUMINOSAE	37.26±15.55	13.60±2.19	0.03±0.01	124.29±80.86	12,429.29±8,085.71
5	*Paramichelia baillonii* (Pierre) Hu	MAGNOLIACEAE	18.63±11.14	9.75±2.36	0.04±0.00	55.33±0.00	5,533.06±0.00
6	*Artocarpus heterophyllus* Lam.	MORACEAE	20.45±5.77	5.88±1.78	0.01±0.00	13.98±7.02	1,397.64±702.10
7	*Macadamia* sp. F. Muell.	PROTEACEAE	16.60±4.83	7.05±1.05	0.03±0.03	23.39±22.00	2,338.85±2,200.02
8	*Prunus persica* (L.) Batsch	ROSACEAE	12.15±6.08	2.60±0.36	0.01±0.00	4.69±6.02	468.95±602.34
9	*Pyrus pyrifolia* L.	ROSACEAE	9.87±0.00	2.70±0.00	0.01±0.00	3.06±0.00	306.33±0.00
10	*Citrus maxima* (Burm.f.) Merr.	RUTACEAE	9.39±3.83	3.30±0.28	0.01±0.00	3.00±2.26	300.43±226.07
11	*Citrus reticulata* Blanco	RUTACEAE	11.95±4.14	3.28±0.96	0.04±0.03	21.01±11.09	2,100.76±1,108.77
12	*Litchi chinensis* Sonn.	SAPINDACEAE	19.37±9.96	4.39±1.76	0.02±0.01	36.15±34.06	3,614.60±3,405.95
13	*Turpinia pomifera* (Roxb.) DC.	STAPHYLEACEAE	21.34±0.00	5.00±0.00	0.01±0.00	14.31±0.00	1,430.92±0.00
14	*Camellia sinensis* (L.) Kuntze var. assamica (Mast.) Kitam.	THEACEAE	4.14±3.39	1.66±1.47	0.08±0.13	7.32±12.20	732.21±1,219.86

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