GROWTH PERFORMANCE, SOIL AND LEAF NUTRIENT CONTENT IN YOUNG RUBBER AS AFFECTED BY SOIL CONSERVATION: CASE STUDY IN NORTHERN THAILAND

NUTTAPON KHONGDEE

A Thesis Submitted to the Graduate School of Naresuan University
In Partial Fulfillment of the Requirements
for the Master in Agricultural Science
December 2015

Thesis entitled "Growth performance, soil and leaf nutrient content in young rubber as affected by soil conservation: Case study in Northern Thailand"

by Mr.Nuttapon Khongdee

has been approved by the Graduate School as partial fulfillment of the requirements for the Master of Science Degree in Agricultural science of Naresuan University

Oral Defense Committee

....Chair/ External Examiner

(Wanwipa Kaewpradit Polpinit, Ph.D.)

....Advisor

(Wanwisa Pansak, Dr.)

....Co – Advisor

(Thomas Hilger, Dr.agr.)

....Co – Advisor

(Jaruntorn Boonyanuphap, Ph.D.)

....Internal Examiner

(Wipa Homhaul, Ph.D.)

Approved

....

(Panu Putthawong, Ph.D.)

(Associate Dean for Administration and Planning

For Dean of the Graduate School

16 DEC 2015

ACKNOWLEDGEMENT

I would like to acknowledge Faculty of Agriculture, Natural Resources and Environment, Naresuan University to support all facilities to complete this thesis.

I would like to thank and offer my sincere gratitude to my advisor, Dr. Wanwisa Pansak and co-advisors, Dr. Thomas Hilger and Associate Professor Dr. Charuntorn Boonyanuphap. I greatly appreciated their guidance, supports, and encouragement provided throughout my Master's degree. I also would like to thank to all thesis committee members and deeply grateful for their helpful comments.

I would like to thank Prof. Gan Zhang, Deputy Director, Guangzhou Institute of Geochemistry, The Chinese Academic of Sciences, Guangzhou China to support this study on a C/N combustion analysis and to accommodate me during the analysis in China.

I would like also to acknowledge Dr. Natta Takrattanasaran, a government officer from the Land Development Department, who classified soil series in the study area and provide a good recommendation for this study.

I greatly appreciate my colleagues, Budsarin Rodprai, Thanachanok Khamkajorn, Itsaranuwhat Winthasombat, Methinee Nakdee, Sureerat Buachun, Kesinee Iamsa-ard and Nuchjaree Jansrida for their helps and assistances. And I would also like to thank Dr. Chakra Chaemfa to improve my thesis writing.

Finally, I would like to give a special thanks to my family for their endless love, understanding, consulting and support.

Nuttapon Khongdee

Title	GROWTH PERFORMANCE, SOIL AND LEAF NUTRIENT CONTENT IN YOUNG RUBBER AS AFFECTED BY SOIL CONSERVATION: CASE STUDY IN NORTHERN THAILAND
Author	Nuttapon Khongdee
Advisor	Wanwisa Pansak, Ph.D.
Co-Advisor	Thomas Hilger, Ph.D.
	Associate Professor Charuntorn Boonyanuphap, Ph.D.
Academic Paper	Thesis M.S. in Agricultural Science, Naresuan University, 2015
Keywords	Rubber, Growth performance, Soil and water conservation Systems

ABSTRACT

Since 1989, para rubber plantation in Thailand has gradually shifted and spread from the South and the East to the North and Northeast of Thailand. This change has impacts on various aspects, e.g. land-use pattern, use of natural resources, economy, and ecology. An introduction of soil conservation technologies, e.g. minimum tillage, intercropping with valuable herbaceous crops and relay cropping to hilly rubber plantation areas in Northern Thailand may be very attractive for local farmers if is they are tailored to their particular needs by using participatory approaches. However, studies on assessing the potential of the soil conservation systems for rubber plantation in the upland areas are still inadequate. Therefore, this study aimed to 1) assess the rubber tree growth performance under various soil conservation systems and 2) determine soil and leaf nutrient changes in different seasons under rubber plantations with various soil and water conservation systems. The study was conducted from June 2013 to August 2014. A field experiment was established on a farmer's field with 3-year-old Para rubber trees (RRIM 600 clone) at Ban Huai Phai, Wang Thong District, Phitsanulok Province. The geography is a rolling slope about 12-30%, in addition, average level is about 190 m above the mean sea level. The climate on site is tropical savannah climate. Annual rainfall is about 1300 mm/year. The average maximum temperature is 33 °C with an average minimum of 23 °C. Relative humidity is ranging from 64-95%. The experimental design was a randomized complete block design (RCBD) for 4 treatments and 3 replicates. In total, twelve plots were established. Each plot size was 9 by 10 m (90 m^2), and the number of rubber trees in each treatment was six rubber trees in two rows with three plants each The treatments were 1) rubber monocrop (control) 2) rubber tree intercropped with maize 3) rubber tree intercropped with maize and soy crops in dry season and 4) rubber tree intercropped with maize and vetiver grass strips. Soil and plant samples and rubber growth measurements were collected during cool season to rainy season (January, May and August). The results showed that rubber growth performances of all treatments were sharply developed in August (rainy season) about 15% of height and 30% of girth. Rubber intercropping with maize and vetiver grass increased rubber girth development significantly. This may due to application of vetiver grass and harvest residue to the soil. The developments of rubber height and girth were significantly correlated at 59%. Soil moisture content was in the range of 3-9% depending on season and was no singnificant difference between each treatment. For plant nutrients in soil of rubber monocropping and rubber intercropping treatments, P (1-4 mg/kg) and Ca (50-70 mg/kg) were low when values compared to the standard rubber recommendation. Soil moisture, K, Ca, and Mg significantly correlated with the girth of rubber (r ranging from 0.79-0.85). Meanwhile, soil nutrients of rubber monoculture and rubber intercropping treatments were in similar ranging value compared to the standard recommendation. In addition, low of plant nutrients in rubber leaves were found for N, P, K and Ca. There were no significantly correction between leaves nutrients and the rubber girth development. Under various soil conservations measures showed that rubber intercropping with maize provided the highest maize grain yield. However, rubber among other tree crops is a means of reducing competition for land and cash flow constraints in the period until latex production begins. On the other hand, rubber intercropping can be used as soil and water conservation systems for increasing a household income and reducing erosion on hillside rubber plantation as well.

LIST OF CONTENTS

LIST OF CONTENTS (CONT.)

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (CONT.)

Figure **Page**

LIST OF FIGURES (CONT.)

Figure **Page**

LIST OF FIGURES (CONT.)

CHAPTER I

INTRODUCTION

Rationale for the significance of the study

In 1899, Para rubber (*Hevea brasiliensis*) was firstly introduced to Thailand and planted in Trang province. Recently, it has become a major economic crop of Thailand. Since 1989, rubber plantation in Thailand has gradually shifted and spread from the South and the East to the North and Northeast of Thailand. The planting area has undergone more significant changes after the Thai government launched the one-million-rai (160,000 hectares, approximately) planting project. Since 2004, the rubber plantation in the North and Northeast has diversified the former main crop varieties, such as rice, sugarcane and cassava. According to RRIT (2015), the total area of rubber plantations in Thailand was 3.54 million hectares (Mha) in 2013. In 2013, the total rubber cultivation area in Northern Thailand (in 17 provinces) was 0.20 Mha (5%), while the expansion for new planting in the low and high land is at high rates (RRIT, 2010). Today, many farmers in the uplands of Northern Thailand replace short-term cash crops by monoculture of rubber tree plantations. Moreover, some of the original forest covering in the upland areas has been converted for agriculture activities including Para rubber cultivation. With the expansion of rubber monoculture in unsuitable areas, farmers in the Northern Thailand have faced a problem about the growth performance of rubber because of poorer soil and environment constraints than traditional rubber cultivation. These include low soil fertility, shallow surface soil, unsuitable physical soil properties and low rainfall (only 1,000-1,200 mm/year, about 6 months for dry period) (Thai Meteorological Department, 2014). Darunee, et al. (2000) reported that rubber trees in the South normally could be tapped when they are about 6 year old. In the North, however, the rubber trees are generally tapped when they are about 8 -10 year old due to the differences of soil properties, land slope, moisture and climate. In addition, homogeneous monocultures could indirectly results in negatively manifold biodiversity and environment. An intensive rubber plantation in upland areas is susceptible to soil nutrient losses, erosion and landslides as a result of land clearing and preparation. The expansion of monocultures such as maize, fruit trees and rubber plantation causes a high pressure to alternation of forest and land use. Climate variability and the conversion of forest to monocultural rubber plantation generate more severe floods along with other risks including stream sediment loads from soil erosion, landslide and flash flood during rainy season. In 2011, Northern, Northeast and Central areas of Thailand faced severe flooding. The floods caused serious damage in many sectors, including agriculture and rural livelihoods. Growing rubber trees together with either agricultural crops or cover crops might be a way to decrease these environmental impacts. For land with steep slopes, terracing has been recommended to prevent erosion (RFD, 2000). The Land Development Department (LDD, 2005) recommended to plant vetiver grass at hilly areas for erosion control. An introduction of soil conservation technologies, e.g. minimum tillage, intercropping with valuable herbaceous crops and relay cropping to hilly rubber plantation areas in Northern Thailand may be very attractive for local farmers if is they are tailored to their particular needs by using participatory approaches. Using rubber intercropping systems, where rubber trees are grown in combination with indigenous plants, food crops and other species, is an option to increase household income for economic stability. Such a pattern allows farmers not only to harvest the rubber but also to collect food crops, herbs, and wood for fuel and construction. It could also increase agro-biodiversity, soil fertility and reduction of soil erosion that may lead to a better sustainable land use in the future. The sustainable land management scheme improves land utilization efficiency, helps maintenance of soil fertility and increases growth performance to rubber plantations in a longer term. It thereby offers a reasonable and sustainable use for land resources in the tropical mountainous areas.

However, studies on assessing the potential of the soil conservation systems for rubber plantation in the upland areas are still inadequate. More studies on the growth performance, soil and leaf nutrient content could be integrated and these might provide more information on the nutrient deficiencies and any imbalance, interaction or antagonisms and determination of whether what nutrients in soil are being utilized by the plants. Therefore, the evaluation of rubber growth performance, soil and leaf nutrient content under soil and water conservation systems in the upland areas should be researched for a better understanding on these matters.

Objectives of the study

1. To assess the rubber tree growth performance under various soil conservation systems

2. To determine soil and leaf nutrient changes in different seasons under rubber plantations with various soil and water conservation systems

Conceptual Framework

This research was designed to assess the performance of rubber trees, soil and leaf nutrient content under various soil and water conservation systems in different seasons. The study was conducted from June 2013 until August 2014 in a 3-year old RRIM 600 clone rubber plantation, located in Wangtong district, Phitsanulok province (16° 55' N, 100°32' E) at an altitude of 209 m above sea level) with a 7 m row spacing and 3 m between trees. The soil classification was carried out according to the USDA Soil Taxonomy and was classified as a fine-loamy, mixed, semiactive, isohyperthermic Typic Haplustults. Three different soil and water conservation systems together with one rubber monoculture were installed on a moderate slope gradient (12-30%) at a farmer's field.

Hypothesis

Soil and water conservation systems can be used for hillside rubber plantation in Northern, Thailand to avoid erosion in young rubber stands. Moreover these systems have no effects on the growth of rubber trees.

Keywords: rubber, growth performance, soil and water conservation systems

Definition

Rubber- Natural rubber is raw material for the manufacture of a great number of products. Rubber is used and fabricated for hard and strong structural materials, resilient elastic materials, conductors and nonconductors of electricity, shock absorbers, mountings for motors, and other machinery, such as transmission belts, gaskets, hoses to transport gases and liquids, transparent and translucent materials, clothing articles to protect from rain, sports goods, cements, paints, plastics, pharmaceuticals, and, most important, the manufacture of tires (Heinz-Hermann Greve, 1993).

Growth performance – Rubber tree growth occurs in two different ways. Firstly, from the root and shoot tips resulting in increases in height and length are called primary growth. Another growth is called secondary growth which increases in thickness of stems and branches. The primary growth occurs in small areas called apical meristems. All leaves, height growth and increases in the length of branches and roots are the result of the growth at apical meristems. One or more leaves are produced at a region called a node, followed by a section of stem called the internode (Feyza Candan, 2013).

Soil and water conservation systems – soil and water can be conserved by protecting soil from raindrops that hit soil surface and cause a crust. Plants and forest intercepting raindrops helps to maintain permeability of soil, consequently, water can infiltrate instead of running off. The soil acts as a reservoir that conserves water and reduce both splash and runoff conserve soil. (Troeh, Frederick R, 2004)

CHAPTER II

REVIEW OF RELATED LITERATURE AND RESEARCH

Botany and distribution of rubber tree (*Hevea brasiliensis*)

Figure 1 Rubber organs

Source: from http://en.wikipedia.org/wiki/Hevea_brasiliensis

Scientific name	*Hevea brasiliensis*
Common name	*Para rubber*
Class	Magnoliopsida
Subclass	Rosidae
Family	Euphorbiaceae
Genus	Hevea
Species	Hevea brasiliensis

Hevea brasiliensis is a tropical tree crop, deciduous, which is mainly cultivated for its production of latex. The latex is a sticky, milky colloid drawn off by making incisions into the bark and collecting the fluid in vessels in a process called "tapping". The genus Hevea is native to South America (the Brazilian and Bolivian region covering the Amazon and Orinoco river basins), which produces a milky sap (latex) that is the primary source of natural rubber. Although some wild-grown trees are still tapped for their sap, most commercial production now comes from rubber tree plantations in southern and southeastern Asia. In 2010, 11 countries accounted for 92% of global production of natural rubber from H. brasiliensis: Cambodia, China, India, Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore, Sri Lanka, Thailand, and Vietnam. Natural rubber is not produced in significant amounts in its native area, South America, because there they are widely affected by South American leaf blight, caused by the fungus Microcyclus ulei (Ascomycota). Nowadays the latex then is refined into rubber ready for commercial processing. Natural rubber is used extensively in many applications and products, either alone or in combination with other materials. Some of the common products that are made of natural rubber are tires, baby toys, gloves, condoms, shock absorbers, watches, underwater equipment, garments, boots, rubber bands, car mats, machine parts, erasers and sporting equipment (Nair, 2010).

1. Botany of Para rubber

1.1 Cultivars and Classification

Rubber belongs to the family of Euphorbiaceae, a huge family with about 280 genera and 8,000 species. The genus Hevea exhibits much morphological variability, with nine species now being recognized, ranging from tall forest trees to little more than shrubs. All of them hold latex in their parts. Other Hevea spp. are tapped in a wild state, but have little economic value. Some of them may, however, be important for breeding:

1.1.1 H. *benthamiana*: occurs only north of the Amazon river in the north-western Part of the Amazon and Upper Orinoco basins; it grows in alluvial lowland areas and bogs and, thus, supports hydromorphic soils; it has a pure white latex which is lower in yield than H. *brasiliensis*;

1.1.2 H. *camporum*: native to open savannas in the headwaters of the Madeira River, Brazil;

1.1.3 H. *guianensis* and its variety latea: 30m high or more; it prefers well-drained upland soils; its yellowish latex yields generally inferior rubber;

1.1.4 H. *microphylla*: endemic in uppermost Rio Negro basin in Brazil, Colombia and Venezuela; up to 20m high; grows in low-lying, often permanently flooded land; its white watery latex almost completely lacks rubber;

1.1.5 H. *nitida*: occurs throughout most of the Amazon valley and upper Orinoco; the tree is medium-sized and usually grows on sandy forest soils; the thin white latex acts as an anti-coagulant with that of other species;

1.1.6 H. *pauciflora*: occurs in Rio Negro and the Upper Orinoco basins and in Guyana; the medium-sized tree grows on rocky hillsides and high well-drained river banks; its white latex has a low rubber and high resin content;

1.1.7 H. *rigidifolia*: endemic to the uppermost Rio Negro basin of Brazil, Colombia and Venezuela; the 20-meter high tree grows on high, well-drained soils; its cream colored latex is poor in rubber and high in resin content;

1.1.8 H. *spruceana*: abundant in lower Amazon basis; it grows on low and flooded river banks; its watery latex is almost devoid of rubber (Verheye, 2010).

1.2 Structure

Hevea brasiliensis (HBK) Muell Arg is a rapid growing tree, rarely exceeding 25 m of height in plantations, where the planting density is optimal for light interception; wild trees might be up to 40 m high in search for sunlight above the dense tree canopy of rain forests. The tree has a well-developed tap-root, 2-5 m long after three years with lateral roots. The lateral roots emerge from the tap-root below the collar and reach a length of up to 10 m, making a dense network of feeder roots and root hairs in the upper soil layers. Some 30 to 60% of feeder roots are found in the top 10 cm of the soil (Verheye, 2010).

1.3 The trunk

The **trunk** of the tree tapers from the base and is conical or cylindrical in shape and shows a periodicity of growth. During the resting stage whorls of scale leaves occur round the terminal bud. A fully grown leaf has a diameter of 15-20 cm. Young leaves are dark red in color, while other leaves are green on top and greyish-green underneath. Terminal buds of branches grow quickly and trees are temporarily bare of leaves, a condition known as "wintering". New leaves are then produced at the proximal end and inflorescences in the axil of scale leaves and lower foliage leaves. This so-called wintering is usually associated with dry weather conditions. It is more pronounced as the seasons themselves differentiate. Beyond 4° latitude north and south wintering is short but sharp, whereas at the equator it becomes apparent only when the trees enter production (Verheye, 2010).

1.4 The crown

The **crown** of the rubber tree is liable to be damaged by wind, causing the trunk to snap. Hence, the need to select clones with balanced tree architecture, i.e. limited growth of the primary axis, with numerous similar but short secondary branches, evenly distributed round the tree. Windbreaks consisting of Tectona and/or Eucalyptus trees might limit the damage (Verheye, 2010).

1.5 Flowers

Flowers are borne in many-flowered, axillary, shortly pubescent panicles on the basal parts of the new flush. Flowers are small, scented, unisexual and shortly-stalked, with larger bell-shaped female flowers at the terminal ends of main and lateral branches, and more numerous smaller male flowers, with 60-80 males to each female flower. Flowering takes place over a period of about two weeks with some male flowers opening first, lasting for one day and then dropping, followed by female flowers open for 3-5 days; the remainder of male flowers then open (Verheye, 2010).

1.6 Fruits and seeds

Fruits and seeds are a small proportion of female flowers set fruit and of these 30-50% fall off after a month, and more fall off later. The mature fruit is a large, compressed, 3-lobbed capsule, 3-5cm in diameter, with 3 oil-containing seeds. The capsule bursts open at the end of the rainy season with a characteristic loud bang, similar to a rifle shot. The seeds are then collected for sowing in the nursery (Verheye, 2010).

Seed has a hard, shiny coat which is brown or greyish-brown in color. Seeds are viable for a short time only, and must, therefore, be planted as soon as possible after harvesting. Viable seeds germinate in 3-25 days. Germination is hypogeal (Verheye, 2010).

1.7 The bark

The **bark** is the most important part of the tree – and even for the plantation as a whole – because it contains the tissues that produce the latex. Figure 2 shows a cross-section of the trunk of an adult rubber tree. It consists of a pith, wood and a cortex, which is separated from the wood by the cambium (regenerative tissue). In the cortex, there are three separate concentric layers: the outer corky layer (periderm), an underlying parenchyma with a large number of stone cells, and finally the phloem with the latex vessels. The thickness of the bark and the proportion of tissue vary with both, the clones and the age of tree (Verheye, 2010).

1.8 Latex vessels

Latex vessels are found in the tree's soft bark. They are modified sieve tubes (cells formed by the cambium and coalescing when the dividing cell walls disintegrate) running anti-clockwise in concentric cylinders at an angle of approximately 30 degrees to the vertical axis of the stem (which is why tapping is done invariably from top left to bottom right in order to cut the vessels at a right angle). Vessels are laterally interconnected with each ring, but connections are disrupted as the trunk expands. The number of vessels per ring and the number of rings vary with age and thickness of the bark and with the clone. When tapping, part of the bark is scraped, whereby the latex vessels are cut causing the latex to flow. Tapping is done with precision using special knives to prevent damaging the underlying cambium. In renewed bark the number of functional vessels is increased (Verheye, 2010).

1.9 Fresh latex

Fresh latex consists of a colloidal suspension of rubber particles in an aqueous serum. The content of rubber hydrocarbon, with formula $(C_5H_8)_n$, varies from 25 to 40%, with an average of about 30%. It is manufactured in the tree from carbohydrates, and it has two major functions: (i) making the plant less attractive to pests because of the taste latex gives to parts of the tree and (ii) protecting the plant by sealing of the cuts so that no aggressors can penetrate into the tree. Latex consists of four main fractions (Delabarre and Serrier, 2000):

1.9.1 Rubber particles (25-40% of total latex volume), variable in shape, but usually pear shaped or spherical, and about 6 nm to 5 micron in size;

1.9.2 Lutoids (10-20%), 0.5 nm to 3 micron in size, having an impact on the stability and flow of the latex;

1.9.3 Frey-Wyssling particles (5%) which play probably a role in the coagulation and oxido-reduction processes; and

1.9.4 Other elements like proteins, resins, sugars, glycosides, tannins, alkaloids, mineral salts, and secondary metabolites (Verheye, 2010).

Rubber tree (*Hevea brasiliensis*) in Thailand

Natural rubber is a plant of economic importance of Thailand, which has been the world's biggest producer and exporter since 1991. In 2014, Thailand covers the cultivation area of natural rubber of 3.6 million hectares, of which tapping area is 2.78 million hectares. Thai rubber production reached 4.2 million tons in 2014. In this year, domestic consumption was 541,000 tons and 3.78 million tons were exported in primary-processing form according to the Office of Agricultural Economics (2015). Natural rubber generated export revenue of over 600,000 million Baht per annum. The cultivation area is mainly in the South, in which the province of Suratthani has the largest cultivation area, followed by Songkhla, Nokornsithammarat, Trang and Yala respectively. In addition to having the large area of rubber plantation, Suratthani is also home to many rubber processing factories. It plays a significant role in generating income and contributes to the economic growth of the country. According to RRIT (2015), the total area of rubber plantations in Thailand was 3.54 million hectares (Mha) in 2013. In 2013, the total rubber cultivation area in Northern, Northeastern, Middle and Southern Thailand were 0.20, 0.70, 0.42 and 2.23 Mha, respectively, while the expansion for new planting in the low and high land is at high rates (RRIT, 2015).

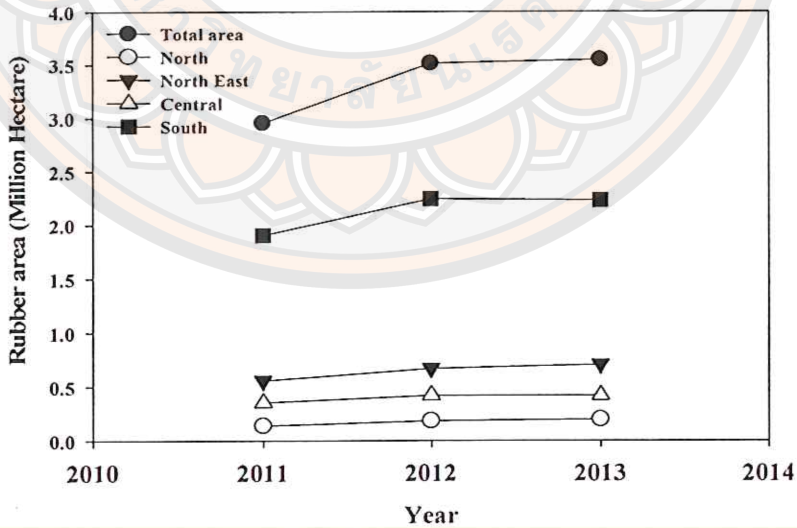

Figure 2 Rubber areas (million hectares) of each regions in Thailand

Source: Data received from Rubber Research Institute of Thailand, 2015

Rubber plantation managements

Nair (2010) reported that rubber plants respond well to a chemical fertilizer. A proper fertilizer added during the immature stage accelerates growth, thereby reducing an unproductive phase and optimizing productivity in the mature phase. The major nutrients (N, P, K, and Mg) provide positive effects on the growth and yield, and application of NPK increases the yield substantially. Additionally, Punnoose, et al. (2000) reported that rubber trees grow better in the immature phase than the mature phase. As rubber is usually planted in association with ground cover and the intercropping becomes a common practice. In modern cropping systems, proper field maintenance is essential during the immature phase so as to provide the best environment for young rubber plants to survive the competition with other species. Important management practices during this phase include establishment of ground cover, intercropping, weed management, mulching, induction of branching, pruning, and thinning. These practices are meant to reduce the immaturity period and to maintain an optimum plant density.

In general, rubber tree best grows in a monoculture, with inter-row areas protected by leguminous cover crops during the immaturity period. On the other hand, the land in such a system is underutilized with regard to the inter-row space. A few years after planting, before the tree canopy closes, it is possible to cultivate a variety of suitable crops in the interspaces between young rubber trees. This brings additional income to the farmer during the immaturity period of 6–7 years of the rubber trees. When the intercropping is properly done, Jessy, et al. (1997) reported that it enhances growth of rubber. The intercrops should not be planted too close to the young rubber plants due to a competition in nutrients uptake. Since the intercropping necessitates tillage at different degrees, unlike monoculture, it requires a restricted practice to level lands and gentle slopes so as to avoid soil erosion (Punnoose, et al., 2000).

Information of nutrient status in soil and plants, ability of plant nutrient uptake, and nutrient removal are required for a proper integrated nutrient management needs to know the standard values for assessing nutrient status in both soil and leaves are essential and recommended values for the rubber plants were proposed by Pushparajah (1977) and Thainugul (1986). However, these values are not comprehensive and, hence, there is still lack of information on that issue. Better standard values could be achieved by associating values of plant nutrient concentration and tree performance or yield (de la Puente and Belda, 1999). Thailand has potential to increase rubber productivity by suitable nutrient management. Nujanart, et al. (2006) found that current farmers' fertilizer practices have an average annual yield of 1,737 kg of dry rubber per hectare. If using the fertilizer rates recommended by the Rubber Research Institute of Thailand (0.3 kg N, 0.05 kg P, and 0.18 kg K per tree and year), yields increased to an average of 1,894 kg per hectare and year. Raising the recommended fertilizer dressing to 1.5 kg per tree and year increased rubber yields to an average of 2,100 kg per hectare and year.

Nutrient management aims to achieve the highest yield of crops by providing adequate supply of all plant nutrients. It is difficult in practicing since there are many factors involved, as well as economic factors. The use of fertilizers that contain only major plant nutrients means that plants have to obtain the other nutrients from the soil alone. When the concentrations of these elements do not meet the plant demand, the use of major nutrients alone will only give limited benefits. Thus, the concept has shifted from fertilization to integrated nutrient management to sustain yield and maintain soil quality and prevent deterioration (FAO, 2005). The integrated nutrient management needs to know the nutrient status in soil and plants, the ability of plant nutrient uptake, and also the nutrient removal, to adopt the balance of nutrient. The standard values for assessing nutrient status both in soil and in leaves are essential. Recommendations for rubber plant have been proposed (Thainugul, 1986; Pushparajah, 1977).

Role of plant nutrients and nutrient cycling

Nitrogen (N) is essential for plant growth and is part of every living cell. It plays many roles in plants and is necessary for chlorophyll synthesis. Plants take up most of their N as the ammonium (NH_4^+) or nitrate (NO_3^-) ion. Some direct absorption of urea can occur through the leaves, and small amounts of N are obtained from materials such as water-soluble amino acids. Healthy plants often contain 3 to 4 percent nitrogen in their above-ground tissues. These are much higher concentrations than those of any other nutrient except carbon, hydrogen and oxygen and are usually not a concern of soil fertility management in most situations. Nitrogen is an important component of many important structural, genetic and metabolic compounds in plant cells. It is a major element in chlorophyll, the compound by which plants use sunlight energy to produce sugars from water and carbon dioxide, or, in other words, photosynthesis (http://www.cropnutrition.com/nutrient-knowledge).

Phosphorus (P) is a vital component of adenosine triphosphate (ATP), the "energy unit" of plants. ATP forms during photosynthesis, has P in its structure and life cycle processes from the beginning of seedling growth to the formation of seeds and maturity. The general health and vigor of all plants requires P. Some specific growth factors associated with P include stimulated root development, increased stalk and stem strength, improved flower formation and seed production, more uniform and earlier crop maturity, increased nitrogen- fixing capacity of legumes, improvements in crop quality, and increased resistance to plant diseases (http://www.cropnutrition.com/nutrient-knowledge).

Potassium (K) is also an essential nutrient and is taken up in significant amounts by crops. Potassium is vital to photosynthesis, protein synthesis and many other functions in plants. Plants take up K in its ionic form (K^+).While potassium doesn't constitute any plant structures or compounds, it plays a part in many important regulatory roles in the plant. It is essential in nearly all processes needed to sustain plant growth and reproduction, including: photosynthesis, translocation of photosynthates, plant respiration, protein synthesis, control of ionic balance, breakdown of carbohydrates, which provides energy for plant growth, regulation of plant stomata and water use, activation of plant enzymes, disease resistance and recovery, turgor, and stress tolerance, including extreme weather conditions (http://www.cropnutrition.com/nutrient-knowledge).

Calcium (Ca) is found all around us. Plants take up Ca as the Ca^{2+} cation. Once inside the plant, Ca functions in several essential ways. Calcium replaces hydrogen (H) ions from the surface of soil particles when limestone is added to reduce soil acidity. This changeover is essential for microorganisms because they turn crop residues into organic matter, release nutrients, and improve soil aggregation and water-holding capacity. Calcium helps enable nitrogen (N)-fixing bacteria that form nodules on the roots of leguminous plants to capture atmospheric N gas and convert it into a form that plants can use. Within the plant, Ca improves plant roots' ability to absorb other nutrients. It activates a number of plant growth-regulating enzyme systems, helps convert nitrate N into forms needed for protein formation, allows cell wall formation and normal cell division to occur, and contributes to improved disease resistance. Further, Ca, along with Mg and potassium (K), helps neutralize organic acids that form during plant-cell metabolism (http://www.cropnutrition.com/nutrient-knowledge).

Magnesium (Mg) nutrition of plants is frequently overlooked and shortages will adversely impact plant growth. Many essential plant functions require adequate Mg supplies, the most visible being magnesium's role in root formation, chlorophyll and photosynthesis. Mg is required for crops to capture the sun's energy for growth and reproduction. All crops require magnesium to capture the sun's energy for growth and production through photosynthesis. Chlorophyll, the green pigment in plants, is the substance through which photosynthesis occurs. Without chlorophyll, plants could not manufacture food. Magnesium is an essential component of chlorophyll, with each molecule containing 6.7 percent Mg. Magnesium also acts as a phosphorus (P) carrier in plants, which is necessary for cell division and protein formation. So, Mg is essential for phosphate metabolism, plant respiration and the activation of several enzyme systems. Soils usually contain less Mg than calcium because Mg is not absorbed as tightly by clay and organic matter and is subject to leaching. The supply of available Mg has been and continues to be depleted in some soils, but growers are noticing good responses to fertilization with Mg (http://www.cropnutrition.com/nutrient-knowledge).

Carbon (C) is responsible for all life on earth. Carbon dioxide (CO_2) released into the atmosphere is recycled endlessly as part of the carbon cycle. Plants take CO_2 from the air and use the C for energy, helping to build essential biological compounds such as carbohydrates and proteins.

Maximizing an efficiency of nutrient cycling through the appropriate management of crop residues constitutes an alternative to increase agricultural sustainability, particularly in soils with low natural fertility in many tropical regions. Legume residues generally contain high N contents and lower C:N ratios compared to cereals. An inclusion of legumes in agricultural systems can enhance the overall soil fertility through an addition of N originating from biological fixation, thereby elevating yields of succeeding or intercropped crops (Kumar and Goh, 2002). During the mineralization of leguminous materials, up to 50% of N can be released into the soil within two months of incorporation (Fageria and Baligar, 2005). Straw produced after grain harvest and threshing of common bean cultivars (Phaseolus vulgaris L.) provides biomass ranging from 0.6-1.5 Mg/ha, 5-12 kg N/ha, and 0.4-1.0 kg P/ha, respectively, which corresponded to 15 and 11% of the total N and P accumulated by the crop at maturity (Araujo and Teixeira, 2003).

Plants are non-mobile organisms and therefore through evolution they have developed the complex sensing and signaling mechanisms to robustly monitor and appropriately respond to dynamic changes of surrounding environments. Among many environmental factors, carbon (C) and nitrogen (N) are crucial for plants to perform the routine and fundamental cellular activities. C compounds include various carbohydrates, in particular sucrose and glucose. These photosynthetic products provide both energy and C-skeletons for ammonium assimilation during amino acid biosynthesis. N nutrients include inorganic compounds (nitrate and ammonium) and the organic compounds (i.e., all amino acids) which are synthesized by incorporating ammonium into the C-skeletons. The amino acids and the resulting proteins are the key to build the blocks of cell. Both C and N nutrients are essential for various cellular functions and an adequate supply of these two nutrients are critical for plant growth, development and response to a wide array of stresses and ultimately the completion of life cycle and the production of harvestable organs (USDA Natural Resources Conservation Service, 2011).

The faster crop residues are consumed by soil microorganisms, less time than those residues covering on the soil surface. The crop residues on the soil surface are very important for protecting soil aggregates from the destructive force of raindrops hitting the soil, for conserving soil moisture, and for providing habitat to arthropods that shred crop residue and consume weed seeds. While it is important to maintain the soil cover, it is also essential that those same residues are decomposed in order to release plant nutrients and provide soil organic matter. Therefore, it is necessary to pay attention on the crop residue C: N ratios to maintain soil cover desired, yet allow the cover to ultimately break down and be recycled. A cropping system of continuous no-till wheat certainly provides a good soil cover, as wheat produces a fair amount of residue containing relatively high C: N ratio (80:1) that is decomposed slowly. However, such the cropping system does not allow the crop nutrients in wheat straw to be available for soil microorganisms or plants. By adding a relatively low C:N ratio crop, such as hairy vetch (11:1) to the rotation, nitrogen is available to the soil microorganisms, thus allowing them to break down the wheat straw more quickly. Likewise, a cropping system of continuous no-till peas would result in very little soil cover as soil microbes consume the pea residue (C:N of 29:1) relatively fast, therefore not much additional nitrogen is necessary for decomposition of the residue (USDA Natural Resources Conservation Service, 2011) .

With regard to the C:N ratios and soil cover mentioned in the previous section, management choices must deliver a balance between crop residues covering the soil and nutrient cycling. An awareness of crop C:N ratios is necessary to select suitable crop types and to keep a cropping sequence on the right path toward sustainability, that of the ultimate C:N ratio of 24:1 which supports soil microorganisms (USDA Natural Resources Conservation Service, 2011) .

The management of residues covering the soil during the growing crop could not provide soil protection requires good planning and experimentation to achieve a proper balance. If crops with high C:N ratios are grown too frequently in a rotation, residues could accumulate on the soil surface, and nitrogen for the growth of crops may be scarce unless there is an additional nitrogen from the other sources. This may result in poor crop performance when soil microorganisms tie up nitrogen during the decomposition of high C:N ratio crop residues (USDA Natural Resources Conservation Service, 2011).

Rubber growing conditions

1. Soil requirements of the rubber tree

Rubber can grow with many soils. The best soil for rubber is a well-drained, clayey and deep clay, but it also can withstand physical conditions ranging from stiff clay with poor drainage to well drained sandy loam. Soil water retention capacity, depth and soil moisture are important factors determining the suitability of a field (Lemmens, et al., 1995). Ground covering with plants can improve the soil physical properties (Krishnakumar and Potty, 1992). An optimal soil pH value for rubber tree is about 5-6 (Lemmens, et al., 1995). The performance of the tree can be restricted to rocky surface, heavy drainage or soil pH values above 6.5 or below 4 (Krishnakumar and Potty, 1992).

The Land Development Department of Thailand has carried out a research in Eastern Thailand in order to identify soil types suitable for rubber planting in the East of Thailand (LDD, 2005). According to this study, essential soil properties for rubber are soil depth of at least one meter and a moderate level of fertility. Shallow soils, heavy stone layers at or above 50 cm from soil surface and low levels of fertility are regarded as unsuitable conditions for rubber cultivation. Around 9,200 hectares of the land area in Eastern Thailand are found to have suitable soil series.

Soils of the rubber growing area in southern Thailand are usually deficient in both macro and micronutrients. Optimum ranges of soil properties and plant nutrients for rubber, maize, and plants in general are provided in Table 1.

Table 1 Optimum ranges of chemical soil properties and plant nutrients for rubber, maize and plants in general

Soil properties	Optimum range for rubber	Optimum range for maize	Optimum range for plants in general
pH[1/]	4.0-6.5	5.0-5.5	5.5-6.5
OM (%)[1/]	1.0-2.6	2-3	1.5-2.5
C (%)[1/]	0.05 – 0.15	-	-
N (%)[1/]	0.11 – 0.25	-	-
P (mg/kg)[1/]	10-25	8-11	10-15
K (mg/kg)[1/]	50-125	81-120	91-140
Ca (mg/kg)[1/]	10-25	>34	151-350
Mg (mg/kg)[1/]	50-600	320-800	1001-200
S (mg/kg)[1/]	25-35	7-12	6-12
Fe (mg/kg)[1/]	30-90	2.5-5.0	2.1-5.0
Mn (mg/kg)[1/]	2-4	1.0-2.0	1.0-20.0
Cu (mg/kg)[1/]	0.5-1.5	0.12-2.5	2.6-5.0
Zn (mg/kg)[1/]	0.5-1.5	0.25-2	0.5-1.0
B (mg/kg)[1/]	0.3-0.7	0.1-2.0	1.1-2.0
K/Mg[2/]	2.0 – 6.0	-	-
K/Ca[2/]	0.4 - 1.4	-	-
Mg/Ca[2/]	0.2 - 0.6	-	-

Sources: [1/] Timkhum, 2013, [2/] Suchartgul, 2012

Rubber is grown on various types of soil in the humid tropics which are mostly acidic. Deep, well-drained soils with a pH below 6.5 and without underground sheet rocks are well suited for the rubber cropping. In India, rubber grows on laterites and lateritic soil, a well-drained soil and abundance of available K and Mg (Krishnakumar and Potty, 1992).

2. Climatic conditions for rubber

The rubber tree is native to evergreen tropical rainforests, usually occurring within the 5° latitude north and south of the equator. The climate of this region is characterized by heavy rainfall and no distinct dry season. According to Rao and Vijayakumar (1992), the optimal climatic conditions for the genus Hevea are:

1. Rainfall of 2000 to 3000 mm evenly distributed without any marked dry season and with 125 to 150 rainy days per annum
2. Maximum temperature of about 29-34°C and minimum of about 20°C or more with a monthly mean of 25-28°C
3. High atmospheric humidity in the range of 80%
4. Bright sunshine amounting to about 2000 h per annum at the rate of 6 h per day through all months
5. Absence of strong winds (RRII, 2015)

Rubber cultivation in new planting areas in Thailand

The RRIT has already grouped rubber clones into three classes according to their latex, timber and joint production potential. Clonal recommendations for the non-traditional rubber cropping area of Thailand could be very useful in order to determine which clones can be best adapted to a marginal cultivation environment. Currently, the best rubber clone recommended for new planning area is RRIM 600.

1. RRIM 600

This high yielding rubber clone was developed by the Rubber Research Institute of Malaysia and is extensively grown in all rubber growing countries. Parents of the clone are Tjir 1 and PB 86. The tall and straight trunk is moderately to fairly heavy branching and branches are rather weak. Young plants show spindly growth and late branching with occasional leaning. The clone shows a rising yield trend of latex. Initial yield of an above average and subsequently high yield does not prominently exhibit yield depression during summer. An average annual yield per ha in estates for more than 20 years is 1,349 kg. RRIM 600 is highly succeptable to Phytophthora and fairly weak to Corynespora leaf disease. Therefore, RRIM 600 should not be planted in areas with high rainfall. Standard values for immature rubber tree of RRIM 600 were assessed by Suchartgul (2012) and are shown in Table 2.

Table 2 Tentative standard values derived from the boundary line approach for nutritional diagnosis in leaves, sampling the second or third leaves at 3-5 months of age from the terminal whorl of branches in canopy

Nutrients	Unit	Range			
		Low	Optimum	High	Very high
N	%	< 2.6	2.6 - 3.2	3.2 – 3.8	> 3.8
P	%	< 0.20	0.20 - 0.25	0.25 - 0.30	> 0.30
K	%	< 0.7	0.7 - 1.0	1.0 - 1.4	> 1.4
Ca	%	< 0.5	0.5 - 1.0	1.0 - 1.5	> 1.5
Mg	%	< 0.25	0.25 - 0.35	> 0.35	-
S	%	< 0.1	0.1 - 0.2	0.2 - 0.3	0.3 - 0.4
Fe	mg/kg	< 50	50 - 90	90 – 130	130 - 170
Mn	mg/kg	< 200	200 - 300	300 - 500	> 500
Cu	mg/kg	< 5	5 - 10	10 - 15	> 15
Zn	mg/kg	unable to establish			
B	mg/kg	< 10	10 - 40	40 - 80	> 80
K/Mg		< 3.0	0.3 - 4.2	>4.2	-
K/Ca		< 0.8	0.8 - 1.4	> 1.4	-
Mg/Ca		< 0.3	0.3 – 0.5	> 0.5	-

Source: Suchartgul, 2012

Soil Conservation systems

Effective soil conservation measures controlling water induced erosion in tropical areas are grass barriers or minimum tillage systems combined with a legume cover (Hilger, et al., 2013). These practices can reduce erosion and nutrient losses on the sloping lands, provide soil cover, and improve soil structure and infiltration. However, the use of hedgerows or other vegetative barriers are hindered by farmers' concerns over a reduction in cropping area and competition between species. There are some studies suggesting that crop yields in the rows closed to barriers or hedgerows are lowered due to competition for light, water, and nutrients (De Costa and Surenthran, 2005; Dercon, et al., 2006; Pansak, et al., 2007).

Principles on conservation agriculture are minimal soil disturbance, permanent soil cover and crop rotations. Soils under conservation agriculture tend to improve their soil organic matter (SOM) content after applying the technology for certain years. SOM can be considered as important soil fertility and quality influencing factors. Furthermore, it may improve other soil properties, such as infiltration, water holding capacity or soil structure (FAO, 2007).

Vegetative systems: Grass or tree species can be used as vegetative strips reducing slope length while providing other services such as fodder, fuel wood and mulch. The vegetative strips can be planted to catch soil, excess nutrients, and chemical pesticides moving along the land's surface before they enter waterways. The strips often lead to the formation of bunds or terraces due to" tillage erosion" - the downslope movement of soil during cultivation. Several benefits of distributed vegetative include increasing ground cover, improving soil structure and infiltration, as well as decreasing erosion by water and wind. Cover crops are beneficial as they:

1. stabilize soil moisture and temperature,
2. protect soil during fallow periods,
3. mobilize and recycle nutrients,
4. improve soil structure and break compacted layers and hard pans,
5. permit a rotation in a monoculture,
6. can be used to control weeds, pests and Produce additional soil organic matter and improve soil structure (FAO, 2007)

Contour farming: Contour farming involves ploughing, planting and weeding along the contour, i.e., perpendicular to the slope direction rather than up and down. The contour lines are lines that run along with the contour of a hill. The line stays at the same height and they does not run uphill or downhill. Many experiments show that contour farming alone can reduce the soil erosion by as much as 50% on moderate slopes. However, for any slopes steeper than 10%, other measurements need to be combined with contour farming to enhance its effectiveness. If contour lines are incorrectly established, then they potentially increase the risk of erosion.

Contour ridges are used mainly in semi-arid areas to harvest water. The grass barrier strips are planted along the contour and with fodder grass such as Napier grass, or are established from natural grasses or vegetation. They are effective soil conservation measures on soils that absorb water quickly and on slopes as steep as 30%.

Many studies on soil and water conservation displayed that soil and water conservation systems can be the way to reduce the environmental impacts and support rubber growth performance. According to Pansak, W., et al. (2005) reported that soil conservation on the highly soil erosion prone areas of Northeast Thailand by using papaya-grass barriers controlled soil loss, runoff and N loss through erosion most effectively, but as a trade-off led to higher N losses through leaching due to an increased infiltration rate. Additionally, Rodrigo, V. H. L. (2005) also reported that rubber intercropped with banana had a positive effect on the growth of rubber throughout the 6 years whilst girth and height of rubber tree were greater in the intercrops.

Plantation Crops

The plantation crops most usually produce coffee, tea, rubber, oil, cacao, and coconuts. Rubber is produced mainly in Southeast Asia, where Malaysia and Indonesia have long been the major producers, although exports from China and India are increasing rapidly (Baulkwill, 1989). All of these crops are profitable products, but need N from fertilizers. N_2-fixing legumes play an important role in the production of plantation crops, both as cover crops and as shade trees. Understory legumes can be used as cover crops with almost all types of plantation crops.

The motivation to use cover crops in plantations certainly came from the soil erosion problem that occurred during the initial cultivation of plantation crops (Maas, 1922; Bunting and Milsum, 1928). Coconut trees (Cocos nucifera), rubber (Hevea brasiliensis), and oil palm (Elaeis guineensis) are generally planted several meters apart on the empty ground; therefore the bare soil has minimal protection from erosion. The use of legumes is to provide the soil cover. Plant and tree legumes such as Crotalaria anagyroides, Flemingia macrophylla and Tephrosia candida have also been used to provide the soil cover and N in plantations. They also can be useful for establishing contour terraces on sloping land (Bunting and Milsum, 1928; Pushparajah and Tan, 1976). In some cases, grain legumes may be cultivated between the rows of plantation crops; for example, P. vulgaris which is often grown between rows of coffee bushes in northern Tanzania.

Legumes are the most successful plants used as cover crops in plantations since they are excellent forage, pasture or green manure plants. Important growth patterns of legumes are their ability to spread over gaps where establishment of trees was poor and to suppress vigorously growing grasses and other weeds. Important characteristics of legume cover crops contain a fast growth and a good root system to bind soils easily. Cover plants need to grow well during the establishing of plantation crops to fulfill their main purpose. Cover crops shall be perennials and be propagated readily, rather by seed (Bunting and Milsum, 1928). Bevan and Gray (1966) describe the practice of cover cropping in plantations in more detail. Legumes are usually sown with rhizobial inoculation after cleared ground has been weeded twice and the weeds are burned (Giller and Fairhurst, 2000).

CHAPTER III

RESEARCHMETHODOLOGY

Description of the study site

The study was conducted from June 2013 to August 2014. A field experiment was established at Ban Huai Phai, Wang Thong District, Phitsanulok Province (16° 55'N, 100° 32'E), which is one of the 17 provinces of the northern region of Thailand (Figure 3). The geography is a rolling slope with 12-30%. In addition, average level of landscape is about 190 m above the mean sea level.

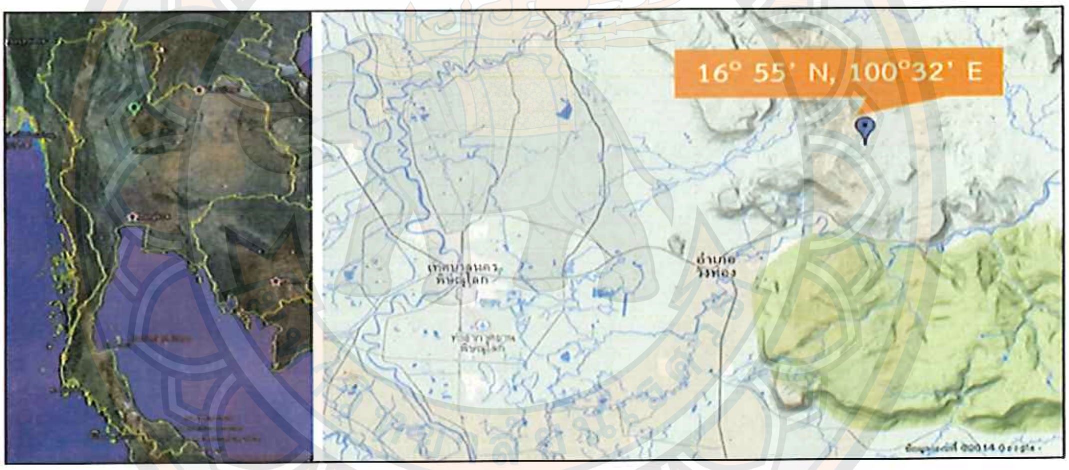

Figure 3 Map of Ban Huai Phai, Wang Thong District, Phitsanulok Province

Soil parent materials are colluvium and residuum from sand stone, which was combined on sedimentary rock: The drainage of the soil is poor and highly runoff. According to the USDA Soil Taxonomy, the soil is classified as a fine-loamy, mixed, semiactive, isohyperthermic Typic Haplustults (Soil Survey Staff, 2014) with 13% sand, 48% silt, and 39% clay in the topsoil (0–25 cm) and a bulk density (BD) of 1.6 g cm^{-3}. The topsoil had a pH (H_2O) of 4.5 with brown-red color, an organic matter content of 3.0%, a total N content of 0.15%, an available P (Bray II) content of 1.5 mg kg^{-1}, an exchangeable K content of 207.3 mg kg^{-1}, CEC of 2.7 me/100g and Infiltration rate of 15.1 mm/hr (Figure 4).

Figure 4 Soil profile of the study area

In February of 2013, an automated weather station was installed at the study site to collect climatic data. The collected data were recorded from June 2013 to August 2014, including daily rainfall amount, temperature, relative humidity, and solar radiation. The climate on site is tropical savannah climate. Annual rainfall was about 1300 mm/year. The average maximum temperature was 33 °C with an average minimum of 23 °C. Relative humidity was ranging from 64-95%. The average sunshine was longest in January, approximately 9 hour per day as shown in Figure 5.

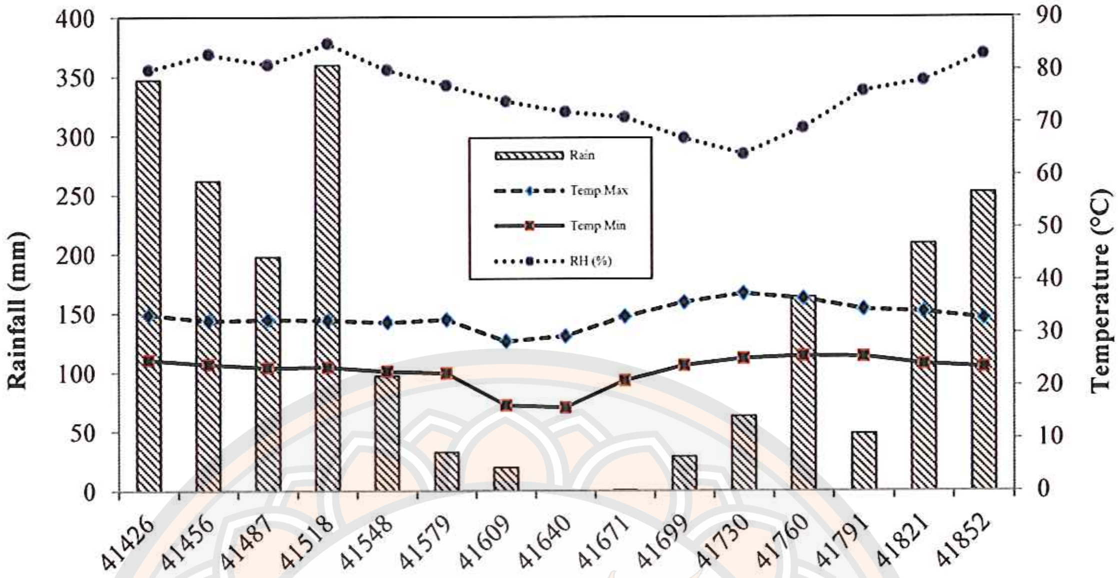

Figure 5 Rainfall, maximum temperature, minimum temperature, mean temperature, and relative humidity between June-2013 to August-2014 at Ban Huai Phai, Wang Thong District, Phitsanulok Province

Experimental design

The experiment was set up on a farmer's field with 3-year-old Para rubber trees. Rubber trees had a spacing of 3 m by 7 m. The experimental design was laid out in a Randomized Complete block Design (RCBD) with four treatments and three replications. The treatments were: (i) T1 = Sole cropping of rubber (control), (ii) T2 = Rubber trees + Maize, (iii) T3 = Rubber trees + Maize + Soybeans, and (iv) T4=Rubber trees + Maize + Vetiver grass (Figure 6). In total, twelve plots were established. Each plot size was 9 by 10 m (90 m^2) and the number of rubber trees in each treatment was six rubber trees in two rows with three plants in each row. In all treatments, the rubber genotype (clone) RRIM 600 was planted in 2011. In Treatments 2, 3, and 4, maize (Zea mays L.), cv. NK 48, was planted (June 16, 2013) between tree rows using a planting stick at a spacing of 25 cm along the row and 75 cm between rows. Vetiver grass (Vetiveria zizanioides (L.) Nash) were planted in two strips wide barriers on June 16, 2013, occupying about 13% of the total plot area (Fig. 4). Soybeans (Glycine max (L.) Merr.) were planted after maize harvest, starting in October 11, 2013. After maize or soybean harvest, maize stover and all soybean material were left on the plots as mulch to protect soil and suppressing weeds in the following growing season. Plot with vetiver grass was pruned three times per year, and pruning spread evenly over the alley. Thus, over a year a total of 2.5 t ha^{-1} plant residues were applied as mulch in the vetiver grass treatment.

Rubber trees were pruned twice a year. Fertilization with N, P, K, and manure was done following the local recommendation for farmers. The combination of three formulas of chemical fertilizers (CF) (15-15-15, 18-18-18 and 18-20-0) were applied twice a year (January and July). The input levels of N, P, and K were 21. 8, 18.7, and 10.2 kg ha^{-1} $year^{-1}$, respectively. Manure (MF) was applied in November at a rate of 133 kg ha^{-1} $year^{-1}$. Maize has got an urea (46-0-0) dressing of 800 g $plot^{-1}$ $crop^{-1}$, 50% at 17 days and 50% at 35 days after sowing.

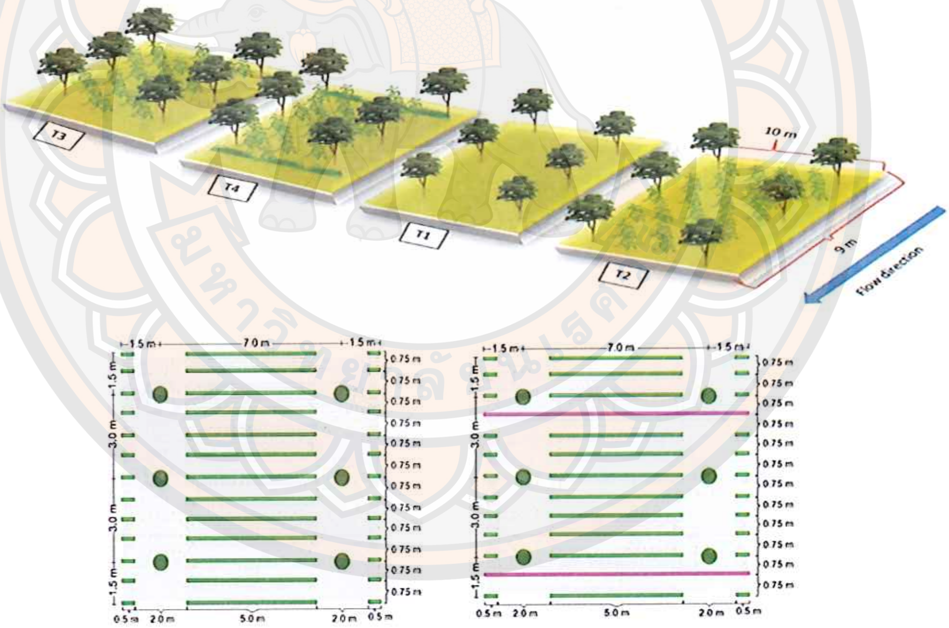

Figure 6 Experimental layout of rubber plantation and crop spacing under various soil and water conservation systems; green lines are maize and purple lines are vetiver grass

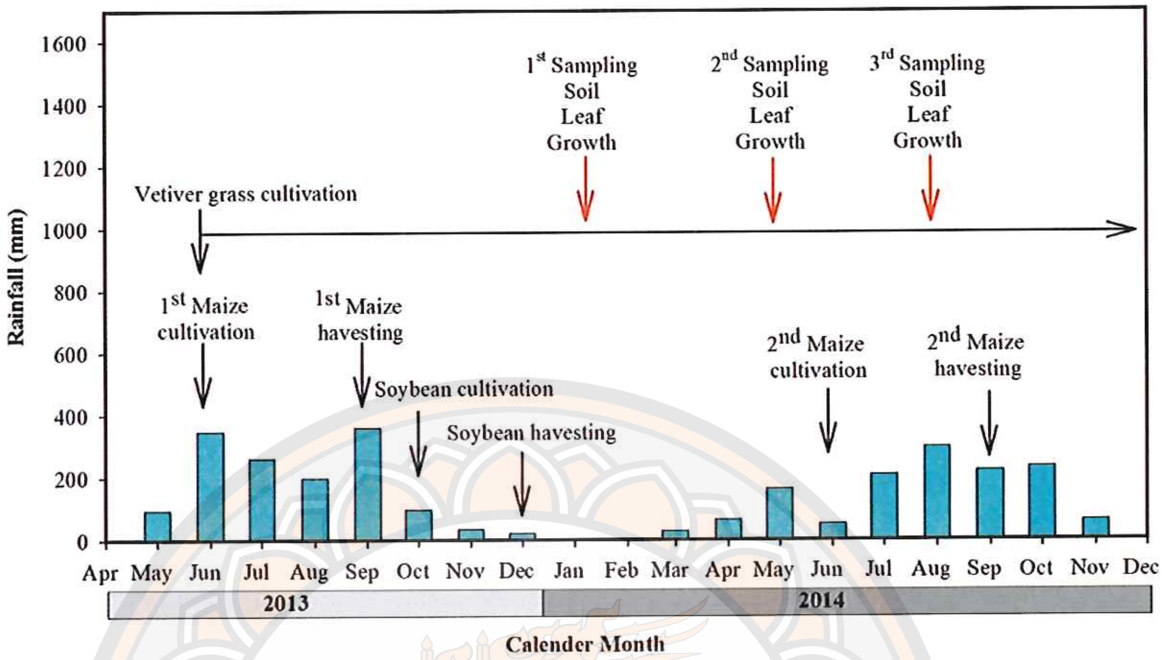

Figure 7 Crop calendar of intercropping plant under various soil and water conservation systems started in June 2013 until Aug 2014; S refers to sampling times, CF refers to chemical fertilizer added and MF refers to manure fertilizer added

Rubber leaf sampling and analysis

Young and mature rubber leaves were sampled in the cool season (January), hot season (May) and rainy season (August) by collecting samples from three out of six trees of a plot. A composite sample (3-5 rubber leaves) of young and mature rubber leaves was collected from the top and lower canopy of three rubber trees in upper, middle and lower parts of each plot as shown in Figure 8. A composite sample was taken for chemical analysis. Leaf samples were dried at 65 – 70 °C, then ground, and sieved through 1 mm sieve. Homogenised plants were analyzed in triplicate for percent total carbon and total nitrogen in a CNH analyser (Vario EL Cube, Elementar, Hanau, Germany), P, K, Ca, Mg (digested with HNO_3:$HClO_4$ = 4: 1), analyzed P by Vanadomolybdate method and K, Ca, Mg analyzed by atomic absorption spectrophotometry.

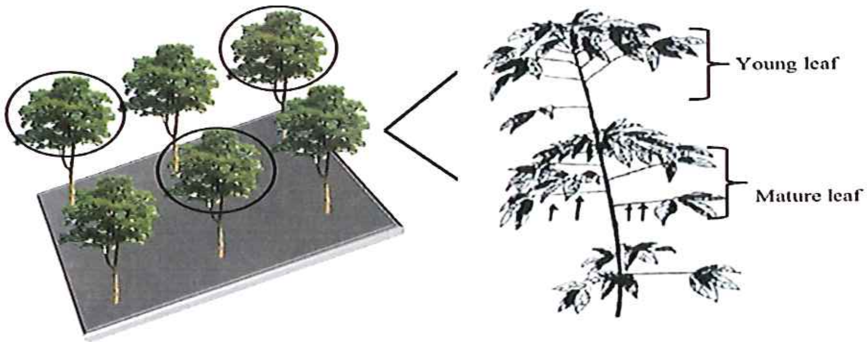

Figure 8 Experimental layout of rubber leaf sampling in each plot of hillside Rubber plantation under soil and water conservation systems

Soil sampling and analysis

Soil samplings were done for three positions per plot at soil depths of 0-20 and 20-40 cm. The soil sampling followed the pattern shown in Figure 7. In each plot, there were six samples per plot (top soil 0-20 cm and sub soil 20-40 cm) for soil moisture and three samples (only top soil 0-20 cm) for soil nutrients. The experimental plots were divided into three parts. First part was the upper part of the plot, second part was the middle and third part was the lower position. Soil in upper plot was collected at 50 cm away from rubber tree. Then soil in middle plot was collected at 350 cm away from rubber tree, and soil in lower plot was collected at 50 cm away from rubber tree.

Soil from all plots were sampled at depths of 0-20 and 20-40 cm. Soil samples were air dried in the shade area, then ground and sieved through a 2 mm sieve. Homogenized soil were analyzed in triplicate for percent total carbon and total nitrogen by a CNH analyzer (Vario EL Cube, Elementar, Hanau, Germany), Organic matter was analyzed by Walkley and Black method. Available phosphorus was analyzed by Bray II method, exchangeable potassium, calcium and magnesium were analyzed by Atomic Absorption Spectrophotometry, Cation exchange capacity (CEC) and base saturation were analyzed at the beginning and at the end of the cropping period. The physical soil properties were annually analyzed including soil texture, infiltration rate and bulk density.

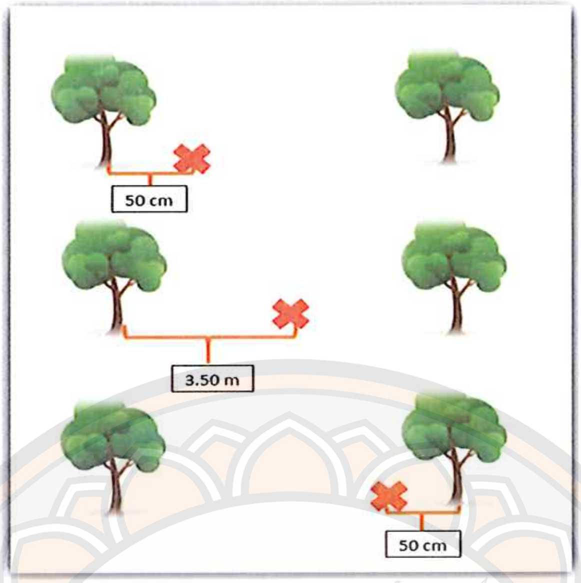

Figure 9 Experimental layout of soil sampling position in each plot of hillside rubber plantation under soil and water conservation systems

Growth Measurements

The height and girth of rubber tree was measured. Girth of the tree was measured at a distance from the ground about 1.5 meters.

Maize growth was determined by measuring height of maize every month. Maize dry matter was determined by harvesting three 6 m² sample areas per plot and economic input and output are monitored. Maize grain yield was be separately collected.

Legumes dry matter production was determined for grain yield.

Statistical analysis

Results were analyzed by using SPSS Statistic version 19 (SPSS, Inc, IBM company). DMRT test was used the least significant difference to determine significant differences in means across treatments.

CHAPTER IV

RESULTS

Study of rubber growth performance

Rubber growth performance was investigated under various soil conservation systems in cool, hot and rainy season from January until August 2014. Results are shown below:

1. Relative height of rubber trees

The rate of growth in height was similar among treatments from cool to rainy season. Figure 10 showed that relative height of rubber tree slightly increased from cool, to hot season about 2%, approximately. During the rainy season, relative height strongly increased by approximately 17% in all treatments. Differences among treatments were not significant ($p<0.05$).

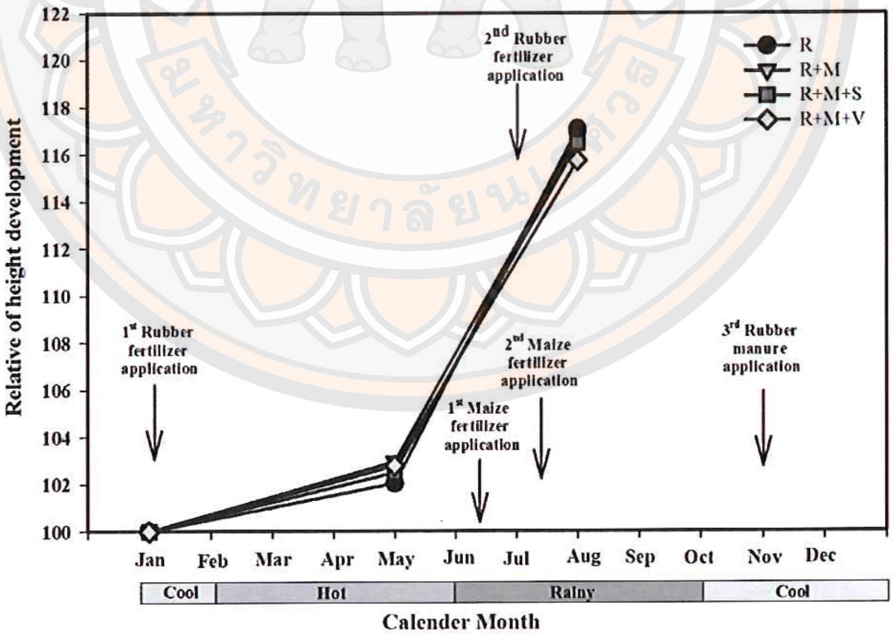

Figure 10 Relative of height development of rubber trees from January to August 2014 at the experimental site

2. Relative girth of rubber tree

Relative value was calculated from initial girth measurement in January 2014. Figure 10 shows that the in all treatments * rubber girth increased by 5-7% from January to May 2014. Relative girth was not significantly different among treatments in May (hot season). Relative girth showed progressive extension of rubber girth in rainy season, with the highest value of 48% in the rubber intercropping with maize and vetiver grass treatment and the lowest value of relative girth 35% in the sole rubber treatment (Figure 11). Differences were significant ($P \leq 0.05$): R+M+V > R+M > R = R+M+S.

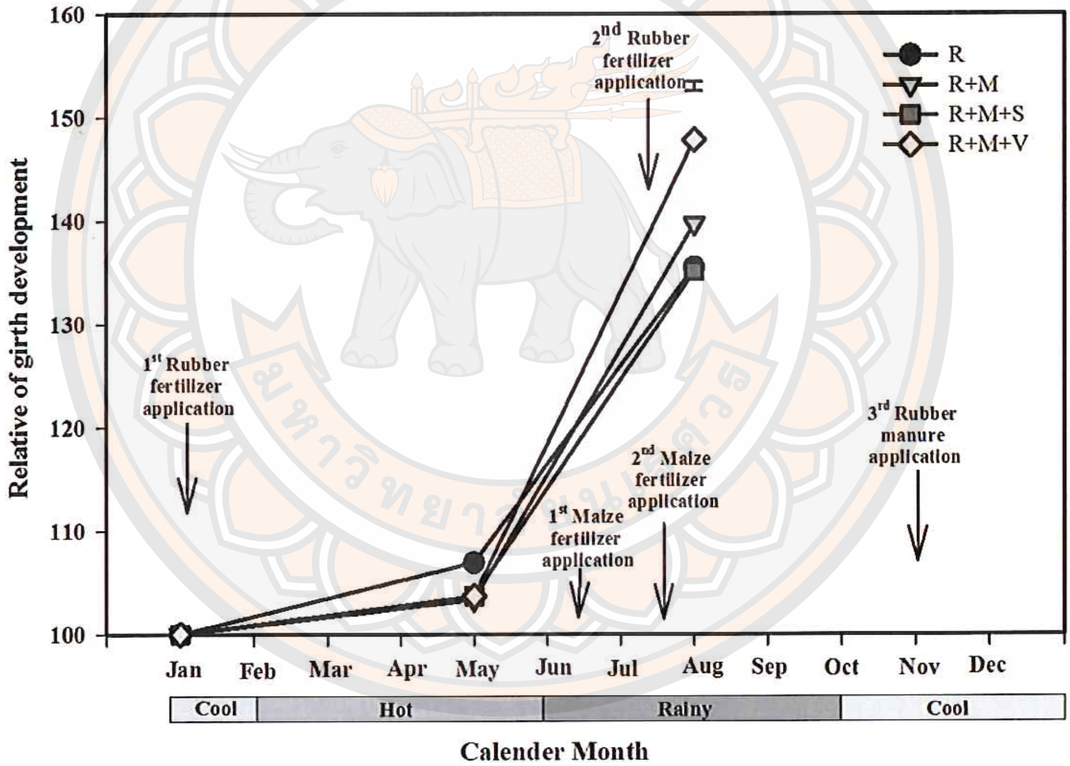

Figure 11 Relative of girth development of rubber trees from January to August 2014 at the experimental site. Vertical bars represent SED

3. Relationships between rubber girth and rubber height

Girth of rubber showed significant and moderate correlation with height of rubber tree for all treatments and all seasons. The correlation between girth and height of rubber tree was 65% using an exponential model (R^2= 0.65, P <0.0001) (Figure 12).

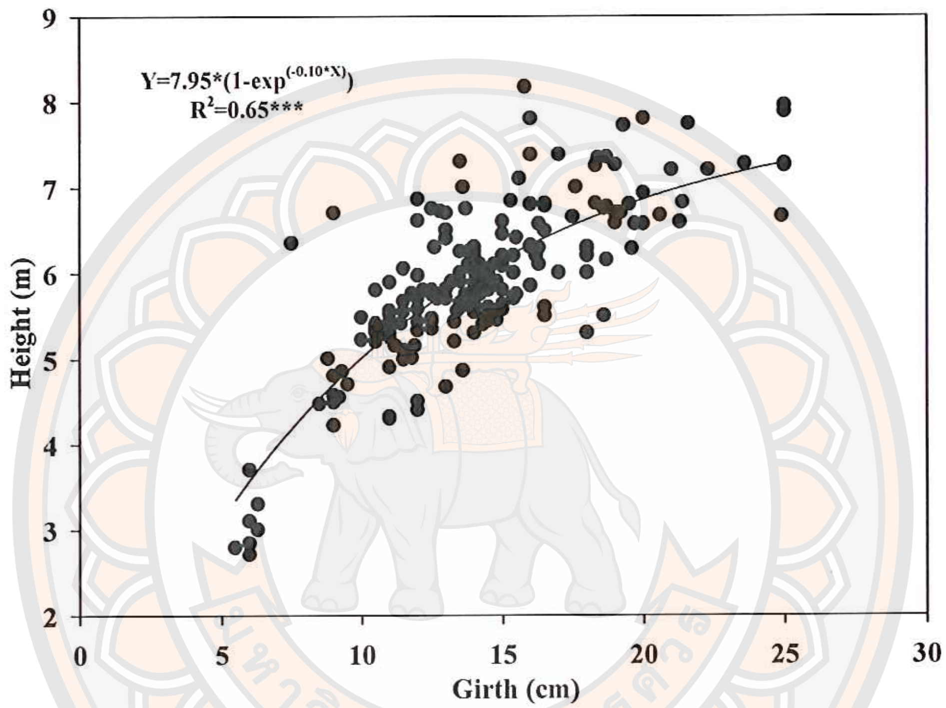

Figure 12 Correlation of rubber girth and rubber height under various soil conservation systems from January to August on hillside rubber plantation, northern, Thailand. The data were fitted by exponential models

Changes in chemical soil properties under hillside rubber plantations with various soil and water conservation systems

Within the top soil (0-20 cm depth), the chemical properties of soils under hillside rubber plantations with various soil and water conservation systems are shown in Figures 14-21. The mean soil organic carbon contents of all treatments in cool, hot and rainy season ranged from 1.13– 1.40% (Figure 13). The results showed that no significant difference in soil organic carbon content between sole rubber and intercrop treatments in cool and hot season. However, in rainy season, there were significant differences in soil organic carbon contents between the sole rubber treatment and three intercropping of immature rubber treatments. The later had significant lower carbon contents.

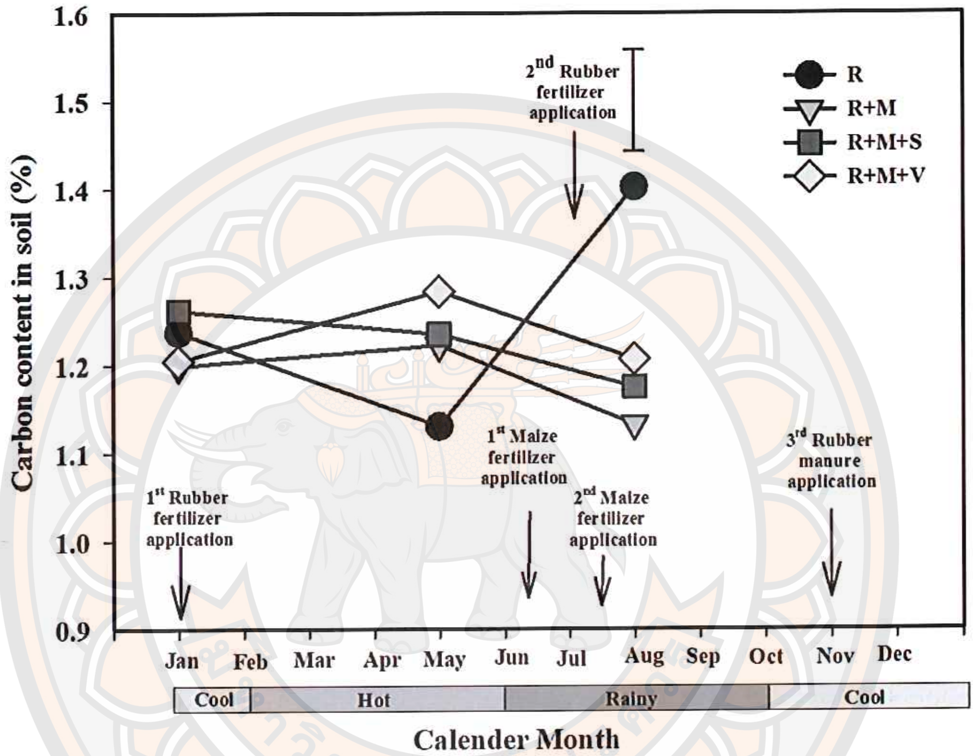

Figure 13 Soil carbon content in various treatments of rubber intercropping systems during January – August 2014. Vertical bar represent SED at the significant at p< 0.05 by LSD.

The pattern of total nitrogen contents was similar to the soil carbon content. In the rainy season, soil nitrogen contents were significant different between the sole rubber treatment and intercropping treatments. In the rainy season, the highest value of soil nitrogen contents was found in sole rubber treatment (0.17 %) while the lowest was observed in maize-rubber intercropping (0.13%) (Figure 14).

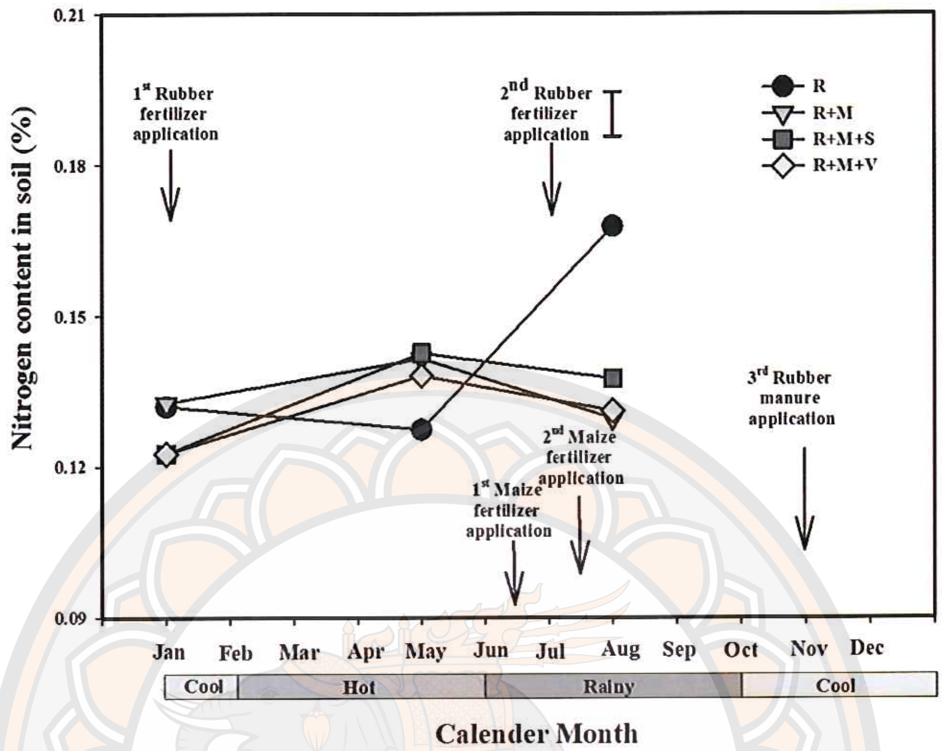

Figure 14 Soil nitrogen content in various treatments of rubber intercropping systems during January – August 2014. Vertical bar represent SED at the significant difference of 95% by LSD.

Figure 15 shows that there were no significant difference in the soil carbon to nitrogen ratio between sole rubber and the other three treatments. C: N ratios of the soil ranged from 9.3 to 10.2 in the cool season, from 8.6 to 9.3 in the hot season, and from 8.5 to 9.2 in the rainy season.

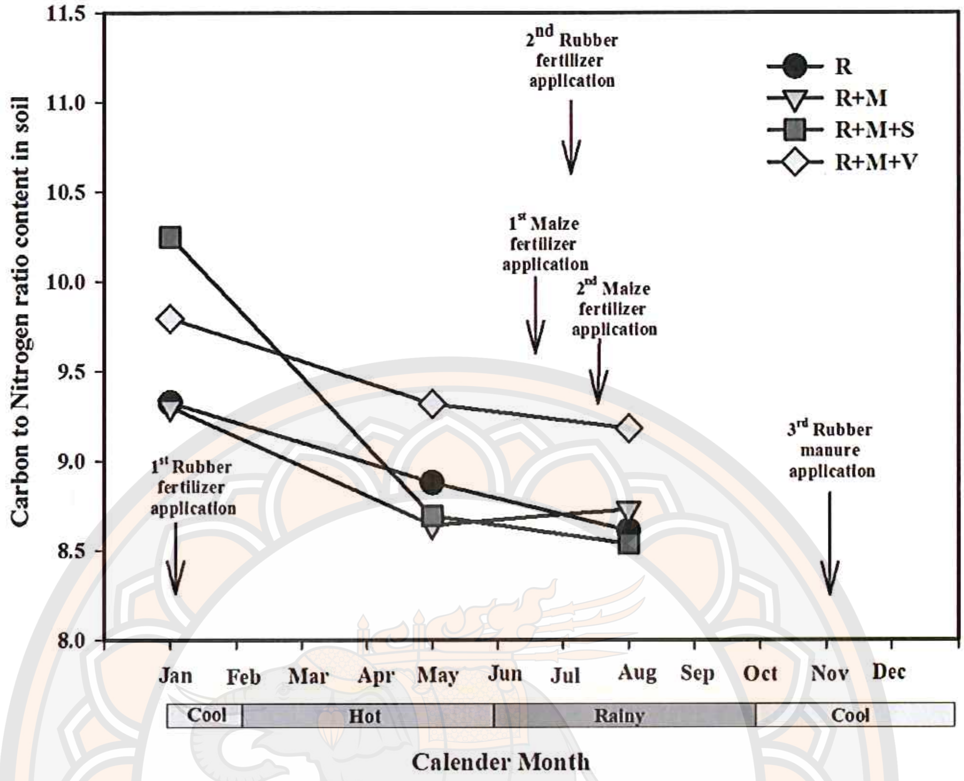

Figure 15 Soil carbon to nitrogen ratio content in various treatments of rubber intercropping systems during January – August 2014

Available phosphorus of the soil was not significant different between treatments for all seasons. Values of available phosphorus in the soil were in the range of 2-4 mg/kg. In addition, the amount of phosphorus in soil slightly changed from January to August 2014 (Figure 16).

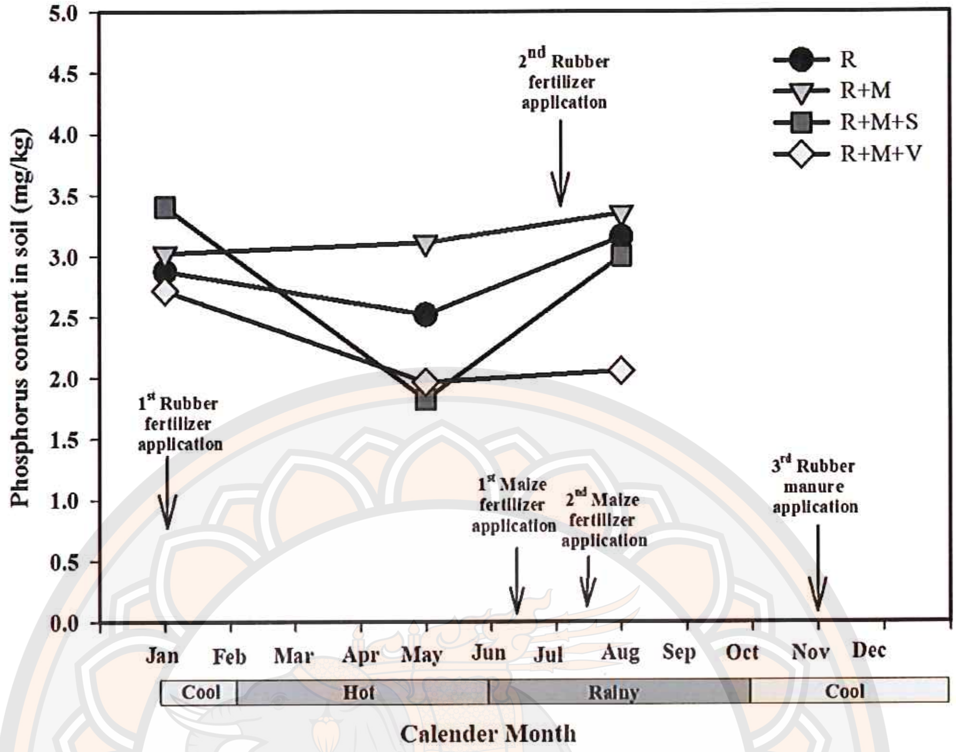

Figure 16 Soil phosphorus content in various treatments of rubber intercropping systems during January – August 2014

The lowest value of exchangeable potassium in soil was found in the rainy season. It showed significant differences between treatments during rainy season. Rubber intercropping with maize was a highest potassium content in soil significantly. Values ranged from 168.4 to 247.9 mg/kg (Figure 17). Figure 18 shows that exchangeable calcium in soil had no significant difference between each treatment in cool and hot season. However, exchangeable calcium content was significant different between sole rubber treatment and intercrop treatments during rainy season. The lowest exchangeable calcium content in soils was found in maize intercropping with rubber and soybean treatment (168.39 mg/kg). Moreover, exchangeable calcium content of the soils decreased from cool to rainy season.

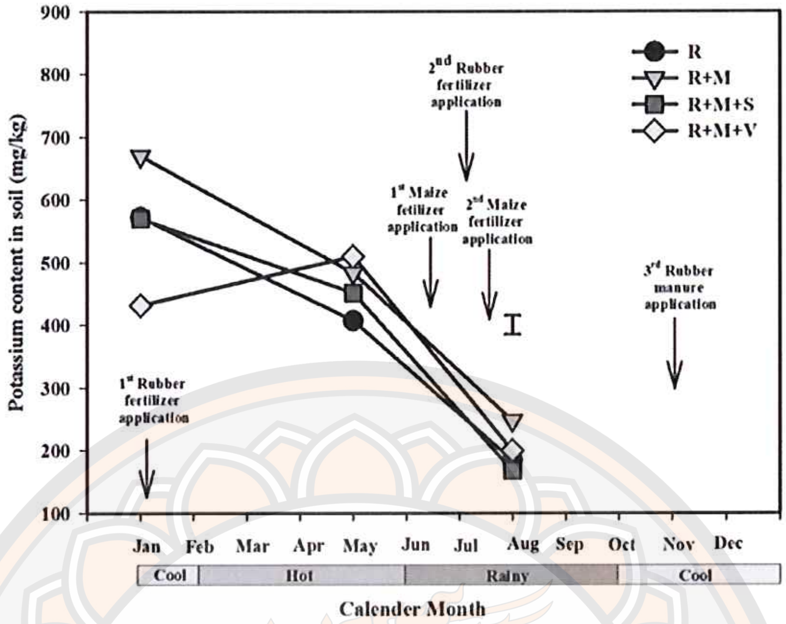

Figure 17 Soil potassium content in various treatments of rubber intercropping systems during January – August 2014. Vertical bar represent SED at the significant difference of 95% by LSD

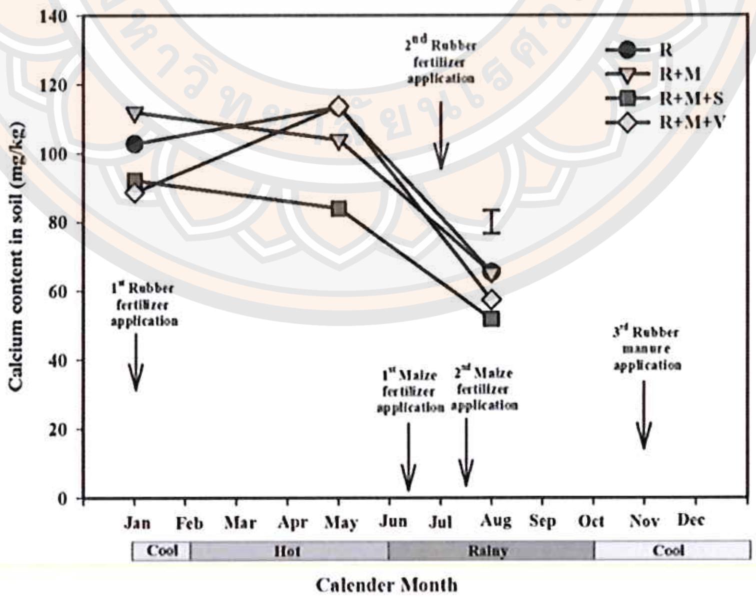

Figure 18 Soil calcium content in various treatments of rubber intercropping systems during January – August 2014. Vertical bar represent SED at the significant difference of 95% by LSD

Figure 19 shows that exchangeable magnesium in soil was significant different between each treatment in hot season. Treatment 4 However, In rainy season, relative girth differed significantly ($P \leq 0.05$) between treatments had the highest value, followed by treatment 1, treatment 3 and treatment 2 with values of 324.3, 304.4, 243.7 and 227.5 mg/kg, respectively. Values of each treatment slightly increased from January 2014 to May 2014 and strongly decreased from May 2014 to August 2014 (Figure 20).

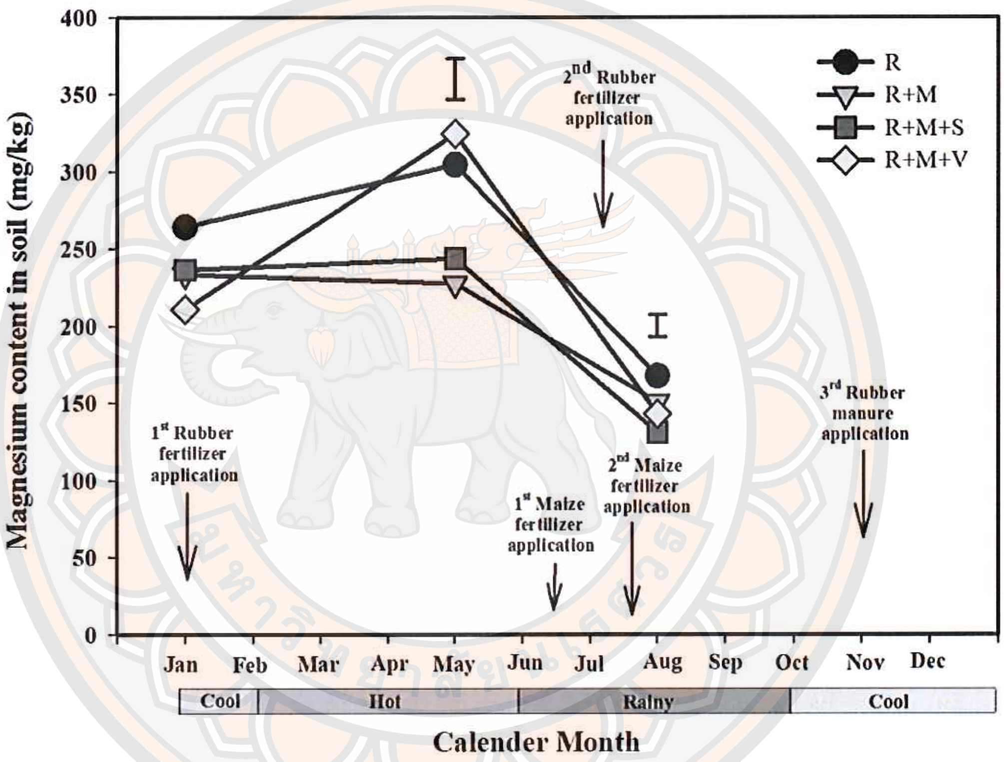

Figure 19 Soil magnesium content in various treatments of rubber intercropping systems during January – August 2014. Vertical bar represent SED at the significant difference of 95% by LSD

In all the treatments, the results showed a similar trend (Figure 19). In the cool season (January) soil moisture values varied from 5.7 to 6.5%, then dropped to 3.6 to 4.0% in th hot season (May) and to increased again in August with values ranging from 8.4 to 9.3%.

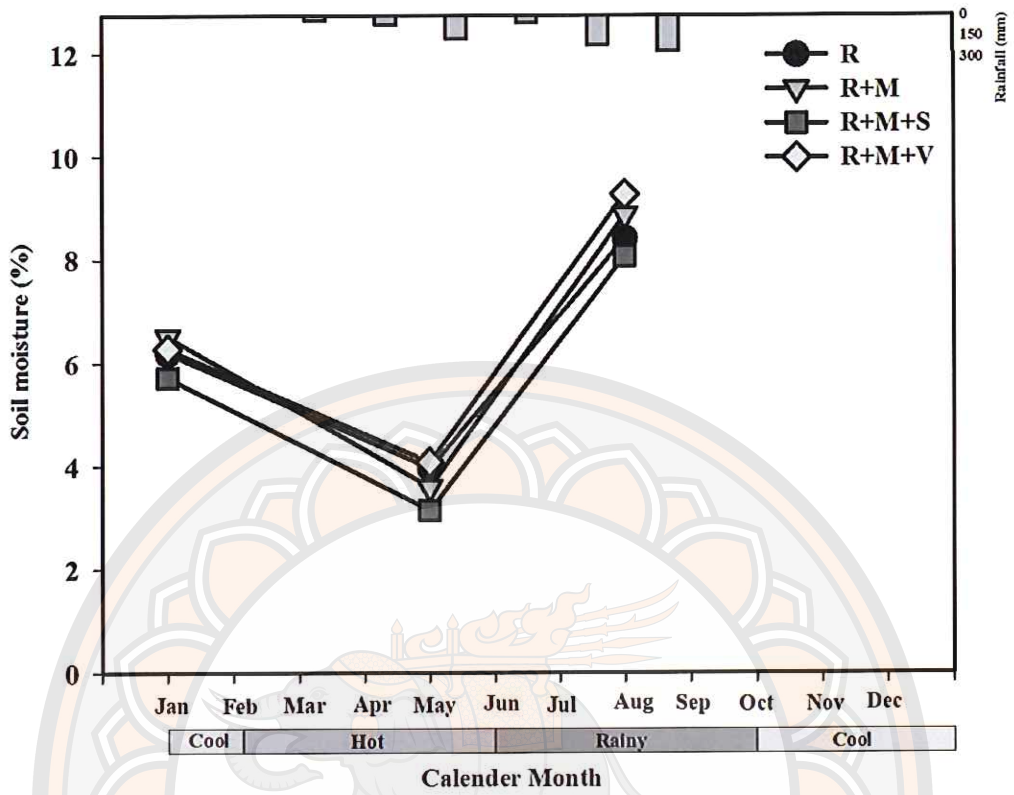

Figure 20 Soil moisture content in various treatments of rubber intercropping systems during January – August 2014

Table 3 shows the difference of mean soil nutrients on hillside rubber plantation during January to August 2014. There were some effects of season to the change of soil nutrients. The results displayed that N, C/N, K, Ca, and Mg in soil were affected by the change of season. The patterns of nutrient translocation were found that cool season (January) was more nutrient accumulated in soil than other two seasons as shown in C:N ratio, K, and Ca. However, there were no major shifts regarding C and P. Obviously, cation elements such as K, Ca, and Mg tend to strongly decrease in rainy season (August).

Table 3 The difference of mean soil nutrients on hillside rubber plantation during January – August 2014

Season (Month)	Soil nutrients						
	C (%)	N (%)	C/N	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
Cool (January)	1.23	0.1280[b]	9.66[a]	3.00	561.2[a]	98.8[a]	236.3[b]
Hot (May)	1.22	0.1369[ab]	8.88[b]	2.35	462.9[b]	103.7[a]	274.9[a]
Rainy (August)	1.23	0.1397[a]	8.76[b]	2.89	200.2[C]	60.0[b]	148.0[C]
F-test	NS	*	*	NS	*	*	*
C.V.(%)	16.2	13.1	9.8	61.48	40.08	34.2	27.7

Note: NS is non-significant different of mean among treatment (P>0.05)

* Significant difference (P<0.05) Mean in the same column with different superscripts differ significantly by DMRT

The result showed that soil organic carbon and exchangeable potassium contents under sole rubber and intercrop treatments were higher than the optimum range (Table 4). The concentrations of total N and exchangeable Mg in soil were in the optimum ranges for the general recommendation of the Rubber Research Institute. Available phosphorus and exchangeable Ca of soils under sole rubber and intercrop treatments were lower than their general recommendations for optimum ranges; therefore it may lead to insufficiency of these elements in the long run. (Table 4)

Table 4 Comparison of soil parameters with the standard recommendation of the Rubber Research Institute

Soil properties	Optimum range	Observed values in the rubber plantation					
		Sole rubber			Rubber intercropping		
		Low	Optimum	High	Low	Optimum	High
Carbon (%)	0.05 -0.15			●			●
Nitrogen (%)	0.11-0.25		●			●	
Phosphorus (mg kg^{-1})	10-20	●			●		
Potassium (mg kg^{-1})	150-250			●			●
Calcium (mg kg^{-1})	50-70	●			●		
Magnesium (mg kg^{-1})	>117		●			●	

Source: Timkhum 2013; Pechkeo, 2014

Changes of nutrient contents in rubber leaves under hillside rubber plantations with various soil and water conservation systems

Nutrient accumulation of rubber leaves in each treatment and each season was investigated, including organic carbon, nitrogen, phosphorus, potassium, calcium and magnesium. Figure 21 shows organic carbon content of rubber leaves. In cool season, rubber intercropping with vetiver grass and sole rubber treatments had significantly lower organic carbon content compared to other treatments. Later in the hot season, it reached an peak with values of 48.2 and 47.6%, but slightly decreased again in the rainy season (46.7 and 47.6%). The changes of organic carbon content in rubber leaves under rubber intercropping with vetiver grass, rubber intercropping with maize and soybean and sole rubber treatments had a similar trend in hot and rainy season; there were no significant difference between treatments in these periods. In the rainy season, the highest value was 47.9%, obtained from rubber intercropping with maize. On the other hand, the lowest value of 46.5 %was obtained from rubber intercropping with maize and soybean (Figure 21).

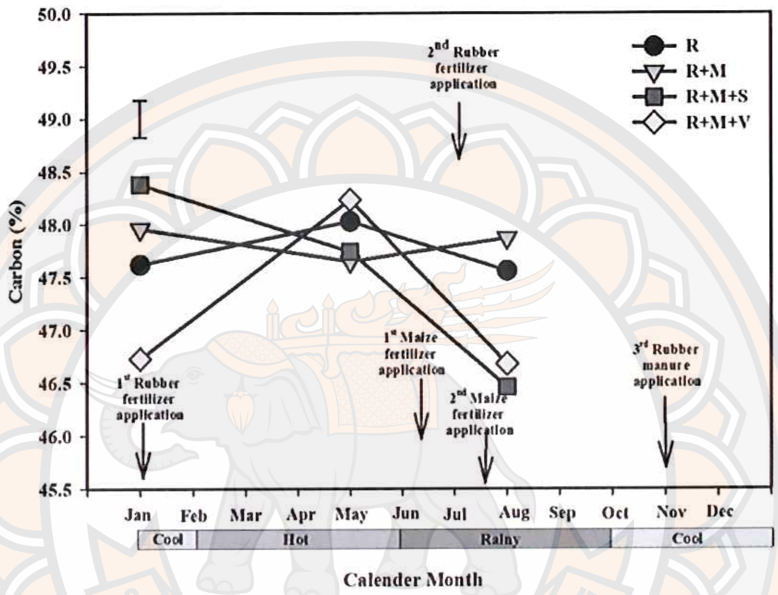

Figure 21 Carbon content of rubber leaves in four rubber based cropping systems Data were recorded during January and August 2014 at Phitsanulok province in Northern Thailand. Vertical bars represent SED at a $p<0.05$ by LSD

Figure 22 shows that nitrogen content of rubber leaves had a similar trend in all treatments over all seasons. In all treatments, nitrogen content of rubber leaves decreased in the hot season, but increased in the rainy season. However, there were no significant differences among treatment in the cool period. The values of nitrogen content in the cool season ranged from 2.90 to 3.08%. In addition, the result clearly showed that sole rubber treatment had the lowest nitrogen content in rubber leaves when compared to rubber intercropping treatments from the cool season to the rainy season. In the hot seasons, nitrogen content in rubber leaves was significantly lowest in the rubber intercropping with maize treatment, while in the rainy season nitrogen content in rubber leaves was significantly lowest in the rubber sole cropping. The values of nitrogen content in rubber leaves were in the range of 2.36-3.08% for the hot season and 2.84-3.44% for rainy season.

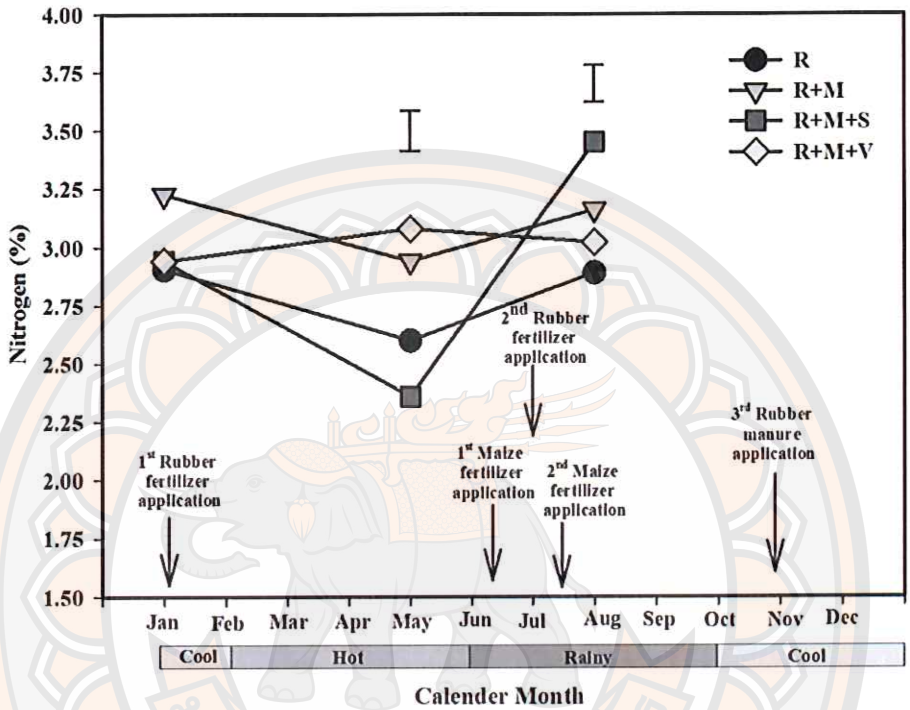

Figure 22 Nitrogen content of rubber leaves in four rubber based cropping systems data were recorded during January and August 2014 at Phitsanulok province in Northern Thailand. Vertical bars represent SED at a $p<0.05$ by LSD

The results showed no significant difference in C:N ratio of rubber leaves between sole rubber and intercrop treatments in the cool season. Similar pattern of C:N ratio during c every sampling period was found in both sole rubber and rubber intercropping treatments. In the cool season, C:N ratio was in the range of 15-17, then moving up to 16-21 in hot season and declining in rainy season (14-17). In the hot season, the rubber intercropping with maize and soybean treatment had the widest value of C:N ratio (21) while in rainy season, the rubber intercropping with maize and soybean treatment had the narrowest C:N ratio (14) (Figure 23).

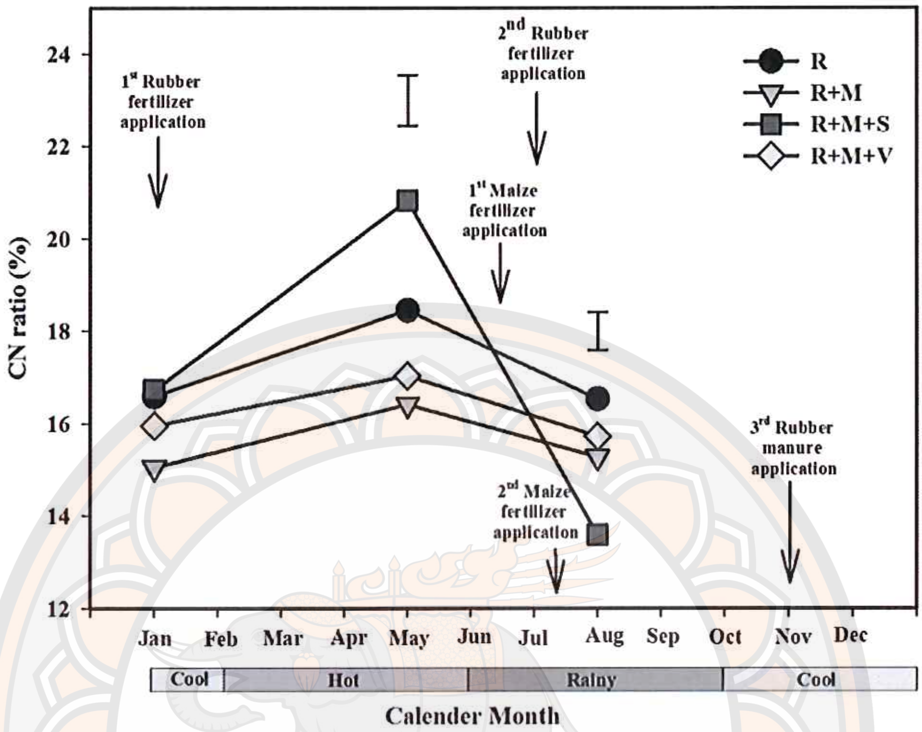

Figure 23 Carbon to Nitrogen ratio of rubber leaves in four rubber based cropping systems. Data were recorded during January and August 2014 at Phitsanulok province in Northern Thailand Vertical bars represent SED at a $p<0.05$ by LSD

Figure 24 shows that phosphorus content in rubber leaves reached a peak in the cool season in all treatments, then strongly declined in hot season and slightly decreased in rainy season. Rubber intercropping with maize had the highest phosphorus content in the cool season; however, there were no significant differences between each treatment. – In the hot and rainy seasons, phosphorus contents of rubber leaves were significant different between sole rubber treatment and intercrop treatments. In addition, the content in sole rubber was the lowest compared to rubber intercropping in both hot (0.14%) and rainy season (0.09%). They were in a range of 0.14-0.24% and 0.09-0.25% in hot and rainy season, respectively (Figure 25).

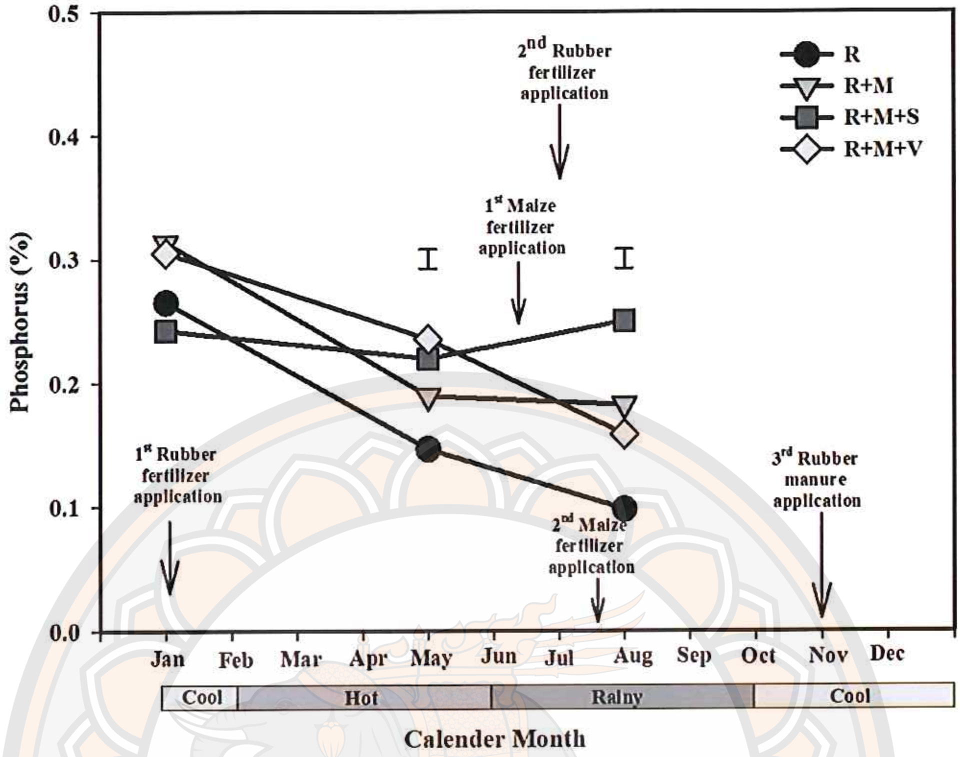

Figure 24 Phosphorus content of rubber leaves in four rubber based cropping systems. Data were recorded during January and August 2014 at Phitsanulok province in Northern Thailand. Vertical bars represent SED at a $p<0.05$ by LSD

No significant differences in potassium content in rubber leaves were observed between sole rubber and intercrop treatments in the cool, hot and rainy season (Figure 25). In sole rubber, rubber intercropping with maize and soybean and rubber intercropping with vetiver grass treatments, potassium contents of rubber leaves were highest in the cool season, then remained at almost the same levels in the hot season and declined in the rainy season. They were in a range of 0.22-0.30%, 0.19-0.30% and 0.14-0.25% in the cool, hot and rainy season, respectively. However, rubber intercropping with maize sharply changed in potassium content in each sampling time. Moreover, only the rubber intercropping with maize were increased potassium content in rubber leaves in rainy season, contrasting with other treatments.

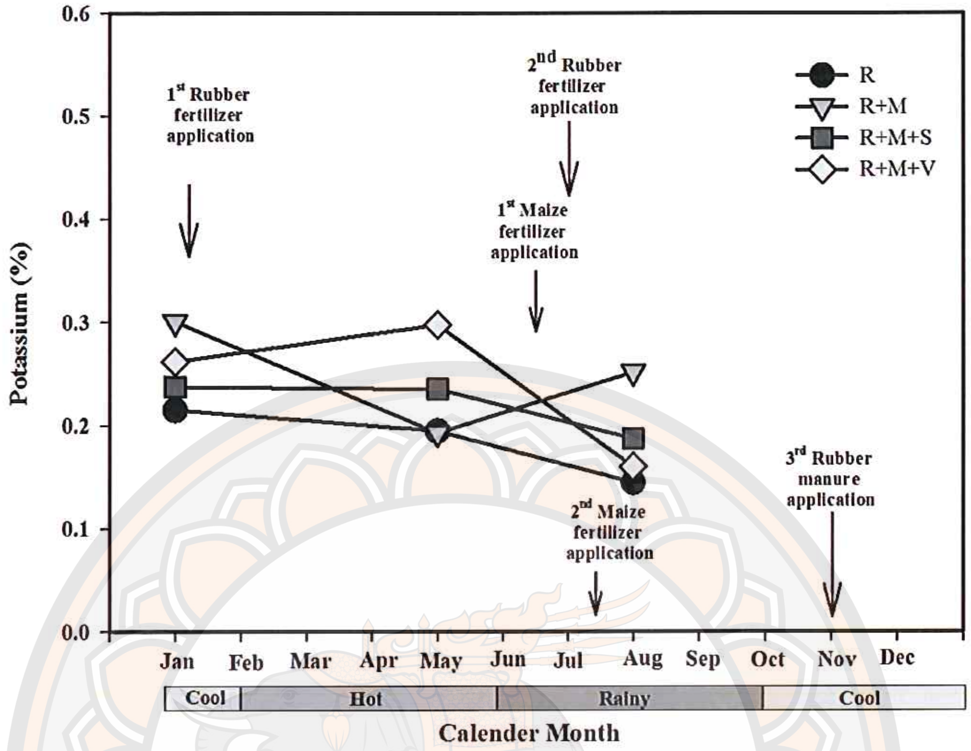

Figure 25 Potassium content of rubber leaves in four rubber based cropping systems. Data were recorded during January and August 2014 at Phitsanulok province in Northern Thailand Vertical bars represent SED at a $p<0.05$ by LSD

Leaf calcium contents varied from 0.08-0.10%, 0.08-0.10%, and 0.09-0.10% in cool, hot and rainy seasons, respectively (Figure 26). It can be clearly seen that the calcium content of rubber leaves in all treatments slightly changed from the cool to the rainy season, except rubber intercropping with maize. Calcium content under rubber intercropping and sole rubber treatments decreased in the rainy season except rubber intercropping with maize compared to the hot season while the others stayed more or less constant or increased slightly.

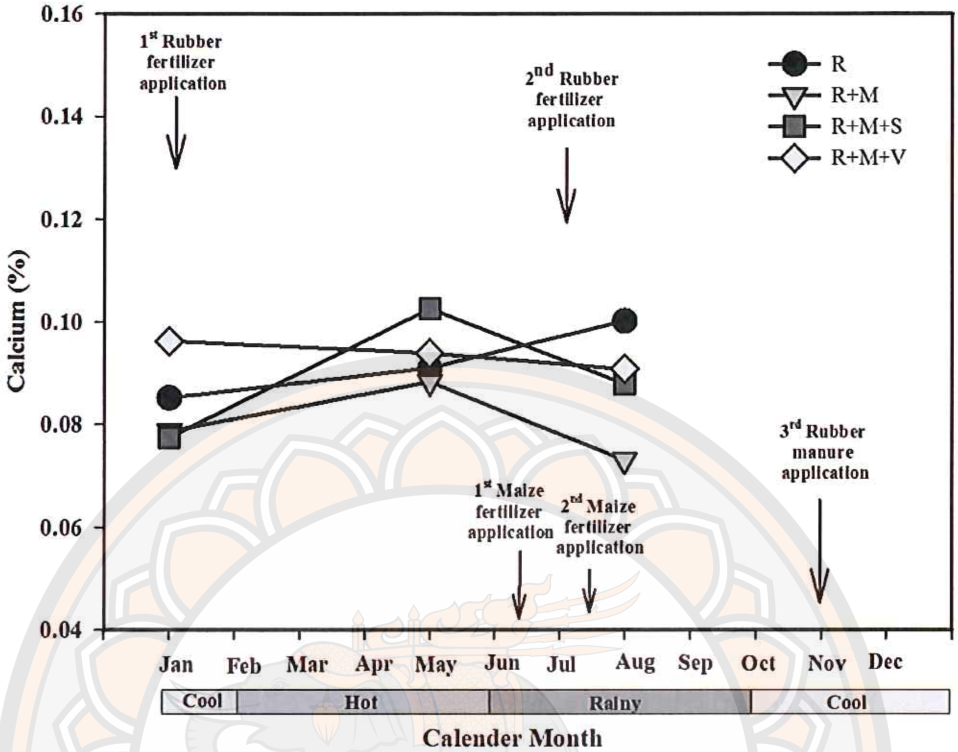

Figure 26 Calcium content of rubber leaves in four rubber based cropping systems. Data were recorded during January and August 2014 at Phitsanulok province in Northern Thailand. Vertical bars represent SED at a $p<0.05$ by LSD

Figure 27 shows that the magnesium content of rubber leaves varied a lot in the cool season, ranging from 0.05 to 0.47%. The highest and lowest values of magnesium content were found and the sole rubber and rubber intercropping with vetiver grass treatments, respectively. However, magnesium content in rubber leaves decreased from hot to rainy season and they were in a range of 0.42 to 0.49 and 0.38 to 0.44 % respectively.

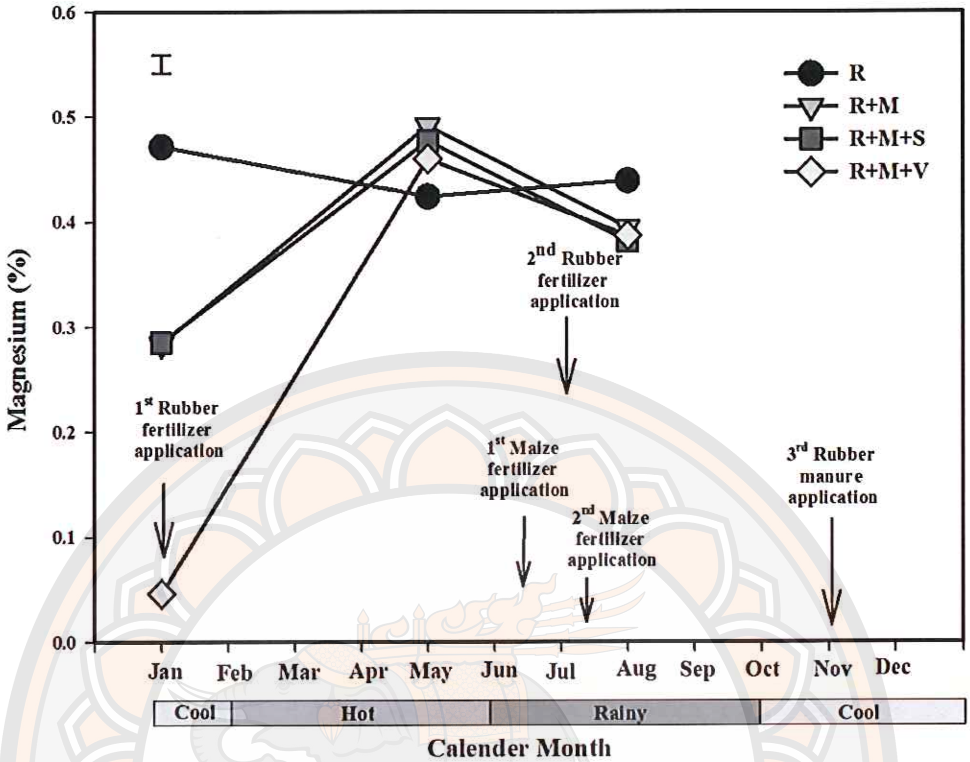

Figure 27 Magnesium content of rubber leaves in four rubber based cropping systems. Data were recorded during January and August 2014 at Phitsanulok province in Northern Thailand. Vertical bars represent SED at a p>0.05 by LSD

Table 5 shows the difference of mean plant nutrients uptake by rubber leaves in rubber based cropping systems during January to August 2014. Plant nutrient in rubber leaves were affected significantly by the change of season including N, C/N, P, K, and Mg. Season had no effect to the translocation of C and Ca. However, the plant nutrient contents of rubber leaves averaged over cropping systems reached an optimum level for Mg(>0.35 %) only, but for all other monitored plant nutrients low levels of rubber requirements were observed (Table 6). Moreover, when compared between sole rubber and rubber intercropping treatments, the result revealed that both, sole rubber and rubber intercropping treatments, were at the same level of the general recommendation of the Rubber Research Institute.

Table 5 Plant nutrients uptake by rubber leaves as mean of four rubber-based cropping system. Data were recorded during January – August 2014 at Phitsanulok in Northern Thailand

Season (Month)	Plant nutrients						
	C (%)	**N** (%)	**C/N**	**P** (%)	**K** (%)	**Ca** (%)	**Mg** (%)
Cool (January)	47.75	3.02[a]	16.15[b]	0.257[a]	0.263[a]	3.06	0.351[b]
Hot (May)	47.95	2.77[b]	17.73[a]	0.200[b]	0.216[b]	2.92	0.445[a]
Rainy (August)	47.73	3.09[a]	15.77[b]	0.170[c]	0.209[b]	3.02	0.418[a]
F-test	NS	*	*	*	*	NS	*
C.V.(%)	14.50	20.39	21.50	38.5	42.48	24.32	34.37

Note: [NS] Non-significant difference of mean among treatment (P>0.05)
[*]Significant difference (P<0.05)
Mean in the same column with different superscripts differs significantly at p<0.05 by DMRT

Table 6 Comparison of leaf nutrient contents under rubber sole and intercropping with the standard recommendations of the Rubber Research Institute

Leaves properties (%)	Optimum range*	Observed values in the rubber plantation					
		Sole rubber			Rubber intercropping		
		Low	Optimum	High	Low	Optimum	High
Nitrogen	3.2-3.8	●			●		
Phosphorus	0.25-0.30	●			●		
Potassium	1.0-1.4	●			●		
Calcium	1.0-1.5	●			●		
Magnesium	>0.35		●			●	

Source: Suchartgul, 2012

The relationship and correlation of soil and leaf nutrients with mean girth of rubber

1. The relationship between soil nutrient contents and mean girth of rubber

The relationship between soil nutrients and mean girth of rubber was studied from January to August 2014. Soil nutrients including soil organic carbon, nitrogen, carbon to nitrogen ratio, phosphorus, potassium, calcium, magnesium and moisture in soil at 0-20 cm depth were fitted with mean rubber girth at 150 cm above the ground by a quadratic polynomial equation ($Y = aX^2 + bX + c$) (see Figure 28).

The results showed that soil organic carbon, nitrogen content, C:N ratio and phosphorus contents had only a very weak relationship with mean rubber girth (Figure 28). The coefficient of determination (R^2) values for soil organic carbon, nitrogen content, C:N ratio and phosphorus content of a quadratic polynomial equation were low to very low, ranging from 0.01-0.19 (Figure 28). Soil potassium, calcium, magnesium contents and soil moisture showed significant and strong correlations with mean rubber girth for all treatments (R^2 ranging from 0.77-0.94, $P \leq 0.01$). (Figure 28 and Table 7). In addition, Table 7 shows Pearson correlation matrix of soil nutrients (soil organic carbon, C:N ratio, nitrogen, phosphorus, potassium, calcium, magnesium contents and soil moisture). Soil moisture showed significant negative correlations with soil potassium, calcium, magnesium contents (r =-0.64, -0.76 and -0.82, respectively). Soil nitrogen content showed significant positive correlation with soil organic carbon (r =0.70). C:N ration had a significant negative correlation with soil nitrogen content (r = -0.65). Soil potassium content showed significant positive correlations with soil calcium, magnesium contents (r = 0.87 and 0.74, respectively). Soil calcium contents showed strongly significant positive correlation with soil magnesium contents (r = 0.94).

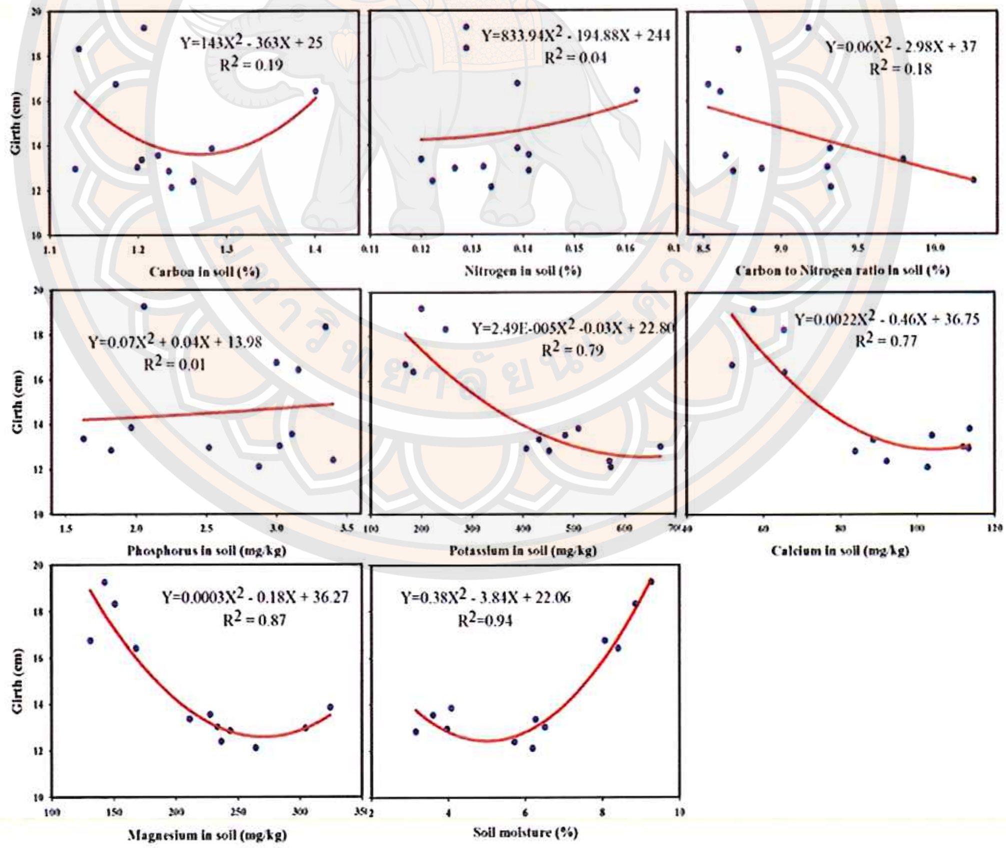

Figure 28 The relationship between soil parameters to rubber girth development at 150cm above ground under soil conservation systems on a hillside rubber plantation

Table 7 Pearson correlation matrix between chemical soil properties and rubber girth at 150 cm height

	C	N	C/N ratio	P	K	Ca	Mg	Girth
Moisture	0.020	0.046	-0.070	0.306	-0.635*	-0.759**	-0.823**	0.796**
C		0.696*	0.076	0.048	-0.013	-0.046	-0.045	-0.083
N			-0.649*	0.193	-0.334	-0.221	-0.150	0.180
C/N ratio				-0.128	0.559	0.334	0.310	-0.421
P					-0.020	0.110	-0.282	0.098
K						0.867**	0.737**	-0.858**
Ca							0.917**	-0.819**
Mg								-0.792**

Source: * and ** indicates statistical significance at 0.05 and 0.01 (2-tailed) level, respectively.

2. The relationship of rubber girth and plant nutrients in rubber leaves

The relationship of rubber girth and plant nutrients in rubber leaves, including carbon, nitrogen, carbon to nitrogen ratio, phosphorus, potassium and magnesium was investigated during January to August 2014. These nutrients were fitted with mean rubber girth at 150 cm above the ground by a quadratic polynomial equation ($Y = aX^2 + bX + c$).

The results showed that all of the investigated nutrients content in rubber leaves were no significant and very weak relationship with mean rubber girth (Figure 29). The coefficient of determination (R^2) values for carbon, nitrogen content, C:N ratio, phosphorus, potassium, calcium, and magnesium content of a quadratic polynomial equation was low with ranging from 0.02-0.48 (Figure 29). In addition, Table 8 shows Pearson correlation matrix of plant nutrients (carbon, nitrogen, C:N ratio, phosphorus, potassium, calcium, and magnesium contents). Plant nitrogen content showed a strongly significant negative correlation ($P \leq 0.01$) with C:N ratio ($r = -0.98$) and plant potassium content had a significant negative correlation ($P \leq 0.05$) with plant magnesium content. Plant phosphorus content had a significant positive correlation ($P \leq 0.05$) with plant potassium content ($r = 0.68$).

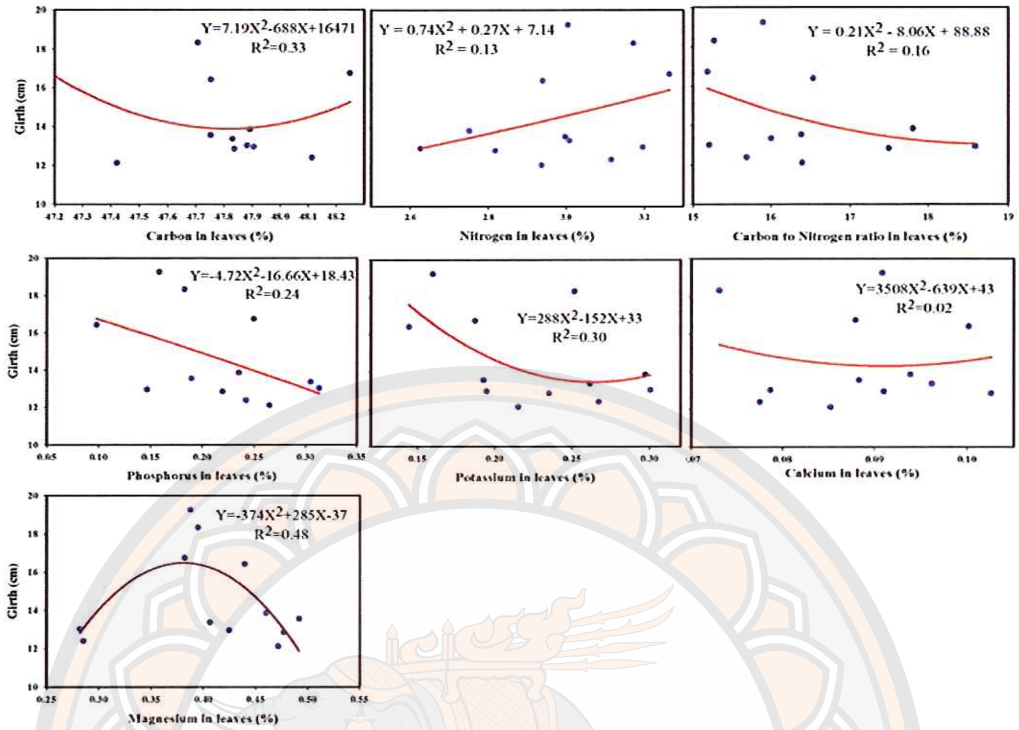

Figure 29 The relationship between leaves nutrients and rubber girth development at 150 cm above ground under soil conservation systems on a hillside rubber plantation

Table 8 Pearson correlation matrix between nutrients in plant and rubber girth at 150 cm height

	N	C/N ratio	P	K	Ca	Mg	Girth
C	0.158	0.007	0.240	0.256	-0.285	-0.311	-0.396
N		-0.980**	0.325	0.264	-0.021	-0.404	0.358
C/N ratio			-0.294	-0.261	-0.053	0.408	-0.392
P				0.676*	0.117	-0.324	-0.476
K					0.395	-0.661*	-0.350
Ca						-0.436	0.163
Mg							0.126

* and ** indicates statistical significance at 0.05 and 0.01 (2-tailed) level, respectively

The relationship of plant nutrients in soil and plant nutrients in rubber leaves

The relationships of plant nutrients in soil and nutrients in rubber leaves are presented in Table 9. Carbon, nitrogen, phosphorus, calcium and magnesium in soil had a negative relationship with their own nutrients in the rubber leaves. However, there were no significant relationships (.05 and 0.01). In contrast to the carbon and nitrogen ratio and potassium, there was a positive relationship but, only potassium showed a significant relationship at p<0.01 with potassium in rubber leaves. Carbon in soil had a significant relationship at 0.05 with calcium in rubber leaves. Nitrogen in soil also had a negative significant relationship at 0.05 with phosphorus in rubber leaves. The significant relationships were found between (i) Carbon to nitrogen and calcium in rubber leaves, (ii) potassium and phosphorus (r= 0.01) / potassium in rubber leaves (iii) Calcium carbon / potassium (r= 0.01), and (iv) magnesium and nitrogen (r = 0.05) and carbon to nitrogen ratio (r= 0.01) in rubber leaves.

Table 9 Pearson correlation matrix between chemical soil properties and nutrients in plant

		Plant						
		C	N	C/N	P	K	Ca	Mg
Soil	C	-0.161	-0.200	0.239	-0.305	-0.232	0.358*	0.166
	N	0.039	-0.030	0.045	-0.344*	-0.239	0.042	0.196
	C/N	-0.166	-0.186	0.228	0.082	0.100	0.380*	-0.148
	P	-0.185	0.165	-0.185	-0.137	0.034	-0.276	-0.037
	K	-0.018	-0.089	0.086	0.491**	0.499**	-0.012	-0.315
	Ca	0.334*	-0.121	0.131	0.296	0.374*	-0.001	-0.288
	Mg	0.152	-0.345**	0.348*	0.187	0.197	0.087	-0.085

*, ** indicate statistical significant differences at p<0.05 and p<0.01 (2-tailed), respectively

Yield of maize and soybean under hillside rubber plantations with various soil and water conservation systems

Rubber intercropping could provide income to the famer during immature stages of rubber trees as shown in Table 10. The results suggested rubber-maize intercropping provides the highest yield of 11,463 kg/ha. Yields from the rubber intercropping with maize and soybean was less with 7,925 and 219 kg/ha, respectively. Rubber intercropping with maize and vetiver grass yielded 0,938 kg/ha.

Table 10 Yield of maize and soybean planted among rubber trees

Treatments	Maize		Soybean
	Area (%)	Yield (kg/ha)	(kg/ha)
R	-	-	-
R+M	75	11,463	-
R+M+S	75	7,925	219
R+M+V	63.75	10,938	-

CHAPTER V

CONCLUSION

Discussion

Rubber growth performance of hillside rubber plantation under various soil conservation systems

Girth at breast height (GBH) and the height of immature rubber trees (RRIM 600 clones) are one of the keys to evaluate the performance of rubber trees. In the last measurement (rainy season), average height of rubber trees in all treatment was 6.33-6.80 m. Therefore, the results for the rate of growth in height of rubber tree were very similar in all treatments. For all treatments, average stem girth of rubber trees ranged 16.42-19.76 cm. According to the standard growth rate based on girth at breast height (GBH), defined by Rubber Research Institute of Thailand (2012), it was shown that the girth of rubber trees aged 3 years planted in sole rubber and rubber intercropping with maize and soybean treatments was 16.42 and 16.74 cm, which was slightly lower than the standard growth rate at low level (GBH: 18 cm) (Rubber Research Institute of Thailand, 2012). However, the girth of rubber trees in rubber intercropping with maize (18.32 cm) and rubber intercropping with maize and vetiver grass (19.76 cm) treatments was slightly higher than the standard growth rate.

Sole rubber and rubber intercropping with maize and soybean treatments may have been affected by water stress. Apart from the low girth extension, water stress could become crucial obstruction, resulting in plantations extending to the dry areas in many countries (Chandrashekar, et al., 1996; Jacob, et al., 1989). Based on soil moisture measurements, it is clearly shown that soil moisture in sole rubber and rubber intercropping with maize and soybean treatments were lower than in the other two treatments. For the dry period in 2013, we found that girth of rubber trees of rubber intercropping with maize and soybean treatments was also lower than the rubber intercropping with maize and vetiver grass and rubber intercropping with maize treatments. Therefore, growing soybean in the dry season showed negative effect on growth rates of rubber based on girth of trees due to competition for water. On the other side, rubber intercropping with maize and vetiver grass treatment showed the highest soil moisture content. Mulching with vetiver grass at an amount of about 66 kg/rai may have reduced water evaporation from soil surface as shown by the study of Khamkajorn, et al. (2015) at the same field experiment. Therefore, rubber intercropping with maize and vetiver grass treatment provided more moisture was available to rubber, so that this treatment also showed a highest girth expansion. A higher level of soil moisture may lead to higher crop yields as found by Craine, et al. (2011).

Rubber growth performance in new plantation area of North and Northeast Thailand is generally poorer than in original rubber plantation of southern Thailand (Chantuma, et al., 2011). There are many factors that affect rubber growth performance in this study area. One thing is that soils are very shallow and underground sheet rock occurs at a soil depth about 60-80 cm, depending on position. It causes poor rubber root development and limits root distribution. Rainfall also influences rubber growth performance. If there is no rain for about six months, rubber growth rate decreases to about 15% (Saengruksawong, et al., 1983). This is the case in this study area. The study area has no supply of irrigation water. Hence, rubber trees only obtain water by rainfall. During the monitoring period of the field experiment, low precipitation occurred for several months. In addition, Chandrashekar, et al. (1996) reported that, rubber trees in India only grew well in the rainy season while the growth rate was low in the dry season. This is probably the reason for the low expansion of rubber girth during the dry period (January to May) of this study, which was significantly higher in the wet season (May to August). Temperature is another important factor for rubber growth and development. Suphat, et al. (2007) reported that a mean temperature above 28 °C decreases rubber growth performance. This needs to be considered in the study area where we always face high temperature of approximately 30 °C throughout the year. An increase in relative air humidity provokes a decrease of rubber growth performance as well (Suphat, et al., 2007).

Another issue is farmers' management, e.g. pest control, pruning, and fertilizer application, that are important for rubber growth performance (Saengruksawong, et al., 1983). RRIT, (2011) recommends the rate and formula of chemical fertilizer for new rubber planting area in differences of soil texture and rubber age. Recommended fertilizer rate for 3-year-old rubber trees is 180 gram per tree of NPK (20-10-12). This amount different from that what farmers do in the area of current study. The farmers generally apply less fertilizer than the recommendation and use a different formula, too. They apply chemical fertilizer twice a year at rate of 21.78, 18.68 and 10.23 kg ha^{-1} $year^{-1}$ for N, P, and K, respectively and once a year for manure fertilizer at a rate of 133 kg ha^{-1} $year^{-1}$. More or less, the rubber of the study area has a lower growth performance than standard of RRIT.

Part 2 Soil and leaf nutrient content under hillside rubber plantation with various soil and water conservation systems in northern Thailand

An intensive monoculture of rubber tree plantations in upland areas without soil and water conservation leads to soil nutrient losses by erosion (Khamkajorn, et al., 2015; Hilger, et al., 2013; Wang Qing and Chen Yong, 2006. Therefore, soil conservation technologies, e.g. terracing, minimum tillage, intercropping with valuable herbaceous crops and relay cropping, have been recommended for hilly rubber plantation areas in Northern Thailand to prevent erosion (Pansak, et al., 2007, Hilger, et al., 2013). Soil and leaf nutrient content can provide information on the nutrient deficiencies and imbalances, interaction or antagonisms and determination of whether and what soil nutrients are utilized by the plants (Suchartgul, 2012).

In rainy season, sole rubber treatment showed the highest soil nitrogen because rubber trees in the sole rubber treatment were slightly uptake nitrogen from the soil as shown in the result of nitrogen value in rubber leaves. The rubber intercropping treatments were more diverse with regard to plant species, even more nitrogen fertilizer was added during growing maize. That means competition between rubber trees and maize was reduced. However, N levels were lower in rubber intercropping treatments than that in the sole rubber treatment. It is generally acknowledged that competition depends on the planting condition of the associated crops (Johnson and Nair, 1985; Alvim and Nair, 1986; Fagon and Topper, 1988; Rodrigo, et al., 2005). In addition, season influences on soil nutrient changes including N, C/N ratio, K, Ca, and Mg, excluding C and P.

Soil fertility is closely linked to soil organic matter which is associated with carbon and nitrogen in soil. Carbon and nitrogen status in soil depend on biomass input and management, mineralization, leaching and erosion (Roose and Barthes, 2001; Nandwa, 2001). In hot season, crop residue application of maize stover, vetiver grass and soybean as surface mulch plays an important role in the maintenance of soil organic carbon levels and mineralization of nitrogen and potassium (Bationo, et al., 2007). In cool and hot seasons the microbial activity was poor because soil moisture is a limiting factor under these circumstances (Brockett, 2012). So each treatments showed no significant difference as shown in carbon and nitrogen content in soil.

Moreover, soil organic carbon and nitrogen are very important to a number of microorganisms. Soil organic carbon and nitrogen in rubber intercropping treatments were lower than in the sole rubber treatment in the rainy season because soil moisture content contributes to a higher microbial activity (Brockett, 2012). Microorganisms need carbon as energy source and nitrogen for structure of their bodies. Leaf nutrient contents were also different between the seasons studied. The leaf nitrogen content was higher during the rainy season. On the other hand, the phosphorus content of rubber leaves was higher during the dry season. Read and Lawrence (2003) observed that in tropical areas, leaf concentrations of phosphorus and nitrogen are reduced during the dry season and increase during the rainy season, as a result of the retranslocation of these nutrients in the plant in the dry season. Since phosphorus is an important limiting nutrient for plant growth in tropical areas (Vitousek, 1984; Read and Lawrence, 2003), phosphorus is rapidly absorbed by soil microorganisms, mycorrhizal fungi and plant roots during the rainy season. Moreover, the soil in this study area is a strongly acid soil, phosphorus is fixed with Al^{+3}, so plant cannot well uptake to the tree. Phosphorus of sole rubber remained more in soil and less in leaf content compared to rubber intercropping treatments, while rubber intercropping treatments were better balance. This happened because microorganisms convert inorganic forms (chemical fertilizer) to organic phosphate (Khan, 2007). Potassium in soil of rubber intercropping with maize and soybean treatments was highest compared to the other treatments. Harvest residues of vetiver grass provided potassium to the soil because potassium in vetiver grass was about 38.17 mg/kg. Leaf concentrations of calcium and magnesium were not different between the seasons. As these nutrients are essential components of plant tissues, they have low mobility. Thus, leaf tissues tend to contain a higher relative concentration of calcium and magnesium than of nitrogen, phosphorus and potassium, nutrients that are reabsorbed by the plant when it is subjected to lack of water stress (Read and Lawrence, 2003; Boerger, et al., 2005).

Soil nutrients in Wang Thong District, Phitsanulok province of northern Thailand were close to values found by Saichai (2010) studying rubber plantation in eastern Thailand. Normally, red-brown and slightly acidic soil contains low carbon, phosphorus and calcium. Yellow to red soils adsorb more ferrous oxide that antagonizes other plant nutrients such as phosphorus, potassium and calcium (Fageria, 2001). In addition, the results of this study were similar to those of Saichai (2010) who investigated soil nutrients under rubber (RRIM 600) plantation in southern Thailand. The plant nutrients in soil of this study were in the range of 0.3-28.0, 18.0-576.0 and 3.0-144.0 mg/kg for phosphorus, calcium and magnesium, respectively.

Plant nutrients in rubber leaves of this study were compared with those of Nuchchanat (2013) from Rubber Research Institute of Thailand. Nuchchanat (2013) studied on plant nutrients in rubber plantation around Thailand during rainy season in order to find out which nutrients are deficit in rubber leaves. The results showed that nitrogen, phosphorus and potassium in rubber leaves were lower than the standard that rubber leaves shall contain for optimum growth development while micronutrients were sufficient (%N, %P, %K, %Ca and %Mg were 2.70, 0.20, 0.81, 0.15 and 0.34, respectively). Moreover, nitrogen was slightly higher and potassium was lower than those reported by Nuchchanat's study, but the levels of magnesium were similar. Furthermore, Timkhum, et al. (2013) investigated plant nutrients in rubber leaves grown in southern Thailand during rainy season. They found that N, P, K, Ca, and Mg were 2.45%, 0.23%, 1.20%, 1.06% and 0.33%, respectively. They also suggested that N and P were limiting factors in their study. This result was also in the range of levels reported by Suchartgul (2013) to establish standard values for nutritional diagnosis in soil and leaves of immature rubber trees. The optimum ranges for N, P, K, Ca, Mg and S concentrations in rubber leaves by the standard are 3.2 - 3.8, 0.25 - 0.30, 1.0 - 1.4, 1.0 - 1.5, > 0.35 and 0.2 - 0.3%, respectively. Based on this study, only Mg reached to the optimum level for rubber leaves.

Conclusion

Rubber can better develop height and girth in rainy season and climatic conditions are one of the contributors affecting the rubber growth performance. Rubber intercropping with maize and vetiver grass increased rubber girth development significantly. Soil parameters of both sole and intercropping are in the range of the standard values recommended for rubber, except P and Ca. N, P, K and Ca levels in the immature rubber leaves exhibited a low value for sole rubber and rubber intercropping treatments. Intercropping of crops and rubber or other tree crops is a means of reducing competition for land. Diversifies farmers' sources of income and reduces cash flow constraints in the period until latex production begins. This study can be an alternative for farmers' decision for using rubber intercropping systems as a soil and water conservation on hillside rubber plantation.

REFERENCES

REFERENCES

Alvim, R. and Nair, P. (1986). Combination of cacao with other plantation crops: an agroforestry system in Southeast Bahia. **Brazil. Agrofor. Syst.,** 4, 3–15.

Araujo, R. and Teixeira, J. (2003). An extension of the structural change model to international economic relations. **Metroeconomica**, 54(4), 458-473.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B. and Kimetu, J. (2007). Soil organic carbon dynamics, functions and management in West African agro-ecosystems. **Agricultural Systems,** 94(1), 13-25.

Baulkwill, W. J. (1989). The history of rubber production. In Webster, C.C. and Baulkwill, W.J. (Eds.), **Longman** (pp. 1–56.). London: n.p.

Bevan J. W. L., Fleming T. and Gray B. S. (1966). **Planting techniques for oil palms in Malaysia.** Kuala Lumpur: corp. Soc. Planters,

Brockett, B. F. T., Prescott, C. E. and Grayston, S. J. (2012). Soil moisture is the major factor influencing microbial community structure and enzyme activities across seven biogeoclimatic zones in western Canada. **Soil Biology and Biochemistry,** 44(1), 9-20.

Bunting, B. and Milsum, J. N. (1928) Cover crops and green manures. **The Malayan Agricultural Journal,** 16, 256–280.

C. Airoldi and A. G. S. Prado. (1999). The influence of moisture on microbial activity of soils, Thermochim. **Acta**, 332, 71-74.

Candan, F. (2013). Some Observations on Plant Karyology and Investigation Methods. In Marina Silva-Opps (Ed.), **Current progress in Biological research**, U.S.A.: Intech-Open Science International Publisher.

Chandrashekar, T. R., Marattukalam, J. G. and Nazeer, M. A. (1996). Growth reation of *Hevea brasiliensis* to heatand drought stress under dry subhumid climatic conditions. **Indian J. Nat. Rubber Res.,** 9, 1-5.

Chantuma, P., Lacote, R., Leconte, A. and Gohet, E. (2011). An innovative tapping system, the double cut alternative, to improve the yield of Hevea brasiliensis in Thai rubber plantations. **Field Crops Research,** 121(3), 416-422.

Compagnon, P. (1987). **Le caoutchouc naturel- biologie, culture, production. techniques agricoles et productions tropicales. G.-P.** Paris: Maisonneuve & Larose.

Craine, J. M. and Gelderman, T. M. (2011). Soil moisture controls on temperature sensitivity of soil organic carbon decomposition for a mesic grassland. **Soil Biology and Biochemistry,** 43(2), 455-457.

Darunee K., Kannika T., Pratueng K. and Chirakorn K. (2000). Study growth performance on various clone at upper mean see level 900 meter. **Full research report in 2000, rubber research Department of Agriculture**. N.P.: n.p.

De Costa WAJM and Surenthran, P. (2005). Tree-crop interactions in hedgerow intercropping with different tree species and tea in Sri Lanka: Production and resource competition. **Agrofor. Syst.,** 63, 199-209.

Delabarre, MA. and Serrier, JB., (2000). Propagation of planting materials. In **Rubber The Tropical Agriculturist** (pp. 22-49). The Netherlands: AJ Wageningen.

de la Puente, L. S. and R. M. Belda. (1999). Square root and quadratic equation for the study of leaf diagnosis in wheat. **Journal of Plant Nutrition**, 22, 1469-1479.

Dercon, G., Deckers, J., Poesen, J., Govers, G., Sa´nchez, H., Ramı´rez, et al. (2006). Spatial variability in crop response under contour hedgerow systems in the Andes region of Ecuador. **Soil Till. Res.**, 86, 15–26.

Fageria, V. D. (2001). Nutrient interactions in crop plants. **Journal of Plant Nutrition,** 24(8), 1269-1290.

Fageria, NK. and Baligar, VC. (2005). Enhancing nitrogen use efficiency in crop plants. **Advances in Agronomy**, 88, 97-185.

Fagon, H. J. and Topper, B. F. (1988). Agronomic research on cocoa in Jamaica: 1960–1980 and current trends. **Trop. Agric. (Trinidad),** 65, 291–294.

Food and Agriculture Organization of the United Nation (FAO). (2005). **State of the World's Forests**. U.S.A.: FAO.

Food and Agriculture Organization of the United Nation (FAO). (2006). **Plant Nutrition for Food Security: A guide for integrated nutrient management.** U.S.A.: FAO.

Food and Agriculture Organization of the United Nation (FAO). (2007). **FAOSTAT Online Statistical Service.** Retrieved October 25, 2014, from http://faostat. fao.org (accessed). United Nations Food and Agriculture Organization (FAO), Rome.

Giller, K. E. and Fairhurst, T. H. (2000). Legume cover plants. In Fairhurst, T.H. and Hardter, R. (Eds.), **The oil Palm. Management for large and sustainable Yields.** Singapore: Phosphorus and Potash Institute.

Grist, P., Menz, K. and Thomas. (1998). Modified BEAM Rubber Agroforestry Models: RRYIELD and RRECON. **ACIAR Technical Reports Series,** 42, 43.

G. J. Burch, G. G. Johns. (1978). Root absorption of water and physiological responses to water deficits by Festuca arundinacea Screb. and Trifolium repens L., Aust. **J. Plant Physiol**, 5, 859- 871.

Heinz-Hermann Greve. (1993). Rubber, 1. Survey. **Ullmann's Encyclopedia Of Industrial Chemistry,** 23, 221-224.

Hilger, T., Keil, A., Lippe, M., Panomtaranichagul, M., Saint-Macary, C., Zeller, M., et al. (2013). Soil Conservation on Sloping Land: Technical Options and Adoption Constraints. In H. L. Fröhlich, P. Schreinemachers, K. Stahr and G. Clemens (Eds.), **Sustainable Land Use and Rural Development in Southeast Asia: Innovations and Policies for Mountainous Areas** (pp. 229-279). Berlin: Springer Berlin Heidelberg.

Jacob, J. L., Prevot, J. C., Roussel, D., Lacrotte, R., Serres, E. and D'Auzac, J. (1989). Yield limiting factors, latex physiological parameter, latex diagnosis, and clonal typology. In J. D'Auzac, J. L. Jacob and H. Chrestin (Eds.), **Physiology of rubber tree latex** (pp. 348-382). Boca Raton: CRC Press.

Jessy, M. D., Varghese, P., Punnoose, K. I., Sethraj, M. R. (November 6, 1996). Multispecies cropping system with rubber: a preliminary report. In **Proceedings of the Symposium on Farming System Aspects of the Cultivation of Natural Rubber (*Hevea brasiliensis*)** (pp. 81–89). Hertford, U.K.: Beruwela, Sri Lanka. International Rubber Research and Development Board, Brickendonbury.

Jiang, A. (1988). Climate and natural production of rubber (Hevea brasiliensis) in Xishuangbanna, southern part of Yunnan province, China. **International Journal of Biometeorology**, 32(4), 280-282.

Johnson, D. V. and Nair, P. K. R. (1985). Perennial crop-based agroforestry systems in Northeast Brazil. **Agrofor. Syst.,** 2, 281–292.

Karthikakuttyamma, M., Joseph, M. and Nair, A. N. S. (2000). Soil and nutrition. In P. J. George and C. K. Jacob (Eds.), **Natural rubber: Agromanagement and crop processing** (pp. 170-198). Kottayam, India: Rubber Research Institute of India.

Khamkajorn, T., Pansak, W., Takrattanararan, N. and Homhual, W. (June 8-13, 2014). Erosion in hillside Para Rubber Plantation of Northern Thailand as Affected by Soil Conservation Measures: A Case Study. In **The 20th World Congress of Soil Science.** Korea: Jeju.

Khan, M., Zaidi, A. and Wani, P. (2007). Role of phosphate-solubilizing microorganisms in sustainable agriculture — A review. **Agronomy for Sustainable Development,** 27(1), 29-43.

Khedari, J. (2002). Thailand climatic zones. **Renewable Energy,** 25(2), 267-280.

K. P. Prabhakaran Nair. (2010). Rubber (*Hevea brasiliensis*). In **The Agronomy and Economy of Important Tree Crops of the Developing World** (p. 238). N.P.: n.p.

Krishnakumar, A. K. and Potty, S. N. (1992). Nutrition of Hevea. In Sethuraj, M. R., Mathew, N. M. (Eds.), **Natural Rubber: Biology, Cultivation and Technology** (pp. 239 – 262). Netherlands: Elsevier, Amsterdam.

Krissada, S. (2004). Is growth performance in rubber (*Hevea brasiliensis*) clones related to xylem hydraulic efficiency? **Canadian Journal of Botany,** 82(7), 886-891.

Kumar, K. and Goh, K. M. (2002). Nitrogen release from crop residues and organic amendments: relationships to biochemical composition. **Soil Biology and Biochemistry**. N.P.: n.p.

Land Development Department of Thailand. (2000). **Para-rubber (Thai economic crop) and soil suitable for planting in the East.** Retrieved May 10, 2014, from http://www.ldd.go.th/EFiles_project/article/article06.html

Lemmens, R. H. M. J., Soerianegora, I. and Wong, W. C. (1995). PROSEA Plant Resources of South-East Asia Timber Trees: Minor Commercial Timbers. Backhuys. **Leiden**, 5(2), 655.

Local-Climatology Sub-division. (1997). **Climate of Thailand.** Bangkok, Thailand: Technical document of Meteorological Department.

Maas, J. G. J. A. (1922). The upkeep of an oilpalm plantation. In Rutgers, A. A. L. (Ed.). **Investigations on Oil palms made at the General Experiment Station of the A.V.R.O.S.** (pp. 36–49). Indonesia: Ruygrok & Co., Batavia,

N. Barros, I. Gomez-Orellana, S. Feijo´o and R. Balsa, (1995). Thermochim. **Acta,** 5, 249.

Nandwa, S. M. (2001). Soil organic carbon (SOC) management for sustainable productivity of cropping and agro-forestry systems in Eastern and Southern Africa. **Nutrient Cycling in Agroecosystems,** 61, 143–158.

Nataraja, K. N and Jacob, J. (1998). Clonal differences in photosynthesis in Hevea Brasiliensis Mull. **Arg. Photosynthetica**, 36, (1-2), 89-98.

Nujanart Kungpisdan, Rasamee Suravanit, Wanpen Prukwiwat, Sumet Prukwarun and Anusorn Ramlee. (2006). **Development of technology in fertilizer utilization to increase yield of rubber. Thai Agricultural.** N.P.: n.p.

Nujanart, K. (2013). **Recommendation fertilizer for rubber in 2013. Soil Water and Nutrients (article in Thai)**. Bangkok: The Ministry of Agriculture and Cooperatives of the Kingdom of Thailand.

Office of economics. (2015). Retrieved May 10, 2015, from http://www.oae.go.th /main.php?filename=indexEN

Pansak, W., Dercon, G., Hilger, T. H., Kongkaew, T. and Cadisch, G. (2007). 13C isotopic discrimination: A starting point for new insights in competition for nitrogen and water under contour hedgerow systems in tropical mountainous regions. **Plant Soil**, 298, 175–189.

Priyadarshan, P. M., Hoa, T. T. T., Huasun, H. and Goncedillalves, P. D. S. (2005). Yielding potential of rubber (Hevea brasiliensis) in sub-optimal environments. **Journal of Crop Improvement**, 14(1-2), 221-247.

Punnoose, K. I., Kothandaraman, R., Philip, V., Jessy, M. D. (2000). **Field upkeep and intercropping.** In George, P.J. , Jacob , C. K. (Eds.), **Natural Rubber: Agro management and Crop Processing** (pp. 149 – 169). India: Rubber Research Institute of India, Kottayam, Kerala State.

Pushparajah, E. and Tan, K. H. (1976) Legumes in the nitrogen economy of rubber cultivation. In Broughton, W. J. (Ed.) **Soil Microbiology and Plant Nutrition** (pp. 413–434). Kuala Lumpur: University of Malaya.

Pushparajah, E. (1977). **Nutrition and fertilizer use in Hevea and associated covers in Peninsular Malaysia**. Malaysia: Quarterly Journal Rubber.

Pushparajah, E. (1977). Nutrition and fertilizer use in Hevea and associated covers in Peninsular Malaysia. **Quarterly Journal Rubber Research Institute of Sri Lanka**, 54, 270-283.

Raj, S., Das, G., Pothen, J. and Kumar Dey, S. (2005). Relationship between latex yield of *Hevea brasiliensis* and antecedent environmental parameters. **International Journal of Biometeorology,** 49(3), 189-196.

Rao, G., Rao, P., Rajagopal, R., Devakumar, A. S., Vijayakumar, K. R. and Sethuraj, M.R. (1990). Influence of soil, plant and meteorological factors on water relations and yield in Hevea brasiliensis. **International Journal of Biometeorology**, 34(3), 175-180.

Rao, P. and Vijayakumar, K. R. (1992). Climatic Requirements. In Sethuraj, M. R. and Mathew, N. M. (Eds.), **Natural Rubber: Biology, Cultivation and Technology. Developments in Crop Science** (pp. 200-220). Netherlands: Elsewier.

Read, L. and Lawrence, D. (2003). Litter Nutrient Dynamics During Succession in Dry Tropical Forests of the Yucatan: Regional and Seasonal Effects. **Ecosystems,** 6(8), 747-761.

Roose, E. and Barthes, B. (2001). Organic matter management for soil conservation and productivity restoration in Africa: a contribution from francophone research. **Nutrient Cycling in Agroecosystems,** 61, 159–170.

Royal Forest Department (RFD). (2000). Status of rubber wood utilization and marketing in Thailand. In **Technical Report** (p. 90). Bangkok, Thailand: Executing Agency, Forest Research Office, Royal Forest Department.

R. I. Griffiths, A. S. Whiteley, A. G. O'Donnell, M. J. Bailey, (2003). Physiological and community response of established grassland bacterial populations to water stress, **Environ. Microbiol**, 69, 6961-6968.

Rodrigo, V. H. L., Stirling, C. M., Silva, T. U. K. and Pathirana, P. D. (2005). The growth and yield of rubber at maturity is improved by intercropping with banana during the early stage of rubber cultivation. **Field Crops Research,** 91(1), 23-33.

Rubber organs. Retrieved June 20, 2015, from http://en.wikipedia.org/wiki/Hevea_brasiliensis

Rubber Research Institute of Thailand. (2010). **Rubber plantation in Thailand.** Retrieved May 10, 2014, from http://www.rubberthai.com/statistic/stat_index.htm

Saengruksawong, C., Soontorn, K., Niwat, A. and Jitti, P. (2012). Growths and Carbon Stocks of Para Rubber Plantations on Phonpisai Soil Series in Northeastern Thailand. **Rubber Thai Journal,** 1, 1-18.

Saichai, S., Somsak, M. and Montree, I. (2010). Fertilizer usage and growth of immature rubber in Chumporn, Surat Thani and Nakhon Si Thammarat Provinces. **Thai Journal of Soils and Fertilizers**, 32(3), 180-197.

Sangsing, K. (2004). **Carbon acquisition and plant water status in response to water stress of rubber (*Hevea brasiliensis*)**. Doctoral dissertation, Ph.D., Kasetsart University, Bangkok.

Sivanadyan, K., Haridas, G. and Pushparajah, E. (1975). **Reduced immaturity period of *Hevea brasiliensis*.** Kuala Lumpur: Proc. Int.

Suchartgul, S., Maneepong, S. and Issarakrisila, M. (2012). Establishment of standard values for nutritional diagnosis in soil and leaves of immature rubber tree. **Rubber Thai Journal,** 1, 19-31.

Supat, I. A., Anoma, D., Ruamchart and T., Teerayut. (2007). The Relationship of Climates and Growths of Rubber Tree cv. In **KKU Annual Agricultural Seminar for Year 2007** (p. 87). Khon Khan: Khon Khan University:

Thai Meteorological Department. (2014). Retrieved May 10, 2014, from http://www.tmd.go.th/en/region.php?RegionID=1

Thainugul, W. (1986). **Soil and leaf analysis as a basis of fertilizer recommendations for *Hevea brasiliensis* in Thailand.** Doctoral dissertation, D.Sc. University of Ghent, Belgium.

The Mosaic Company. (n.d.). **Crop nutrition.** Retrieved October 1, 2015, from http://www.cropnutrition.com/nutrient-knowledge

Timkhum, P., Maneepong, S., Issarakrisila, M. and Sangsing, K. (2013). Nutrient Assessment with Omission Pot Trials for Management of Rubber Growing Soil. **Journal Of Agricultural Science,** 5(10), 10.

Troeh, F. R., J. A. Hobbs and R. L. Donahue. (2004). **Soil and water conservation: For productivity and environmental protection**. Upper Saddle River, N.J.: Pearson/Education.

USDA Natural Resources Conservation Service. (2011). Carbon to Nitrogen Ratios in Cropping Systems. In **USDA NRCS East National Technology Support Center, Greensboro, NC, in cooperation with North Dakota NRCS.** Retrieved October 1, 2015, from www.nrcs.usda.gov/wps/...NRCS Consumption/download?...nrcs142p2

Varinderpal-Singh, Bijay-Singh, Yadvinder-Singh, H. S. Thind R. and K. Gupta. (2010). Need based nitrogen management using the chlorophyll meter and leaf colour chart in rice and wheat in South Asia: a review. **Nutr Cycl Agroecosyst**, 88, 361–380.

Verheye, W. (2010). Growth and production of rubber. In Verheye, W. (Ed.), **Soils, Plant Growth and crop production. Encyclopedia of Life Support Systems (EOLSS)**. Oxford: UNESCO-EOLSS.

Vitousek, P. M. (1984). Litterfall, nutrient cycling and nutrient limitation in tropical forests. **Ecology,** 65, 285–298.

Vitousek, P. (1984). Litterfall, nutrient cycling, and nutrient limitation in tropical forests. **Ecology,** 65, 285–298.

Wang, Q. and Chen, Y. (2007). Dynamic mechanisms for evolution of mountain rural settlements and soil conservation in Upper Yangtze River basin. **Wuhan University Journal of Natural Sciences,** 12(4), 710-714.

Watson, G. A. (1989). Climate and soil. In Webster, C.C. and Baulkwill, W.J. (Eds.), **Rubber** (p. 614). New York: Longman.

Withanage, S. P., D. P. S. T. G. Attanayake and K. B. A. Karunasekara. (2005). Adaptability of recently recommended rubber clones for agro-climatic variability of Srilanka. **Journal of Rubber Research Institute of Sri Lanka**, 87, 1-6.

Yingjajaval, S. and Bangjan, J. (2006). Major nutrient content in para rubber (RRIM 600). **Agricultural Science Journal**, 37(4), 353-360.

APPENDIX

Table 11 Plant nutrients in each treatments of maize and vetiver grass that were planted among rubber tree

Treatments	Intercrop plants	Plant nutrients				
		N (%)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
R	-	No intercropping plant				
R+M	Maize	1.18	134	38.71	551	14.14
R+M+S	Maize	1.07	106	37.86	440	13.73
	Soybean	Out of sampling time				
R+M+V	Maize	1.20	131	38.30	605	15.31
	Vetiver grass	0.75	40	38.17	184	1874