สัตว์ขาปล้องขนาดเล็กในดินบริเวณพื้นที่ป่าปลูกพืชวงศ์ยางระยะต้นกล้าที่มีอายุการปลูกที่แตกต่างกัน

นางสาวชฎาภรณ์ เสวีวัลลภ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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SOIL MICROARTHROPODS IN REFORESTED AREA OF DIPTEROCARPUS SEEDLINGS AT DIFFERENT STAGES

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ชฎาภรณ์ เสวีวัลลภ : สัตว์ขาปล้องขนาดเล็กในดินบริเวณพื้นที่ป่าปลูกพืชวงศ์ยางระยะต้นกล้าที่มีอายุการปลูกที่แตกต่างกัน (SOIL MICROARTHROPODS IN REFORESTED AREA OF DIPTEROCARPUS SEEDLINGS AT DIFFERENT STAGES) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. ชัชวาล ใจซื่อกุล, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ดร. นิพาดา เรือนแก้ว ดิษยทัต, 124 หน้า.

ความหลากหลายและความชุกชุมของสัตว์ขาปล้องขนาดเล็กในดินและปัจจัยทางกายภาพและชีวภาพได้ถูกประเมินในพื้นที่การปลูกป่าฟื้นฟูด้วยต้นกล้าไม้วงศ์ยางนาที่ใส่เชื้อราเอคโตไมคอร์ไรซาที่มีอายุการปลูก 1 ปี, 2 ปี และพื้นที่ที่ไม่มีการปลูกฟื้นฟู ในพื้นที่จุฬาลงกรณ์มหาวิทยาลัย อำเภอแก่งคอย จังหวัดสระบุรี สัตว์ขาปล้องขนาดเล็กในดินถูกสกัดด้วย Berlese-Tullgren funnels จากตัวอย่างดินที่เก็บเดือนละหนึ่งครั้งตั้งแต่เดือนตุลาคม พ.ศ. 2557 ถึงเดือน ตุลาคม พ.ศ. 2558 พบสัตว์ขาปล้องขนาดเล็กในดินมีความชุกชุมสูงสุดในพื้นที่ป่าปลูกพืชวงศ์ยางอายุ 2 ปี (3,596 ± 227 ตัวต่อตารางเมตร) อายุ 1 ปี (2,989 ± 334 ตัวต่อตารางเมตร) และพื้นที่ที่ไม่มีการปลูก (2,496 ± 361 ตัวต่อตารางเมตร) ($F = 1.988$, $df = 2, 73$, $p = 0.051$) ตามลำดับ โดยพบสัตว์ขาปล้องขนาดเล็กในดินทั้งหมด 9 กลุ่ม ซึ่งไร (74-83%) และแมลงหางดีด (15-21%) เป็นชนิดพันธุ์เด่นในทั้ง 3 พื้นที่ ตะขาบฝอย (symphylan), กิ้งกือ (spirobilid), ตะขาบ (geophilomorph) และแมลงเสี้ยนนม (proturan) มีความชุกชุมในพื้นที่ที่มีการปลูกฟื้นฟูมากกว่าพื้นที่ที่ไม่มีการปลูก ในขณะที่แมงป่องเทียม (pseudoscorpion) มีความชุกชุมสูงในพื้นที่ที่ไม่มีการปลูก นอกจากนี้พบว่ากลุ่มของสัตว์ขาปล้องขนาดเล็กในดินที่มีบทบาทเป็นผู้ย่อยสลายและกินรามีความชุกชุมมากสุดในทั้ง 3 พื้นที่ รองลงมาคือกลุ่มของผู้ล่าและผู้ย่อยสลายตามลำดับ สำหรับความหลากหลายของสัตว์ขาปล้องขนาดเล็กในดินพบว่าบริเวณพื้นที่ที่ไม่มีการปลูก มีค่าดัชนีความหลากหลายในระดับชนิดพันธุ์เชิงสัณฐาน (morphospecies) ของสัตว์ขาปล้องขนาดเล็กในดินต่ำสุด ($H' = 0.85$) เมื่อเทียบกับพื้นที่ที่มีการปลูกฟื้นฟูอายุ 1 ปี ($H' = 0.92$) และพื้นที่ที่มีการปลูกฟื้นฟูอายุ 2 ปี ($H' = 0.93$) ปัจจัยทางกายภาพและชีวภาพในพื้นที่พบว่าความชื้นในดินแสดงความแตกต่างอย่างมีนัยสำคัญทางสถิติ ($F = 93.602$, $df = 2, 33$, $p < 0.001$) โดยมีค่ามากในพื้นที่ที่มีการปลูกฟื้นฟูอายุ 2 ปี 1 ปี และ พื้นที่ที่ไม่มีการปลูกตามลำดับ อย่างไรก็ตามพบความสัมพันธ์ของสัตว์ขาปล้องขนาดเล็กในดินกับค่าความชื้นในดินเฉพาะในพื้นที่ที่ไม่มีการปลูกฟื้นฟู ($r = 0.752$, $p = 0.003$) สรุปผลการศึกษาแสดงให้เห็นว่าอายุของต้นกล้าที่เพิ่มขึ้นมีความสัมพันธ์ต่อปัจจัยแวดล้อมหลายประการ โดยเฉพาะอย่างยิ่งความชื้นในดินที่มีความสัมพันธ์ต่อทิศทางการเพิ่มขึ้นของความหลากหลายและความชุกชุมของสัตว์ขาปล้องขนาดเล็กในดิน

ภาควิชา	ชีววิทยา	ลายมือชื่อนิสิต .....
สาขาวิชา	สัตววิทยา	ลายมือชื่อ อ.ที่ปรึกษาหลัก .....
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CHADAPHORN SEWEEWALLOP: SOIL MICROARTHROPODS IN REFORESTED AREA OF DIPTEROCARPUS SEEDLINGS AT DIFFERENT STAGES. ADVISOR: ASST. PROF. CHATCHAWAN CHAISUEKUL, Ph.D., CO-ADVISOR: NIPADA RUANKAEW DISYATAT, Ph.D., 124 pp.

The diversity and abundance of soil microarthropods and physical and biological factors had been evaluated in 1-year and 2-year reforested areas planted with dipterocarpus seedlings inoculated with ectomycorrhizae and a non-reforested area at Chulalongkorn University Area, Saraburi Province, Thailand. Soil microarthropods were extracted with Berlese-Tullgren funnels from monthly collected soil samples from October 2014 to October 2015. The total abundance of soil microarthropods was highest in the 2-year dipterocarpus reforestation area (3,596 ± 227 ind./m^2), followed by the 1-year reforestation area (2,989 ± 334 ind./m^2) and the non-reforested area (2,496 ± 361 ind./m^2), respectively ($F = 1.988$, $df = 2, 73$, $p = 0.051$). Mites (74-83%) and collembolans (15-21%) were the most abundant groups from the nine groups of collected soil microarthropods in all three areas. Symphylans, spirobilids, geophilomorphs and proturans were more abundant in the reforestation areas than the non-reforested area, while pseudoscorpions were most abundant in the non-reforested area. Detrito-fungivorous microarthropods were the most abundant guild in all three areas, followed by predatory arthropods and detritivore microarthropods. Diversity index of soil microarthropods at morphospecies level was lowest in the non-reforested area ($H' = 0.85$) when compared to the 1-year reforestation area ($H' = 0.92$) and the 2-year reforestation area ($H' = 0.93$). Soil moisture was significantly different in three areas ($F = 93.602$, $df = 2, 33$, $p < 0.001$), and was highest in the 2-year dipterocarpus reforestation area, followed by the 1-year reforestation area and the non-reforested area, respectively. However, soil microarthropods were positively correlated with soil moisture only in the non-reforested area ($r = 0.752$, $p = 0.003$). This study shows that increasing age progression of seedling affected several environmental factors, particularly soil moisture, which in turn relate to an increasing trend of the diversity and abundance of soil microarthropods.

Department:	Biology	Student's Signature	.....
Field of Study:	Zoology	Advisor's Signature	.....
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CONTENTS

Page

Page

Page

LIST OF TABLE

LIST OF FIGURE

CHAPTER I

INTRODUCTION

1.1 Rationale

Soil microarthropods are small invertebrates that inhabit soil ecosystems and have very important roles in controlling the rate of litter decomposition and, therefore, nutrient cycling (Heneghan and Bolger, 1998; Kardol et al., 2011; Moore et al., 1988), and soil formation (Rumble and Gange, 2013). They also control the population dynamics of organisms in soils (Rusek, 1998) and soil fungal composition and activity (Behan-Pelletier, 2003). Dominant soil microarthropods are commonly springtails and mites found in several habitats, such as montane spruce forest (Farská et al., 2014), hill evergreen forest, agricultural areas (Cortet et al., 2002; Tabaglio et al., 2009) and green roofs (Rumble and Gange, 2013). Most soil microarthropods are detritivores, and therefore assist in decomposition of organic matter (Kardol et al., 2011) and movement of fungal spores through soils (Gormsen et al., 2004). They are commonly found in fertile soils, so they can be used as biological indicators for soil quality and changes of reforested area.

At present, deforestation in Thailand has continually deteriorated the soil ecosystems. The adverse impacts come from the increase of activities, such as urbanization or agricultural intensification which resulted in the loss of biodiversity. Restoration of forest ecosystems is needed to decrease or revert the impacts of deforestation. Forest restoration can be done with various techniques which are appropriate for different levels of forest degradation. Common restoration techniques include: protection (prevention of encroachment, fire, cattle and hunting of seed dispersers), enhancing the natural processes of forest regeneration (using seedlings, saplings and live stumps of indigenous forest tree species, and encourage seed

dispersal includes the protective measures), planting framework species (planting mixtures of 20-30 indigenous forest tree species) and enrichment planting with planting nurse trees (such as hardy nitrogen-fixing trees) (Elliott et al., 2013).

One of the forest restoration methods currently applied at Chulalongkorn University is planting dipterocarpus seedlings inoculated with ectomycorrhizal fungi (ECM). Ectomycorrhizal associations are formed between ECM fungal species and trees from a restricted group of higher plant families, such as Pinaceae, Betulaceae, Fabaceae, Myrtaceae, Fagaceae and Dipterocarpaceae. Trees in the Dipterocarpaceae dominate deciduous forests in South East Asia, and form the most important commercial hardwoods in the region (Ingleby et al., 1998; Yazid et al., 1994). There has been much speculation regarding the role of ectomycorrhizae in determining the successful establishment and survival of Dipterocarpaceae seedlings, and most ECM fungi are able to establish symbioses with a broad range of hosts in both temperate and tropical ecosystems (Phosri et al., 2012). ECM fungi help plants capture nutrients, such as phosphorus, sulfur, nitrogen and micronutrients from the soil (Bardgett et al., 1993; Read, 1991; Yazid et al., 1994), which are important in physiological processes, growth and survival rate of trees and may have positive effects on soil microarthropods through increase of organic matter in soil. ECM fungi could be food sources for fungivorous soil microarthropods.

Reforestation with dipterocarpus seedlings inoculated with ECM fungi would likely help to increase diversity and abundance of soil microarthropods, and may consequently increase the abundance of predators, especially with increasing age of seedlings (Siddiky et al., 2012). Some environmental factors, such as soil moisture and soil temperature, influence the abundance of soil microarthropods because the soil microarthropods are highly sensitive to changes in environment and habitat. Rising temperature has resulted in increasing abundance of soil microarthropods (Harte et al., 1996). Reforestation with dipterocarpus seedlings inoculated with ECM

fungi would likely help to maintain appropriate soil temperature, soil moisture and other factors to promote plants growth over the increasing age the reforested plots. Chulalongkorn University began a reforestation effort using dipterocarpus seedlings inoculated with ectomycorrhizae to promote the growth and survival of tree seedlings at the Chulalongkorn University Center of Learning Network for the Region (CU-CLNR), Kangkhoi District, Saraburi Province, which are divided into three areas, as follows:

1. Non-reforested areas
2. One-year old reforested areas (planted with ECM dipterocarpus seedlings in 2013)
3. Two-year old reforested areas (planted with ECM dipterocarpus seedlings in 2012)

Thus, it is important to know how the soil microarthropod community would change during reforestation stages, as well as biological and physical factors that might influence the diversity and abundance of soil microarthropods. The results of this study will help in monitoring, planning, managing, and restoration of forest ecosystems.

1.2 Objectives

1.2.1 To evaluate the diversity and abundance of soil microarthropods in reforested area of dipterocarpus seedlings inoculated with ectomycorrhizae at different stages

1.2.2 To study physical and biological factors in reforested areas of dipterocarpus seedlings inoculated with ectomycorrhizae at different stages

1.2.3 To study the relationships of physical and biological factors with the diversity and abundance of soil microarthropods.

CHAPTER II

LITERATURE REVIEW

2.1 Soil microarthropods

Soil microarthropods are small invertebrates that are classified into the soil mesofauna group with a body size between 0.2-2.0 mm (Briones, 2014; Neher et al., 1999; Swift et al., 1979) (Table 1 and Figure 1). Soil microarthropods are extremely important in the ecosystems where they inhabit because of their diversity and their habitats. Typical microarthropods, such as mites, springtails, pseudoscorpions, and small diplopods (Figure 1), are found throughout the soil profile, in surface litter, on grasses, herbs and low-growing shrubs, bark, twigs and leaves of trees, and in aquatic, semi-aquatic and coastal habitats (Behan-Pelletier, 1999; Rusek, 1998).

Table 1 Classification of soil fauna (Hopkin, 1997; Neher et al., 1999)

Class	Example (s)	Biomass (g/m^2)	Length (mm)
Microfauna	Protozoa	1.5-6.0	0.005-0.2
Mesofauna	Mites, Collembolans	0.01-10	0.2-2
Macrofauna	Millipedes, Centipedes	0.1-2.5	2-20
Megafauna	Earthworms	10-40	>20

The majority of arthropods inhabit in soils. Surveys of rainforest arthropods found about 42 million of arthropods per hectare and more than half of them are collembolans and mites that inhabit in soil (Hopkin, 1997; Stork, 1988).

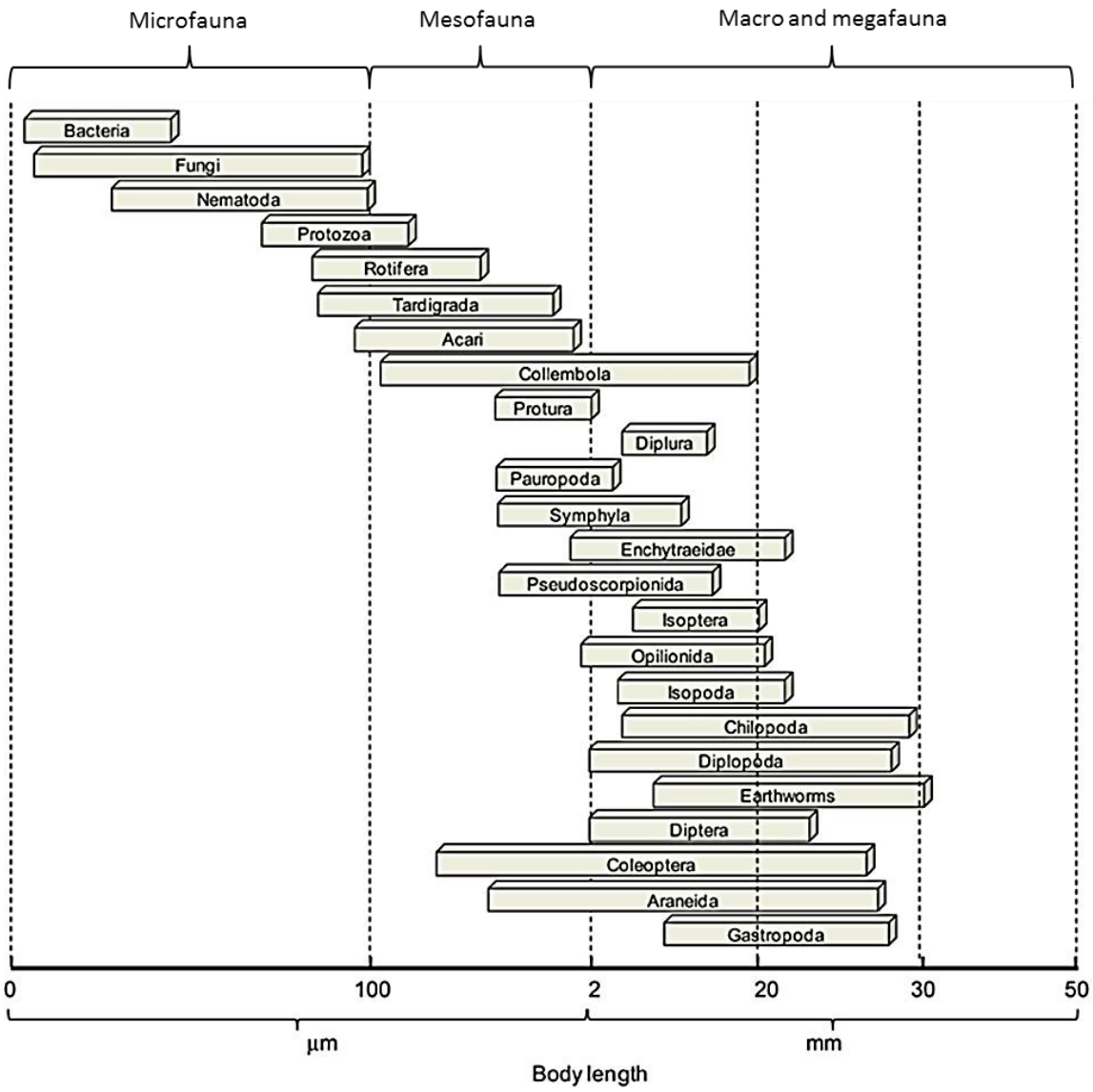


Figure 1 Size classification of soil fauna by body length (Briones, 2014)

2.1.1 Taxonomic diversity

At the class level, soil microarthropods belong to the Arachnida, Insecta, Symphyla, Diplopoda and Chilopoda (Table 2). Important groups are described below.

Table 2 Taxonomic diversity of soil microarthropods

Class	Sub class or Order	Suborder	Common name
Arachnida	Acari	Mesostigmata	Mesostigmatid mites
		Prostigmata	Prostigmatid mites
		Astigmata	Astigmatid mites
		Oribatida	Oribatid mites
	Araneae		Spiders
	Pseudoscorpionida		Pseudoscorpions
Insecta	Collembola		Springtails
	Diplura		Diplurans
	Protura		Proturans
Symphyla			Symphylans
Diplopoda			Millipedes
Chilopoda			Centipedes

1. Mesostigmata

Mesostigmata or Gamasida are group of mites found in a wide range of habitats. Mesostigmatid mites are dominant predators of nematodes, collembolans, insect larvae in soil, and those living on plants, making them efficiently control pests like spider mites. These mites have been used as efficient biological control agents in

above-ground ecosystems (Dindal, 1990). They are also used as bioindicators in agroecosystems (Koehler, 1999).

2. Astigmata

Soil mites in Astigmata are almost entirely composed of detritus feeder guilds. Astigmatid populations are widely found in soil and litter (Dindal, 1990).

3. Oribatida

Oribatid mites, the mites in suborder Oribatida or Cryptostigmata, have been often called 'moss mites' or 'beetle mites', and they are involved in decomposition of organic matters in terrestrial ecosystems (Behan-Pelletier, 1999). Oribatid mites have five active postembryonic instars and all feed on a wide variety of materials including living and dead plants, fungal material, lichens, and carrion, but some are predaceous (Behan-Pelletier, 2003). Although adult oribatid mites usually have strong exoskeleton, they also respond to changes in environmental conditions, such as soil humidity (Crossley et al., 1992; Wallwork, 1983).

4. Prostigmata

Prostigmatid mites are a large and diverse group of predatory mites, including some fungivore species. Members of the Prostigmata, especially in the families Eupodidae, Tarsonemidae and Tydeidae, are among the most abundant soil mites in cultivated agroecosystems (Pimentel and Paoletti, 2012).

5. Araneae

Spiders are arthropods belonging to the class Arachnida and order Araneae. Spiders are predaceous and mostly feeding on insects and on other spiders (Nyffeler and Sunderland, 2003). Spiders have several adaptations that distinguish them from other soil microarthropods such as can build webs to ensnare prey (Griswold et al., 1998).

6. Pseudoscorpionida

Pseudoscorpions are microarthropods belonging to the class Arachnida. Most species of the pseudoscorpions inhabit the soil and litter and feed on small arthropods, such as mites, beetle larvae or springtails. Some larger species may also attack ants (Dindal, 1990). All pseudoscorpions possess conspicuous chelate pedipalps, which function in prey capturing (Zeh, 1987).

7. Collembola

Collembolans or springtails are small, wingless, and hexapodous arthropods. They have been found in all soil habitats. Most but not all of them are able to jump using forked abdominal appendage, called furca. Collembolans and mites are important microarthropods of soil mesofauna in most terrestrial ecosystems (Neher et al., 1999), and collembolans are usually numerically dominant in all habitats (Behan-Pelletier, 2003). Life cycle of most collembolans is about weeks to months. Collembolans, particularly sminthurids and onychiurids, are suggested as root feeder (Dindal, 1990). Onychiurids are attracted to plant roots, but perhaps are primary fungivorous. Collembolans are also significant food sources of predaceous mites and other predators (Crossley et al., 1992).

8. Diplura

Diplurans are small hexapods with chewing mouthparts. They generally live in damp humus or soil and in caves. Two groups basically make up most of the order. These are campodeids, with their long filamentous cerci, and japygids, with their forceps-like cerci. Japygids have been known to consume collembolans, isopods, symphylans and campodeid diplurans (Dindal, 1990).

9. Protura

Proturans are minute, slender, wingless insects. They are found in forest litter and humus (Chao and Chen, 1996). Proturans are an often-neglected group of

soil fauna and are especially common in the rhizospheres of trees with mycorrhizae and feed on mycorrhizal fungi (Malmström and Persson, 2011).

10. Symphyla

Symphyla is both an order and a class of phylum Arthropoda. Symphylans are white, ranging from 0.2 – 1.5 cm in length, with 12 pairs of legs at adult stage. They are extremely common inhabitants of soil, and they are found in many habitats. They are important in decomposition (Dindal, 1990).

11. Diplopoda

Millipedes are common and conspicuous in the fauna of upper soil and litter. Most diplopods are detritivores, and they feed opportunistically and generally on leaf litter and decomposing plant materials (Dindal, 1990).

12. Chilopoda

Centipedes are fauna belonging to the class Chilopoda. They are found in a variety of habitats, but usually occur in a protected situation, such as in the soil. They are predators that feed on small insects and spiders (Dindal, 1990).

2.1.2 Functional role of soil microarthropods

Soil microarthropods are diverse and perform important functions in ecosystems. They control the rate of litter decomposition, nutrient cycling (Heneghan and Bolger, 1998; Kardol et al., 2011; Moore et al., 1988) and soil formation (Rumble and Gange, 2013). They even control the population dynamics of other organisms in soil (Rusek, 1998) and influence fungal composition and activity (Behan-Pelletier, 2003). Soil microarthropods speed up decomposition of large organic matter by converting it into soil inorganic substances that plant roots can absorb as nutrients from soil. Oribatids and collembolans feed on fungi and dead organic matters, and their faecal pellets are secreted into the soil for decomposition by bacteria and fungi, and their faecal pellets are an integral component of soil structure (Rusek, 1998).

Moreover, some plants absorb nutrients through mycorrhiza that have relationship with their roots (Kardol et al., 2011), for example, mycorrhiza which is a symbiotic association between mycorrhizal fungi and live plant roots. Mycorrhizal fungi play a main role in increasing absorption of nutrients, especially phosphorus that tropical soils often lack. Mycorrhiza not only help increasing springtail population because fungus spores are food of some springtails, but these two soil organisms can also increase soil formation process efficiently (Siddiky et al., 2012).

2.1.3 Role as bioindicators

Apart from their important ecosystem roles, soil microarthropods have been used to indicate soil fertility. Environmental changes may be subtle and a result of complex interactions between abiotic and biotic components that cannot be measured directly. Most studies still focus on sensitive species. Collembolans are typically sensitive to soil moisture and temperature level changes and they interact with other microarthropods and fungi in soil (Huhta and Hänninen, 2001; Malmström, 2008; Parwez and Sharma, 2014; Turnbull and Lindo, 2015). Some soil microarthropods are commonly found in fertile soils, with appropriate temperature and humidity, and good drainage and ventilation (Ponge, 2003). Many workers have used assessments of soil microarthropod communities to examine soil quality and the effect of human-induced changes, such as deforestation, plowing, agricultural and the landscape level (Cortet et al., 2002; Farská et al., 2014; Tabaglio et al., 2009).

2.1.4 Feeding guilds type of soil microarthropods

A guild is defined as a group of species that exploit the same class of environmental resources in a similar way (Root, 1967).

Detritivore

Detritivores are heterotrophs that obtain nutrients by consuming detritus. All these detritivores contribute to decomposition and the nutrient cycles. They can live on any soil with an organic component. Typical detritivorous animals include some species of mites, Symphyla and Diplopoda (Neher et al., 1999).

Detrito-fungivore

Detrito-fungivores, such as collembolans, proturans and almost all oribatid mites, feed on both decaying plant materials and fungi (including mycorrhizae) (Neher et al., 1999).

Predator

Soil microarthropods may be predators or serve as prey for predaceous mites and other groups of predators, such as Pseudoscorpionida, Araneae, Chilopoda, Diplura, and almost all Gamasina mites (Mesostigmata). They attack small arthropods (collembolans, soft-bodied mites, insect larvae and eggs) (Neher et al., 1999).

2.1.5 Extraction of soil microarthropods

A Tullgren apparatus, based on the Berlese funnel thus often called Berlese–Tullgren funnel, and its various modifications, is the most commonly used method to extract microarthropods, such as mites and collembolans from soil and litter. The funnel creates dry conditions at the upper part by a lighting source from a small lamp on the top, under which a soil sample is placed on the sieve at the top of funnel. Modifications of the Berlese – Tullgren funnel in extraction efficiency are improved by enhancing humidity and temperature gradients (Rusek, 1998; Sakchoowong et al., 2007; Wu et al., 2014). This method is however not suitable with soil microarthropods that became desiccated easily, such as immobile larvae and soft-bodied arthropods.

2.1.6 Factors influence soil microarthropods

1. Soil moisture and soil temperature

Soil temperature is the main factor affecting the activity of the soil microarthropods and is correlated with the moisture in the soil (Turnbull and Lindo, 2015). Soil microarthropods were found most abundant in the wet area (Kardol et al., 2011). High soil temperature and low soil moisture decrease collembola and mite abundance (Parwez and Sharma, 2014). Soil moisture has a positive correlation with the population of soil microarthropods from study in dry dipterocarpous forest and dry evergreen forest in Thailand (Kongnirundonsuk et al., 2014) and grassland in India (Parwez and Sharma, 2014), and soil moisture positively relates to rainfall from study in the coniferous forest in China (Wu et al., 2014). However, heavy rains or flooding may lead to waterlogged conditions that cause mortality of adult collembolans and require water-resistant eggs for the populations to persist (Tamm, 1984). Moreover, moisture changes may also affect the fungal community, which have indirect effect on the fungivorous microarthropods (Hågvar, 1998). The distribution, abundance and life cycles of soil microarthropods are directly affected by soil temperature and moisture (Tsiafouli et al., 2005).

2. Soil pH

Soil pH is a key factor to the spread of the soil microarthropods. Generally the microarthropods living in the soil where soil pH is in the range of 6-7 (Sylvia et al., 2005). Sumanothum (2007) found that collembolans and acari inhabit soil with is acidic pH 5 or 6 due to the rapid growth of fungi in acidic conditions (Yamanaka, 2003), making fungi an important food source for collembolans and oribatid mites (Behan-Pelletier, 2003; Rusek, 1998).

3. Organic matter

Organic matter influences physical, chemical and biological factors of the soil. Because the amount of organic matter from fossil as well as organic compounds from degradation will assist soil structure stability as well as soil moisture and nutrients. Saitoh et al. (2011) reported that density of soil microarthropods, particularly collembolans and acari, were positively correlated with soil organic matter.

2.1.7 Dispersal of soil microarthropods

In theory, body size, life cycle and number of offspring have often been used to explain successional patterns of soil microarthropods. Oribatid mites often take longer time to recovery after disturbances than collembolans (Lindberg et al., 2002). Although, collembolans are able to jump using special structure (furcula) for movement and escape from predators, this ability does not correlate with dispersal rate (Farská et al., 2014). Most soil microarthropods can disperse from the surrounding areas by wind and water (Ojala and Huhta, 2001). Dispersal rates depend on various characteristics of each species, while some species of oribatid mites and collembolans can disperse to new habitats faster than the others. However, information about soil microarthropods dispersal abilities of soil fauna is very limited.

2.2 Mycorrhizal fungi

Mycorrhizae are the mutualistic relationship between non-pathogenic fungi and young plant root system which still absorb water and nutrients. ECM fungi help plants capture nutrients from the soil (Bardgett et al., 1993; Read, 1991; Yazid et al., 1994). Metabolism of plants gives fungi carbohydrates and other essential compounds, while fungi help plants to tolerate drought by increasing or producing nutrients. Therefore, mycorrhizal relationship may increase plant growth rate (Marx, 1972; Smith et al., 2003). Bucking et al. (2002) reported that xylem and phloem of plant root with ectomycorrhizae have more magnesium, phosphorus, sulfur, potassium and calcium than those without ectomycorrhizae. Furthermore, mycorrhizae protect plants from pathogenic fungi.

2.2.1 Types of mycorrhizal fungi

1. Ectomycorrhizal fungi (ECM)

Ectomycorrhizal associations are formed by fungi and a restricted group of plant families such as Pinaceae, Betulaceae, Fabaceae, Myrtaceae, Fagaceae and Dipterocarpaceae (Ingleby et al., 1998; Yazid et al., 1994). Ectomycorrhizae consist of a hyphal sheath, or mantle, covering the root tip and a hartig net of hyphae surrounding the plant cells within the root cortex (Taiz and Zeiger, 2002) (Figure 2).

2. Endomycorrhizal fungi (arbuscular mycorrhizae, AM)

An endomycorrhiza is a type of mycorrhiza into which the fungus penetrates cortical cells of vascular plant roots. Endomycorrhizae are mutualisms formed between fungi in phylum Glomeromycota and plant roots. This association the fungus occurs inside the cells of the plant root by the formation of unique structures such as arbuscules and vesicles. AM fungi help plants to capture nutrients such as

phosphorus, sulfur, nitrogen and micronutrients from the soil (Taiz and Zeiger, 2002) (Figure 3).

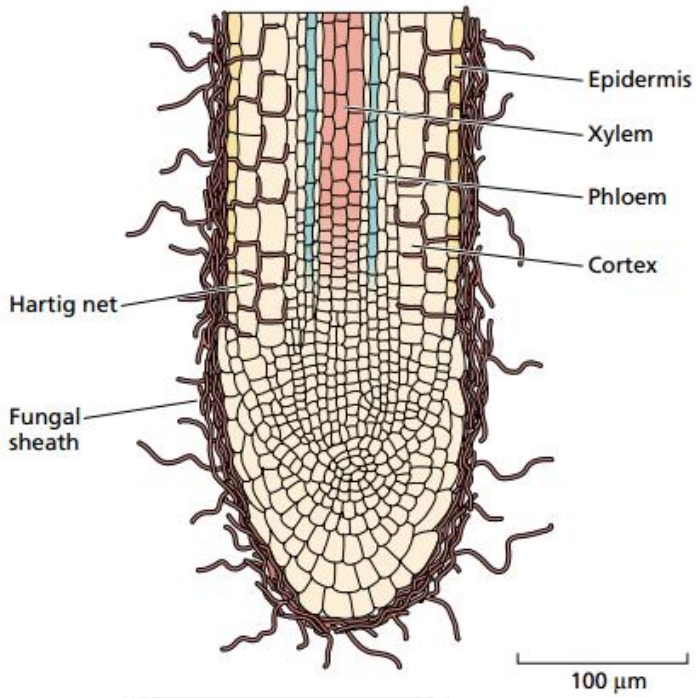


Figure 2 Root infected with ectotrophic mycorrhizal fungi (Taiz and Zeiger, 2002)

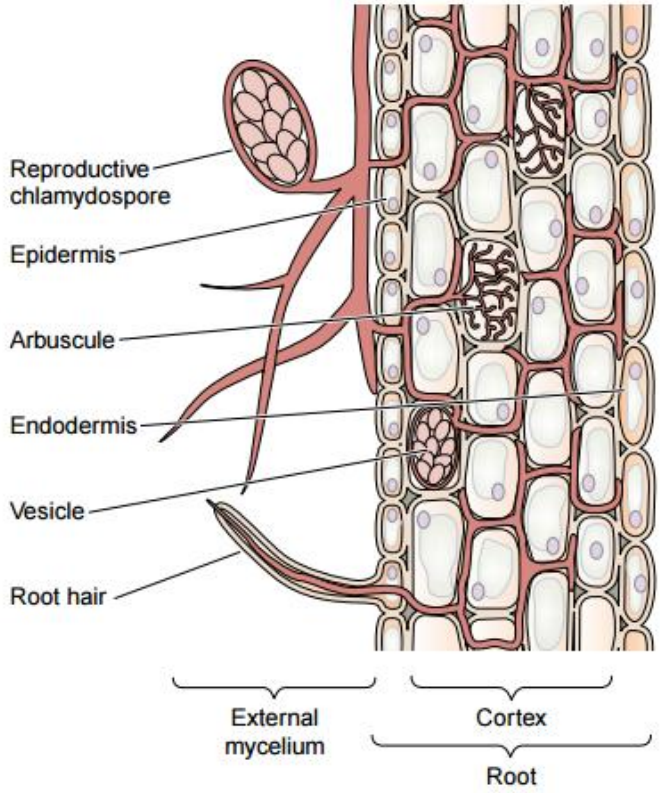


Figure 3 Association of vesicular-arbuscular mycorrhizal fungi with a section of a plant root (Taiz and Zeiger, 2002)

2.2.2 Application of ectomycorrhizae in forest restoration

Artificial inoculation of ectomycorrhizae has been used in nursery seedlings and seems to be an important contributor to the survival potential of seedlings in the forest production. Growth of the inoculated seedlings has also showed positive correlation with ectomycorrhizal association to seedlings (Arenla and Ajungla, 2014). Approximately10-50% of the host plant's net photosynthetic product is estimated to be transferred to ectomycorrhizal fungi (Sakakibara et al., 2002). See (1992) reported that seedlings of *Shorea leprosula*, *Shorea acuminate*, and *H. odorata* grow in sterile soil inoculated with ectomycorrhizal root fragments for 7 months were 1.5 times taller than uninoculated seedlings. The high growth of ectomycorrhizal *S. acuminata*, *S. leprosula* and *H. odorata* was associated with improved phosphorus nutrition

through the increased phosphorus uptake by ectomycorrhizal association (See, 1992). However, the seedlings at the fourth month did not show much difference between the inoculated and control, but 8-month-old seedlings showed significant difference. This shows that plant growth improved with ectomycorrhizal association and active ectomycorrhizal root tips (Arenla and Ajungla, 2014). Thus, ectomycorrhizal (ECM) associations may be of great importance for seedlings growing in low nutrient conditions (Tennakoon et al., 2005).

2.2.3 The relationship between ectomycorrhizae and soil microarthropods

Interactions between microarthropods and ectomycorrhizal fungi are important to many processes in soil, such as decomposition and nutrient cycling (Cortet et al., 2002). Ectomycorrhizal (ECM) fungi are very common in forest soils, and may be food resources for fungivorous soil animals (Malmström and Persson, 2011). Mycorrhizae increase collembolan population because collembolans feed on mycorrhizae (Siddiky et al., 2012). Furthermore, collembolans are potential vectors for dispersal of individual mycorrhizae beyond the zone of mycelium extension (Gormsen et al., 2004). On the other hand, collembolans feeding on mycorrhizal hyphae may reduce the mycorrhizal benefits for the host plants (Porazinska et al., 2003). Oribatids also disperse bacteria and fungi, both externally on their body surface and by feeding, with subsequent survival of spores during passage through their alimentary tracts. However, there are few studies about the interactions between soil fungi and oribatid mites, collembolans, or other microarthropods.

2.3 Dipterocarpus trees as ectomycorhizal host species

Kingdom: Plantae

Phylum: Tracheophyta

Class: Magnoliopsida

Order: Malvales

Family: Dipterocarpaceae

Dipterocarpaceae are the dominant tree family in many of the forests of Southeast Asia and therefore these trees have the capacity to strongly influence the ecology of forests in this region. Some species of the Dipterocarpaceae, such as *Dipterocarpus intricus*, *D. obtusifolius*, *D. tuberculatus*, *Shorea obtusa* and *S. siamensis*, are dominant species in dominate deciduous forests, especially in northeastern and north Thailand (Figure 4). Some species, such as *D. alatus*, is a common tree species found in the canopy of evergreen forest types normally found in central, eastern and southern Thailand. Dipterocarpaceae are economically valuable trees because their wood can be used in construction and furniture manufacturing. Dipterocarpus trees, therefore, are one of the most important commercial hardwoods from Southeast Asia (Ingleby et al., 1998; Yazid et al., 1994). However, they have been less attractive to replant due to their slow growth rate and low survival rate (Appanah and Turnbull, 1998).

Plantations involving dipterocarps have been established since the 1980s. Researchers have found since 1920s that most dipterocarpaceae form a symbiotic relationship with ectomycorrhizal fungi and some dipterocarp species form an association with vesicular-arbuscular mycorrhizae (VAM) (Appanah and Turnbull, 1998). Lee (1998) reported that most ectomycorrhizae in the Philippines which associate with dipterocarpaceae are *Russula* sp. and *Lactarius* sp. There have been

many speculations regarding the role of ectomycorrhizae in determining the successful establishment and survival of Dipterocarpaceae seedlings (Phosri et al., 2012; Yazid et al., 1994).

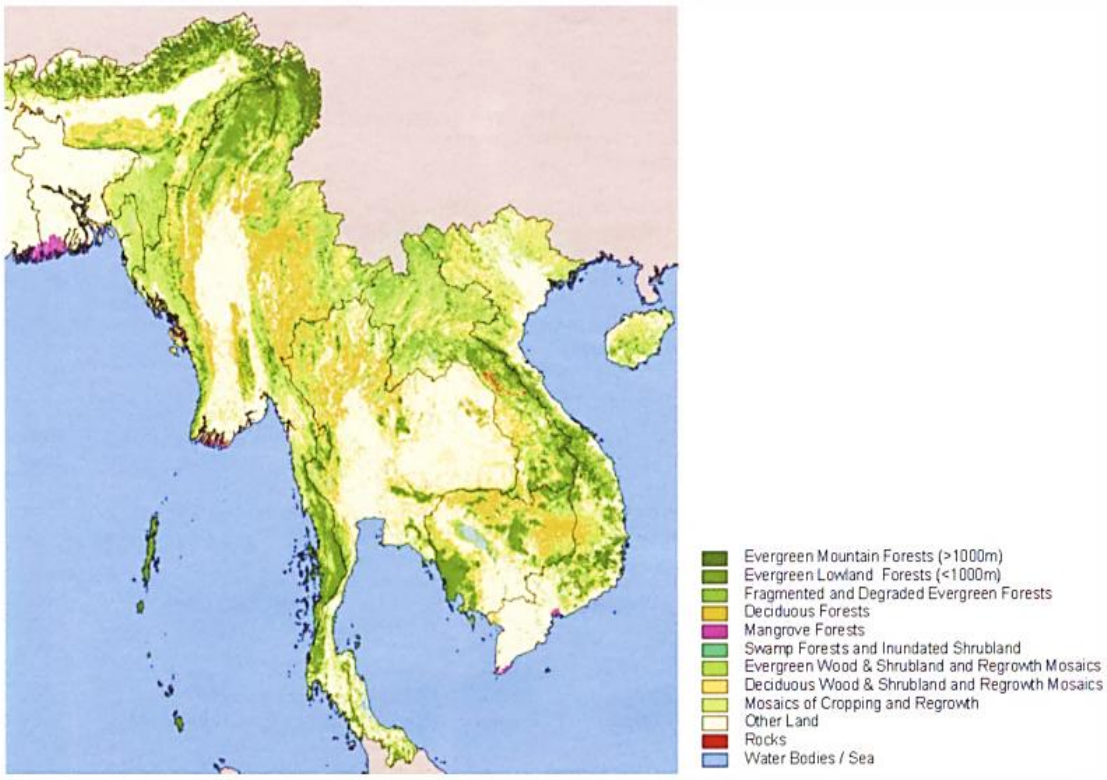


Figure 4 The forest map in Southeast Asia (Stibig et al., 2004)

CHAPTER III

METHODOLOGY

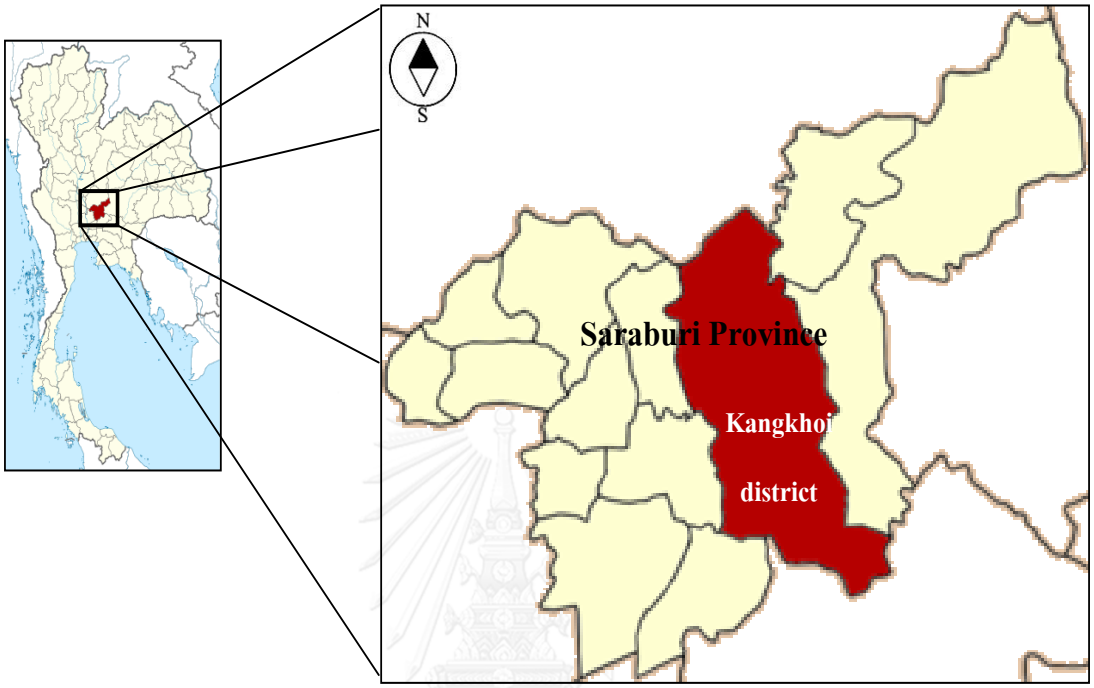


Figure 5 Map of Kangkhoi District, Saraburi Province, Central Thailand (Wikipedia, 2016).

3.1 Study sites

The study was conducted at the Chulalongkorn University Center of Learning Network for the Region (CU-CLNR) (14°31'N, 101°01'E), Kangkhoi District, Saraburi Province, in central Thailand (Figure 5). The climate is a tropical savanna type with 1,264 mm annual precipitation and average temperature of 28.80 °C. Plain land surrounded by mountains at elevations of 40–190 m, and has reservoir and several ponds. The total area size is 538.24 ha. A reservoir was constructed in 2007 and several ponds were dug in 2007-2015 to irrigate the area. During the pond excavation, soils from 3 m below the surface was turned over to form the pond rim, which was approximately 8-10 m wide. The pond rim was then plug-planted with Dipterocarp

seedlings, usually a mixture of *Hopea odorata*, *Dipterocapus alatus*, *Shorea roxburghii*, *Shorea obtuse* and *Shorea siamensis*, in proportions of approximately 3: 8: 2: 2: 3, respectively. The seedlings were inoculated with ectomycorrhizal fungi of mixed species, such as *Russula* spp., *Lactarius* sp. and possibly others from the local soils. The seedlings were kept in a nursery until approximately 1 year old before being planted in a grid with 2-m spacing. There was no fertilization or supplementary watering. The study was conducted in three sites as follows (Figure 6):

1). Non-reforested areas (Figures 7 and 8)

The non-reforested areas were lands around two ponds in the middle and the west of the CU-CLNR that were not planted with Dipterocarp seedlings. Herbaceous weeds dominated the ground all year round, but were removed by monthly cutting.

2). One-year reforested areas (Figures 9 and 10)

Two sites were located around two adjacent ponds in the middle of the CU-CLNR. Dipterocarp seedlings were plug-planted in 2013. At the time of sampling start, seedlings were approximately 0.5 m tall with 0.1 m^2 crown size. Herbaceous weeds dominated the ground all year round, but were removed by monthly cutting.

3). Two-years reforested areas (Figures 11 and 12)

Two sites were located on the rim of the ponds (E and F) to the north of the CU-CLNR and plug-planted in 2012 with Dipterocarp seedlings. At the time of sampling start, the seedlings were 2 m tall with 0.25 m^2 crown size. Herbaceous weeds dominated the ground all year round, but were removed by monthly cutting.

3.2 Sampling

The soil of the study areas was obtained from pond excavation during which 3 m depth of soil was inverted. Each plot of approximately 10 x 10 m^2 with two replicates per treatment. Six 1-m^2 quadrats were placed at random in each plot. Soil samples were taken from 20 x 20 x 10 cm^3 subplots randomly chosen, within the quadrats (Figure 13). Samples were collected once a month for 13 months from October 2014 to October 2015. The soil samples were weighed to determine wet weight, and microarthropods were extracted with Berlese-Tullgren funnels (Figure 14) for three days (Sakchoowong et al., 2007) and were stored in 1.5 ml microtubes with 70% ethanol for each sample.

3.3 Soil microarthropod identification

Soil microarthropods from each sample were sorted and counted based on groups of Class, Subclass or Order (Dindal, 1990; Johnson and Triplehorn, 2004; Zhang, 2003), morphospecies and guilds (detritivore, detrito-fungivore and predator). The identification of microarthropods to the morphospecies level required a high-magnification microscope and soil microarthropods specimens were temporarily mounted in lactic acid on cavity microscope slides (Coleman et al., 2004), and they were placed to 1.5 ml microtubes according to groups of each sample.

Figure 6 Location of the study areas from pond excavation in the non-reforested areas (A and B), 1-year reforested areas (C and D) and 2-year reforested areas (E and F) (Googlemap, 2016)

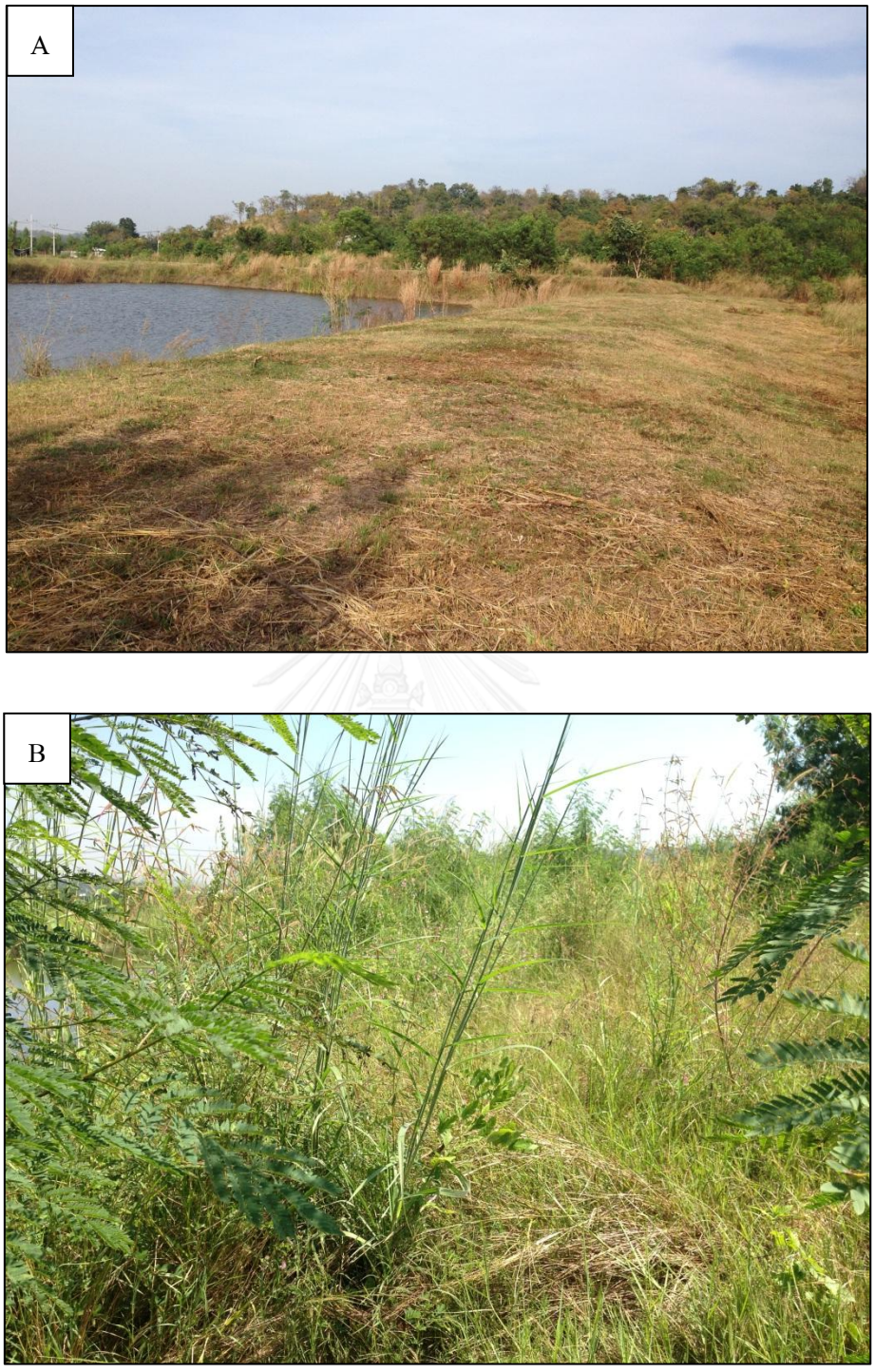


Figure 7 Non-reforested areas in plot one, photographed in October 2014 (A) and October 2015 (B)

Figure 8 Non-reforested areas in plot two, photographed in October 2014 (A) and October 2015 (B)

Figure 9 One-year reforested areas in plot one with seedlings planted in 2013, photographed in October 2014 (A) and October 2015 (B)

Figure 10 One-year reforested areas in plot two with seedlings planted in 2013, photographed in October 2014 (A) and October 2015 (B)

Figure 11 Two-year reforested areas in plot one with seedlings planted in 2012, photographed in October 2014 (A) and October 2015 (B)

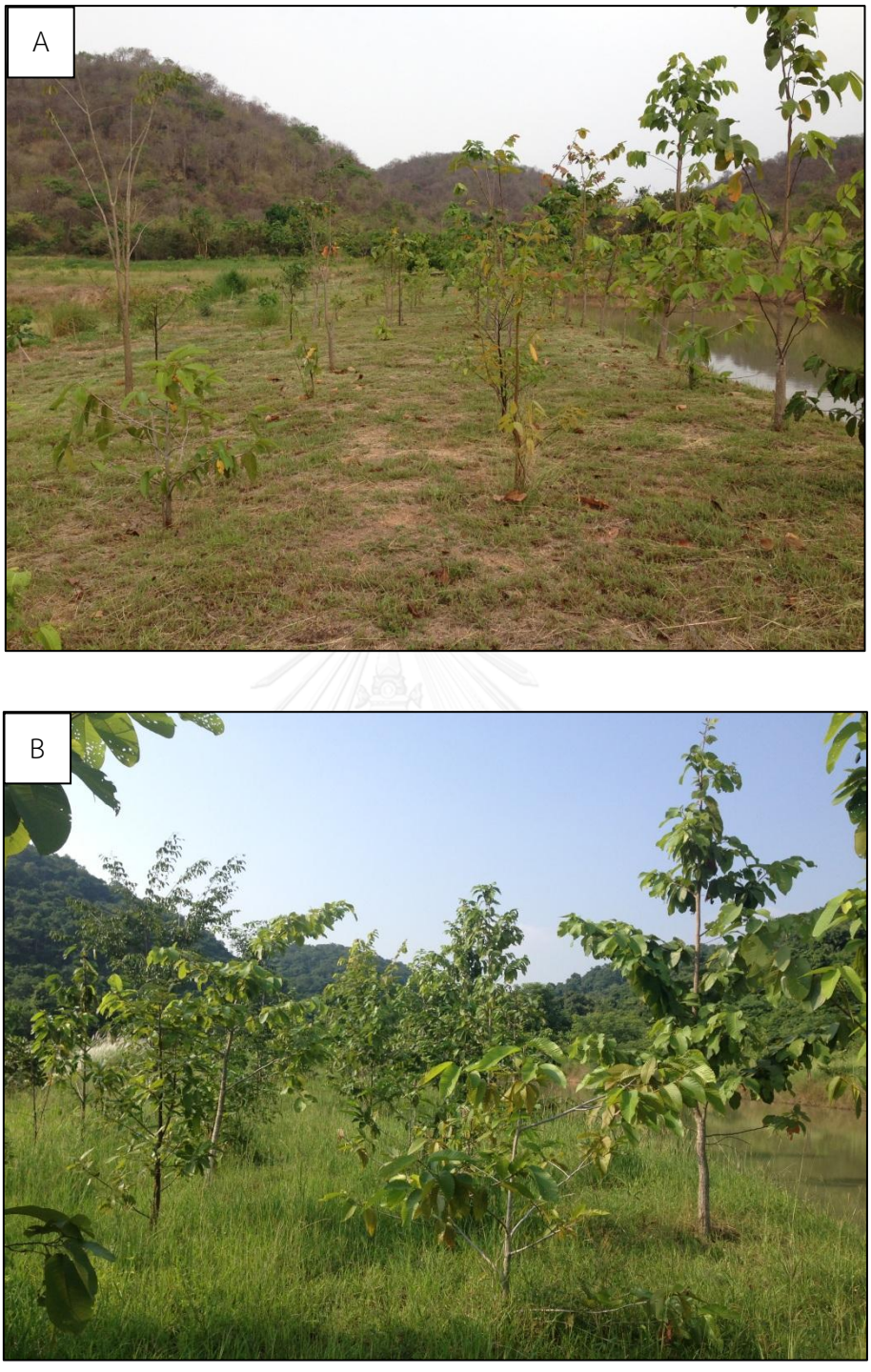


Figure 12 Two-year reforested areas in plot two with seedlings planted in 2012, photographed in October 2014 (A) and October 2015 (B)

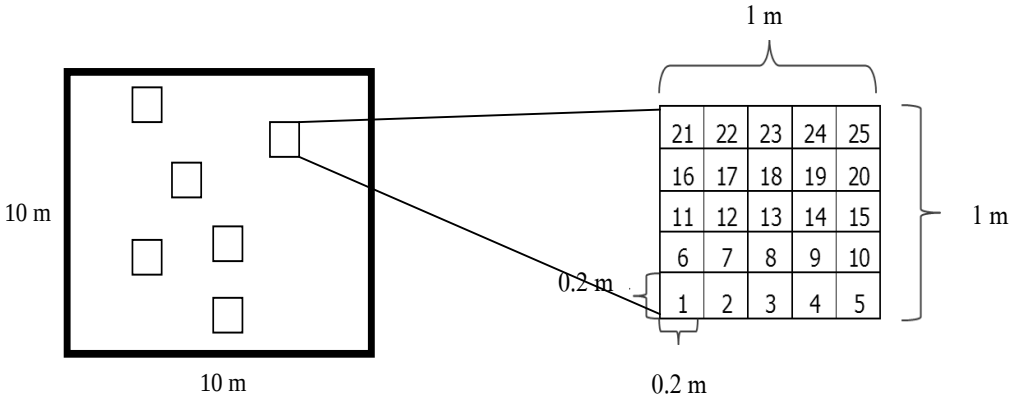


Figure 13 The design of sampling plots for soil sampling

Figure 14 Berlese-Tullgren funnels for extraction of soil microarthropods

3.4 Biological factors

a) Ectomycrorhizal fungi (ECM) Infection

Percent ECM infection was obtained by sampling the soils in the vicinity of existing dipterocarpus seedlings at different stages. Soil samples were taken from 10 x 10 x 20 cm^3 (Figure 15) in July 2015. The roots were separated from the soils and observed under a stereo microscope, and ECM root tips were characterized on the basis of color and branching shape (Arenla and Ajungla, 2014). Percent ECM infection was calculated as the number of ECM root tips per the total number of root tips obtained. The procedure was only performed once to limit the impact on the restoration forest community (Rumble and Gange, 2013).

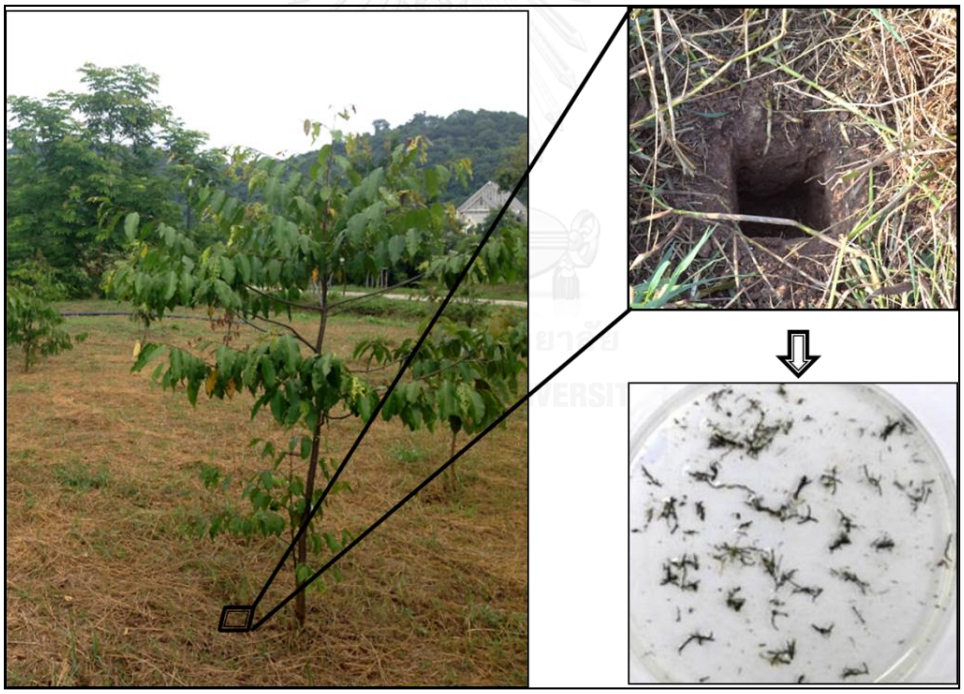


Figure 15 Percent ECM infection counts were obtained from soil sample in reforestation areas

b) Herbaceous cover, herbaceous biomass and organic matter

Herbaceous cover was estimated with naked eye with the aid of 1x1 m^2 quadrat frame (Figure 16) (Braun-Blanquet, 1932; Rumble and Gange, 2013). Additionally, the aboveground herbaceous material was collected from 0.25 x 0.25 m^2 subplot and oven-dried to measure biomass. Soil samples (100g) were mixed with water, filtered the organic matter with sieve and oven-dried at 105 ± 5 $^{\circ}C$ for 24 hours to measure soil organic matter (Ertel et al., 1991).

Figure 16 Quadrat for the estimation of herbaceous cover

3.5 Physical factors

a) Soil temperature

Soil temperature was measured using a thermometer placed at 10 cm depth in the soil (Figure 17).

Figure 17 Thermometer

b) Soil moisture and water holding capacity

Soil moisture was measured by drying 100 g soil sample at 105 ± 5 °C for 24 hours (Farská et al., 2014; Zhao et al., 2008). Water holding capacity (WHC) of soil was also tested.

$$\text{Soil moisture} = \frac{\text{weight of soil before incubating (g) - weight of soil after incubating (g)}}{\text{weight of soil before incubating (g)}} \times 100$$

$$\text{Water holding capacity (WHC)} = \frac{\text{Total water in the wet soil}}{\text{Oven dry weight of total soil}} \times 100$$

c) Soil pH

Soil pH was measured by mixing soil samples with distilled water at 1:1 ratio and tested with pH meter.

d) Soil texture

Soil samples (200g) were mixed with water in 1,000 ml cylinder and the thickness of each of the sand, silt and clay layers precipitated (Figure 18) was measured to estimate soil texture class from the soil textural triangle (Figure 19) (Eo and Nakamoto, 2008; Zhao et al., 2008).

Figure 18 The settling of particles in soil suspension

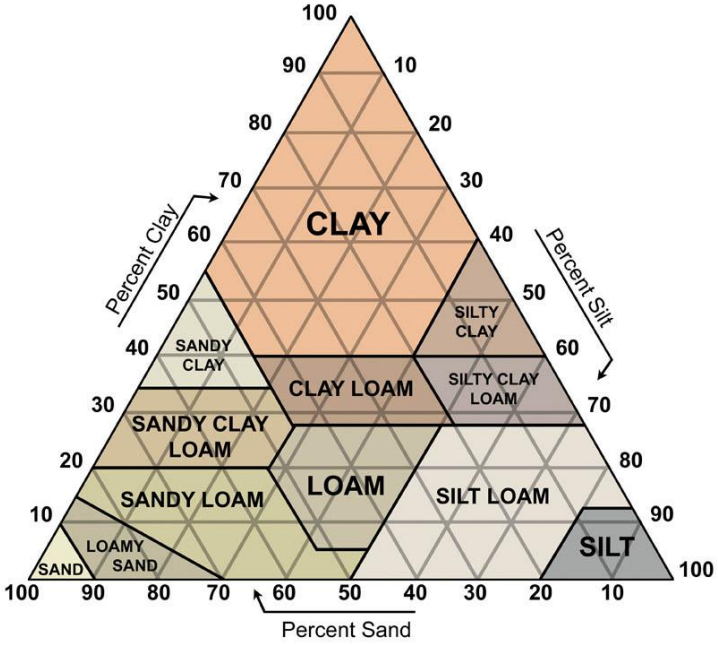


Figure 19 Soil textural triangle (SoilSensor, 2011)

e) Rainfall

Average monthly rainfall from October 2014 to October 2015 was obtained from the Office of Hydrology Irrigation Center for Central Region.

f) Soil nutrients

Soil samples were sent to the Central Laboratory and Greenhouse Complex (Kasetsart University Kamphaeng Saen Campus) for analyses of some nutrients, such as nitrogen (KCl extraction and distillation), phosphorus (Bray II extraction and spectroscopy) and potassium (NH_4OAc extraction and atomic spectroscopy).

3.6 Statistical analyses

All statistical tests were performed in SPSS 17.0. Differences between biological and physical factors in the three study areas were tested using one-way ANOVA. The ANOVA tests will require homogeneity of variance and normality. Relationships between soil microarthropods with biological and physical factors were examined using Pearson's correlation analysis. Multiple linear regression was used to analyze the relationship between factors that affect to abundance of soil microarthropods. Diversity based on morphospecies was measured and compared using the Shannon-Wiener index, Simpson Diversity Index, evenness index, Margalef's index (Krebs, 1989). Furthermore, similarities in composition of biological and physical factors were analyzed, using Principle Component Analysis (PCA) in R program (Kaplunovsky, 2005).

a) Shannon-Wiener diversity index

$$H' = - \sum_{i=1}^{S} (p_i \log p_i)$$

Whereas H' = index of morphospecies diversity (individuals)

S = total number of morphospecies

Pi = proportion of total samples belonging to i^{th} species in S ($pi = ni/N$; $i = 1, 2, 3,...,$)

b) Simpson's Dominance Index

$$D = \sum_{i=1}^{S} pi^2$$

Whereas D = Simpson's dominance index

S = total number of morphospecies in the community (richness)

pi = proportion of S made up of the i^{th} species

c) Shannon-Wiener's Evenness Index

$$E_H = H / \ln S$$

Whereas E_H = equitability (evenness)

H = Shannon's diversity index

S = total number of morphospecies in the community (richness)

$\ln$ = natural logarithm

d) Species richness (Margalef's Index) (Margalef, 1958).

$$R = (S-1) / \ln N$$

Whereas R = species richness

S = total number of morphospecies

N = total number of individuals in the sample

In = natural logarithm

e) Similarity index (Sorensen's Index)

$$S_s = 2a / (2a+b+c)$$

Whereas S_s = Sorensen's similarity coefficient

a = number of species common to both quadrats

b = number of species unique to the first quadrat

c = number of species unique to the second quadrat

CHAPTER IV
RESULTS

4.1 Physical and biological factors

The average monthly rainfall of the study site was 97.26 mm between October 2014 to October 2015, with the minimum of 0 mm in December 2014 and maximum of 287.30 mm in September 2015. The average monthly air temperature was 28.80 ºC from October 2014 to October 2015, with the minimum of 25.30 ºC in January 2014 and maximum of 31.30 ºC in May 2015.

The climatic conditions of the study areas were determined by constructing a climograph of average monthly air temperature and rainfall (Figures 20 and 21). The dry season was during November 2014 to June 2015 with monthly air temperature ranging from 26.7-31.3ºC and 0-83.4 mm monthly rainfall. The wet season was between October 2014 and July to October 2015 with monthly air temperature ranged from 28.0-30.1 ºC and rainfall ranged from 125.8-287.3 mm.

The soil texture was classified as sandy loam in all three areas. The non-reforested area had more sand than the reforestation areas and were significantly different between the non-reforested area and the 2-year dipterocarpus reforestation areas ($F = 4.730$, $df = 2, 33$, $p = 0.016$). The soil pH was 6.4-7.2 in all study areas. In addition, available nitrogen and available phosphorus were not significantly different among the three areas, except available potassium which was significantly different between non-reforested area and the dipterocarpus reforestation areas at the 1-year ($F = 7.337$, $df = 2, 21$, $p = 0.001$) and 2-year dipterocarpus reforestation areas ($F= 7.337$, $df = 2, 21$, $p = 0.046$). However, phosphorus was slightly lower in the 2-year dipterocarpus reforestation areas. The water holding capacity (WHC) was significantly lower in the non-reforested area than the reforested areas ($F= 42.963$, $df = 2, 33$, $p < 0.001$), with 23.31% average WHC in non-reforested area and 29.15-29.95% in

reforested areas (Table 3). Soil temperature was significantly different in reforested areas at 2-year (F= 4.310, df = 2, 33, p = 0.022). However, the soil temperature was not significantly different between seasons in three areas (Figures 22, 23 and Table 4). Furthermore, soil moisture was significantly different in three areas (F= 93.602, df = 2, 33, $p < 0.001$), and was highest in the 2-year dipterocarpus reforestation area, the 1-year reforestation area and the non-reforested area, respectively, but not significant difference between seasons (Figure 24, 25 and Table 4).

Higher ECM infection was found in the 2-year dipterocarpus reforestation area (77%) than in the 1-year dipterocarpus reforestation areas (47%) (Table 3). Herbaceous plant biomass was significantly higher in the reforestation area at 2-year (F = 3.939, df = 2, 33, p = 0.029) (Table 3). Herbaceous plant biomass in the wet season was significantly higher than the dry season in all areas (Figures 26, 27 and Table 4). The herbaceous cover was not significantly different between the three areas (Figures 28, 29 and Table 4). The herbaceous biomass and herbaceous cover were lowest in February 2014 because the grass in this month was cut during the sampling date. Organic matter was not significantly different between areas (Table 3). Organic matter in the dry season was higher than the wet season but the significant difference between seasons was only found in the reforested areas at 2-year (t = -2.594, p = 0.025) (Figures 30, 31 and Table 4).

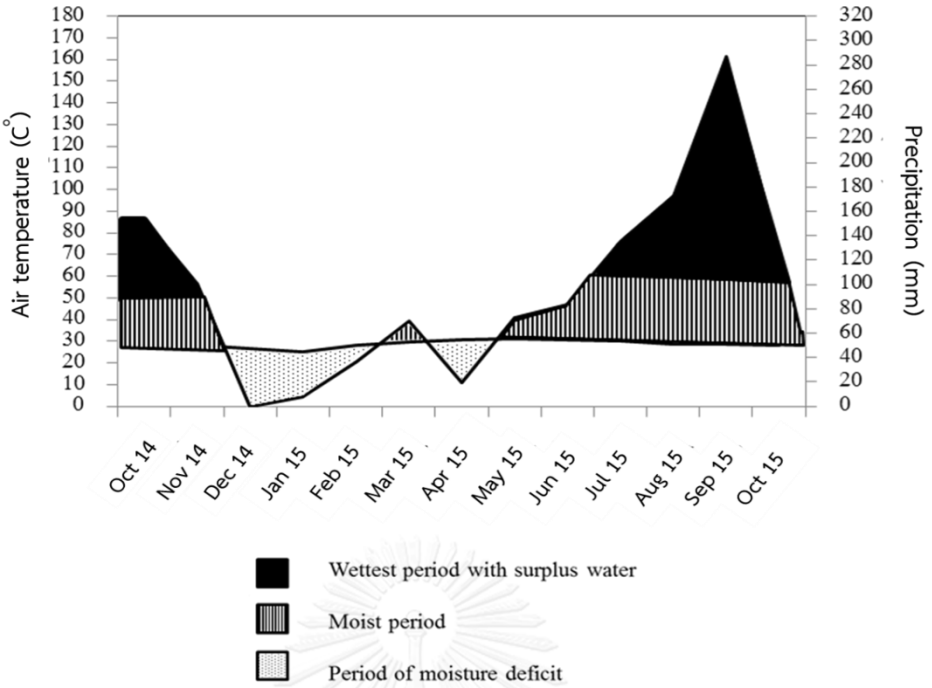


Figure 20 Climate conditions at the Chulalongkorn University Center of Learning Network for the Region (CU-CLNR), Kangkhoi District, Saraburi Province, based on air temperature and precipitation from October 2014 to October 2015

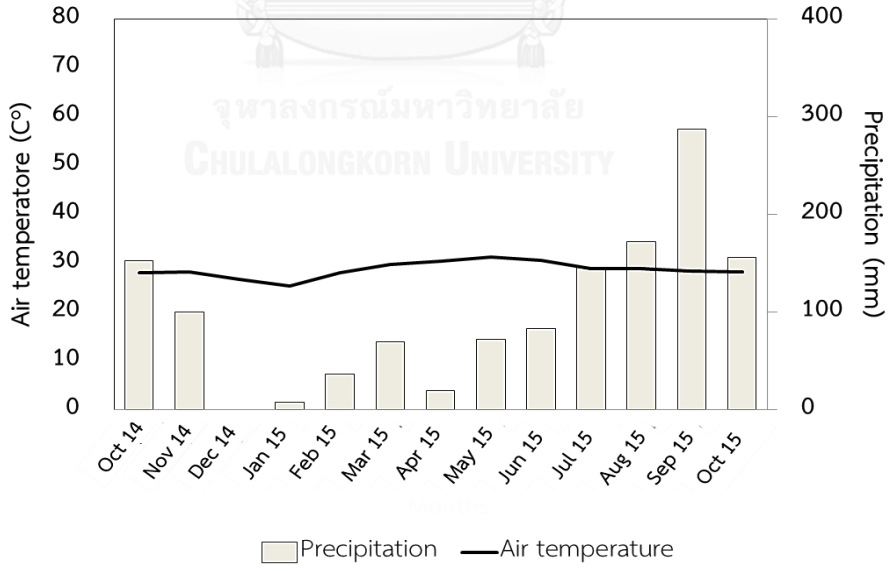


Figure 21 The October 2014 to October 2015 climograph at the Chulalongkorn University Center of Learning Network for the Region (CU-CLNR), Kangkhoi District, Saraburi Province, based on air temperature and precipitation

Table 3 Physical and biological factors (mean ± SE) measured in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0). P-value from ANOVA with LSD (parametric). Same superscript letters means no significant difference at $p \leq 0.05$

	Study areas			p-value
	RF0	RF1	RF2	
Soil texture	sandy loam	sandy loam	sandy loam	
Sand (%)	50.50±2.84[a]	47.00±1.32[ab]	38.66±3.69[b]	0.016
Silt (%)	45.00±1.71[a]	33.66±2.14[b]	48.00±4.31[a]	0.002
Clay (%)	11.00±1.58[a]	16.42±1.72[a]	13.25±1.47[a]	0.074
Soil pH	6.4-7.2	6.7-7.1	6.7-7.1	
WHC (%)	26.31±0.37[a]	29.95±0.20[b]	29.15±0.28[b]	0.000
Available N (mg/kg)	9.77±1.3[a]	11.55±1.3[a]	9.77±1.3[a]	0.546
Available P (mg/kg)	6.3±2.32[a]	9.67±2.19[a]	5.62±1.19[a]	0.317
Available K (mg/kg)	164.73±14.77[a]	238.14±12.42[b]	197.45±13.43[a]	0.004
Soil temperature (°C)	29.78±0.24[a]	29.38±0.32[a]	29.02±0.20[b]	0.022
Soil moisture (%)	9.23±0.43[a]	12.06±0.46[b]	12.65±0.57[c]	0.000
Organic matter (%)	0.73±0.14[a]	0.85±0.12[a]	0.73±0.22[a]	0.805
Herbaceous biomass (g/m^2)	231.33±40.25[a]	264.34±35.78[ab]	278.82±33.81[b]	0.008
Herbaceous cover (%)	49.55±6.62[a]	64.49±5.50[a]	55.16±3.81[a]	0.090
ECM infection (%)	n/a	47	77	

n/a means not applicable

Table 4 Physical and biological factors (mean ± SE) measured between seasons in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0). Same superscript letters denotes no significant difference between wet and dry seasons of the same reforested stage. (Independent samples t-test, $p \leq 0.05$)

	Study areas					
	RF0		RF1		RF2	
	wet	dry	wet	dry	wet	dry
Soil pH	6.4-7.7	6.6-7.2	7.2-7.4	6.6-7.2	6.7-7.1	6.7-7.4
Available N (mg/kg)	8.9±1.8^{a}	10.7±2.0^{a}	10.7±2.0^{a}	12.4±1.8^{a}	7.1±0.0^{a}	12.4±1.8^{a}
Available P (mg/kg)	3.0±1.0^{a}	9.6±4.1^{a}	10.2±4.0^{a}	9.1±2.5^{a}	5.7±1.6^{a}	5.5±2.0^{a}
Available K (mg/kg)	159.8±14.7^{a}	169.7±28.0^{a}	225.0±14.6^{a}	251.2±19.7^{a}	198.0±23.5^{a}	196.8±17.0^{a}
Soil temperature (°C)	31.0±0.3^{a}	29.0±0.2^{a}	31.2±0.4^{a}	28.5±0.3^{a}	30.4±0.2^{a}	28.3±0.2^{a}
Soil moisture (%)	9.9±0.4^{a}	8.8±0.4^{a}	14.1±0.5^{a}	10.81±0.4^{a}	14.2±0.3^{a}	11.7±0.7^{a}
Organic matter (%)	0.6±0.1^{a}	0.8±0.2^{a}	0.6±0.1^{a}	1.0±0.2^{a}	0.4±0.1^{a}	0.9±0.3^{b}
Herbaceous biomass (g/m^2)	367.5±73.5^{a}	146.2±19.5^{b}	412.9±63.4^{a}	171.5±18.6^{b}	413.3±55.5^{a}	194.8±20.3^{b}
Herbaceous cover (%)	63.2±7.3^{a}	41.0±6.2^{a}	78.8±5.0^{a}	55.6±5.8^{a}	56.2±3.3^{a}	54.5±4.2^{a}
ECM infection (%)	n/a	n/a	47	0	77	0

n/a means not applicable

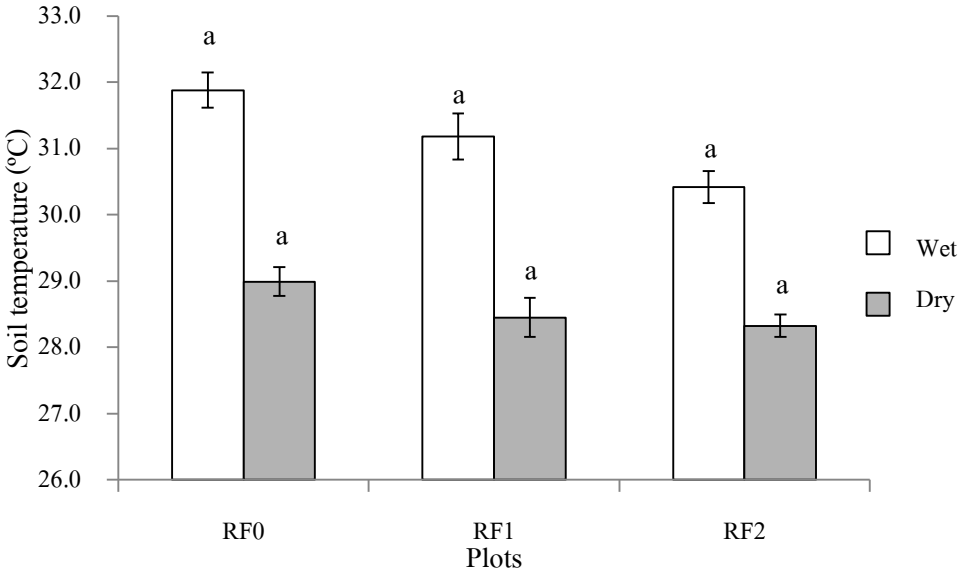


Figure 22 Soil temperature (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015. Same letter indicate no significant difference between the wet and dry seasons in each area (Independent samples t-test, $p \leq 0.05$).

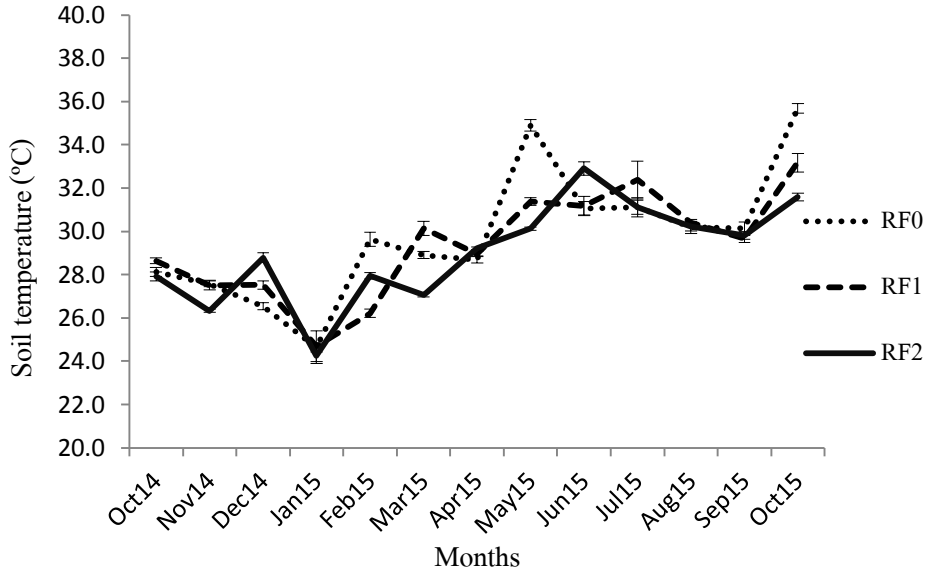


Figure 23 Soil temperature (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015.

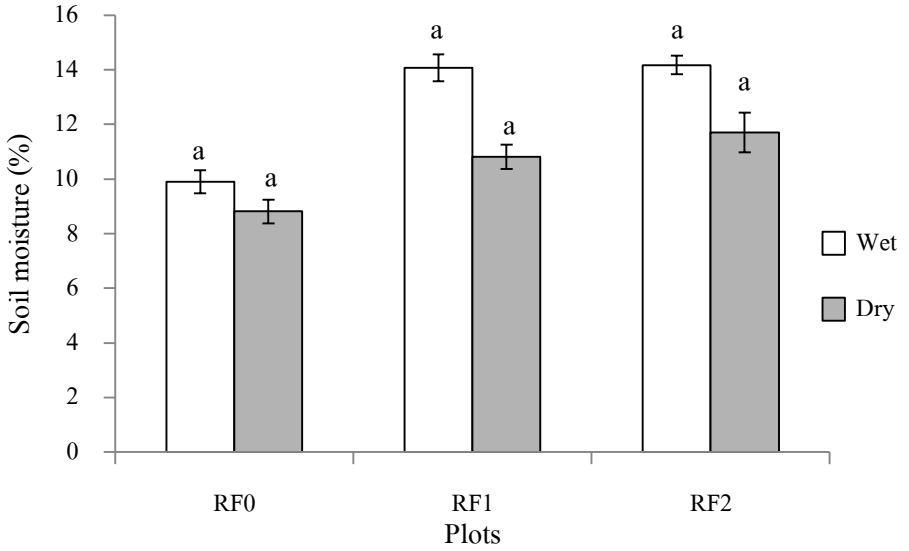


Figure 24 Soil moisture (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015. Same letter indicate no significant difference between the wet and dry seasons in each area (Independent samples t-test, $p \leq 0.05$).

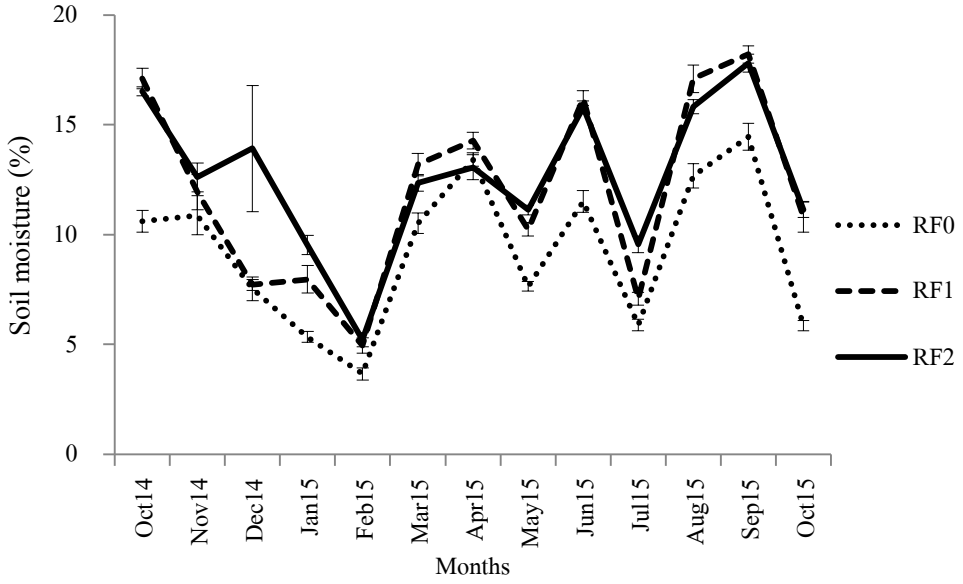


Figure 25 Soil moisture (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015.

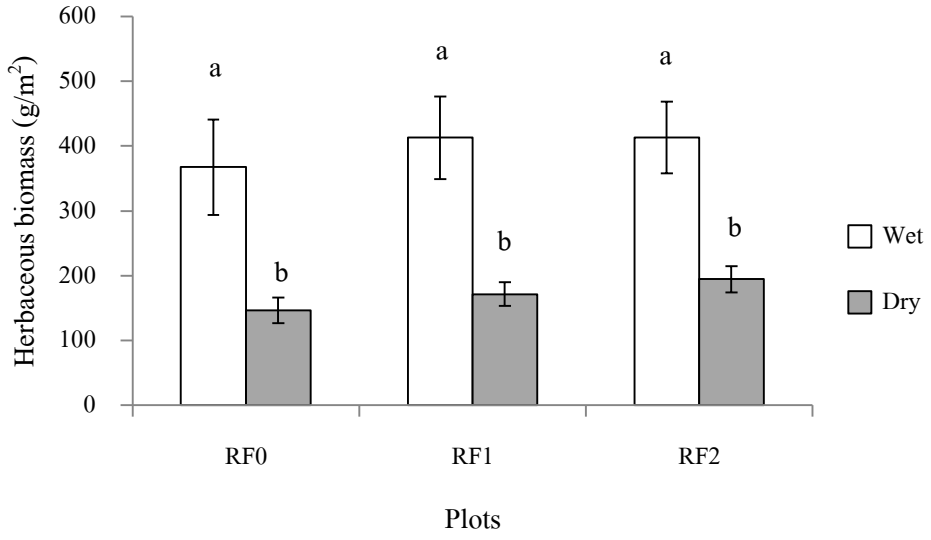


Figure 26 Herbaceous biomass (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015. Same letter indicate no significant difference between the wet and dry seasons in each area (Independent samples t-test, $p \leq 0.05$).

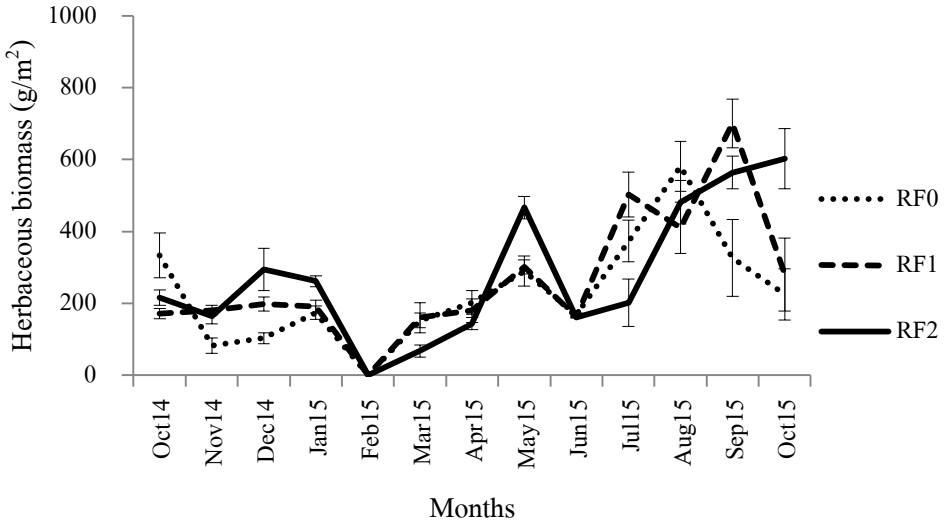


Figure 27 Herbaceous biomass (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015.

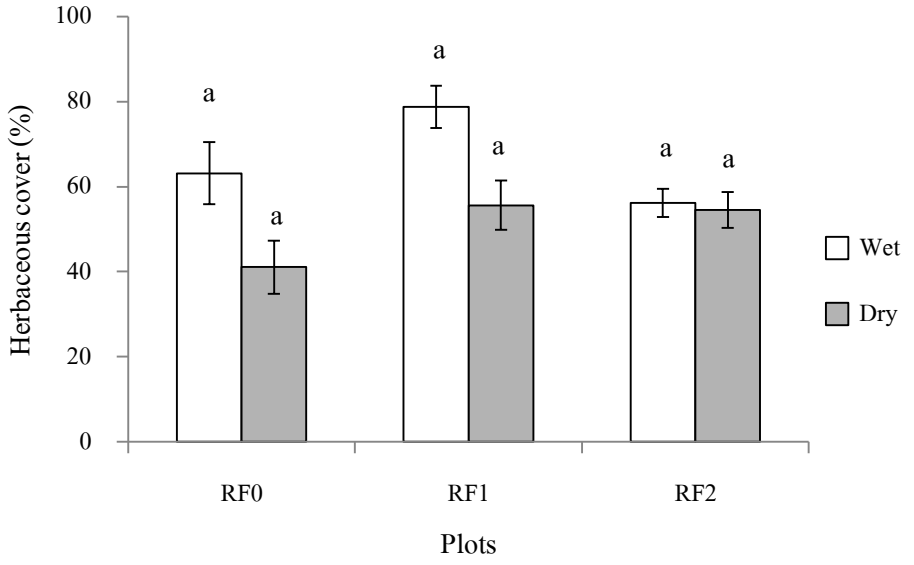


Figure 28 Herbaceous cover (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015. Same letter indicate no significant difference between the wet and dry seasons in each area (Independent samples t-test, $p \leq 0.05$).

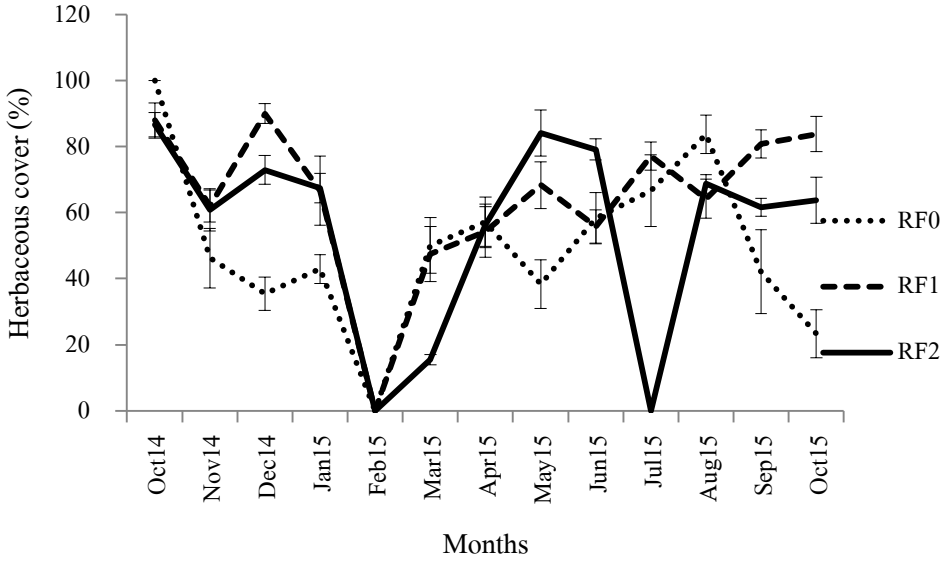


Figure 29 Herbaceous cover (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015.

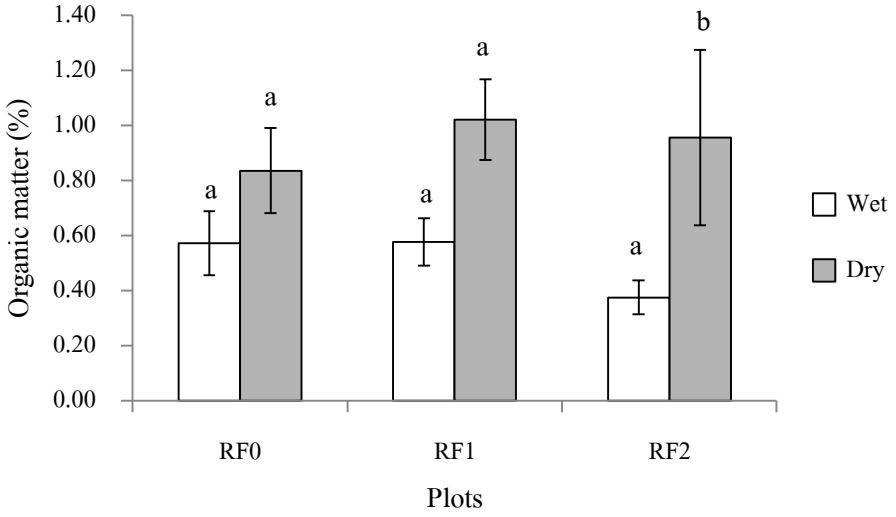


Figure 30 Organic matter (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015. Same letter indicate no significant difference between the wet and dry seasons in each area (Independent samples t-test, $p \leq 0.05$).

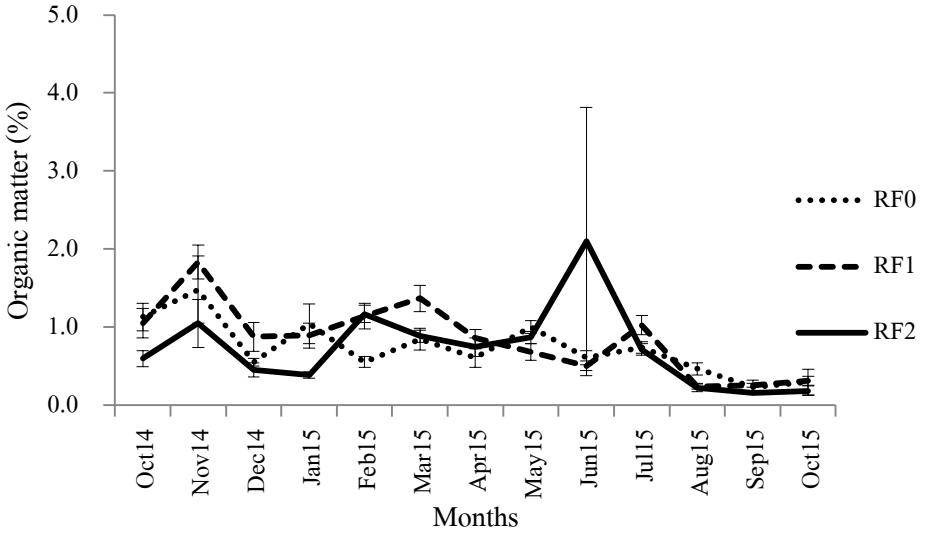


Figure 31 Organic matters (average ± SE) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) from October 2014 to October 2015.

4.2 Soil microarthropods

4.2.1 Abundance of soil microarthropods

1. Total soil microarthropods

The overall soil microarthropods found in all study areas from October 2014 to October 2015 belonged to nine groups, 29 families and 34 morphospecies (Figures 32 to 44 and Table 5). Soil microarthropods collected from the non-reforested area belonged to six groups, 24 families and 27 morphospecies. Nine major groups, 25 families and 29 morphospecies were found in the 1-year dipterocarpus reforestation area, and 27 families and 32 morphospecies were found in the 2-year dipterocarpus reforestation area. The total abundance of soil microarthropods was highest in the 2-year dipterocarpus reforestation area (3,596 ± 227 ind./m^2), followed by the 1-year reforestation area (2,989 ± 334 ind./m^2) and the non-reforested area (2,496 ± 361 ind./m^2). However, the abundance of soil microarthropods was not significantly different among three areas ($F = 1.988$, $df = 2, 73$, $p = 0.051$). Acari (74-83%) and Collembola (15-21%) were the most abundant groups in three areas (Figures 45, 46 and Table 6).

2. Acari

Acari were most abundant in the 2-year dipterocarpus reforestation area (2,080 ± 336 ind./m^2), followed by the 1-year reforestation area (2,292 ± 245 ind./m^2) and the non-reforested area (2,678 ± 331 ind./m^2). Four orders of Acari found in three areas were Oribatida (5 families), Prostigmata (5 families), Mesostigmata (3 families) and Astigmata (1 family). Oribatida were the most abundant group in the non-reforested area and the 2-year dipterocarpus reforestation area, while Mesostigmata were most abundant in the 1-year dipterocarpus reforestation area. Furthermore, the abundance of Mesostigmata was significantly different

between the non-reforested area and reforestation areas (F = 8.404, df = 2, 73, p = 0.001). (Figure 47 and Table 7).

3. Collembolans

Collembolans were highest in the 2-year dipterocarpus reforestation area, the 1-year reforestation area and the non-reforested area, respectively, but not significantly different among three areas. Collembolans found consisted of four families; Isotomidae, Entomobryidae, Sminthuridae and Hypogastruridae. Family Isotomidae were most abundant in three areas, followed by Entomobryidae, Sminthuridae and Hypogastruridae (Figure 48 and Table 7).

4. Other soil microarthropods

Other groups of soil microarthropods were found much rarer, with only 0.01-2.2% of the total abundance. These rare groups included Symphyla, Protura, Diplura, Araneae, Spirobolida, Geophilomorpha and Pseudoscorpionida. Symphyla, Protura and Spirobolida were only found in the reforestation areas. Two families of Diplura were found: Japygidae and Camphosidae. They were most abundant in reforestation areas and were significantly different between non-reforested area and reforestation areas (F = 9.733, df = 2, 73, p < 0.001). The abundance of Araneae in three areas was not significantly different. However, Family Corinidae of Araneae was the most abundant group in three areas when compared with other familes of Araneae. Pseudoscoripionida were most abundant in the non-reforested area (F = 12.539, df = 2, 21, p < 0.001). Furthermore, Geophilomorpha were highest abundant in the 1-year dipterocarpus reforestation area (F= 3.830, df = 2, 73, p = 0.026) (Table 6 and 7).

5. Comparisons of abundance between the wet and dry seasons

The abundance of soil microarthropods was significantly different between seasons in the 1-year dipterocarpus reforestation area (t = 2.530, p = 0.043). (Table 8). Acari (t = 2.670, p = 0.030) and Geophilomorpha (t = 2.600, p = 0.025) in

the wet season was higher than the dry season but the significant difference between seasons was only found in the reforested areas at 1-year. However, Symphyla were the most abundant in the wet season and were significant different between seasons in the 1-year ($t = 3.697$, $p = 0.004$) and 2-year ($t = 3.148$, $p = 0.026$) dipterocarpus reforestation areas (Figure 49 and Table 9).

6. Morphospecies accumulation curves

Morphospecies accumulation curves (Figure 50) showed decreased rates of species accrual with increased sampling effort. The morphospecies accumulation curves for the number of found morphospecies was on the increase, showing that there are probably more species not collected.

Table 5 Number of morphospecies of soil microarthropods in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

Class/order	Suborder	Family	Number of morphospecies		
			RF0	RF1	RF2
Acari	Mesostigmata	Digamasellidae	1	1	1
		Rhodacaridae	1	1	1
		Unknown 1	1	1	1
	Prostigmata	Cunaxidae	3	3	3
		Trombididae	1	1	2
		Bdellidae	1	1	1
		Smaridiidae	1	0	0
		Caeculidae	0	0	1
	Astigmata	Acaridae	1	2	2
	Oribatida	Galumnidae	2	2	2
		Phthiracaridae	1	1	1
		Eremulidae	1	1	1
		Lohmanniidae	1	1	1
		Trhypochthoniidae	1	1	1
Araneae		Corinnidae	1	1	1
		Unknown 2	0	1	1
		Gnaphosidae	1	0	1
		Lycosidae	1	0	1
Pseudoscorpionida		Unknown 3	1	1	1
Collembola		Isotomidae	1	1	1
		Hypogastruridae	1	1	1
		Entomobryidae	1	1	1
		Sminthuridae	1	1	1
Diplura		Japygidae	1	1	1
		Campodeida	1	1	0
Protura		Unknown 4	0	1	1
Symphyla		Scutigerellidae	0	1	1
Geophilomorpha		Unknown 5	1	1	1
Spirobolida		Unknown 6	0	1	1
	Total		27	29	32

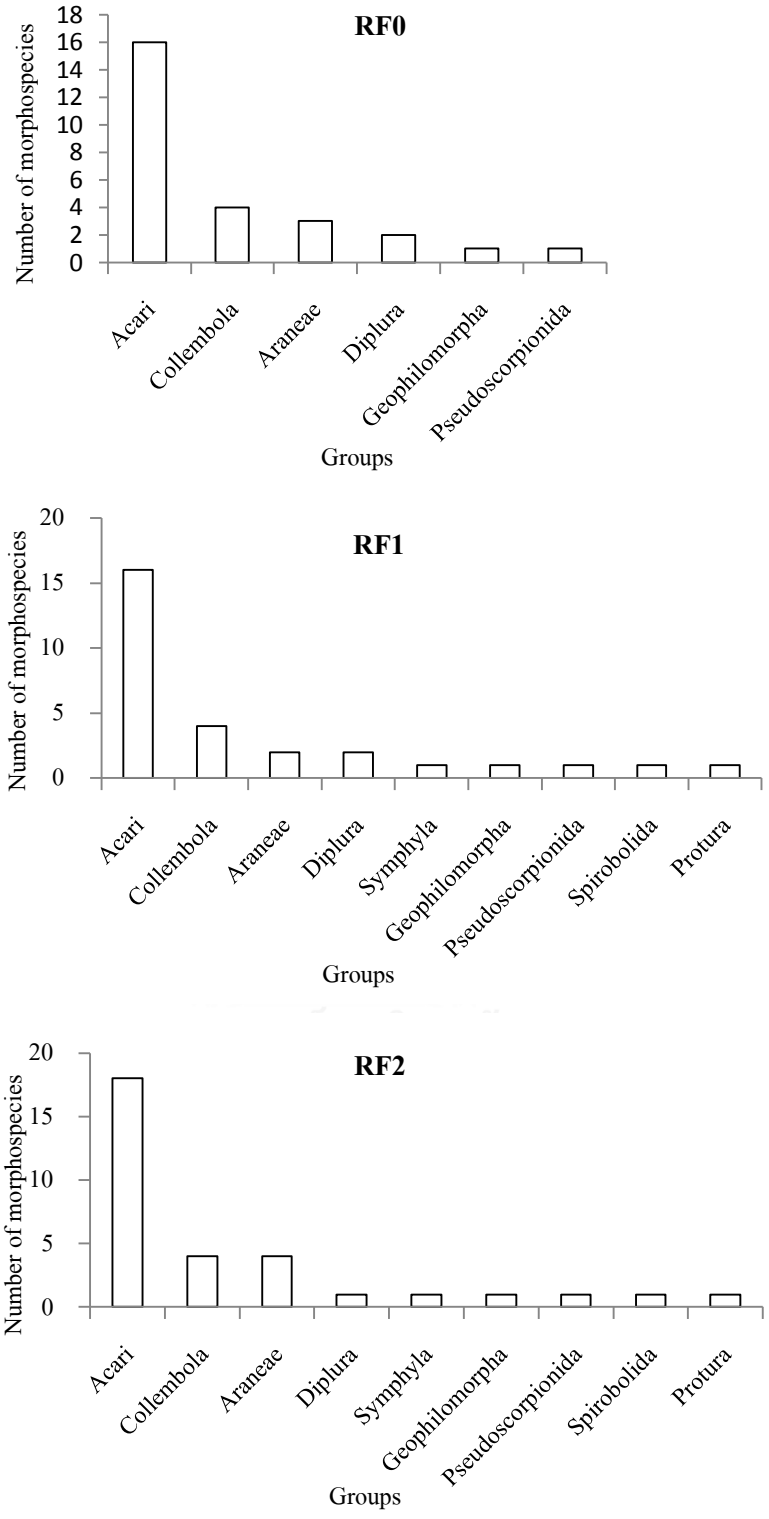


Figure 32 The number of morphospecies in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

Family Digamasellidae

Family Rhodacaridae

Unknown 1

Figure 33 Mesostigmata found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

Family Cunaxidae

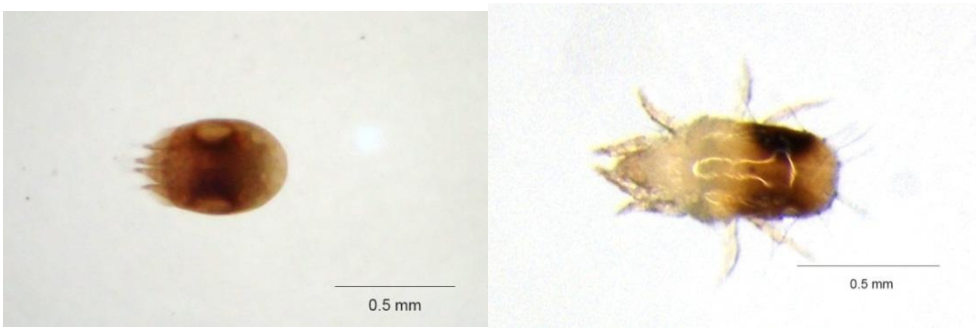
Family Bdellidae

Family Trombidiidae

Family Caeculidae

Family Smaridiidae

Figure 34 Prostigmata found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

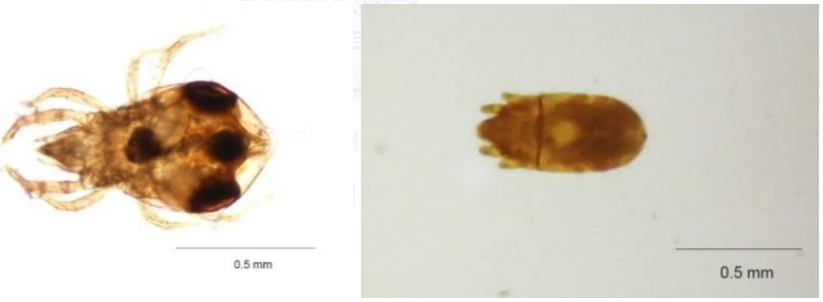


Family Acaridae

Figure 35 Astigmata found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

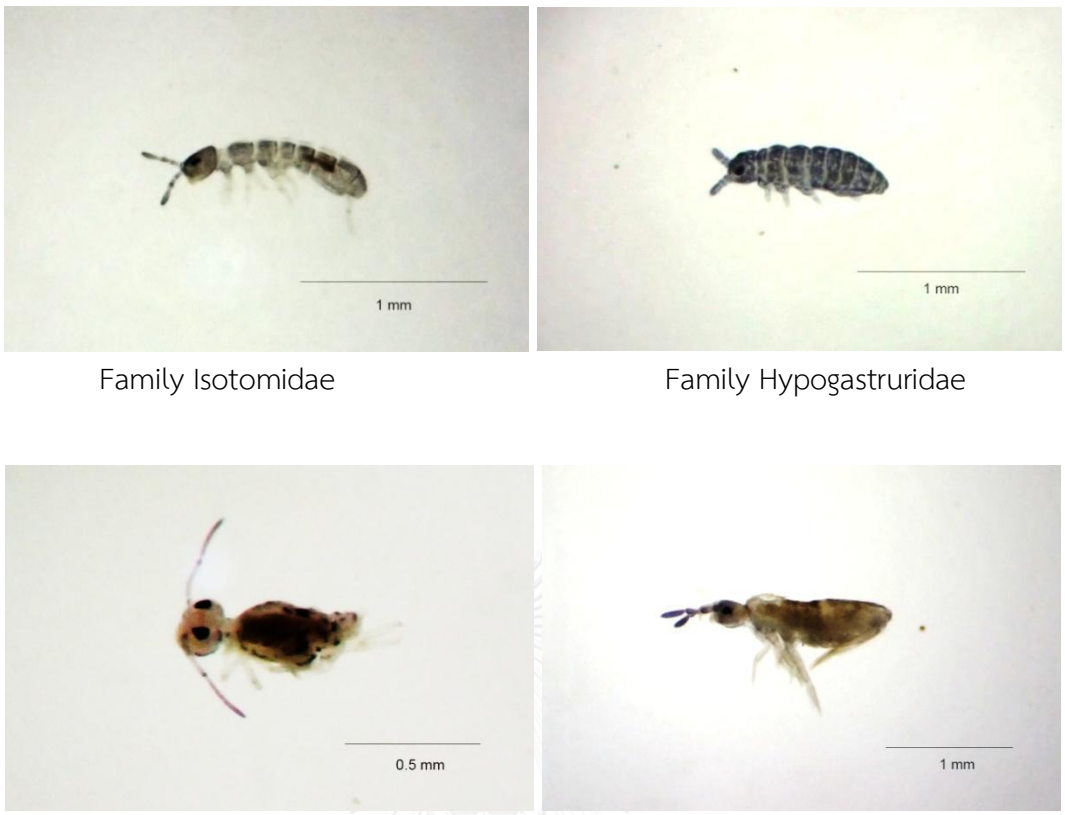
Family Galumnidae

Family Phthiracaridae Family Eremulidae



Family Trhypochthoniidae Family Lohmanniidae

Figure 36 Oribatida found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015



Family Isotomidae Family Hypogastruridae

Family Sminthuridae Family Entomobryidae

Figure 37 Collembola found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

Family Corinnidae

Unknown 2

Family Gnaphosidae

Family Lycosidae

Figure 38 Araneae found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

Family Japygidae

Family Campodeidae

Figure 39 Diplura found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

Figure 40 Symphyla found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

Figure 41 Geophilomorpha found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

Figure 42 Pseudoscorpionada found in the dipterocarpus reforestation areas at the 1-year and 2-year stages and the non-reforested area from October 2014 to October 2015

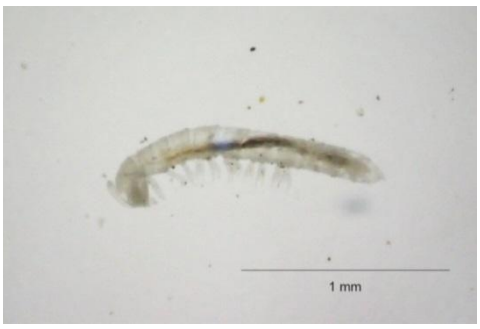


Figure 43 Spirobolida found in the dipterocarpus reforestation areas at the 1-year and 2-year stages from October 2014 to October 2015

Figure 44 Protura found in the dipterocarpus reforestation areas at the 1-year and 2-year stages from October 2014 to October 2015

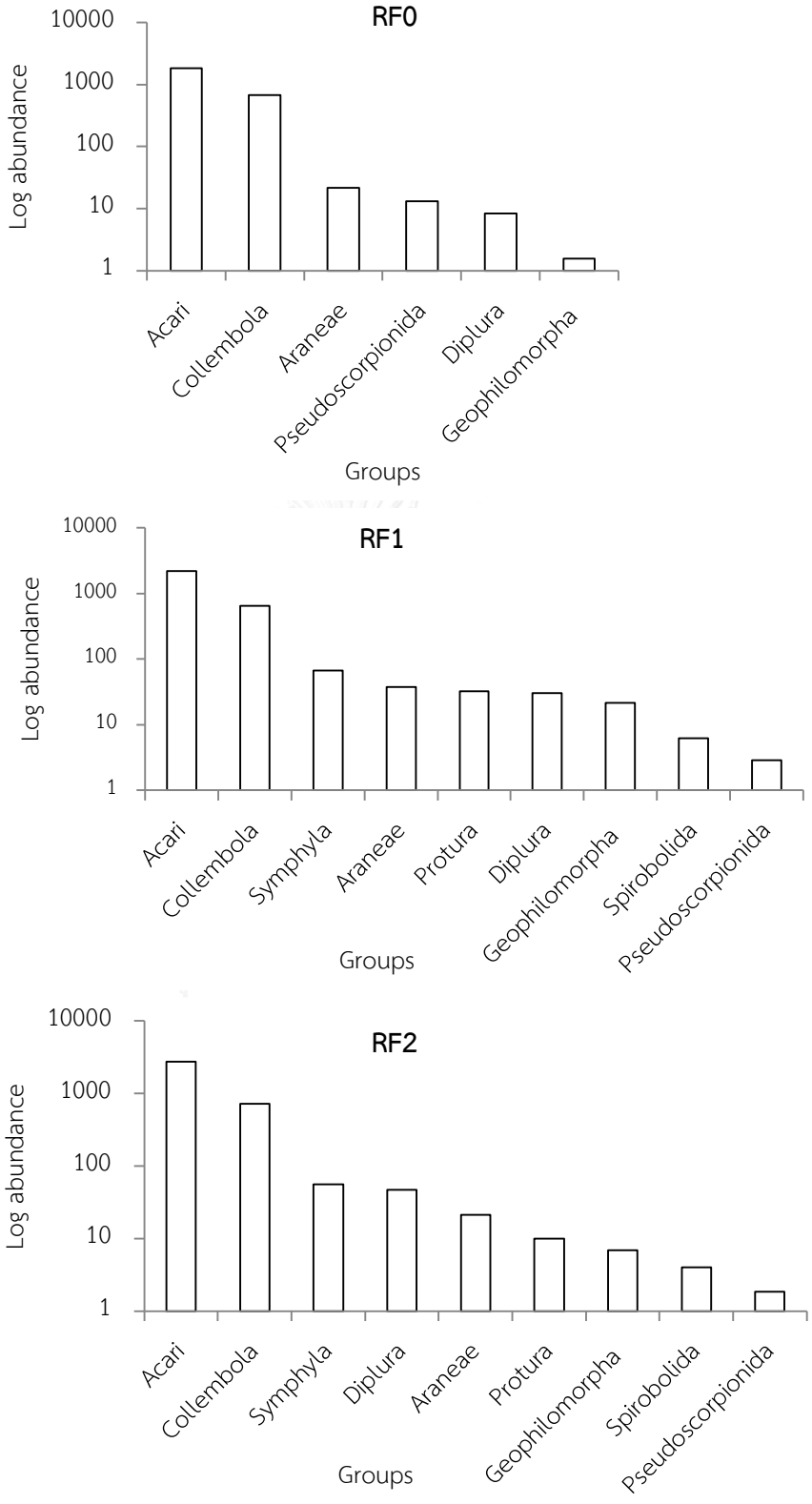


Figure 45 The abundance in each group in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0)

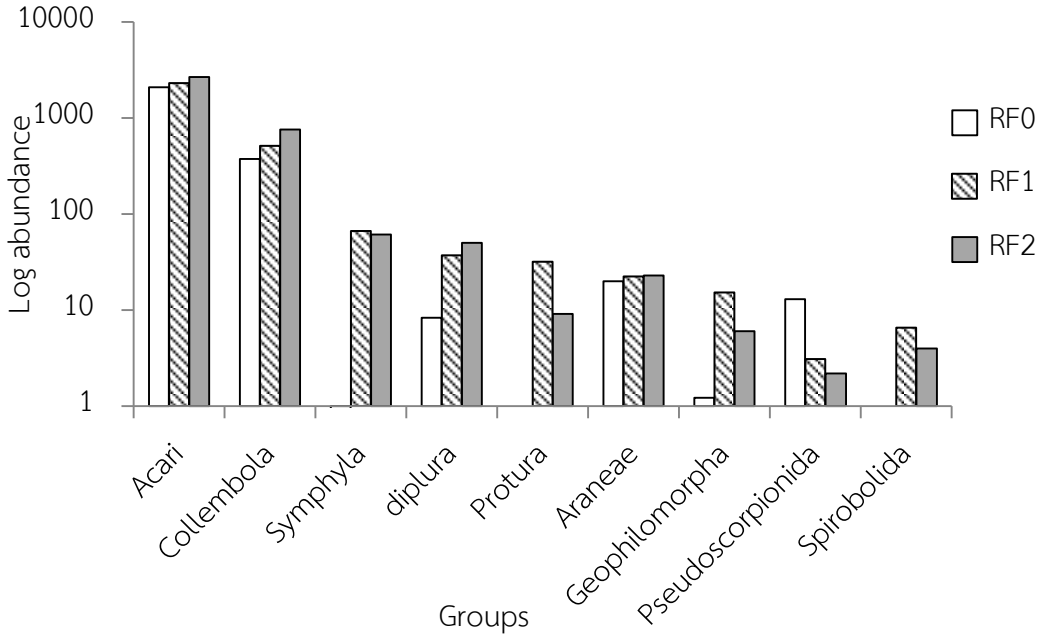


Figure 46 The abundance in soil microarthropod groups in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0)

Table 6 Abundance of soil microarthropods in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0). P-value obtained from ANOVA with LSD. Superscript letter in the same row indicate no significant difference at $p \leq 0.05$

Groups	RF0		RF1		RF2		*P*
	Abundance (ind./m^2)	%	Abundance (ind./m^2)	%	Abundance (ind./m^2)	%	
Acari	2080 ± 336^{a}	83.1	2292 ± 245^{a}	76.7	2678 ± 331^{a}	74.5	0.38
Collembola	373 ± 116^{a}	14.9	514 ± 92^{a}	17.2	763 ± 246^{a}	21.2	0.26
Symphyla	0 ± 0^{a}	0.0	67 ± 17^{b}	2.2	61 ± 14^{b}	1.7	0.001
Diplura	8 ± 4^{a}	0.3	37 ± 8^{b}	1.2	50 ± 7^{b}	1.4	0.00
Protura	0 ± 0^{a}	0.0	32 ± 16^{b}	1.1	9 ± 4^{ab}	0.3	0.03
Araneae	20 ± 4^{a}	0.8	22 ± 4^{a}	0.7	23 ± 4^{a}	0.6	0.87
Geophilomorpha	1 ± 1^{a}	0.0	15 ± 6^{b}	0.5	6 ± 2^{ab}	0.2	0.03
Pseudoscorpionida	13 ± 3^{a}	0.5	3 ± 1^{b}	0.1	2 ± 1^{b}	0.1	0.00
Spirobolida	0 ± 0^{a}	0.0	7 ± 5^{a}	0.2	4 ± 2^{a}	0.1	0.31
Total	2496 ± 360.5^{a}	100	2989 ± 333.5^{a}	100	3596 ± 227.3^{a}	100	0.14

Table 7 Abundance (average ± SE) of soil microarthropods (individuals/m^2) by family in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0)

No.	Order	Families	RF0		RF1		RF2	
			Abundance±SE	%	Abundance±SE	%	Abundance±SE	%
1	Mesostigmata	Digamasellidae	85±18	3.4	284±58	9.5	163±38	4.5
2		Rhodacaridae	14±7	0.6	184±47	6.1	156±52	4.3
3		Unknown 1	327±47	13.1	633±88	21.2	662±102	18.4
4	Prostigmata	Cunaxidae	71±17	2.9	197±39	6.6	52±11	1.4
5		Trombididae	88±18	3.5	66±25	2.2	195±55	5.4
6		Bdellidae	5±3	0.2	1±1	0	2±1	0
7		Smaridiidae	0.2±0.2	0	0	0	0	0
8		Caeculidae	0	0	0	0	1±0.1	0
9	Astigmata	Acaridae	55±14	2.2	113±38	3.8	124±43	3.5

Table 8 (Cont.). Abundance (average ± SE) of soil microarthropods (individuals/m^2) by family in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0)

No.	Order	Families	RF0		RF1		RF2	
			Abundance±SE	%	Abundance±SE	%	Abundance±SE	%
10	Oribatida	Galumnidae	983±226	39.4	616±103	20.6	807±102	22.4
11		Phthiracaridae	17±7	0.7	12±5	0.4	22±6	0.6
12		Eremulidae	79±22	3.2	83±24	2.8	301±72	8.4
13		Lohmanniidae	6±2	0.2	31±15	1.0	35±10	1.0
14		Trhypochthoniidae	351±94	14.0	74±26	2.5	160±36	4.5
15	Araneae	Corinnidae	16±4	0.6	20±5	0.7	13±4	0.3
16		Unknown 2	0	0	3±1	0.1	2±1	0
17		Gnaphosidae	2±1	0.1	0	0	5±3	0.1
18		Lycosidae	2±2	0.1	0	0	4±2	0.1
19	Pseudoscorpionida	Unknown 3	13±3	0.5	3±1	0.1	2±1	0.1

Table 9 (Cont.). Abundance (average ± SE) of soil microarthropods (individuals/m^2) by family in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0)

No.	Order	Families	RF0		RF1		RF2	
			Abundance±SE	%	Abundance±SE	%	Abundance±SE	%
20	Collembola	Isotomidae	155±94	6.2	244±74	8.2	478±240	13.3
21		Hypogastruridae	89±22	3.6	53±14	1.8	80±19	2.2
22		Entomobryidae	66±15	2.7	153±28	5.1	131±21	3.6
23		Sminthuridae	62±14	2.5	64±13	2.1	74±23	2.1
24	Diplura	Japygidae	7±3	0.3	37±8	1.2	50±7	1.4
25		Campodeida	1±0	0	0	0	0	0
26	Protura	Unknown 4	0	0	32±16	1.1	9±4	0.3
27	Symphyla	Scutigerellidae	0	0	67±17	2.2	61±14	1.7
28	Geophilomorpha	Unknown 5	1±1	0	15±6	0.5	6±2	0.2
29	Spirobolida	Unknown 6	0	0	7±5	0.2	4±2	0.1
Total			2497±361	100	2990±334	100	3596±227	100

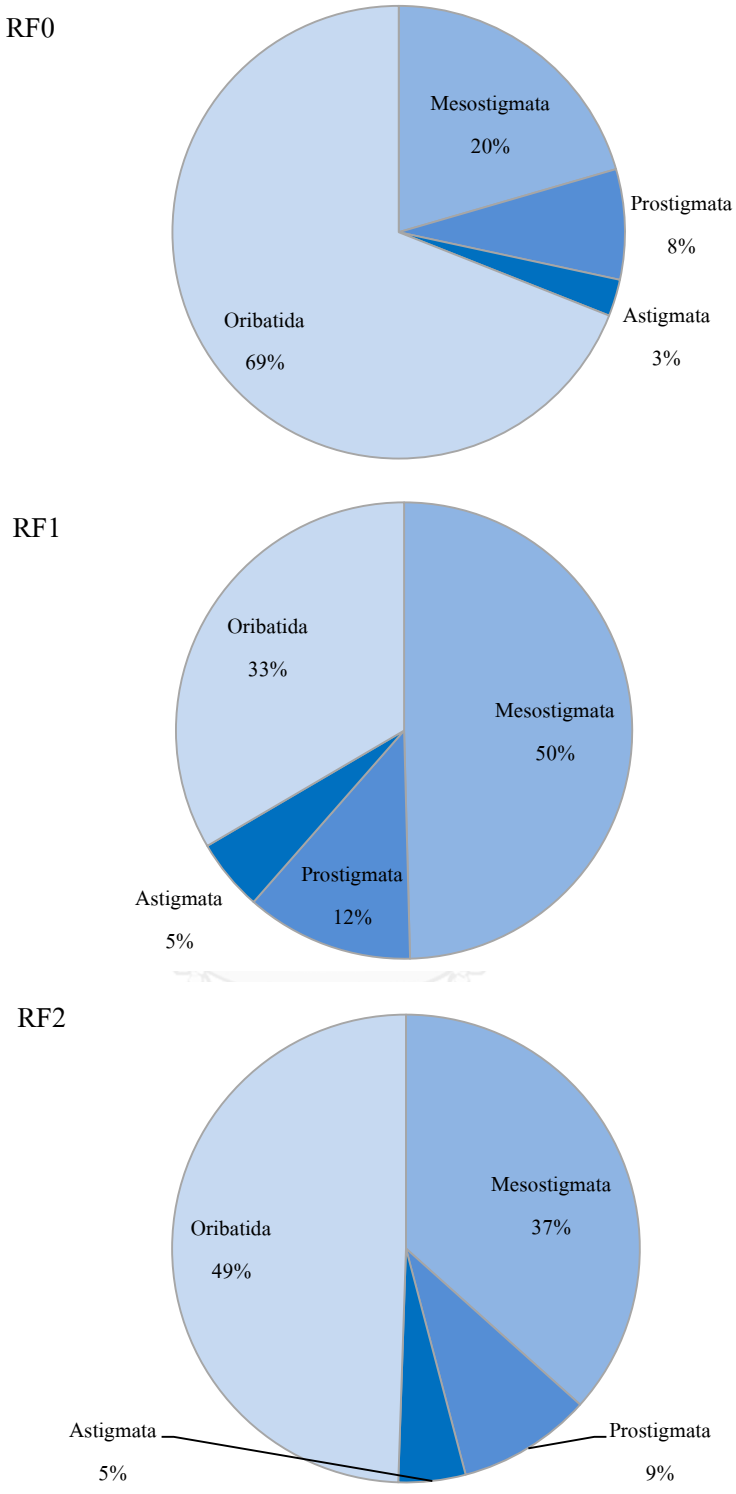


Figure 47 Relative abundance of different suborders of Acari in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested plot (RF0).

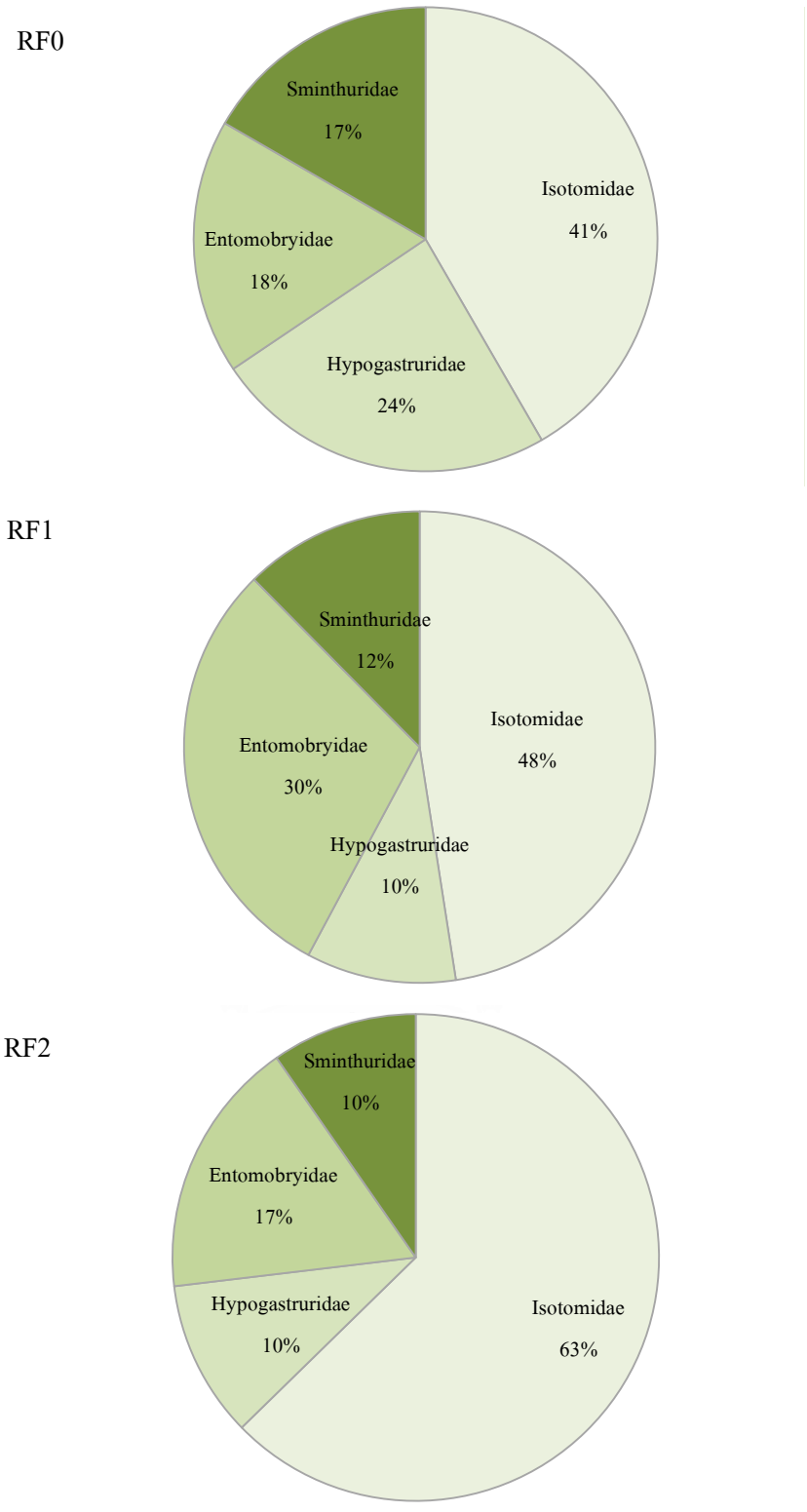


Figure 48 Relative abundance of different families of Collembola in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested plot (RF0).

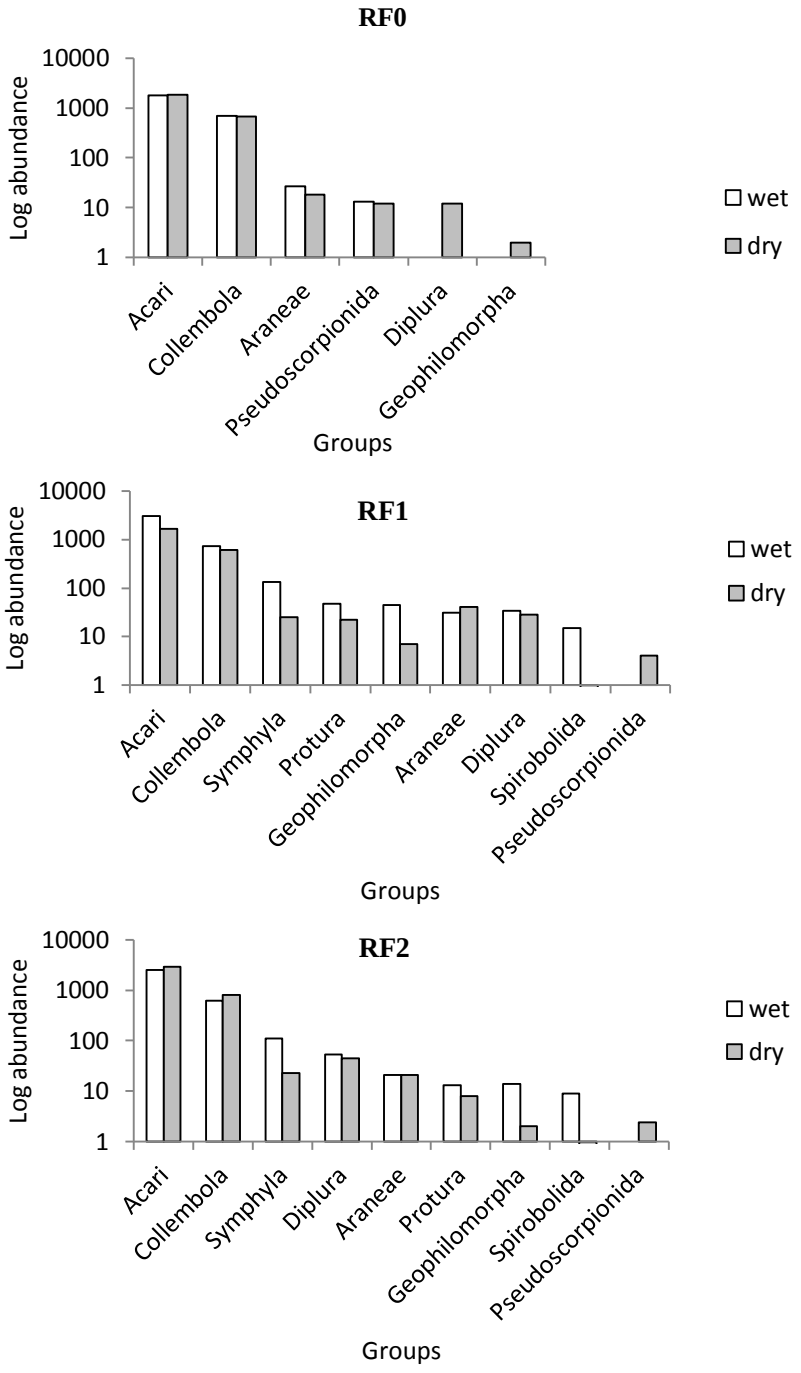


Figure 49 Log-abundance of different groups of soil microarthropods in the dipterocarpus reforestation areas between seasons at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0). White and gray bars represent wet and dry seasons, respectively. Microarthropod groups are arranged from the most abundant to the least abundant in each area.

Table 10 Total abundance of soil microarthropods (individual/m^2) between wet and dry seasons (Independent samples t-test, $p \leq 0.05$) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0) and abundance of soil microarthropods between areas in each season (ANOVA with LSD, $p \leq 0.05$).

Season	RF0	RF1	RF2	p-value
Wet	2,487±499	4,080±635	3,410±602	0.203
Dry	2,500±491	2,009±264	3,712±652	0.106
p-value	0.986	0.024	0.755	

Table 11 Total abundance of major groups of soil microarthropods between seasons in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0). Different superscript letter in the same row indicate significant difference among seasons in each area (Independent samples t-test, $p \leq 0.05$).

Groups	Abundance (ind./m^2)					
	RF0		RF1		RF2	
	wet	dry	wet	dry	wet	dry
Acari	1815±187^a	1831±475^a	3081±444^a	1650±299^b	2529±707^a	2921±432^a
Collembola	687±279^a	669±422^a	725±251^a	608±245^a	617±156^a	798±351^a
Symphyla	0^a	0^a	135±32^a	25±13^b	109±26^a	23±9^b
Diplura	1±0.5^a	12±6^a	34±17^a	28±12^a	53±18^a	44±10^a
Protura	0^a	0^a	48±8^a	22±11^a	13±8^a	8±6^a
Araneae	27±7^a	18±5^a	31±7^a	41±22^a	21±7^a	21±7^a
Geophilomorpha	1±1^a	2±1^a	45±17^a	7±5^b	14±8^a	2±2^a
Pseudoscorpionida	13±6^a	12±3^a	1±1^a	4±1.5^a	1±0.6^a	2.4±1.6^a
Spirobolida	0^a	0^a	15±11^a	0.8±0.8^a	9±6^a	0.8±0.5^a

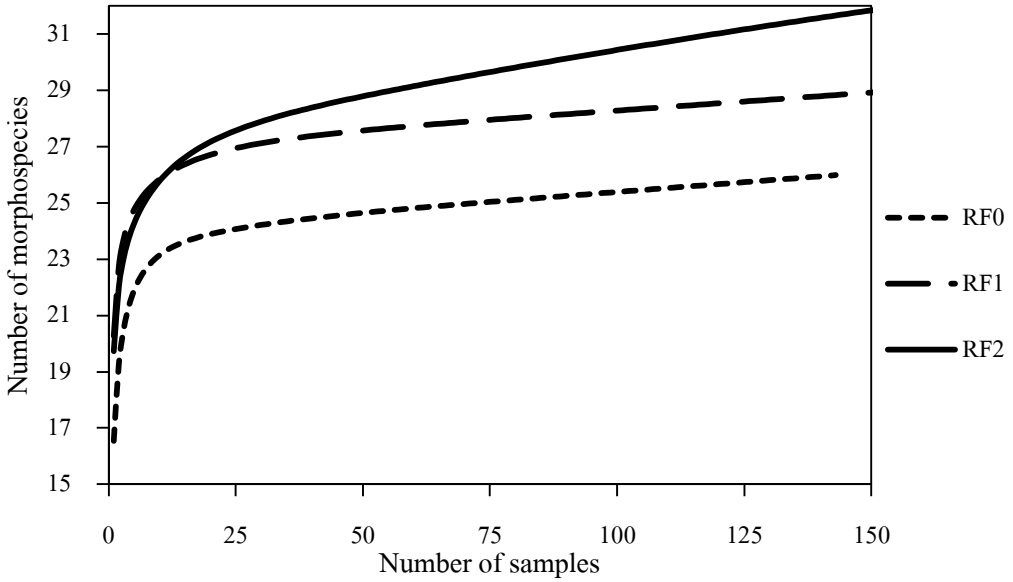


Figure 50 Morphospecies accumulation curve (Coleman rarefaction method) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

4.2.2 Diversity indices and similarity index of soil microarthropods

Shannon-Wiener's diversity index, Margalef's index and evenness index were highest in the 2-year dipterocarpus reforestation area, while Simpson's index was highest in the non-reforested area. However, the diversity indices were not significantly different between the three areas (Table 11).

Furthermore, the Shannon's diversity index, Margalef's index and evenness index were higher in the wet season, while the Simpson's index was higher in the dry season. The Shannon's diversity index was significantly different between wet and dry seasons in the non-reforested area ($t = 2.335$, $p = 0.046$) (Table 11). Sorensen's index based on morphospecies yielded very high value of 85 to 92 % between the study areas, suggesting very high similarity or overlap of soil microarthropod communities (Table 12).

Table 12 Morphospecies richness (Margalef Index), Simpson diversity index, Shannon diversity index and Shannon-Wiener's Evenness Index of soil microarthropods communities (base on morphospecies) in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0). (ANOVA with LSD, $p \leq 0.05$).

	Richness (Margalef)	Simpson	Shannon	Evenness
RF0	1.94±0.08	0.21±0.01	0.85±0.03	0.31±0.01
RF1	2.12±0.11	0.17±0.01	0.92±0.03	0.32±0.01
RF2	2.18±0.09	0.17±0.01	0.93±0.03	0.32±0.01
p-value	0.196	0.190	1.22	0.638

Table 13 Morphospecies richness (Margalef Index), Simpson diversity index, Shannon diversity index and Shannon-Wiener's Evenness Index of soil microarthropods communities between wet and dry seasons in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0). (Independent samples t-test, $p \leq 0.05$).

	Richness		*p*	Simpson		*p*	Shannon		*p*	Evenness		*p*
	wet	dry		wet	dry		wet	dry		wet	dry	
RF0	2.12	1.85	0.12	0.17	0.22	0.07	0.92	0.82	0.03	0.33	0.31	0.31
RF1	2.29	2.01	0.22	0.16	0.18	0.43	0.96	0.90	0.27	0.32	0.33	0.94
RF2	2.32	2.08	0.24	0.16	0.18	0.43	0.99	0.89	0.07	0.33	0.31	0.06

Table 14 Sorensen's similarity index for soil microarthopods base on morphospecies in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

	RF0	RF1	RF2
RF0	1	-	-
RF1	0.86	1	-
RF2	0.85	0.92	1

4.2.3 Guilds of soil microarthropods

Soil microarthropods were divided into detrito-fungivorous, detritivorous, and predatory guilds. Detrito-fungivorous microarthropods were the most abundant guild in all three areas, followed by predatory microarthropods (Figure 51). Three, 5 and 4 morphospecies of detritivorous microarthropods were found in the non-reforested area, the 1-year and 2-year dipterocarpus reforestation area, respectively. Ten, 11 and 11 morphospecies of detrito-fungivorous microarthropods were found in the non-reforested area, the 1-year and 2-year dipterocarpus reforestation area, respectively. Fifteen, 13 and 17 morphospecies of predatory microarthropods were found in the non-reforested area, the 1-year and 2-year dipterocarpus reforestation area, respectively (Figure 52).

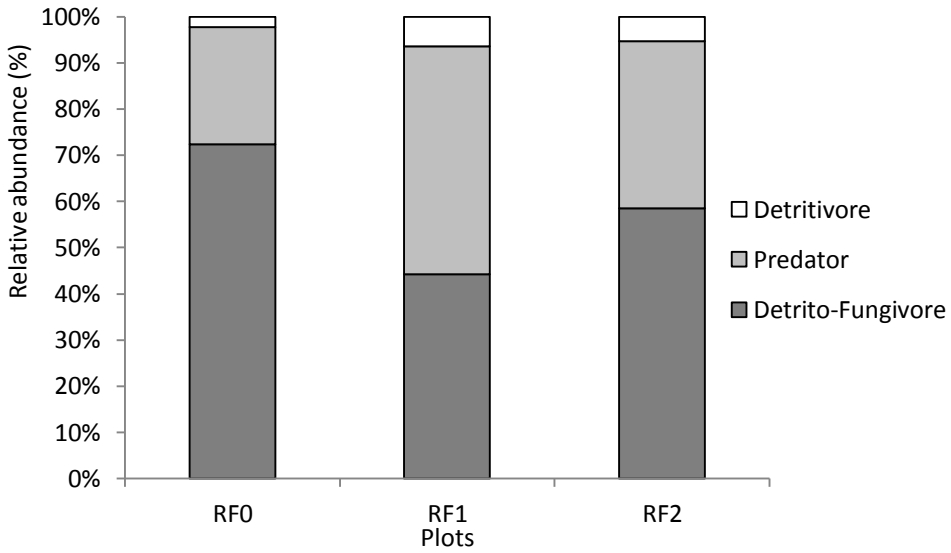


Figure 51 Relative abundance of guilds in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested plot (RF0).

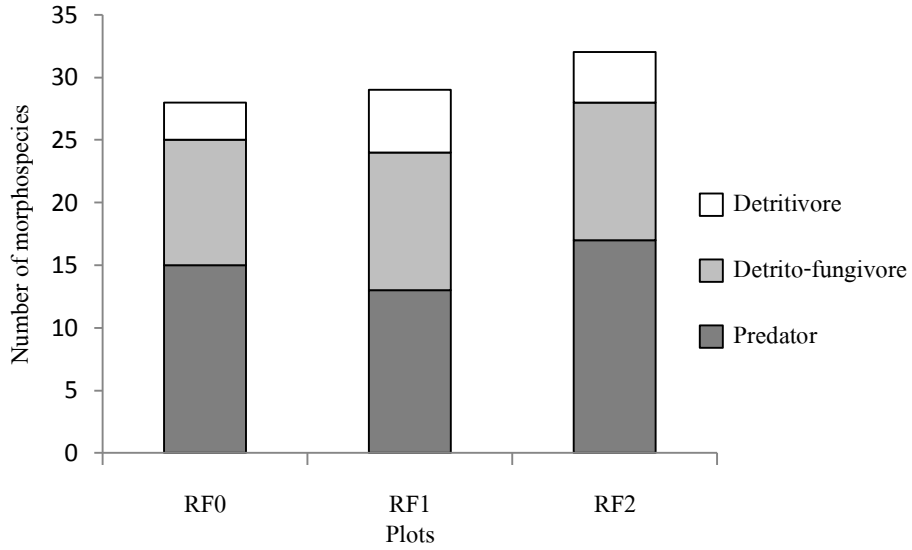


Figure 52 Number of morphospecies of guilds in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested plot (RF0).

Predators

There were six groups (Mesostigmata, Prostigmata, Geophilomorpha, Diplura (Japygidae), Araneae and Pseudoscorpionida) 15 families and 19 morphospecies of predatory microarthropods in the three study areas. Predatory soil microarthropods were found to be most abundant in the dipterocarpus reforestation areas. The difference was significant between non-reforested area and reforestation areas ($F = 10.019$, $df = 2, 73$, $p < 0.001$) while not significant between the wet and dry seasons. Mesostigmata was the dominant group of predatory soil microarthropods in all three areas, followed by Prostigmata. The abundance of Mesostigmata, Diplura (Japygidae), Pseudoscorpionida and Geophilomorpha were different between the non-reforested area and reforestation areas. Pseudoscorpionida were most abundant in the non-reforested area while Geophilomorpha were most abundant in the reforestation areas (Table 13 and Figure 53a).

Detritivores

Detritivorous microarthropods consisted of four groups, namely Astigmata, Diplura (Family Campodeidae), Spirobolida and Symphyla. Detritivorous microarthropods were found to be more abundant in the reforestation areas than the non-reforested area and ($F = 4.785$, $df = 2, 73$, $p = 0.011$). However, their abundance was not significantly different between the wet and dry seasons. Astigmata were the dominant group in the detritivorous group (Table 4.11). Furthermore, Symphyla were most abundant in the dipterocarpus reforestation areas ($F = 7.730$, $df = 2, 73$, $p = 0.001$) (Table 13 and Figure 53b).

Detrito-fungivores

Detrito-fungivorous microarthropods were the most abundant group among all guilds. The majority of the detrito-fungivorous microarthropods were from three orders (Oribatida, Collembola and Protura) and 10 families. However, the abundance of detrito-fungivorous microarthropods was not significantly different between three areas. Oribatida (Family Galumnidae) were most abundant in three areas, followed by Collembola (Family Isotomidae). Oribatida ($F = 2.957$, $df = 2, 73$, $p = 0.028$) and Protura ($F = 2.777$, $df = 2, 73$, $p = 0.026$) were significantly different between the non-reforested area and the dipterocarpus reforestation areas at the 1-year. Moreover, the abundance levels of detrito-fungivorous microarthropods were significantly different between wet and dry seasons in and the dipterocarpus reforestation areas at the 1-year ($t = 3.414$, $p = 0.002$). (Table 13 and Figure 53c).

Table 15 Abundance of soil microarthropods in each guild in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0), ANOVA with LSD. Same superscript letters means no significant difference at $p \leq 0.05$

Guilds	Order	Family	Individual / m^2 (%)			*p*-value
			RF0	RF1	RF2	
Predator			**631**[a]	**1442**[b]	**1312**[b]	**<0.001**
	Mesostigmata		426[a]	1101[b]	981[b]	0.010
		Digamasellidae	85 (13.5)	284 (19.7)	163 (12.6)	
		Rhodacaridae	14 (2.2)	184 (12.8)	156 (12.0)	
		Unknown 1	327 (51.8)	633 (43.9)	662 (51.0)	
	Prostigmata		164[a]	264[a]	250[a]	0.255
		Cunaxidae	71 (11.3)	197 (13.6)	52 (4.0)	
		Bdellidae	5 (0.8)	1 (0.1)	2 (0.1)	
		Smaridiidae	0.2 (0.0)	0 (0.0)	0 (0.0)	
		Trombididae	88 (13.9)	66 (4.6)	195 (15.0)	
		Caeculidae	0 (0.0)	0 (0.0)	1 (0.0)	
	Araneae		20[a]	22[a]	23[a]	0.870
		Corinnidae	16 (2.6)	20 (1.4)	13 (1.0)	
		Unknown 2	0 (0.0)	3 (0.2)	2 (0.1)	
		Gnaphosidae	2 (0.3)	0 (0.0)	5 (0.4)	
		Lycosidae	2 (0.3)	0 (0.0)	4 (0.3)	
	Pseudoscorpionida	Unknown 3	13 (2.1)[a]	3 (0.2)[b]	2 (0.2)[b]	<0.001
	Diplura	Japygidae	7 (1.2)[a]	37 (2.6)[b]	50 (3.8)[b]	<0.001
	Geophilomorpha	Unknown 4	1 (0.2)[a]	15 (1.1)[b]	6 (0.5)[ab]	0.030
Detritivore			**56**[a]	**187**[b]	**189**[b]	**0.011**
	Astigmata	Acaridae	55 (97.7)[a]	113 (60.8)[a]	124 (65.3)[a]	0.336
	Diplura	Campodeidae	1 (1.5)[a]	0 (0.1)[ab]	0 (0.0)[b]	0.470
	Spirobolida	Unknown 5	0 (0.0)[a]	7 (3.5)[a]	4 (2.1)[a]	0.310
	Symphyla	Scutigerellidae	0 (0.0)[a]	67 (35.9)[b]	61 (32.3)[b]	0.001
Detrito-Fungivore			**1811**[a]	**1362**[a]	**2069**[a]	**0.614**
	Collembola		373[a]	514[a]	763[a]	0.260
		Isotomidae	155 (8.6)	244 (19.0)	478 (22.8)	
		Hypogastruridae	89 (4.9)	53 (4.1)	80 (3.8)	
		Entomobryidae	66 (3.7)	153 (11.9)	131 (6.3)	
		Sminthuridae	62 (3.4)	64 (5.0)	74 (3.5)	
	Protura	Unknown 6	0 (0.0)[a]	32 (2.5)[b]	9 (0.4)[ab]	0.030
	Oribatida		1436[a]	816[b]	1324[ab]	0.050
		Galumnidae	983 (54.3)	616 (47.8)	807 (38.5)	
		Phthiracaridae	17 (0.9)	12 (0.9)	22 (1.0)	
		Eremulidae	79 (4.4)	83 (6.4)	301 (14.4)	
		Lohmanniidae	6 (0.3)	31 (2.4)	35 (1.7)	
		Trhypochthoniidae	351 (19.4)	74 (5.8)	160 (7.6)	

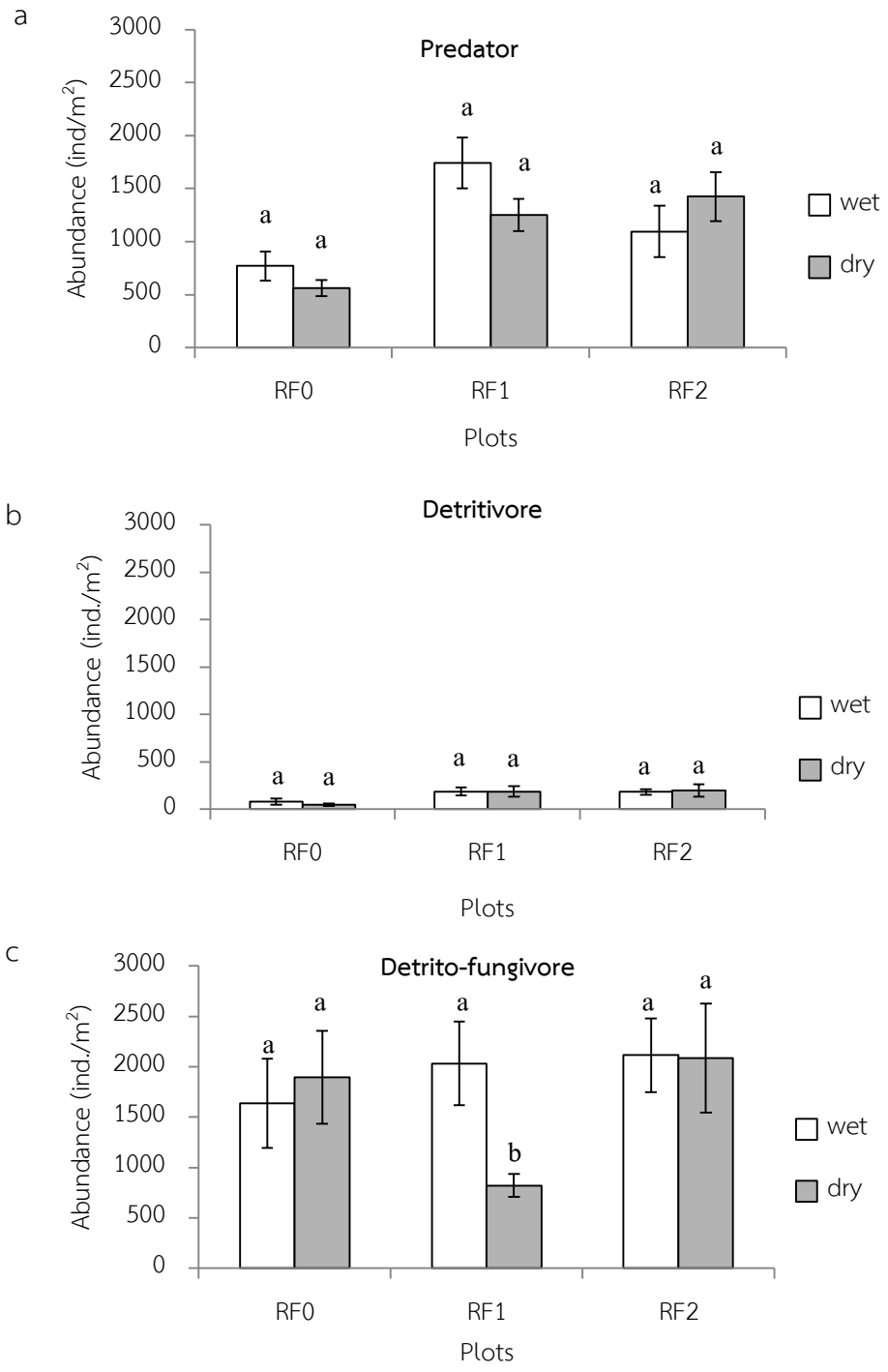


Figure 53 Total abundance of soil microarthropods by guild in the dipterocarpus reforestation areas between seasons at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0): (a) predator, (b) detritivore and (c) detrito-fungivore. Same letters denote no significant difference between wet and dry seasons of the same reforested stage. (Independent samples t-test, $p \leq 0.05$)

4.3 Relationships between biological factors, physical factors and abundance of soil microarthropods

4.3.1 Principal component analysis (PCA)

Factor extraction from six environmental factors include soil moisture, soil temperature, herbaceous cover, herbaceous biomass, organic matter and water holding capacity in each area were determined considered. The result shows that three principal components for factor extraction in the non-reforested area included PC1 (soil moisture, herbaceous cover and herbaceous biomass) with 33% of variance loading, PC2 (soil temperature) with 20% of variance loading, and PC3 (organic matter and water holding capacity) with 17% of variance loading (Figure 54). In the dipterocarpus reforestation area found one PC for factor extraction; 81% of variance loading in 1- year reforested area (Figure 55) and 84% in 2-year reforested area (Figure 56) respectively. The results of the extraction factors by principal component analysis (PCA) require the Kaiser-Mayer-Olkin index (KMO) value equal to be greater than 0.5 to be considered as strong factors. The factors with KMO values more than 0.5 was shown in Table 14 and significant result from Bartlett's Test showed that the variables are related.

The principal component analysis was conducted to examine the variation of the environmental factors based on the loading plots of PCA in three areas. Soil moisture in three areas were the main groups associated with the separation of the component 1 (soil moisture in three areas), it is explained 40.7 % of the total variation. The component 2 (soil temperature in three areas) explained 20.7 % of the total variation, the component 3 (herbaceous biomass in RF0, RF1 and organic matter in RF2), the component 4 (organic matter in RF0, RF1 and herbaceous cover in RF0) and the component 5 (herbaceous cover in RF1, RF2 and herbaceous biomass in RF2) explained 12.9%, 7.9% and 7.6% of the total variation, respectively (Figure 57).

Table 16 Kaiser-Mayer-Olkin index (KMO) and Bartlett's Test

Areas	KMO	Bartlett's Test
Non-reforested	0.530	0.00
Dipterocarpus reforestation areas at the 1-year	0.614	0.00
Dipterocarpus reforestation areas at the 2-year	0.596	0.00

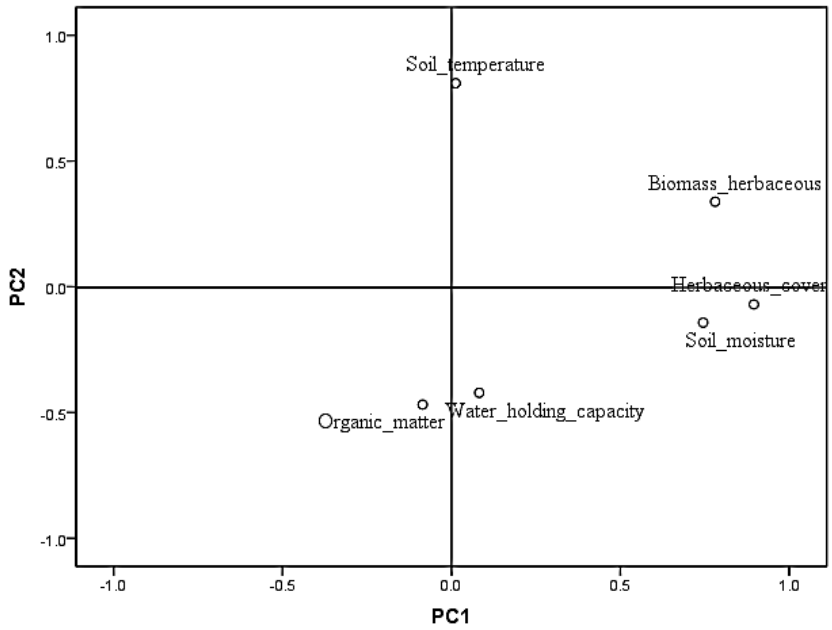


Figure 54 Loading plots of principal components analysis (PCA) in the non-reforested area

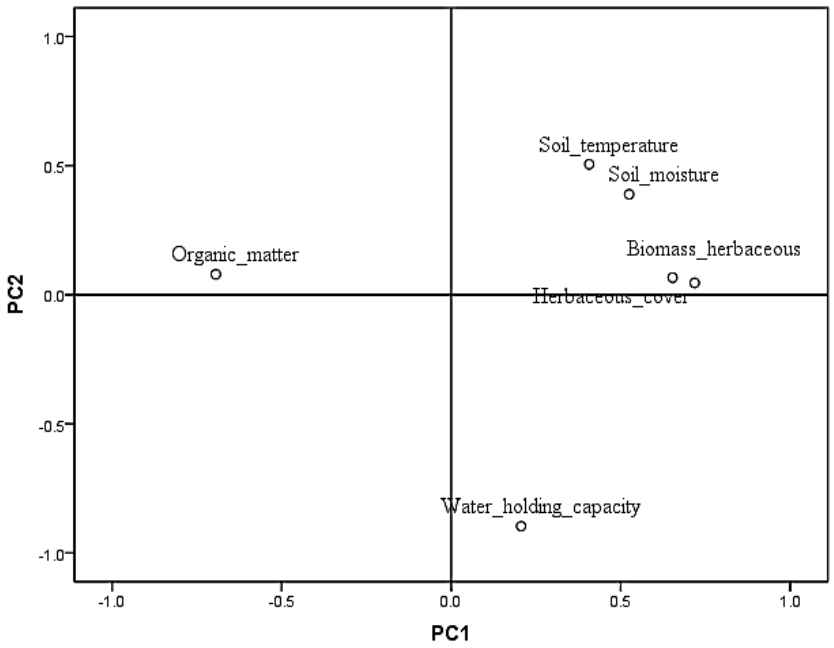


Figure 55 Loading plots of principal components analysis (PCA) in the dipterocarpus reforestation areas at the 1-year

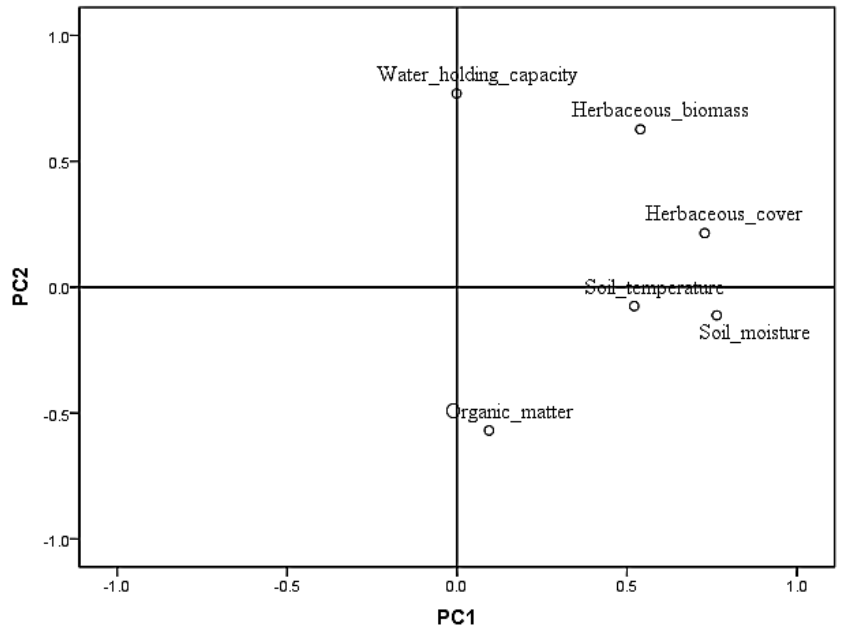


Figure 56 Loading plots of principal components analysis (PCA) in the dipterocarpus reforestation areas at the 2-year

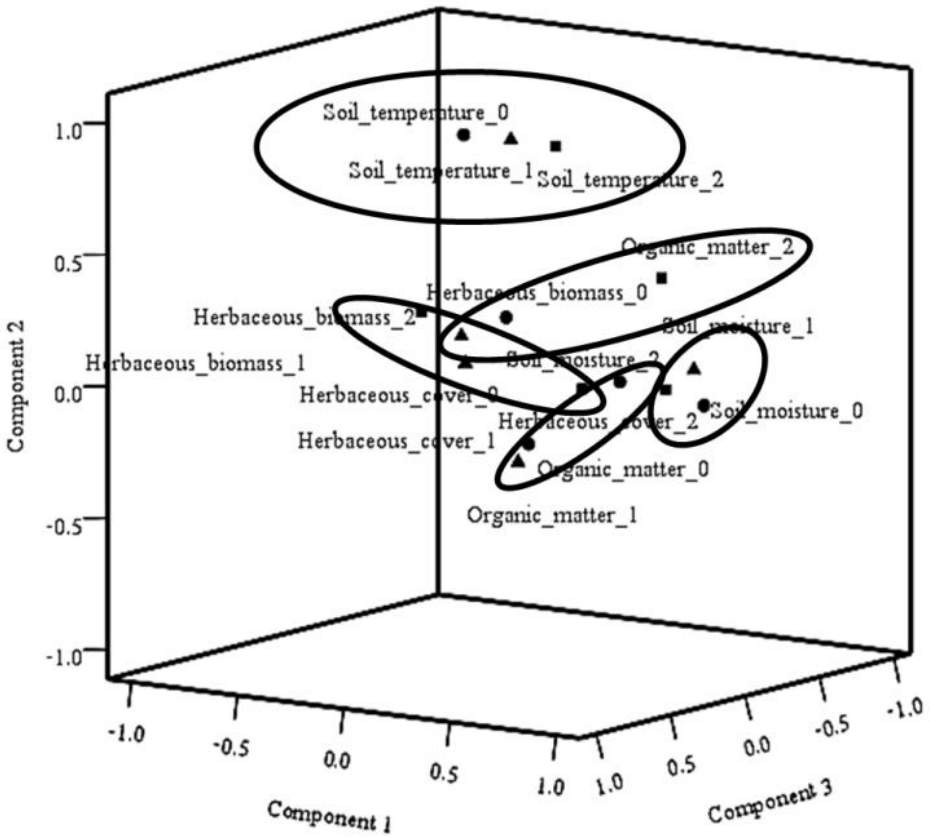


Figure 57 Loading plots of principal components analysis (PCA) of environmental factors in the non-reforested area (0) and the dipterocarpus reforestation areas at 1-year (1) and 2-year stages (2).

4.3.2 Correlation analysis

1. PC score from factor extraction by PCA and abundance of soil microarthropods

In the non-reforested area, PC1 and PC3 score were positively correlated with abundance of Diplura, while PC1 score was negatively correlated with total of soil microarthropods, Mesostigmata, Oribatida, Collembola, Araneae, Symphyla and Geophilomorpha. PC2 score was positively correlated with Astigmata. Moreover, PC1 score was negatively correlated with predator and detrito-fungivore, while PC2 score was positively correlated with detritivore.

In the 1-year dipterocarpus reforestation area, PC1 score was negatively correlated with total of soil microarthropods, Mesostigmata, Oribatida, Diplura, Collembola, Araneae and Symphyla, and PC1 score was negatively correlated with predator, detritivore and detrito-fungivore.

In the 2-year dipterocarpus reforestation area, PC1 score was positively correlated with Prostigmata and Araneae. Moreover, PC1 score was negatively correlated with Diplura.

2. Environmental factors and abundance of soil microarthropods

In the non-reforested area, soil microarthropods abundance was positively correlated with soil temperature, soil moisture, herbaceous cover and herbaceous biomass. Collembola was positively correlated with soil temperature, soil moisture and herbaceous biomass. Oribatida was positively correlated with soil moisture and herbaceous cover. Mesostigmata was positively correlated with herbaceous cover and herbaceous biomass. Astigmata was positively correlated with herbaceous cover, but was negatively correlated with soil temperature. Araneae was positively correlated with soil moisture, herbaceous cover and herbaceous biomass. Geophilomorpha was positively correlated with soil moisture and herbaceous cover. Diplura was negatively correlated with soil temperature (Table 15).

In the 1-year dipterocarpus reforestation area, soil microarthropods abundance was positively correlated with soil temperature, herbaceous cover and herbaceous biomass. Mesostigmata was positively correlated with soil temperature, soil moisture, herbaceous cover and organic matter. Oribatida was positively correlated with soil temperature, soil moisture, organic matter, herbaceous cover and herbaceous biomass. Collembola was positively correlated with soil moisture, herbaceous cover and herbaceous biomass. Prostigmata was positively correlated with organic matter, but was negatively correlated with soil temperature, soil moisture and herbaceous biomass. Astigmata was positively correlated with herbaceous biomass and herbaceous cover, but was negatively correlated with soil temperature and soil moisture. Symphyla was positively correlated with soil moisture, herbaceous cover and herbaceous biomass, but was negatively correlated with organic matter. Diplura was positively correlated with herbaceous cover. Spirobolida was positively correlated with herbaceous biomass (Table 16).

In the 2-year dipterocarpus reforestation area, soil microarthropods abundance was negatively correlated with herbaceous cover. Oribatida was positively correlated with soil temperature. Prostigmata was negatively correlated with soil temperature, soil moisture, herbaceous cover and herbaceous biomass. Astigmata was negatively correlated with soil temperature. Symphyla was positively correlated with soil temperature, soil moisture, herbaceous biomass and WHC. Diplura was positively correlated with soil temperature, soil moisture, herbaceous cover and organic matter. Geophilomorpha was positively correlated with herbaceous biomass and soil moisture. Araneae was negatively correlated with herbaceous cover. Pseuduscorpionida was positively correlated with organic matter. Protura was negatively correlated with soil temperature (Table 17).

Detrito-fungivore abundance was positively correlated with soil moisture, herbaceous cover and herbaceous biomass in non-reforested area and 1-

year dipterocarpus reforestation area. Detrito-fungivore abundance was positively correlated with soil temperature and WHC in non-reforested area. Moreover, detrito-fungivore abundance was negatively correlated with organic matter in 1-year dipterocarpus reforestation area.

Predator abundance was positively correlated with herbaceous biomass in non-reforested area and 2-year dipterocarpus reforestation area, and was positively correlated with herbaceous cover in non-reforested area and 1-year dipterocarpus reforestation area.

Detritivore abundance was positively correlated with herbaceous cover in non-reforested area and 1-year dipterocarpus reforestation area, while detritivore abundance was negatively correlated with soil temperature in non-reforested area and 2-year dipterocarpus reforestation area (Table 18).

In this study showed that soil moisture was positively correlated with abundance of total soil microarthropods, Protura, Symphyla, Spirobolida and detritivore group. Soil temperature moisture was positively correlated with abundance of detritivore group, while was negatively correlated with abundance of predator group and herbaceous cover was positively correlated with predator group. Herbaceous biomass was positively correlated with abundance of Symphyla and Spirobolida. Organic matter was negatively correlated with abundance of Symphyla and predator group. Age of seedling was positively correlated with abundance of total microarthropods, Acari, Symphyla and predator group (Table 19).

Table 17 Pearson's Correlation in the non-reforested area

Factors	Soil temperature	Soil moisture	Herbaceous cover	Herbaceous biomass	OM	WHC
Total microarthropod	0.170*	0.335**	0.393**	0.223**	-0.087	0.167*
Oribatida	0.127	0.254**	0.353**	0.115	-0.069	0.173*
Mesostigmata	0.14	0.062	0.393**	0.226**	0.025	0.065
Prostigmata	0.053	0.091	0.053	0.068	-0.132	0.047
Astigmata	-0.250*	0.046	0.202*	-0.039	0.095	0.072
Araneae	0.006	0.278**	0.170*	0.207*	-0.003	-0.004
Pseudoscorpionida	0.106	-0.053	0.110	0.075	-0.038	0.085
Collembola	0.166*	0.372**	0.149	0.298**	-0.097	0.006
Diplura	-0.217**	-0.072	-0.14	-0.162	0.035	-0.124
Geophilomorpha	0.036	0.200*	0.165*	0.103	0.034	-0.016

Remark: * $p \leq 0.05$

** $p \leq 0.01$

Table 18 Pearson's Correlation in the 1-year dipterocarpus reforestation area

Factors	Soil temperature	Soil moisture	Herbaceous cover	Herbaceous biomass	OM	WHC
Total microarthropod	0.231*	0.157	0.302**	0.194*	-0.166*	-0.092
Oribatida	0.253**	0.259**	0.252**	0.250**	-0.173*	-0.010
Mesostigmata	0.191*	0.177*	0.277**	0.085	-0.127	-0.115
Prostigmata	-0.259**	-0.304**	-0.121	-0.178*	0.269**	-0.031
Astigmata	-0.250**	-0.172*	0.162*	-0.034	0.014	-0.034
Araneae	0.032	0.032	0.139	0.262**	-0.107	-0.041
Pseudoscorpionida	0.009	0.022	-0.010	-0.001	0.028	-0.105
Collembola	0.066	0.324**	0.171*	0.212**	-0.135	-0.137
Diplura	0.060	0.207	0.214**	0.184*	-0.094	-0.064
Protura	0.017	0.258	0.031	-0.041	-0.097	-0.075
Symphyla	0.097	0.350**	0.223**	0.246**	-0.203**	-0.039
Geophilomorpha	0.136	0.197*	0.012	0.031	-0.136	0.049
Spilobolida	0.006	0.118	0.093	0.179*	-0.087	-0.015

Remark: * $p \leq 0.05$

** $p \leq 0.01$

Table 19 Pearson's Correlation in the 2-year dipterocarpus reforestation area

Factors	Soil temperature	Soil moisture	Herbaceous cover	Herbaceous biomass	OM	WHC
Total microarthropod	-0.003	0.01	-0.063	-0.117	-0.04	-0.006
Oribatida	0.226**	0.068	0.011	0.019	-0.065	0.027
Mesostigmata	0.032	-0.046	0.016	-0.125	-0.012	-0.105
Prostigmata	-0.365**	-0.384**	-0.276**	-0.311**	0.039	-0.084
Astigmata	-0.382**	-0.02	0.078	-0.078	-0.027	0.034
Araneae	0.123	-0.043	-0.163*	-0.15	0.11	0.011
Pseudoscorpionida	-0.006	-0.08	-0.041	-0.098	0.216*	-0.012
Collembola	-0.098	0.051	-0.144	-0.119	-0.024	0.008
Diplura	0.253**	0.173*	0.168*	0.155	0.181*	0.083
Protura	-0.208**	0.048	0.120	-0.008	-0.041	0.088
Symphyla	0.263**	0.181*	0.127	0.313**	0.005	0.222*
Spilobolida	0.086	0.088	0.019	0.136	-0.042	0.084
Geophilomorpha	0.129	0.188*	0.126	0.174*	-0.072	0.084

Remark: * $p \leq 0.05$

** $p \leq 0.01$

Table 20 Pearson's Correlation analysis for guilds abundance and environmental factors

Factors	RF0			RF1			RF2		
	Predator	Detritivore	Dettrito-fungivore	Predator	Detritivore	Dettrito-fungivore	Predator	Detritivore	Dettrito-fungivore
Soil temperature	0.131	-0.256**	0.167*	0.106	-0.189	0.204	-0.049	-0.289**	0.050
Soil moisture	0.1	0.047	0.346**	0.092	0.008	0.336**	-0.130	0.046	0.072
Herbaceous cover	0.205*	0.196*	0.376**	0.229**	0.260**	0.249**	-0.053	0.120	-0.091
Herbaceous biomass	0.221**	-0.041	0.194*	.046	.103	.261**	-0.185*	0.034	-0.071
OM	-0.034	0.1	-0.093	-0.051	-0.088	-0.184*	0.010	-0.029	-0.051
WHC	0.069	0.072	0.165*	-0.115	-0.050	-0.071	-0.109	0.112	0.021

Remark: * $p \leq 0.05$

** $p \leq 0.01$

Table 21 Pearson's Correlation analysis for abundance in each group and environmental factors in three areas

	Soil temperature	Soil moisture	Herbaceous cover	Herbaceous biomass	Organic matter	Age of seedling
Total microarthropods	0.212	0.428**	0.121	0.128	-0.097	0.327*
Acari	0.223	0.277	0.146	0.108	-0.127	0.324*
Collembola	-0.010	0.309	0.069	-0.039	-0.046	0.027
Protura	-0.022	0.349*	0.112	0.121	-0.234	0.114
Symphyla	0.181	0.636**	0.291	0.454**	-0.391*	0.380*
Spirobolida	0.118	0.378*	0.086	0.347*	-0.193	0.148
Detritivore	0.453**	0.260	0.011	0.123	-0.121	0.243
Detrito-fungivore	0.232	0.462**	0.032	0.161	0.086	0.167
Predator	-0.383*	0.113	0.332*	-0.050	-0.360*	0.323*

Remark: * $p \leq 0.05$

** $p \leq 0.01$

4.3.3 Multiple linear regression

Multiple linear regression showed that soil moisture had significant effects on the abundance of total soil microarthropods, Collembola, Protura, Symphyla and detrito-fungivores (Model 1, 3, 4, 5, 6 and 8). Increasing herbaceous biomass had positive effect on the abundance of Symphyla and Spirobolida (Model 5 and 6) and increasing age of seedling had positive effect on the abundance of Acari and the abundance of detritivores (Model 2 and 7). Organic matter had negative effect on the abundance of Symphyla and the predators (Model 5 and 9). Herbaceous cover seedling had positive effect on the abundance of predators (Model 9). Soil temperature had positive effect on the abundance of Acari and the detritivores (Model 2 and 7), while had negative effect on the abundance of predators (Model 9).

Model 1

$Y_1 = 1310.67 + (157.18*X_1)$, r = 0.428, $P = 0.007$

Model 2

$Y_2 = -1926.56 + (124.92*X_2) + (520.31*X_6)$, r = 0.418, $P = 0.032$

Model 3

$Y_3 = -9.41 + (61.47*X_1)$, r = 0.309, $P = 0.05$

Model 4

$Y_4 = -20.57 + (3.06*X_1)$, r = 0.349, $P = 0.03$

Model 5

$Y_5 = -50.82 + (6.50*X_1) - (2.80*X_3) + (2.08*X_5)$, r = 0.766, $P < 0.001$

Model 6

$Y_6 = -9.07+ (0.77*X_1) + (0.24*X_5)$, r = 0.378, $P = 0.02$

Model 7

$Y_7 = -2306.14+ (101.87*X_2) + (196.65*X_6)$, r = 0.544, $P = 0.02$

Model 8

$Y_8 = 129.07 + (123.61*X_1)$, r = 0.462, $P = 0.003$

Model 9

$Y_9 = 2229.02 - (63.22*X_2) - (18.81*X_3) + (6.90*X_4)$, r = 0.607, *P* = 0.001

Where:

	Y_1	=	Abundance of total soil microarthropods
	Y_2	=	Abundance of Acari
	Y_3	=	Abundance of Collembola
	Y_4	=	Abundance of Protura
	Y_5	=	Abundance of Symphyla
	Y_6	=	Abundance of Spirobolida
	Y_7	=	Abundance of detritivores
	Y_8	=	Abundance of detrito-fungivores
	Y_9	=	Abundance of predators
	X_1	=	Soil moisture
	X_2	=	Soil temperature
	X_3	=	Organic matter
	X_4	=	Herbaceous cover
	X_5	=	Herbaceous biomass
	X_6	=	Age of seedling

CHAPTER V
DISCUSSION

5.1 Reforestation with environmental factors

Some environmental factors changed over stages of reforestation plots of dipterocarpus seedlings inoculated with ectomycorrhizal fungi. Particularly, soil moisture increased with the increasing age of the reforested plots. Madsen and Larsen (1997) reported that beech saplings in Denmark increased the regeneration growth with increased soil water content. This change was caused by several influencing factors, such as soil texture, soil organic matter and canopy cover. The proportion of small, medium and large particles (clay, silt and sand, respectively) in the non-reforested area had more sand than the reforestation areas. Silt and clay has the higher ability to retain water than sand (Wischmeier and Mannering, 1969). The water holding capacity was higher in reforestation areas more than in the non-reforested area. The water holding capacity is controlled primarily by soil texture and organic matter (Naeth et al., 1991). Plant roots also help to change the soil structure, which affect the soil's ability to retain moisture (Bais et al., 2006). Furthermore, the reforestation area at 2 years had a larger canopy cover of seedlings more than that of the 1-year reforestation areas, while the non-forested area had no seedling canopy cover. Therefore, the rate of evaporation of water in the reforestation areas would be less than the non-reforested area, and the effect of solarization to soil temperature in the reforestation areas would be lower than in the non-reforested area. Moreover, soil moisture could help supporting the survival of the mycorrhizal fungi, which subsequently increases the survival rate of the dipterocarp seedlings over age progression of the seedlings, and the root growth would be more conducive to increase EMC fungal infection. Furthermore, the study by Arenla and Ajungla (2014), after 8 months of inoculation with ectomycorrhiza (*Russula* sp.), demonstrated that the inoculated seedlings were significanty growing faster than the non-inoculated dipterocarp seedlings.

Soil nitrogen and phosphorus were not significantly different between the three areas in this study. The range of soil nitrogen was 9.77-11.55 mg/kg, which was rather low. The range of phosphorus was 6.3-9.7 mg/kg, which values were at the low level of available soil phosphorus (Complex, 2016). Phosphorus is an essential element in plant growth and becomes available for plant absorption only if the soil pH is lower than 6.8 (Complex, 2016). The soil pH from this study was in the range 6.4-7.2, and available phosphorus was relatively low, especially in reforestation area at 2-year, possibly due to the phosphorus uptake in the seedlings that was also improved by ECM infection (Yazid et al., 1994).

Herbaceous biomass was significantly lower in the non-reforested area than in the 2-year reforestated area. High soil moisture of the soil in the 2-year reforestation plots are responsible for the higher herbaceous plant growth and subsequently higher biomass. In contrast, lower nutrients in the soil may be caused by high absorption from highly proliferated herbaceous plants. Differences of herbaceous biomass were found between the wet and dry seasons. Herbaceous biomass in the wet season was greater than the dry season in all three areas. However, the percent herbaceous cover did not differ in the three areas due to weed management by cutting every month to prevent competition between grasses and seedling for soil nutrient use (James, 1949). Huhta and Hanninen (2001) reported that the plant cover appears to increase soil moisture. Organic matter was at a low level, and not different among three areas, ranging from 0.73 to 0.85%. Mushrooms or fruiting bodies of *Russula* sp. were found in the 2-year reforestation area in July 2015. This was a proof of ECM association between dipterocarp seedlings and ECM fungi. In addition, there were some other factors which were not recorded in this study but could possibly be important to the soil microarthropods community and environmental condition such as canopy cover of seedling and sapling, more detailed ECM infection, root biomass, or other group of soil fauna.

5.2 Soil microarthropods community with reforestation

This study demonstrates that the abundance of soil microarthropods was lowest in non-reforested area, with weedy or grassy cover, and increased with the age of the seedlings in the reforested areas. The highest abundance of soil microarthropods was found in the 2-year-old dipterocarpus reforestation area. The reforested areas have the abundance of soil microarthropods (3,596 ± 227 individual/m^2) similar to the natural dry evergreen forest at Sakaerat environmental Research Station, Nakhon Ratchasima Province (3,381 ± 463 individual/m^2) (Kongnirundonsuk et al., 2014) (Table 20). The similar trend was found in the major soil microarthropod groups of Acari and Collembola, which account for over 90% of all soil microarthropods. Other groups of rare soil microarthropods such as Symphyla, Protura and Spirobilida, even though present in a small proportion, might be important indicators for soil conditions.

Acari and collembolans dominated the soil community in all three areas, as they are groups with very high taxonomic diversity (Singh, 1977). Many researchers reported that Acari and collembolans dominated a wide range of habitats, including roadside, green roof, teak forest, hill evergreen forest, dry dipterocarp forest and agricultural areas (Cortet et al., 2002; Farská et al., 2014; Kongnirundonsuk et al., 2014; Rumble and Gange, 2013; Tabaglio et al., 2009; Widyastuti, 2004) (Table 21). Acari have diverse feeding habits and living areas, and some of them have structures that assist in hunting. Oribatid mites, the dominant acari in the non-reforested area and reforestation area at 2-year, have exoskeleton that enables them to survive in dry conditions better than other soft bodied mites. The low soil moisture and high soil temperature of the non-reforested area would have minimal effects on oribatid mites due to their ability to resist the unfavorable conditions (Gergócs and Hufnagel, 2009; Malmström, 2008; Starzomski and Srivastava, 2007), while some soft bodied arthropods cannot survive in this area. Furthermore, the 2-year reforestation area was found to be highly infected with ectomycorrhizal fungi, providing fungal mycelium that could be an important food source of Oribatid mites as well as collembolans (Behan-Pelletier, 1999; Devi et al., 2012; Lindberg et al., 2002; Siddiky et al., 2012).

Although collembolans were in all three areas, there was a difference in abundance between the reforestation area containing seedlings inoculated with ectomycorrhizal fungi and the non-reforested area. The tendency was apparent with increasing age of the seedlings. Moreover, soil moisture was positively correlated with the abundance of oribatid mites and collembolans in the non-reforested area and reforestation area at 1-year. The reforestation area at 2-year did not exhibit this relationship because the soil in this area can retain the soil moisture well. Rumble and Gange (2013) also reported that collembolan density was negatively affected by high temperature and low soil moisture.

Symphyla, Protura and Spirobolida can only be found in reforestation areas. Proturans were negatively correlated with soil temperature. Soil temperature in the non-reforested area was higher than other areas since there was no canopy cover and soil moisture was poorly retained. Symphylans were positively correlated with soil moisture and were more abundance in the wet season than dry season. Rumble and Gange (2013) reported that drought negatively affected symphylans. Symphylans, proturans and spirobolids were only found in restoration because they are relatively sensitive to the changes of soil moisture, and forest restoration helps retain moisture in the soil and are suitable for soft-bodied soil microarthropods that are relatively sensitive to environmental change. The reforested areas in this study have the abundance of Protura and Symphyla more than the natural dry evergreen forest and dry dipterocarp forest at Sakaerat environmental Research Station, Nakhon Ratchasima Province (Kongnirundonsuk et al., 2014), teak forest in India (Widyastuti, 2004) and eucalyptus Plantations in India (Nazia and Sanil, 2015) (Table 22). Verhoef and Witteveen (1980) and Kardol et al. (2011) reported that many soft-bodied animals are sensitive to desiccation during dry conditions, and they can be used as good bioindicators. On the other hand, pseudoscorpions were mostly found in the non-reforested area. However, the reforestation areas at 1-year and 2-year had variety of predators, but they had low abundance of pseudoscorpions probably in part because of reduced competition in area with other predators. Pseudoscorpions have hard external structures to make them possible to live in an arid area better than other soft-bodied predators, such as mesostigmatid mites and diplurans.

The abundance of Diplura (Family Japygidae) which are soft-bodied predators increased over the progression of early stage reforestation. They were also negatively correlated with soil temperature in the non-reforested area and positively correlated with soil moisture and with soil temperature in the reforestation area at 2-year. The 2-year reforestation area can retain soil moisture well and the soil temperature was in the range suitable for soil microarthropods. Diplurans reflect the clear difference between the non-reforested area and the reforestation area.

The non-reforested area and reforestation areas at 1-year and 2-year were mainly composed of detrito-fungivore group. The most common detrito-fungivore groups were oribatid mites and collembolans. Siddiky (2012) showed that mycorrhizae increased the collembolan population because collembolans may feed on mycorrhizae (Devi et al., 2012; Lindberg et al., 2002; Siddiky et al., 2012) and oribatid mites feed on a wide variety of materials, including living and dead plant and fungi (Behan-Pelletier, 1999). However, proturans are detrito-fungivores and were only found in reforestation area with high retention of soil moisture, and they are rather sensitive to soil moisture. Detrito-fungivore group was found in the non-reforested area more than other areas because oribatid mites dominated in the dry area (Wallwork, 1983). Oribatid mites have the hard external structure and can live by feeding fungi and organic matters. They can also benefit from reduced competition with collembolans and other detritivores, which cannot live in the dry conditions. Group of detrito-fungivores and detritivore are likely to induce predatory soil microarthropods. Mesostigmatid mites and diplurans were the dominated predators in reforestation areas. Reforestation areas have retained soil moisture well, so soft-bodied predators, such as mesoatigmatids and diplurans can be found, while pseudoscorpions can live in either wet or dry area and they were mostly found in the non-reforested area. Moreover, mesostigmatid mites were more numerous at constant temperature (Huhta and Hänninen, 2001). Pseudoscorpions were found in reforestation area only during the dry season during which the soft-bodied predators depopulate particularly Acari and Geophiromorpha.

Analysis of the diversity index and similarity index showed the non-difference among the three areas. This might be because the soil was inverted from the 3-

meter depth subsoil where microarthropods were not expected to live in that condition. Thus, soil microarthropods may disperse passively by water or actively by migration (Ojala and Huhta, 2001) from surrounding area. Furthermore, the Shannon-Weiner diversity index values were 0.93±0.03, and higher than the dipterocarpus forest at Sakaerat Environmental Research Station (0.64±0.05) (Kongnirundonsuk et al., 2014).

5.3 Projection of future abundance and composition of soil microathropods in the area

This pattern of forest restoration demonstrates the change of factors in area when increasing age of plant and the ability to retain moisture in the area increased as well. The changes of soil composition, canopy cover of seedlings and percent infection of ectomycorrhiza fungi associated with the change of roots and canopy. These components support the increase in abundance of soil microarthropods, particularly detrito-fungivore and soft-bodied microarthropods. The analysis of morphospecies accumulation curve shows a continuous increase in the number of morphospecies, especially in areas with forestation. This restoration pattern reduces period of restoration area and induced increases in the abundance and diversity of soil microarthropods.

5.4 The benefits of reforestation with dipterocarpus seedlings inoculated with ECM fungi

The soil in this study area was obtained from pond excavation during which 3 m depth of soil was inverted. The result of environmental factors and soil microarthropods community during planting at different stages showed that some differences between factors with an increasing trend of soil microarthropods abundance with increasing age of seedling. This pattern of reforestation will help increasing survival rate of the plants in dry conditions (Arenla and Ajungla, 2014) and induced shifts in abundance and composition of soil microarthropods in the area. Soil microarthropods are important to the ecosystem and changes of soil quality in

decomposition process (Ford, 1937; Heneghan and Bolger, 1998). Thus, the increase in abundance and diversity of soil microarthropods can be used as biological indicators for soil quality of changes occurring in the area (Lindberg et al., 2002) and will help in monitoring, planning, managing, and recovery of forest ecosystems.

Table 22 The abundance of soil microarthropods in tropical forests

Area	Abundance (individual/m^2)	Reference
Non-reforested area	2,496	This study
One-year reforestation area	2,989	
Two year reforestation area	3,596	
Teak forest in India	771	Widyastuti, 2004
Dry evergreen forest at Sakaerat environmental Research Station, Thailand	3,381	Kongnirundonsuk et al., 2014
Dry dipterocarp forest at Sakaerat environmental Research Station, Thailand	685	Kongnirundonsuk et al., 2014

Table 23 The abundance of Acari and Collembola in tropical forests

Area	Abundance (individual/m^2)		Reference
	Acari	Collembola	
Non-reforested area	2080	373	This study
One-year reforestation area	2292	514	
Two year reforestation area	2678	763	
Teak forest in India	261	490	Widyastuti, 2004
Dry evergreen forest at Sakaerat environmental Research Station, Thailand	2401	46	Kongnirundonsuk et al., 2014
Dry dipterocarp forest at Sakaerat environmental Research Station, Thailand	434	313	Kongnirundonsuk et al., 2014

Table 24 The abundance of Protura and Symphyla in tropical forests

Area	Abundance (individual/m^2)		Reference
	Protura	Symphyla	
Non-reforested area	0	0	This study
One-year reforestation area	32	67	
Two year reforestation area	9	61	
Teak forest in India	6	13	Widyastuti, 2004
Dry evergreen forest at Sakaerat environmental Research Station	0	34	Kongnirundonsuk et al., 2014
Dry dipterocarp forest at Sakaerat environmental Research Station	0	7	Kongnirundonsuk et al., 2014

CHAPTER VI

CONCLUSION

Soil microarthropods have an important role in the litter decomposition, nutrient cycling and soil formation. Reforestation with dipterocarpus seedlings inoculated with ectomycorrhizal (ECM) fungi resulted in the increase of the diversity and abundance of soil microarthropods, especially with increasing age of seedlings, as shown in this research (Figure 58).

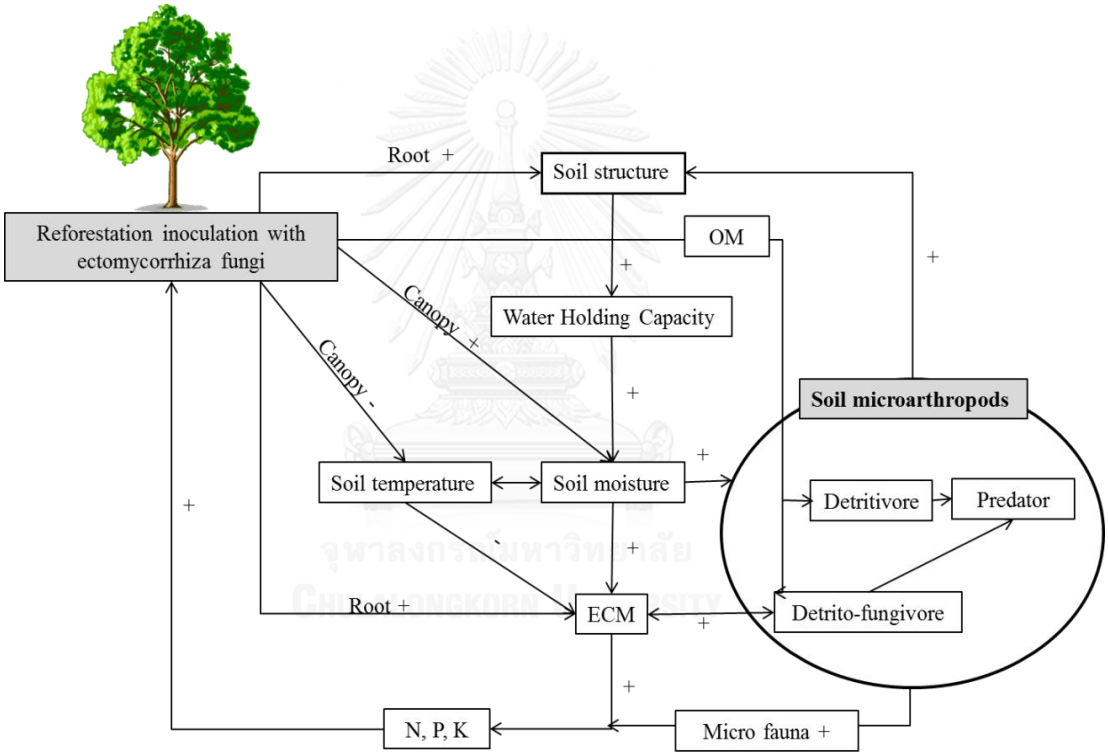


Figure 58 Framework of the study

The reforestation areas with dipterocarpus seedlings inoculated with ECM fungi had significantly higher abundance of soil microarthropods than the non-reforested area. Overall, the dominant soil microarthropod groups were Acari and Collembola which were observed to be in high abundance in all areas. Some soil microarthropods that were sensitive to dry conditions, such as symphylans,

spilobolids, geophilomorph and proturans, were significantly higher in abundance in the reforested areas, and could be used as bioindicators. Dipterocarpus seedlings inoculated with ECM fungi appeared to attract the detrito-fungivorous microarthropods. Species richness of soil microarthropods increased with the age of reforestation, resulting from additional Acari species found in the reforestation plots.

Analyses of the physical and biological factors in the reforestation areas showed that the changes in the soil characteristics, including soil water holding capacity and soil moisture, increased in the reforestation areas with the increasing age of seedlings. Soil microarthropods were positively correlated with soil moisture in the non-reforested area, indicating that reforestation increased the soil potential to retain moisture.

This study showed that the diversity and abundance of soil microarthropods increased over the progression of the early stage of reforestation. The increase was explained by the changes in environmental factors, particularly increasing soil moisture and lower soil temperature.

Recommendations

Future studies may focus on long-term exploration of plant and animal communities during stages of reforestation. The results of this study showed that increasing age of plants and changes in environmental factors, such as soil moisture, canopy cover, and percent ectomycorrhizal infection, affected the soil microarthropod community. Potentially, proturans and Symphyla can be used as bioindicators to monitor the progress of the early stages of forest restoration. In addition, comparing the diversity and abundance of soil microarthropods in the reforestation areas to that of the mature forests in the vicinity may help assess the progress or success of forest restoration. From the result of this study, soil moisture is the main factor determining the diversity and the abundance of soil

microarthropods and is correlated with other factors. The restoration forest in the future may attempt to increase the soil moisture retention ability of the landscape by employing methods, such as ground covering or mixing moisture-retaining materials in the planting soil, to promote the growth and survival of seedlings and associated ECM fungi as well as soil fauna.

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APPENDIX

Table A-1 Abundance of soil microarthropods in each month between October 2014 to October 2015 in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

Months	Abundance (individuals / m^2)		
	RF0	RF1	RF2
October 2014	1785	3877	1854
November 2014	2556	3144	3225
December 2014	1015	2958	2375
January 2015	1235	2163	4063
February 2015	463	1217	2335
March 2015	3790	3103	6800
April 2015	3805	1565	2746
May 2015	3623	1825	3288
June 2015	4050	3300	5675
July 2015	2275	3700	4800
August 2015	3125	5750	6725
September 2015	3625	2400	2100
October 2015	1900	4000	2250

Table A-2 Soil temperature in each month between October 2014 to October 2015 in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

Months	Soil temperature (ºC)		
	RF0	RF1	RF2
October 2014	28.12	28.64	27.91
November 2014	27.58	27.52	26.33
December 2014	26.54	27.53	28.79
January 2015	24.64	24.71	24.24
February 2015	29.63	26.21	27.95
March 2015	28.90	30.14	27.05
April 2015	28.70	28.95	29.22
May 2015	34.91	31.39	30.13
June 2015	31.05	31.18	32.91
July 2015	31.12	32.38	31.11
August 2015	30.18	30.40	30.22
September 2015	30.13	29.65	29.81
October 2015	35.68	33.18	31.58

Table A-3 Soil moisture in each month between October 2014 to October 2015 in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

Months	Soil moisture (%)		
	RF0	RF1	RF2
October 2014	10.62	17.11	16.53
November 2014	10.87	11.93	12.61
December 2014	7.54	7.72	13.92
January 2015	5.34	7.96	9.52
February 2015	3.65	4.95	5.23
March 2015	10.52	13.20	12.36
April 2015	13.42	14.28	13.07
May 2015	7.64	10.24	11.12
June 2015	11.52	16.21	15.80
July 2015	5.88	7.07	9.56
August 2015	12.68	17.10	15.84
September 2015	14.46	18.20	17.81
October 2015	5.86	10.82	11.12

Table A-4 Soil organic matter in each month between October 2014 to October 2015 in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

Months	Organic matter (%)		
	RF0	RF1	RF2
October 2014	1.13	1.05	0.60
November 2014	1.48	1.83	1.05
December 2014	0.55	0.87	0.45
January 2015	1.04	0.89	0.38
February 2015	0.55	1.14	1.17
March 2015	0.85	1.37	0.88
April 2015	0.60	0.86	0.74
May 2015	1.00	0.68	0.87
June 2015	0.61	0.50	2.10
July 2015	0.74	1.03	0.72
August 2015	0.46	0.24	0.22
September 2015	0.23	0.25	0.16
October 2015	0.30	0.31	0.18

Table A-5 Herbaceous biomass in each month between October 2014 to October 2015 in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

Months	Herbaceous biomass (g/m^2)		
	RF0	RF1	RF2
October 2014	334	171	216
November 2014	82	180	164
December 2014	103	198	294
January 2015	173	191	261
February 2015	0	0	0
March 2015	152	160	68
April 2015	202	180	143
May 2015	289	301	467
June 2015	168	162	161
July 2015	373	502	202
August 2015	580	410	482
September 2015	326	701	564
October 2015	224	281	603

Table A-6 Herbaceous cover in each month in the dipterocarpus reforestation areas at the 1-year (RF1) and 2-year (RF2) stages and the non-reforested area (RF0).

Months	Herbaceous cover (%)		
	RF0	RF1	RF2
October 2014	100.00	87.92	86.67
November 2014	46.25	62.08	60.83
December 2014	35.42	90.00	72.92
January 2015	42.92	66.67	67.50
February 2015	0.00	0.00	0.00
March 2015	50.00	47.50	15.42
April 2015	57.08	54.17	56.25
May 2015	38.33	68.33	84.17
June 2015	58.33	55.83	79.17
July 2015	66.67	77.08	0.00
August 2015	83.75	64.17	68.75
September 2015	42.08	80.83	61.67
October 2015	23.33	83.75	63.75

Table A-7 One way ANOVA to compare the abundance between areas

Source of variation	Sum of Squares	df	Mean Square	F	*p*-value
Acari	11776075.524	2	5888037.762	2.224	0.115
Collembola	78713.104	2	39356.552	0.042	0.958
Protura	13348.807	2	6674.404	2.715	0.073
Diplura	18928.538	2	9464.269	7.986	0.001
Symphyla	63467.390	2	31733.695	7.507	0.001
Spirobolida	472.705	2	236.353	1.035	0.361
Pseudoscorpionida	1930.578	2	965.289	12.306	0.000
Araneae	4232.791	2	2116.395	1.201	0.037
Geophilomorpha	5330.765	2	2665.382	4.663	0.012

Table A-8 One way ANOVA to compare guilds abundant between areas

Source of variation	Sum of Squares	df	Mean Square	F	*p*-value
Detrito-fungivore	8729334.678	2	4364667.339	1.857	0.164
Detritivore	287328.314	2	143664.157	4.785	0.011
Predator	9198400.394	2	4599200.197	10.019	0.000

Table A-9 One way ANOVA to compare the environmental factors between areas

Source of variation	Sum of Squares	df	Mean Square	F	*p*-value
Sand	886.9	2	443.4	4.7	0.015
Silt	1563.6	2	781.8	7.5	0.002
Clay	177.7	2	88.9	2.8	0.074
WHC (%)	87.7	2	43.9	42.9	<0.001
Available N (mg/kg)	16.8	2	8.4	0.6	0.546
Available P (mg/kg)	75.2	2	37.6	1.2	0.317
Available K (mg/kg)	21634.9	2	10817.5	7.3	0.004
Soil temperature (°C)	1.5	2	0.8	4.3	0.022
Soil moisture (%)	83.7	2	41.9	93.6	<0.001
Organic matter (%)	0.05	2	0.03	0.2	0.805
Herbaceous biomass (g/m^2)	59.8	2	29.9	3.9	0.029
Herbaceous cover (%)	590.3	2	295.2	2.595	0.090

Table A-10 Multiple linear regression (Model 1)

	Coefficient	Std. Error	t	P	VIF
Constant	1310.69	653.56	2.00	0.05	
Soil moisture	157.18	54.57	2.88	0.007	1.00

Table A-11 Multiple linear regression (Model 2)

	Coefficient	Std. Error	t	P	VIF
Constant	-1926.56	2146.87	-0.90	0.35	
Age of seedling	520.31	222.82	2.34	0.03	1.02
Soil temperature	124.92	71.46	1.74	0.09	1.02

Table A-12 Multiple linear regression (Model 3)

	Coefficient	Std. Error	t	P	VIF
Constant	-9.41	372.4	-0.03	0.98	
Soil moisture	61.47	31.09	1.98	0.06	1.00

Table A-13 Multiple linear regression (Model 4)

	Coefficient	Std. Error	t	P	VIF
Constant	-20.57	16.20	-1.27	0.21	
Soil moisture	3.06	1.35	2.26	0.03	1.00

Table A-14 Multiple linear regression (Model 5)

	Coefficient	Std. Error	t	P	VIF
Constant	-50.82	21.43	-2.37	0.23	
Soil moisture	6.50	1.89	3.44	0.02	1.28
Organic matter	-2.80	0.84	-3.34	0.02	1.34
Herbaceous biomass	2.08	0.71	2.96	0.05	1.29

Table A-15 Multiple linear regression (Model 6)

	Coefficient	Std. Error	t	P	VIF
Constant	-9.07	4.90	-1.85	0.07	
Soil moisture	0.77	0.44	1.76	0.08	1.18
Herbaceous biomass	0.24	0.16	1.45	0.16	1.18

Table A-16 Multiple linear regression (Model 7)

	Coefficient	Std. Error	t	P	VIF
Constant	-2306.14	879.74	-2.62	0.01	
Soil temperature	101.87	29.28	3.48	0.001	1.02
Age of seedling	196.65	91.31	2.15	0.04	1.02

Table A-17 Multiple linear regression (Model 8)

	Coefficient	Std. Error	t	P	VIF
Constant	129.07	467.32	0.28	0.78	
Soil moisture	123.61	39.02	3.17	0.003	1.00

Table A-18 Multiple linear regression (Model 9)

	Coefficient	Std. Error	t	P	VIF
Constant	2229.02	764.93	2.91	0.006	
Soil temperature	-63.22	25.89	-2.44	0.02	1.04
Organic matter	-18.81	7.96	-2.36	0.02	1.05
Herbaceous cover	6.87	2.48	2.77	0.01	1.00

VITA

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