ปัจจัยที่มีผลต่อการกระจายของขนาด การงอก และความอยู่รอดของต้นกล้าและไม้หนุ่มของพืชวงศ์โปโดคาร์เปซีอี ณ อุทยานแห่งชาติเขาใหญ่ ประเทศไทย

นางสาวเจมิกา อัครเศรษฐนนท์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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FACTORS AFFECTING SIZE DISTRIBUTION, SEED GERMINATION, AND SEEDLING AND SAPLING SURVIVAL OF PODOCARPACEAE AT KHAO YAI NATIONAL PARK, THAILAND

Jemika Akkarasadthanon

A Thesis Submitted in Partial Fulfillment of the Requirements for the

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FACTORS AFFECTING SIZE DISTRIBUTION, SEED GERMINATION, AND SEEDLING AND SAPLING SURVIVAL OF PODOCARPACEAE AT KHAO YAI NATIONAL PARK, THAILAND

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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วัตถุประสงค์ของการศึกษานี้เพื่อศึกษาปัจจัยที่มีผลต่อการงอกของเมล็ดและความรอดของต้นกล้า (ความสูงน้อยกว่า 0.15 เมตร) และไม้หนุ่ม (ความสูงระหว่าง 0.15-1.35 เมตร) และศึกษาปัจจัยที่มีผลต่อความรอดของต้นกล้าของพืชวงศ์โปโดคาร์เปซีอี ณ อุทยานแห่งชาติเขาใหญ่ในประเทศไทย จำนวน 4 ชนิดคือ พญาไม้ (*Podocarpus neriifolius*) ขุนไม้ (*Nageia wallichiana*) มะขามป้อมดง (*Dacrycarpus imbricatus*) และสนสามพันปี (*Dacrydium elatum*) พื้นที่ทั้งหมดของการวิจัย 20 เฮกเตอร์ มีจำนวน 70 แปลงและ 15 แปลงที่เลือกเพิ่ม จากการศึกษาความหนาแน่นของพืชวงศ์โปโดคาร์เปซีอี พบว่าต้นพญาไม้มีความหนาแน่นมากที่สุด ส่วนต้นสนสามพันปีมีความหนาแน่นน้อยที่สุด การงอกของเมล็ดต้นพญาไม้ที่ตรวจพบมีจำนวนน้อยกว่า 50% ของจำนวนเมล็ดที่ปลูกในแต่ละแปลงย่อย ซึ่งพบว่าการงอกของเมล็ดและการอยู่รอดของต้นกล้าที่พึ่งงอกในแปลงย่อยที่มีกำจัดวัชพืชในแปลงก่อนการปลูกจะมีมากกว่าแปลงย่อยที่มีไม่มีการกำจัดวัชพืชในแปลง เมื่อทำการศึกษาความสัมพันธ์ระหว่างต้นพญาไม้และต้นขุนไม้พบว่ามีความสัมพันธ์เชิงบวกเช่นเดียวกันกับต้นขุนไม้และต้นมะขามป้อมดง คาดการณ์ว่าการเกิดไม้หนุ่มได้รับอิทธิพลจากการรวมกันของปัจจัยต่างๆดังนี้ สารอาหารในดิน การปกคลุมเรือนยอด ความลาดชันของพื้นที่ และสิ่งรบกวน ดังนั้นจึงทำการศึกษาลำดับของโมเดลต่างๆสำหรับไม้หนุ่มแต่ละชนิด โดยใช้วิธี Akaike’s Information Criterion (AICc) ในการเปรียบเทียบค่าน้ำหนักของแต่ละโมเดล พบว่าโมเดลที่สนับสนุนมากที่สุดในการคาดการณ์การเกิดไม้หนุ่มของแต่ละชนิดมีความแตกต่างกันและมีความแปรปรวน มีความสัมพันธ์เชิงบวกระหว่างไนโตรเจนในดิน ความลาดชันของพื้นที่ ความลึกของดินและการเกิดไม้หนุ่มของพืชวงศ์โปโดคาร์เปซีอีทุกชนิดที่สำรวจ ความสัมพันธ์ของฟอสฟอรัสในดินร่วมกับความลึกของดินมีความเหมาะสมมากที่สุดในการอธิบายการเกิดไม้หนุ่มของพญาไม้ ในทางตรงกันข้าม การเกิดไม้หนุ่มของพญาไม้จะลดลง เมื่อฟอสฟอรัสในดินเพิ่มขึ้น และยังพบว่าไม้หนุ่มของมะขามป้อมดงก็ลดลงเช่นเดียวกัน ในขณะที่ไม้หนุ่มของขุนไม้กลับเพิ่มขึ้น ความลึกของดินเป็นโมเดลที่สำคัญที่สุดสำหรับการคาดการณ์ของการเกิดไม้หนุ่มของต้นขุนไม้ แต่อย่างไรก็ตาม ไม้หนุ่มของมะขามป้อมดงนั้นมีโมเดลที่เหมาะสมที่สุดคือความเป็นกรด-เบส การวิเคราะห์ความแปรปรวนขนาดอนุภาคของดินกับตัวแปรต่อเนื่องแสดงให้เห็นความแปรปรวนของขนาดอนุภาคของดินขึ้นอยู่

กับค่าความเป็นกรด-เบสของดิน ฟอสฟอรัสในดิน ไฮโดรเจนในดินและความลึกของดิน ความสัมพันธ์ของความลาดชันในพื้นที่กับตัวแปรอิสระแสดงให้เห็นว่าความลาดชันในพื้นที่มีความสัมพันธ์กับฟอสฟอรัสในดินและไฮโดรเจนในดิน จากการศึกษาพบว่าแนวโน้มทั่วโลกที่เห็นได้ชัดก็คือพืชชั้นสูงครอบครองผืนป่าส่วนใหญ่ ข้อเสนอแนะก็คือควรมีการพลิกฟื้นผืนป่าโปโดคาร์เปซีอีขึ้นมา หากเป็นไปได้ควรเข้าไปปลูกต้นกล้าในผืนป่าและ/หรือการกำจัดเรือนยอดชั้นบนสุดลงบ้างเพื่อให้ต้นกล้าได้เจริญเติบโตและอยู่รอด

สาขาวิชาชีววิทยา
ปีการศึกษา 2557

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JEMIKA AKKARASADTHANON : FACTORS AFFECTING SIZE DISTRIBUTION, SEED GERMINATION, AND SEEDLING AND SAPLING SURVIVAL OF PODOCARPACEAE AT KHAO YAI NATIONAL PARK, THAILAND. THESIS ADVISOR : PAUL J. GROTE, Ph.D. 153 PP.

PODOCARPACEAE/KHAO KHIEW/*PODOCARPUS NERIIFOLIUS*/ *NAGEIA WALLICHIANA*/*DACRYCARPUS IMBRICATUS*/*DACRYDIUM ELATUM*/ SEEDLING/GERMINATION/SURVIVAL

The objectives of this study were to examine factors affecting seed germination, seedling (height<0.15 m) and sapling (height 0.15-1.35 m) survival of Podocarpaceae at Khao Yai National Park. There were four species of Podocarpaceae at Khao Khiew in Khao Yai National Park used for study, *Podocarpus neriifolius*, *Nageia wallichiana*, *Dacrycarpus imbricatus*, and *Dacrydium elatum*. The total area encompassed 20 hectares, with 70 systematically placed plots and 15 subjectively placed plots. It was found that the density of *P. neriifolius* was the highest, and the lowest was for *D. elatum*. Seed germination of *P. neriifolius* was detected in less than 50% in each successful subplot. It was found that cleared subplots showed seed germination and early seedling survival more than uncleared subplots. The positional relationship between *P. neriifolius* and *N. wallichiana* was positive. *N. wallichiana* and *D. imbricatus* were positive as well. It was expected that sapling occurrence is influenced by a combination of factors, including soil nutrients, canopy cover, local slope, and disturbance. Therefore series of candidate models for each species were tested. Akaike's Information Criterion (AIC_c) was used to compare the weight of evidence for each model. The most support for models of each species was different and variable. A positive relationship was found between soil nitrogen (N), local slope, soil depth and sapling occurrence of all species surveyed. The relationship of soil phosphorus (P) combined with soil depth had most support in explaining the occurrence of *P. neriifolius* saplings. In contrast, *P. neriifolius* sapling occurrence declined with increasing soil phosphorus. *D. imbricatus* also declined with increasing soil P, while *N. wallichiana* increased. For saplings of *N. wallichiana*, the depth of the soil was very important for prediction of sapling occurrence. However, *D. imbricatus* sapling occurrence was supported by the pH model. The analysis of variance of soil particle size with continuous variables indicated that variance of soil particle size depended on soil pH, P, H, and depth. The relationship of local slope with the independent variables showed that the local slope correlated with soil P and H. Given that the studied forest fits the apparent global trend for angiosperm ascendancy, this study suggests that manipulations will be required to restore podocarps. Possible interventions are planting seedlings and/or removing some canopy.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Podocarpaceae are a family of 17 genera and 122-165 species of conifers (division Pinophyta, order Pinales), consisting of evergreen trees or shrubs with scale, clawed, or flattened needlelike or broader leaves, usually with a single, undivided midvein (multiple veins in *Nageia*), distributed mainly in the Southern Hemisphere, but infrequently in the tropics (Eckenwalder, 2009). *Podocarpus* is by far the largest genus with the next largest genus being *Dacrydium*. The family is represented in Thailand by four genera, *Dacrycarpus*, *Dacrydium*, *Nageia* and *Podocarpus* with 7 species (Phengklai, 1975; Eckenwalder, 2009).

Trees of Podocarpaceae provide important ecosystem services, such as shade, habitat and food for birds and squirrels, and mitigate natural disasters, such as from flooding and storms. Furthermore, the timber of *Dacrycarpus imbricatus* (Bl.) de Laubenf. has been used for construction of houses. This species can be grown in plantations as it grows relatively fast. The benefits of *Dacrydium elatum* (Roxb.) Wall. ex Hook. are use as water resistant timber for boats, bridges and furniture construction. The resin is used for incense sticks. This species has potential as an ornamental tree. This genus may be a source of chemicals with insecticidal properties. Wood of *Nageia walichiana* (C. Presl) Kuntze is used for musical instruments, chopsticks, fine crafts and household tools. The leaves are used as a traditional cure for coughs. Because of its termite and water resistant wood, *Podocarpus neriifolius* D. Don is used for construction and other uses, including boat building. Trees of this species have attractive red new growth and are highly ornamental in character (Nguyen and Thomas, 2004).

Regeneration or the production of new generations of conifer trees requires the success of each step in the life cycle, including pollination, seed dispersal, seed germination and seedling survival. Seed germination and seedling establishment are the most vulnerable phases in plants life cycles (Solbrig, 1980), and information about them is especially important in understanding the distribution of rare plants. Seeds must be distributed to appropriate areas to allow sprouting of seedlings. The emerging seedlings must survive and grow to saplings and then to mature trees (Corlett, 2009). Carswell et al. (2007) investigated the factors related to the survival of seedlings of Podocarpaceae in New Zealand. They concluded that the best supported model to predict the survival and occurrence of seedlings of two podocarp species included all of the following factors: soil nutrients, canopy composition, land form index and disturbance type. A positive relationship was found between soil nitrogen (N) and seedling occurrence of all species studied. For two additional podocarp species the most important factors were soil nitrogen (N) and phosphorus (P) levels. The seedlings of podocarp species were found on soils with low soil P, but high soil N concentrations; the authors concluded that soil nutrient status should be taken into account during forest management (Carswell et al., 2007). In other studies in New Zealand, variation in mature conifer-angiosperm forest composition was linked to soil nutrients with greater podocarp dominance at lower concentrations of total P and higher total N concentrations, whereas soils of higher P concentrations are more likely to give rise to increased angiosperm dominance (Richardson et al., 2004; Coomes et al., 2005).

A study was made of shade tolerance of *Podocarpus latifolius* (Thunb.) R.Br. ex Mirb. in various forests in southern Africa. The results showed that *Podocarpus* regenerated in the well-shaded angiosperm forest more than angiosperms. Seedlings of angiosperms were present in the less shaded *Podocarpus* forest, whereas the conifer seedlings were suppressed by ginsses. Few seedlings of *Podocarpus* were found in the high light thicket environment (Adie and Lawes, 2009).

Nguyen and Thomas (2004) found that all the species of Podocarpaceae in Vietnam, which include the four species in the present study, regenerate in the shade, under the forest canopy. This differs from species of Pinaceae, including *Pinus merkusii* Jungh. & De vriese and *P. khesiya* Royal ex Gordon found in Thailand, which regenerates in open areas. Furthermore, it is important to know the potential for regeneration of conifers in the face of natural threats such as severe storms and seedling-attacking fungi, and human caused threats, including deforestation and climate change (Carswell et al., 2007).

There have been few studies of conifers in Thailand, other than *Pinus*. However, conifers are important species in their ecosystems as well as economically. Conifers provide the majority of the world’s construction timber, plywood, pulp, paper products, and are an important source of resin and an important source of food for animals (Nguyen and Thomas, 2004). The objective of this study is to investigate the factors affecting the distribution, seed germination and seedling survival of four species of Podocarpaceae in Thailand. In addition, this research can provide basic information useful for the conservation and management of Podocarpaceae in this area and education for those interested.

1.2 Research objectives

The objectives of the study were:

1.2.1 To examine factors affecting seed germination and survival of Podocarpaceae in the forest at Khao Yai National Park.

1.2.2 To examine factors affecting seedling and sapling survival of *Podocarpus neriifolius*, *Nageia wallichiana*, *Dacrycarpus imbricatus*, and *Dacrydium elatum* at Khao Yai National Park.

1.3 Research hypotheses

1.3.1 Seed germination and early seedling (height < 15 cm) survival are influenced by environmental factors including competition with other plants, and predation.

1.3.2 Sapling (0.15-1.35 m. height) survival is influenced by environmental factors including soil nutrients (nitrogen and phosphorus), and soil quality percentage, canopy cover, disturbance and landform.

1.4 Scope and limitation of the study

1.4.1 The study site was situated at Khao Khiew (Pha Diew Dai and the adjacent ridge) in Khao Yai National Park, Nakorn Nayok.

1.4.2 Four species of Podocarpaceae were studied: *Dacrycarpus imbricatus, Dacrydium elatum, Nagiea wallichiana* and *Podocarpus neriifolius*.

1.4.3 The study examined the following factors:

1.4.3.1 Size distribution of trees of Podocarpaceae (first year).

1.4.3.2 Environmental factors affecting seed germination and early seedling (<15 cm height) survival of Podocarpaceae, which were studied in the natural forest conditions, including ground cover and seed predation (second year).

1.4.3.3 Environmental factors affecting sapling (0.15 to 1.35 m. height) survival, including soil nutrient level and quality, percent canopy cover, disturbance, and local slope were examined at the sites (first year).

1.4.4 The field research was carried out over 2 years.

1.5 Expected results

This study will provide fundamental information on seed germination and seedling survival of trees of Podocarpaceae in Thailand, which can be used as a guideline for preparing the seedlings for reforestation and to use as a database for conservation, monitoring and management in the future.

CHAPTER II

LITERATURE REVIEW

2.1 Podocarpaceae

Podocarpaceae is a large family of mainly Southern Hemisphere conifers with scale or claw-like flattened or broader leaves. Reproductive organs are separate pollen cones and seed cones. Pollen cones are small to medium in size, single at tips of small branches or single or in clusters in the axils of leaves. Seed cones are single or clustered in the axils of leaves or at the tips of shoots. The mostly single seeds are folded in the epimatium (a modified seed scale) and wingless or plump (Eckenwalder, 2009).

The majority of conifer species are found in montane regions in temperate or subtropical latitudes, generally in areas of high rainfall. However, some species also occur in dry climates or in extremely cold areas close to the Arctic Circle. In the Northern Hemisphere, large areas of Europe, Asia and North America are dominated by only a few species; for example, *Pinus sylvestris* occurs from the west coast of Scotland almost as far as the eastern part of China and the former Soviet Union. The areas that lack conifers are either arid deserts or lowland tropical forests. Conifer diversity is greatest in the Northern Hemisphere in areas such as Mexico /southwestern USA and China/ Indo China (including Vietnam). The majority of these species belong to the families Pinaceae and Cupressaceae. On the other hand, the main families in the Southern Hemisphere are the Araucariaceae and Podocarpaceae. This division reflects ancient tectonic history and continental plate movements, especially over the last 65 million years (Figure 2.1).

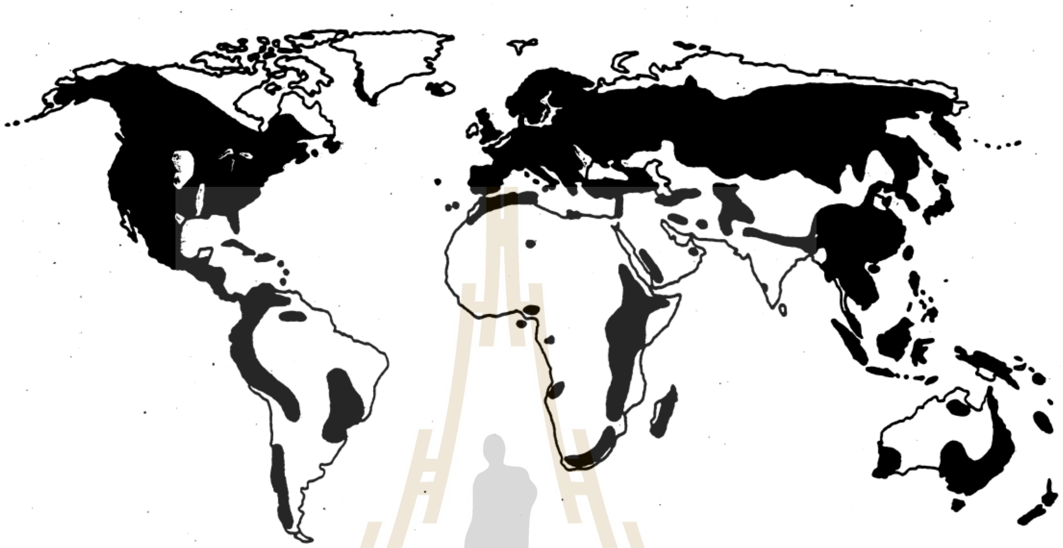

Figure 2.1 The global distribution of conifers. Source: Nguyen and Thomas (2004).

Most Podocarpaceae, which comprise about 122-165 species and 17 genera of evergreen trees and shrubs, are found in the Southern Hemisphere. The family is diverse in Australasia, particularly New Caledonia, Tasmania and New Zealand, and to a slightly lesser extent Malesia and South America. Several genera extend north of the equator into Indo-China and the Philippines. *Podocarpus* reaches as far north as southern Japan and southern China in Asia, and Mexico in the Americas, and *Nageia* into southern China and southern India (Farjon, 2008). Propagation of Podocarpaceae is shown in Tables 2.1. However, there are 4 genera, *Dacrydium*, *Dacrycarpus*, *Nageia* and *Podocarpus* in Thailand (Phengklai, 1975; Eckenwalder, 2009). Their characteristics are described below.

Dacrycarpus is a genus of conifers belonging to the podocarp family and consists of evergreen trees and shrubs to 55-60 meters in height. This genus has 9 species in northern Myanmar, southern China, Thailand, Malesia (Malaysia, Indonesia, Philippines, Papua New Guinea and East Timor and Brunei), New Caledonia, Fiji and New Zealand. The leaves are spirally distichous. Pollen cones are spherical to cylindrical, single at the tips of short axillary stalks or shoots. Seed cones are single at the tip of short leafy stalks in the axils of foliage leaves or at the ends of short shoots. Seeds are surrounded by a leathery black or brown seed scale covered with a thin, waxy film epimatium (Eckenwalder, 2009). Trees of *Dacrycarpus* are used in the production of lumber and provide habitat for birds. Fossils are found in Eocene sediments 40 million years old in southern South America and in southeastern Australia where the genus has become locally extinct (Eckenwalder, 2009).

Dacrycarpus imbricatus (Figures 2.2A and 2.3A) is the only species occurring in Thailand, found in Phitsanulok, Loei, Phetchabun, Nakorn Ratchasima, Nakorn Nayok and Trat provinces. The trees are scattered in evergreen forest at an altitude of 700-1,200 m. Cone production occurs in January to May and seed maturation in March to September (Phengklai, 1975).

Podocarpus is the most numerous and widely distributed genus of Podocarpaceae. The eighty two species of *Podocarpus* are evergreen, mostly dioecious trees or shrubs up to 25 m in height. This genus occurs in the tropics and southern temperate region, but also extends into the Northern Hemisphere. The leaves are 0.5-15 cm long, lanceolate to oblong, and falcate (sickle-shaped) in some species. Pollen cones are 5-10 mm long, often clustered several together. Seed cones have two to five fused scales, of which only one, rarely two, are fertile, each fertile scale with one apical seed. At maturity, the seed cones become brightly colored red to purple and fleshy, and are eaten by birds which then disperse the seeds in their droppings. The earliest known fossils of *Podocarpus* are from the Cretaceous. Most fossils are known from the far south (the former continent of Gondwanaland), but other fossils have been reported from eastern Asia and North America (Dilcher, 1969; Eckenwalder, 2009). Wood of *Podocarpus* is used for furniture (Eckenwalder, 2009).

The three species in Thailand are *P. neriifolius* (Figures 2.2B and 2.3B), *P. polystachyus* R.Br. ex Endl. and *P. pilgeri* Foxw. *Podocarpus neriifolius* is found in northern, northeastern, southeastern, and southern Thailand. The trees are frequent in evergreen forest at an altitude of 600-1,300 m. Cone production occurs in January to March, and seed maturation in March to June. *P. polystachyus* is known only from Phu Luang in Loei province. It is infrequently found in evergreen forest by streams on sandstone hills at an altitude of about 800 m. This species is often found in other regions at low elevations on granitic rocks along seashores, rivers or in mangrove swamps. *P. pilgeri* has only been reported from Trat province in hill evergreen forest, at an altitude of 1,000 m (Phengklai, 1975).

Table 2.1 Cutting propagation for Podocarpaceae in Vietnam.

Species	Source of materials	Time of collection	Age/D/H of mother tree	Position of materials	Length of cuttings, cm	Rooting hormone	Duration of rooting, month	Rooting rate, %
Dacrycarpus imbricatus	Northern Vietnam	February-October	3-4 years	Coppice	7-10	ABT	3	80
Dacrydium elatum	Central Vietnam	September	Height>8m	Coppice	10	IBA 300 ppm	NA	80
Nageia fleuryi	Northern Vietnam	August-September, February-April	NA	Coppice	10-15	ABT	NA	65-70
Podocarpus neriifolius	Northern Vietnam	August-October February-April	3-4 /years	Coppice	10	NA	NA	60-65

Note: D, diameter: H, stem height (H).
NA: not available
Source: Nguyen and Thomas (2004).

Nageia is a genus of 5 species, which includes evergreen shrubs and trees up to 54 meters in height. *Nageia* is distributed in southern and eastern Asia, from India, China, and Japan, to New Guinea (Eckenwalder, 2009). The species of *Nageia* are distinguished from other genera in the Podocarpaceae by their broad, flat sub-opposite and multi-veined leaves, with no midrib. Seed cones have several sterile and one (rarely two) fertile scales, each fertile scale with one seed. The cones remain unmodified or become fleshy. The seed coat develops a drupe-like fleshy covering 1-2 cm in diameter, which attracts birds, which then disperse the seeds in their droppings. The history of this genus is still not clear, as no recognized fossil has been reported (Eckenwalder, 2009). *Nageia wallichiana* trees are important for lumber (Eckenwalder, 2009).

Two species are known from Thailand, *Nageia wallichiana* (Figures 2.2C and 2.3C), which can be found in northern, northeastern, southeastern, and southern Thailand., and *Nageia motleyi* (Parl.) de Laubenf., known from Narathiwat. *N. wallichiana* occurs in evergreen forest from sea level to 2,000 m altitude, whereas *N. motley*i can be found in lowland tropical evergreen forests or swamp forests, usually at low altitudes (Phengklai, 1975).

Dacrydium is a genus with 21 presently recognized species of evergreen dioecious trees and shrubs. Distribution of *Dacrydium* is in Asia and southeastern New Zealand. The leaves are either scale-like or variously awl-shaped. *Dacrydium* pollen cones are egg-shaped to cylindrical. Seed cones are at or near the tips of branchlets, one or several bearing a solitary reversed ovule seated in a cup-shaped aril (Eckenwalder, 2009). Fossils are known from the Eocene, 45 million years old, to the Miocene, 20 million years ago, in Australia. Pollen of *Dacrydium* has been recorded from the Paleocene to the Pliocene (56 to less than 5 million years ago) of Australia and from the Pliocene of New Guinea (Eckenwalder, 2009). The wood of *Dacrydium elatum* is used to make cabinets and masts. Resin is used for torches and incense sticks, and oil is used in traditional medicine (Eckenwalder, 2009).

One species is widespread in Thailand, *Dacrydium elatum* (Figures 2.2D and 2.3D). The trees are found along streams in lower montane forests at an altitude of 1,000-1,300 m. Cone production occurs in January to February, and seed maturation, in August to September (Eckenwalder, 2009).

The four podocarp species in this study are among the 32 species of conifers occurring in Vietnam. In Vietnam, these four species were found to occur in the following environments. *Dacrycarpus imbricatus* occurs in evergreen sub-tropical rain forest mainly on deep fertile soil, in a monsoon tropical climate, with a mean annual temperature of 21-26 degrees Celsius and annual rainfall above 1,500 mm. The regeneration of *D. imbricatus* can occur under the forest canopy, in the shade. *Dacrydium elatum* occurs at an altitudinal range of 700-2,000 m in subtropical rainforest on slopes and ridges on either granite or limestone derived soils, with a monsoon tropical climate, mean annual temperature of 19-24 degrees Celsius, and annual rainfall greater than 1,700 mm. Regeneration was occasional for *D. elatum*. *Nageia wallichiana* was found at altitudes of 700-2,100 m, in evergreen subtropical forests, usually montane, on granite derived soil. The climate was tropical monsoon, with a mean annual temperature of 20-26 degrees Celsius and annual rainfall above 1,700 mm. Associated with *N. wallichiana* were *Dacrycarpus imbricatus* and *Podocarpus neriifolius*. *Podocarpus neriifolius* occurred at 600-1,500 m in altitude in evergreen subtropical rain forest mainly on deep fertile soil. The climate was monsoon tropical, with a mean annual temperature of 21-26 degrees Celsius and annual rainfall above 1,500 mm. Associated with *P. neriifolius* were almost all species of conifer except two *Pinus* species and *Pseudotsuga*. Natural regeneration occurred in shaded areas (Nguyen and Thomas, 2004).

Adie and Lawes (2009) studied the relative amount of regeneration of *Podocarpus latifolius* and angiosperms in forests of South Africa. In well-shaded angiosperm forests, seedlings but not saplings of angiosperms were observed, indicating a failure in regeneration of the angiosperms. However, all size classes of regenerating *P. latifolius* plants were found. In the less shaded *Podocarpus*-dominated forest, the forest floor was covered with grass which suppressed most regeneration of *P. latifolius*. Both *P. latifolius* and angiosperms grew in the forest gaps. Few *P. latifolius* seedlings were found in the open, well-lit thickets. The authors concluded that regeneration of shade tolerant conifers such as *P. latifolius* is favored in shaded and infrequently disturbed forest sites (Adie and Lawes, 2009).

A B

C D

Figure 2.2 Species of Podocarpaceae occurring on Khao Khiew. A: *Dacrycarpus imbricatus*, B: *Podocarpus neriifolius*, C: *Nageia wallichiana*, and D: *Dacrydium elatum*.

Figure 2.3 Branchlet with a seed cone of *Dacrycarpus imbricatus* (A), *Podocarpus neriifolius* (B), *Nageia wallichiana* (C) and *Dacrydium elatum* (D) Source: Nguyen and Thomas (2004).

2.2 Seed dispersal and germination and seedling survival of Podocarpaceae

An essential process in the life cycle of plants that determines migration patterns and affects whether seeds can germinate and survive to produce the next generation is seed dispersal (Chanthorn and Brockelman, 2008). Seeds are dispersed by animals themselves or as part of the intact seed cones (Eckenwalder, 2009). Willson et al. (1996) studied frugivory and seed dispersal of *Podocarpus nubigenus* Lindley in Chiloe, Chile, and reported that Austral thrushes (*Turdus falckandii*) were the predominant agent of seed dispersal, carrying about half of the seeds at least three tree-crowns away from the parent tree, and Chilean pigeons (*Columba araucana*) virtually always dropped seeds below the parent tree. Frugivorous birds were found to disperse seeds of *Dacrycarpus dacrydioides* (A.Rich.) de Laub., which were extremely common in the fruiting season of Kahikatea forest in South Westland, New Zealand (Robertson and Hackwell, 1995). Nguyen and Thomas (2004) reported that all the species of Podocarpaceae in Vietnam, including the four species also found at Khao Khiew, had seeds dispersed by birds.

A seedling is a young sporophyte plant developing out of a plant embryo from a seed (Raven et al., 2005). The results of Minore (1986) showed that conifer seed survival and growth did not differ significantly between habitat types such as among humus treatments. Germination in the greenhouse allowed better survival and growth than in natural forest regeneration because of the difficulty in protecting from animal predation (Minore, 1986). Nguyen and Thomas (2004) reported that seedlings of Podocarpaceae are shade tolerant; however, older trees require more light than the seedling (Table 2.2). In general, conifer species appear to be adapted to growth on infertile and poorly drained soils, where there is less competition with angiosperms (Coomes et al., 2005).

In a study of four species of Podocarpaceae plus one common angiosperm species in New Zealand (see 3.2), factors found to be involved in regeneration were soil nutrients (phosphorus and nitrogen), canopy composition, landform index and disturbance. Podocarp seedlings preferentially grew in soils with low phosphorus and high nitrogen content. The above factors could be used to predict seedling occurrence (Carswell et al., 2007).

Table 2.2 Ecology of Podocarpaceae in Vietnam.

Number	Species	Altitude range,(m)			Soil type[a]			Climate			Regeneration	
		0-700	700-1500	>1500	Lime stone	Well Drained	Water logged	Mountain	Cold winter	Warm winter	Open	Shade
1	*Dacrycarpus imbricatus*	X	X X			X			X	X		X
2	*Dacrydium elatum*	X	X X	X	X	X		X	X	X		X
3	*Nageia Fleuryi*	X	X X		X				X			X
4	*Nageia wallichiana*		X X	X		X		X	X	X		X
5	*Podocarpus neriifolius*	X	X X			X		X	X			X
6	*Podocarpus pilgerii*	X	X X		X				X			X

[a] Soil type: - limestone: humic soil on limestone, - drained soil: usually ferralite derived from granite or basalt materials, - waterlogged: seasonally waterlogged soil.

Source: Nguyen and Thomas (2004).

2.3 Studies of Podocarpaceae and other conifers in Thailand and nearby regions

Studies of conifers for the Flora of Thailand project were done by Phengklai who reported 11 species of conifers: two species of Pinaceae (Phengklai, 1972a), one species of Cephalotaxaceae (Phengklai, 1972b), one species of Cupressaceae (Phengklai, 1972c), and seven species of Podocarpaceae (Phengklai, 1975).

Santisuk (1997) studied the geographical and ecological distributions of the two tropical pines, *Pinus kesiya* Royle ex Gordon and *Pinus merkusii* Jungh. & de Vriese, in Southeast Asia, including Thailand. *P. kesiya* occurs in lower montane pine-oak forest in Thailand and grows well on mountain ridges and slopes with granitic soil types. *P. merkusii* can be found in pine-deciduous dipterocarp forests on mild slopes in rolling hills with sandy, gravelly, or lateritic soils. *P. kesiya* also occasionally occurs in pine-deciduous dipterocarp forests. Both species are often found in non-calcareous soils. Both *P. kesiya* and *P. merkusii* are found in pine-oak savannas on flat-topped sandstone mountain tops. In Thailand, *P. kesiya* grows optimally above 1,000 m, while *P. merkusii* appears to grow optimally at less than 1,000 m altitude.

Suwanpatra (2006) reported *Dacrydium elatum*, *Dacrycarpus imbricatus*, *Nageia wallichiana* and *Podocarpus neriifolius* from Khao Khiew Peak in Khao Yai National Park. He studied cambial activity in ten trees of *P. neriifolius* and found activity throughout the year. The soils in the area were classified as clay and loam types, with high percentages of sand. They were considered to be low in fertility.

2.4 Environmental factors on seedling survival and occurrence of Podocarpaceae

Major influences of soil nutrients, canopy composition, landform index and disturbance have been well documented for many species of Podocarpaceae. The above factors could be used to predict seedling occurrence (Carswell et al., 2007).

2.4.1 Soil nutrients

Nutrient concentration and contents for individual species differs from biomass because species with a low number of plants or a low amount of biomass can still have a large impact on the ecosystem. Different understory species uptake varying amounts of individual nutrients (VanderSchaaf et al., 2004). Coniferous plants have long been regarded as requiring relatively small quantities of nutrient salts and as being quite tolerant of soils characterized by low levels of available nutrients (Carswell et al., 2012). Nitrogen (N) and phosphorus (P), either individually or in combination, limit primary productivity in most terrestrial ecosystems, and investment by plants in acquisition of these soil nutrients can have important implications for plant growth and nutrient dynamics. Traditionally, inorganic N compounds (i.e., ammonium and nitrate) have been regarded as the principal N sources for plants. Several studies have shown that a range of plant species, including conifers, can take up organic N, notably a range of amino acids (Öhlund and Näsholm, 2001). P is essential in photosynthesis because it is an important component of nucleic acids, proteins and triose phosphate, the starting component of the Calvin cycle. Although there have been fewer studies investigating the importance of phosphorus, as compared with nitrogen, to photosynthetic capacity, a clear correlation has been observed between photosynthesis and the foliar concentration of phosphorus, particularly in conifers (Carswell et al., 2005). Plants can obtain P through the manufacture of enzymes that mineralize organic P in the soil, through the cultivation of associations with mycorrhizal fungi, or through the production of P-carrier enzymes in roots. Likewise, nitrogen can be acquired through N-carrier enzymes. In addition, root production increases the foraging capacity for several nutrients, including N and P. Each option demands distinct levels of investment of carbon (C), nitrogen, or phosphorus, and each has its own potential consequences for nutrient cycling (Treseder and Vitousek, 2001). C and N in soils are bound together in organic matter and the accumulation of C and N in forest soil organic matter occurs through the same mechanism, i.e., production of dead organic matter and microbial turnover (Gurmesa et al., 2013).

There is evidence that conifers are "ecosystem engineers" that alter habitats to their own favor: the tough, fibrous leaves of conifers are slow to decompose (Hoorens et al., 2010), resulting in the accumulation of organic matter within soils, which increases soil C:P and N:P ratios and affects the community structure of soil microflora. Conifers form symbiotic relationships with mycorrhizal fungi, providing the decomposers with sugars such that they are no longer carbon limited. In return, the conifers gain access to otherwise inaccessible forms of N and P (Wardle et al., 2008). However, many researchers have emphasized that excess N in forest ecosystems reduces tree vitality (Hüttl and Frielinghaus, 1994) because of accelerated soil acidification, reductions in the mineral elements essential for plant growth, and nutrient imbalances in trees (Nakaji et al., 2001).

2.4.2 Canopy composition

Canopy cover (Avery and Burkart, 1994) is defined as the percent forest area occupied by the vertical projection of tree crowns. It is also referred to as crown closure, crown cover and canopy closure. Canopy cover is commonly used as a measure of stand density and is often used as an important indicator of wildlife habitat. Canopy cover data can also be used for predicting woody plant composition, tree volume, or potential forage production, and for the evaluation of forest pest damage (O'Brien, 1989). Field and photographic methods for estimating canopy cover include stem and crown mapping, line intercept transects, visual estimation, moosehorns, and densiometers. Of these methods, stem and crown mapping is probably the most accurate, but it is expensive. Visual estimation is simple, but often biased. Densiometers are relatively simple to use, but biased (Cook et al., 1995). Densiometers and moosehorns are inconsistent among observers (Vales and Bunnell, 1988). The most prevalent method for estimating canopy cover is through aerial photointerpretation (Avery and Burkart, 1994).

Canopy trees play a central role in forest ecosystem processes such as net primary productivity, hydrology and nutrient cycling. They also moderate the forest microclimate and form the trophic and structural template that supports a diversity of forest biotic communities. “Mixed” forests, in which two or more tree species are prominent in the canopy, are often considered to have greater productivity. Early successional forest canopies are dominated by shade-intolerant species, whereas later in-succession shade-tolerant species (typically the conifers) gain prominence in the canopy (Cavard et al., 2011). Wardle (1991) reported that New Zealand conifer-angiosperm forests are often composed of emergent Podocarpaceae conifers above a broadleaved angiosperm canopy. As with many conifer-angiosperm forests at similar latitudes in both hemispheres, conifer persistence has sometimes been likened to a “tortoise” in that the species are thought to grow more slowly than their angiosperm counterparts but live longer, especially in harsher conditions (Carswell et al., 2012).

2.4.3 Local slope

Local slope remains the most commonly used measure of site quality by practicing foresters. Slope aspect also affects forest productivity due to its influence on solar radiation and microclimate, but aspect alone does not completely explain the variability in productivity across a landscape. The predominant distribution of conifers tend to be found on the most infertile sites, generally on upper slopes, ridges, or on the poorly drained mid-altitude plateaus where the P concentration was lower (Burns and Leathwick, 1996). Infertility of ridge top and upper slope soils can be understood as a result of the weathering and leaching of stable soils on interfluves, a region between the valleys of adjacent watercourses. However, conifers are also implicated in making soils more infertile through their acid, moor-forming litter. The distribution of conifers on infertile soils may therefore act in a "positive feedback" manner by decreasing soil fertility further, or by maintaining low soil fertility, making it more likely that these sites will be recolonised by conifers (Burns and Leathwick,1996).

2.4.4 Disturbance

Disturbances can be divided into major and minor events. A major disturbance is defined as one that kills practically all trees in a stand, while a minor one kills single trees or a group of trees (Oliver and Larson, 1990). Extensive fires and insect outbreaks, windstorms and large clear-cuts are examples of major disturbances. They promote recruitment of new even-aged cohorts. Minor disturbances are windthrows, fires, insect attacks, browsing and selective cuttings. Regeneration in canopy openings (gaps) leads to multi-aged stand structures (Adrian et al., 2009).

In mixed angiosperm-conifer forests worldwide, infrequent landscape-level catastrophic disturbances create a mosaic of persistent and different aged forest stands in the landscape with varying levels of dominance by the conifer component. In the ‘temporal stand replacement model’ (TSRM), disturbance creates conditions favouring a colonising cohort that is replaced by a suite of relatively shade-tolerant canopy species, which establish following the synchronous senescence of the pioneer canopy. The essential components of the TSRM are infrequent landscape-level disturbance causing synchronous establishment of long-lived pioneers, subsequent canopy senescence and gap formation, and declining opportunities for regeneration by the first generation species in favour of more shade-tolerant species (Ogden et al., 2005). Tree regeneration occurring inside canopy gaps after a disturbance has been studied worldwide. Canopy senescence is another key element of the TSRM because the resultant gap creation facilitates the establishment of a relatively shade-tolerant suite of species, which replaces the colonising cohort in the absence of further catastrophic disturbance (Ogden et al., 2005). Shade-tolerant conifers will succeed against angiosperms in forests where gaps are small, in well-shaded forest environments or on infrequently disturbed sites has received little support. Growth prior to gap formation confers a competitive advantage on shade-tolerant species over faster growing species in tree-fall gaps (Adie and Lawes, 2009), but any advantage to shade-tolerant conifers will be neutralised if associated angiosperms are equally shade-tolerant (Midgley et al., 1990). The conifer *Podocarpus latifolius* was well represented by all size classes beneath the intact angiosperm-dominated canopy indicating continuous regeneration and confirming its status as a shade-tolerant species (Everard et al., 1994). Angiosperm regeneration was poor in well-shaded angiosperm forest environments and in gaps. Although seedlings of certain angiosperm canopy species established in angiosperm forest, pole-sized individuals were rare. Incident light was highest in canopy gaps in both angiosperm and *Podocarpus* forest. An increase in light availability generally has a positive effect on seedling growth and survival. Yet, neither *P. latifolius* nor angiosperm canopy species regenerated abundantly in these high light environments. However, seedlings of some light demanding-species of podocarp have been observed to regenerate in canopy opened areas that were artificially disturbed by fire, grubbing, thinning or partial cutting (Malcolm et al., 2001).

CHAPTER III

MATERIALS AND METHODS

3.1 Study sites

This study was carried out on Khao Khiew (Pha Diew Dai and the adjacent ridge located on Khao Kiew) in Khao Yai National Park, central Thailand (101°22' E and 14°26'N, 1129 m in altitude), in Nakhon Nayok province (Figures 3.1 and 3.2).

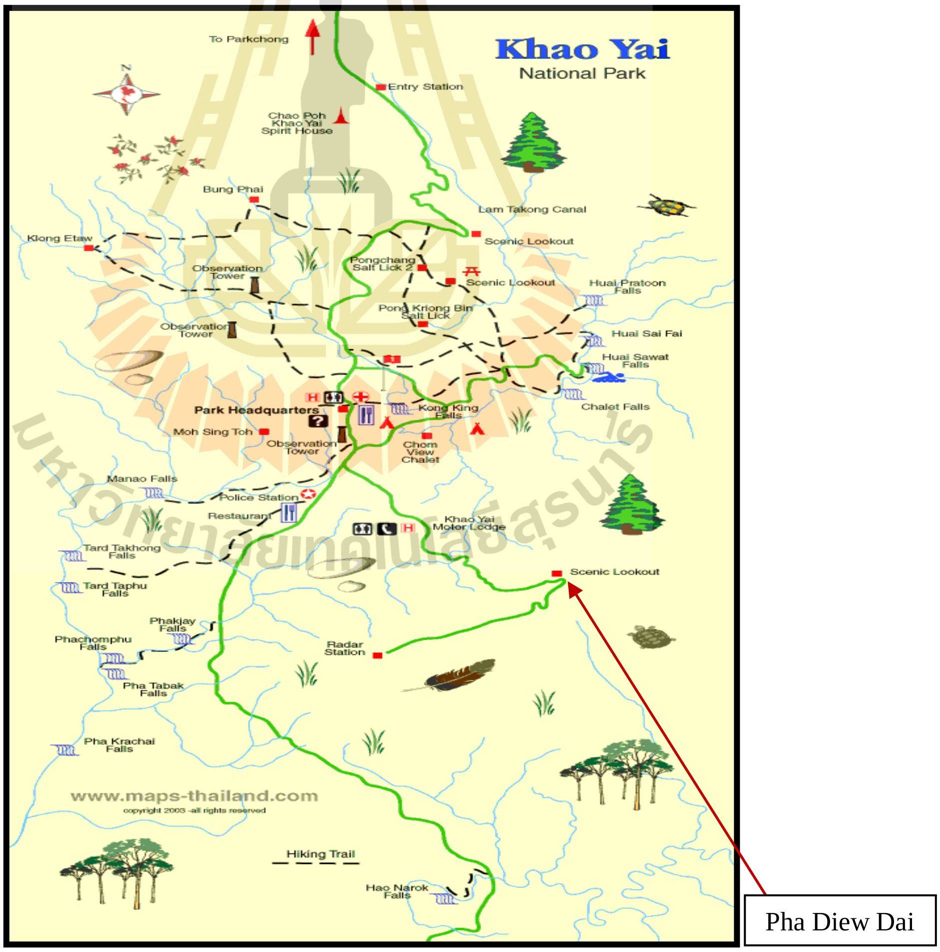

Figure 3.1 Khao Khiew at Khao Yai National Park. The arrow shows site at Pha Diew Dai (Guide to Thailand, 2012).

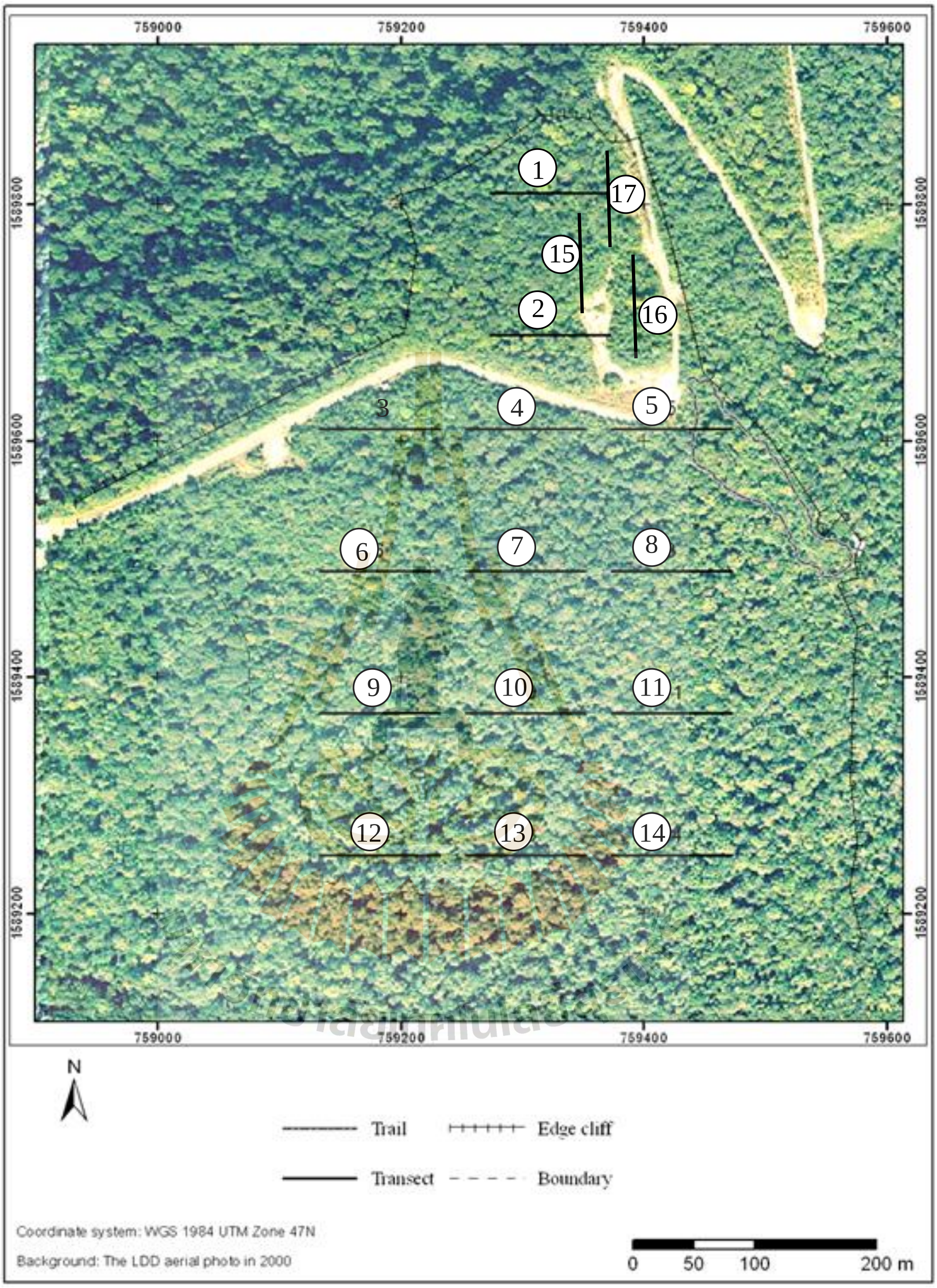

Figure 3.2 Geographical study site showing arrangement of intercept and 14 transects. The subjective were 3 transect (number 15,16 and 17).

Pha Diew Dai reaches an altitude of around 1,129 meters above sea level (Department of National Parks, Wildlife and Plant Conservation, 2008). Khao Khiew has average relative humidity of 89.85 percent, an average temperature of 21.8 °C and the rainfall throughout the year 2010 was 4,444.75 mm. The rock type at Pha Diew Dai is sedimentary and classified as part of the Phra Wihan Formation, Korat Group, from the Jurassic-Cretaceous period (Suwanpatra, 2006). This area is a tropical lower montane seasonal evergreen forest. Dipterocarpaceae is not present at all, but conifers are found, such as *Podocarpus neriifolius* D. Don (Pha ya mai), *Nageia wallichiana* (C. Presl) Kuntze (Khun mai), *Dacrycarpus imbricatus* (Blume) de Laub. (Phaya ma kham pom), and *Dacrydium elatum* (Roxb.) Wall. ex Hook. (Son sampun pee). Other trees include *Syzygium gratum* (Wight) S.M. Mitra (Samet daeng), *Quercus brandisiana* Kurz (Ko ta kwai) and *Quercus kerrii* Craib (Ko ta moo noi) (Fagaceae), *Cinnamomun iners* Reinw. ex Blume (Aob chei) (Lauraceae), *Schima wallichii* Korth. (Ta lo) (Theaceae), *Anneslea fragrans* Wall. (Saraphi pa) (Pentaphylacaceae) *Cedrela toona* Roxb. (Yom haom) (Meliaceae), and *Pandanus* sp. (Pandanaceae). The ground flora includes herbaceous plants, ferns and the terrestrial orchid *Spathoglottis eburnea* Gagnep. In addition, several types of moss occur along streams (Foundation for Khaoyai National Park Protection, 2010; Grote, personal communication, 2015).

3.2 Study species

Podocarpaceae species were studied at Khao Khiew, including Pha Diew Dai, at Khao Yai National Park. There are four species of Podocarpaceae as present in Table 3.1.

Table 3.1 Summary of study species at Khao Khiew in Khao Yai National Park.

Species	Common name	Where found in Khao Khiew
Dacrydium elatum	Son Samphan Pee, Son hang Krarok, Chuang Pha	The adjacent ridge and Pha Diew Da mixed angiosperm conifer evergreen closed canopy forest
Dacrycarpus imbricatus	Makhampom Dong	Pha Diew Dai mixed angiosperm conifer evergreen closed canopy forest
Nageia wallichiana	Khun Mai	Pha Diew Dai mixed angiosperm conifer evergreen closed canopy forest
Podocarpus neriifolius	Phaya Mai	Pha Diew Dai and the adjacent ridge mixed angiosperm conifer evergreen forest, young trees in open area with shallow, sandy soil

3.3 Size-frequency distributions

Size-frequency distributions were determined to survey the trees of Podocarpaceae within a 10 meter radius surrounding seventy systematically arranged plots. All the trees of Podocarpaceae were mapped (location, altitude, slope) and the diameter at breast height (dbh) was measured in an area of a radius of ten meter around each of the seventy systematic plots. The height of a tree and DBH were measured followed this equation:

Height of tree = (Tan angle of elevation x distance to tree) + height of eye above ground

For DBH, the circumference of the tree's trunk was measured at a height of 1.3 m. The circumference was then divided by pi. The size-frequency distributions graphs were made according to Enright (1995).

3.4 Seed germination and early survival

Effects of competition with other plants and seed and seedling predation on seed germination and early seedling survival were tested with *P. neriifolius* germination in situ in a conifer-angiosperm forest at Pha Diew Dai. *P. neriifolius* produces many seeds most years compared to the other three species. The ripen seeds of *P. neriifolius* were collected from Pha Diew Dai during July-August. Seeds that fell near the trees which were fully ripen, were selected. These seeds were chosen because they had complete aril, red color, indicating that they were good seeds and could germinate well. At the experimental site, an area of 1 m x1 m was cleared of the ground plants (ferns and herbs). An adjacent area of 1 m x 1 m was left un-cleared (control). Ten seeds of *P. neriifolius* were distributed uniformly within a 30 cm x 20 cm marked area in the center of the cleared and control plots (Adie and Lawes, 2009). The procedure was repeated at each site to control for seed predation and seedling herbivores by placing mesh enclosures (30 cm x 20 cm x 10 cm heights) over a second set of cleared and control plots, each with 10 seeds. Six plots (each with four 1 m x 1 m subplots) were randomly positioned in the forest of Pha Diew Dai in May (time of seed maturation, personal observation). Seed germination and seedling success was sampled in August and November in two years (Table 3.3). Establishment of *P. neriifolius* was analyzed using a repeated measures randomized block design ANOVA with the sites as blocks (Adie and Lawes, 2009).

3.5 Sapling survival

Saplings 15 to 135 cm in height) were surveyed to indicate regeneration at the study site of Khao Khiew at Khao Yai National Park. The study site included Pha

Diew Dai and the adjacent ridge with an area of 400 by 500 m. The size of the site is limited by cliffs. Transects were selected for sampling in the site. Fourteen transects were arranged in the site in a grid of 120 m x 80 m rectangles. Part of the study site consists of steep cliffs and was excluded. A transect length was 100 m oriented parallel to each other, and began on each intersect. Seedling plots of 2 m radius were positioned at 25 m intervals along each transect. Additionally, three more transects were measured with the positions placed subjectively to maximize the number of seedling in the plots. Five seedling plots were positioned subjectively along each of these transects (Carswell et al., 2007).

In each sapling plot, saplings (> 0.15m and < 1.35m in height) of *Dacrydium elatum*, *Dacrycarpus imbricatus*, *Nageia wallichiana* and *Podocarpus neriifolius* were counted. The definition of seedlings used by Carswell et al. (2007) was: plants up to 1.35 m in height. However, in the present study these plants are referred to as saplings. Densities of saplings of the four study species were calculated from the data. Environmental parameters that are considered to possibly influence sapling survival were measured.

3.5.1 Percentage of total canopy cover

Percentage of total canopy cover above 1.35 m in height was measured along a 4 m line (north to south) in each plot.

3.5.2 Local slope

For each of the seedling plots, mean-scale local slope was measured, indicating whether the plots are ridges, gullies, or slopes (Carswell et al., 2007). Flat plots were defined as having a slope of 10 degrees or less, low slope plots with a slope greater than 10 up to 45 degrees, and high slope plots with a slope greater than 45 degrees.

3.5.3 Soil sampling and analysis

In each transect, soil samples of 500 g at 0-30 cm depth, were collected in a plastic bag for analysis.

The soil samples were carried back to the Center for Scientific and Technological Equipment 2 (F2 building), Suranaree University of Technology, where various analyses were conducted. In the laboratory, the soil samples were dried indoors under laboratory conditions for 24 hours. The soils were crushed using a pestle and mortar and filtered with a 2 mm sieve, rejecting roots and stones to give the fine earth fraction. Then an analysis was conducted in the following steps:

1) Soil pH was measured by pH meter. Ten grams of soil was dispensed to water (1:1). The soil was stirred and slurry was set. The pH was monitored using a pH meter (Mettler-Toledo MP220, Schwerzenbach, Switzerland).

2) Carbon, hydrogen, and nitrogen were analyzed with Leco CHN-628 analyzer. Soil samples were dried at 105 °C for one hour prior to analysis. The 0.2 g of the soil was weighted into a 502-186 Tin Foil Cup and seal. The samples were then transferred to the analyzer (Leco CHN-628, LECO Corporation, MI., U.S.A.).

3) Phosphorus was measured using inductively coupled plasma (ICP) spectroscopic methods. Soils were dried at 35 ºC and ground to pass a 2.0-mm screen. Two grams of dried, ground soil were extracted with 20 ml of M3 extracting solution (0.2M CH_3COOH, 0.25M NH_4NO_3, 0.015M NH_4F, 0.013M HNO_3, and 0.001M EDTA) for 5 minutes at 200 reciprocations per minute on an end-to-end Eberbach shaker. The mixture was filtered using P4 filter paper (Fisher Scientific,

Pittsburgh, PA). The same filtrate was analyzed spectroscopically (ICP-P) using a Spectra CirOs Inductively Coupled Argon Plasma Spectrometer (Spectra CirOs, ICAP, Fitchburg, MA) for M3P at 178.2 nm (Pittman et al., 2005).

4) Soil particle size was measured using the hydrometer method. Briefly, pre-treatment for soil high in organic matter was carried out using hydrogen peroxide (30%). Fifty grams of soil (dry weight equivalent) were placed into a soil dispersing cup. The weight was recorded to at least 0.1g. The cup was filled with distilled water to within two inches of the top and 5 ml of 1*N* sodium hexametaphosphate was added. The cup was then attached to a mixer and mixed for 5 minutes. Suspension was transferred to a sedimentation cylinder, distilled water was added to the cylinder to 1000-mL mark, and the suspension was mixed with a plunger. The hydrometer was carefully placed into the suspension and read at 40 seconds. After removing the plunger, timing began. The temperature (°C) was recorded. The suspension was mixed again and timing began for the two-hour reading. The hydrometer was read at 2 hours, followed by a temperature reading. A blank cylinder was made up with water and sodium hexametaphosphate. Calculations of soil particle size were determined as follows;

A). Temperature correction factor, **T** (may be different for each reading):

T = (Observed temperature -20 °C) * 0.3

B). Corrected 40-second reading:

40-sec(c) = 40-sec - Blank + **T**

C). Corrected 2-hour reading:

2-hr(c) = 2-hr - Blank + **T**

D). $$\% \text{ Sand } (2 - 0.05\,\text{mm}) = \frac{(\text{OD soil wt.}) - (\text{corr. 40 sec reading})}{\text{OD soil wt.}} * 100\%$$

[OD (oven dried)]

E). $$\% \text{ Clay } (< 0.002\,\text{mm}) = \frac{\text{corr. 2 hr reading}}{\text{OD soil wt.}} * 100\%$$

F). % Silt (0.05 - 0.002 mm) = 100% - (% sand + % clay)

Textural class was determined from the textural triangle (Figure 3.3)

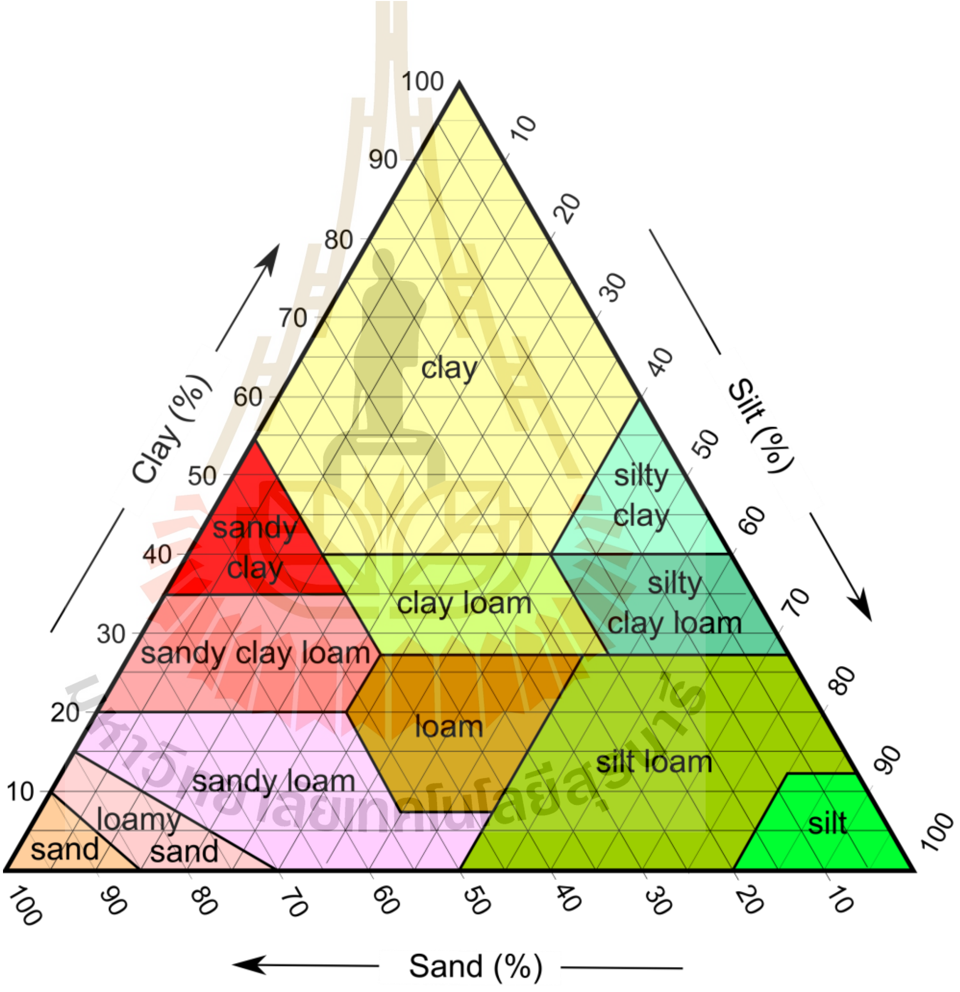

Figure 3.3 Soil textural triangle (Source: US Department of Agriculture).

5) Soil depth was also measured using rod penetrometer.

3.5.4 Categories of disturbance

Three categories were used to describe disturbance: 1) no disturbance (10% or less of the plot area showing evidence of disturbance; 2) disturbance caused by humans (more than 10% of the plot), such as cutting trees for trail construction; 3) natural disturbance, e.g., more than 10% of the plot consisting of treefalls or landslides (Carswell et al., 2007).

3.5.5 Air temperature

Air temperature was measured at each plot site. Detailed weather information was obtained from the weather station at the summit of Khao Khiew.

3.5.6 Density of *Syzygium gratum*

Syzygium gratum is a dominant competing angiosperm tree species at Pha Diew Dai but absent from the ridge. This species is found in wetter soil. For each seedling plot, the distance to the nearest *Syzygium gratum* tree was measured. The distance of the nearest tree to a plot was measured. A tree less than 10 meters was classified as present, and trees more than 10 meters were classified as absent.

3.6 Data analysis

3.6.1 Seed germination and early seedling survival at Pha Diew Dai

Germination and seedling survival of *P. neriifolius* were analyzed using ANOVA with the sites as blocks (Adie and Lawes, 2009).

3.6.2 Sapling survival at Khao Khiew

A Chi-square contingency test was used to determine possible spatial correlations between pairs of saplings of the four podocarp species. For example *Nageia wallichiana*, and *Podocarpus neriifolius* appear to occur together at the study site. In addition, a series of models with various combinations of predictor variables were proposed, using generalized linear mix effects models (GLMM) with a binomial distribution, using maximum likelihood. The R version 3.1.2 statistical package was used (Venables and Smith, 2010; Mathiopoulos, 2011). The majority of plots lacked podocarp saplings, so the models used presence/absence data (binomial data). Data from systematic plots were used, but individual analyses were made for each species (Carswell et al., 2007).

Based on the literature (Ogden and Stewart, 1995; Coomes et al., 2005; Carswell et al., 2007; Adie and Lawes, 2009), we expect that sapling occurrence is influenced by a combination of factors, including soil nutrients, canopy cover, landform index and disturbance. Therefore series of candidate models for each species were tested (Table 3.2). Akaike's Information Criterion (AIC_c) was used to compare the weight of evidence for each model, using R version 2.13.1 (Carswell et al., 2007). The probability of sapling occurrence in relation to various parameters was analyzed. Sapling survival of each group, average values with SEM (Structural Equations Modeling or regression analysis) were analyzed using ANOVA with the sites as blocks (Adie and Lawes, 2009). A probability values < 0.05 of Tukey's HSD (Tukey Honestly Test) Post Hoc Test denoted the presence of a statistical difference.

Curves were fitted using binomial regression. Additionally, correlations between the environmental variables were analyzed using Pearson's correlations for continuous predictor variables and analysis of variance (ANOVA) for categorical variables (Carswell et al., 2007).

Table 3.2 Candidate models for describing relationships between sapling occurrence and environmental factors in a conifer-angiosperm forest on Khao Khiew at Khao Yai National Park.

Model terms	Justification
Soil N+P	The balance between N and P may be an important predictor of regeneration success of conifers (Coomes et al., 2005; Carswell et al., 2007).
Each nutrient individually (N, P, C, H)	Some New Zealand podocarp species appear to be sensitive to individual nutrients (Carswell et al., 2007).
% Canopy cover	Some podocarp species regenerate after catastrophic disturbances that reduce canopy cover, and podocarp species are thought to exhibit a range of shade tolerances (Carswell et al., 2007; Adie and Lawes, 2009).
Soil particle size	Important factor related to seedling survival.
Soil carbon	Important factor related to seedling survival.
Soil pH	Important factor related to seedling survival.
Soil depth	Important factor related to seedling survival.
Density of *Syzygium gratum*	A dominant angiosperm tree species at Pha Diew Dai but absent from the ridge. This species is found in wetter soil.

Table 3.2 (Continued) Candidate models for describing relationships between sapling occurrence and environmental factors in a conifer-angiosperm forest on Khao Khiew at Khao Yai National Park.

Model terms	Justification
Three categories of disturbance: 1) none, 2) human disturbance, and 3) natural disturbance	Saplings of some podocarp species have been observed to preferentially regenerate in disturbed logging areas; evidence of past human disturbance may indicate past canopy openings (Carswell et al., 2007).
Local slope	Adult podocarp trees show a tendency of growing on mid-slope to ridge positions (Ogden and Stewart, 1995; Carswell et al., 2007).
Full model	Podocarp sapling distributions are influenced by all the above variables.
Null	Podocarp sapling distributions are random with regard to the above variables.

CHAPTER IV

RESULTS

4.1 Podocarpaceae species found at Khao Khiew in Khao Yai National Park

There were four species of Podocarpaceae at Khao Khiew in Khao Yai National Park used for study in this thesis, which were *Dacrycarpus imbricatus*, *Podocarpus neriifolius*, *Nageia wallichiana*, and *Dacrydium elatum* (Figures 4.1 and 4.2).

Figure 4.1 *Dacrycarpus imbricatus* (A) and *Podocarpus neriifolius* (B) found in Khao Khiew.

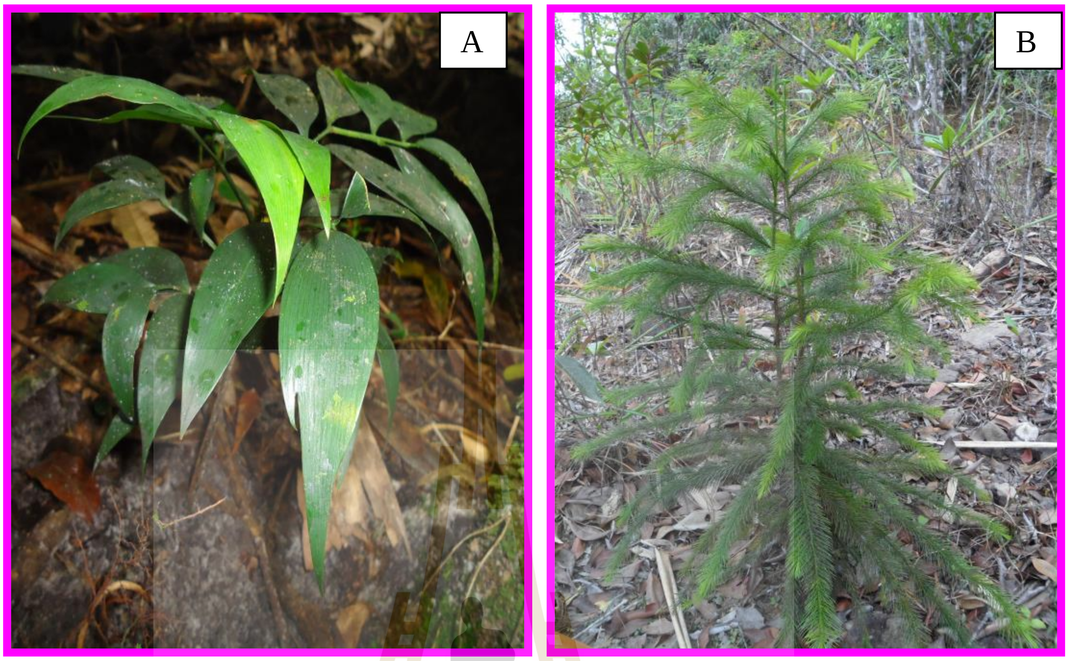

Figure 4.2 *Nageia wallichiana* (A) and *Dacrydium elatum* (B) found in Khao Khiew.

4.2 Size-frequency distributions

Geographical maps were used to show the local slope of each of the 14 systematically placed transect lines (Figures 4.3 and 4.4). The overall forest structure was slope. However, transect line 6 was both slope and gully. Considering all 70 plots, the local slope was flat (0-10 degrees), low slope (10-45 degrees), and high slope (>45-80 degrees).

All the trees of Podocarpaceae within a 10 meter radius surrounding seventy systematically arranged plots were surveyed. The height and dbh (diameter at breast height) was measured for each tree (Table 4.1). Graphs were made according to Enright (1995) of the size-frequency distributions. The trees were placed in categories based on dbh: 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, and 50-60 cm. The results can be summarized as follows: For *Dacrydium elatum*, the majority of the trees, 11 out of 18, were small (0-10 cm dbh). The remaining 7 trees ranged from 20 to 60 cm dbh with no medium sized trees of 10-20 cm (Figure 4.5). For *Dacrycarpus imbricatus*, all size classes of trees were present except for 40-50 cm dbh. Trees with dbh of 0-10 and 20-30 were most numerous (Figure 4.6). For *Nageia wallichiana*, trees of all size classes were present, but with smaller trees, 0-10 and 10-20 cm dbh being the most numerous (Figure 4.7). Finally, for *Podocarpus neriifolius*, all size classes were present, but small trees, 0-10 cm dbh, were the most numerous with 9 trees (Figure 4.8).

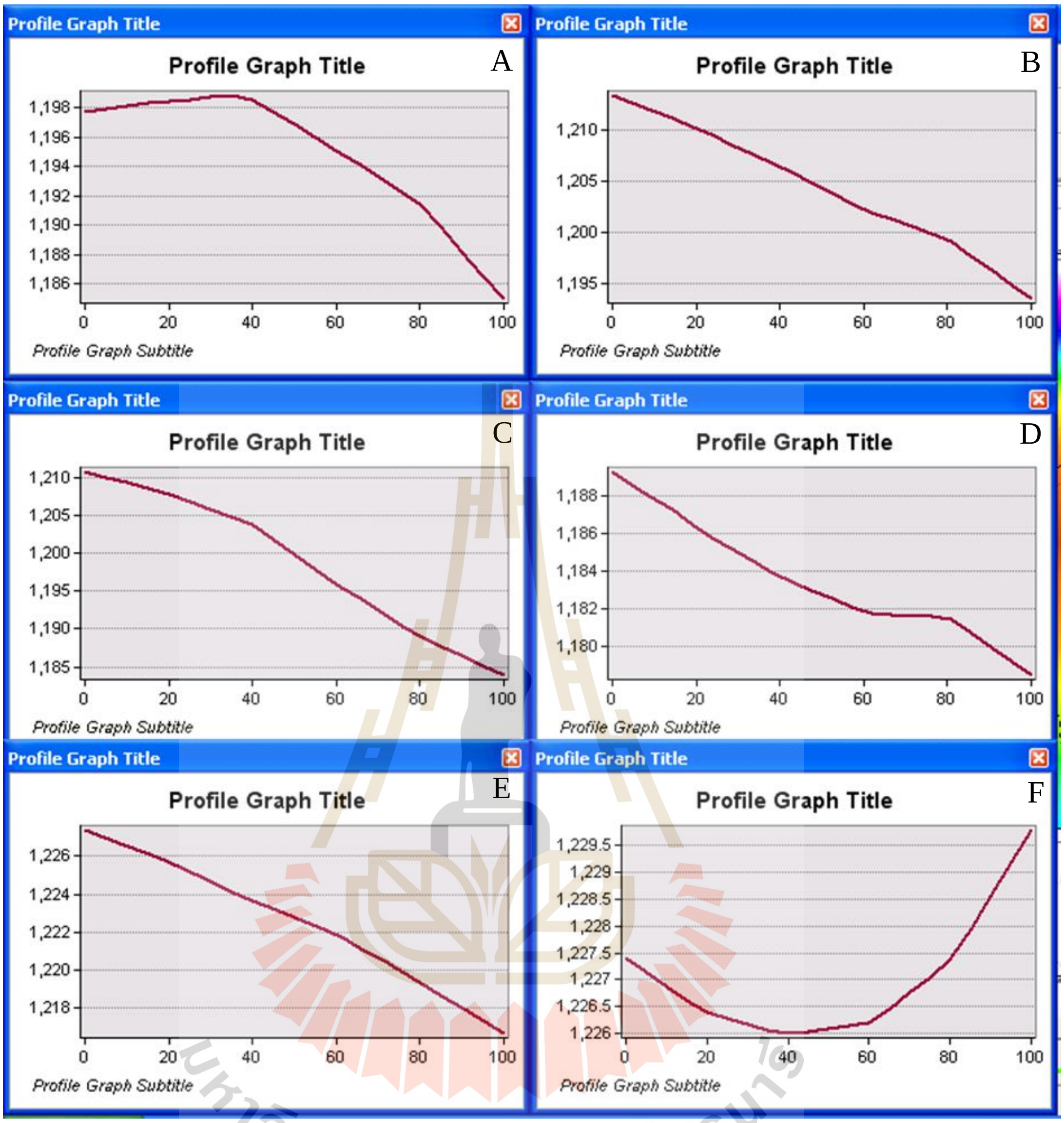

Figure 4.3 Local slope of transect 1 (A), 2 (B), 3 (C), 4 (D), 5 (E), and 6 (F).

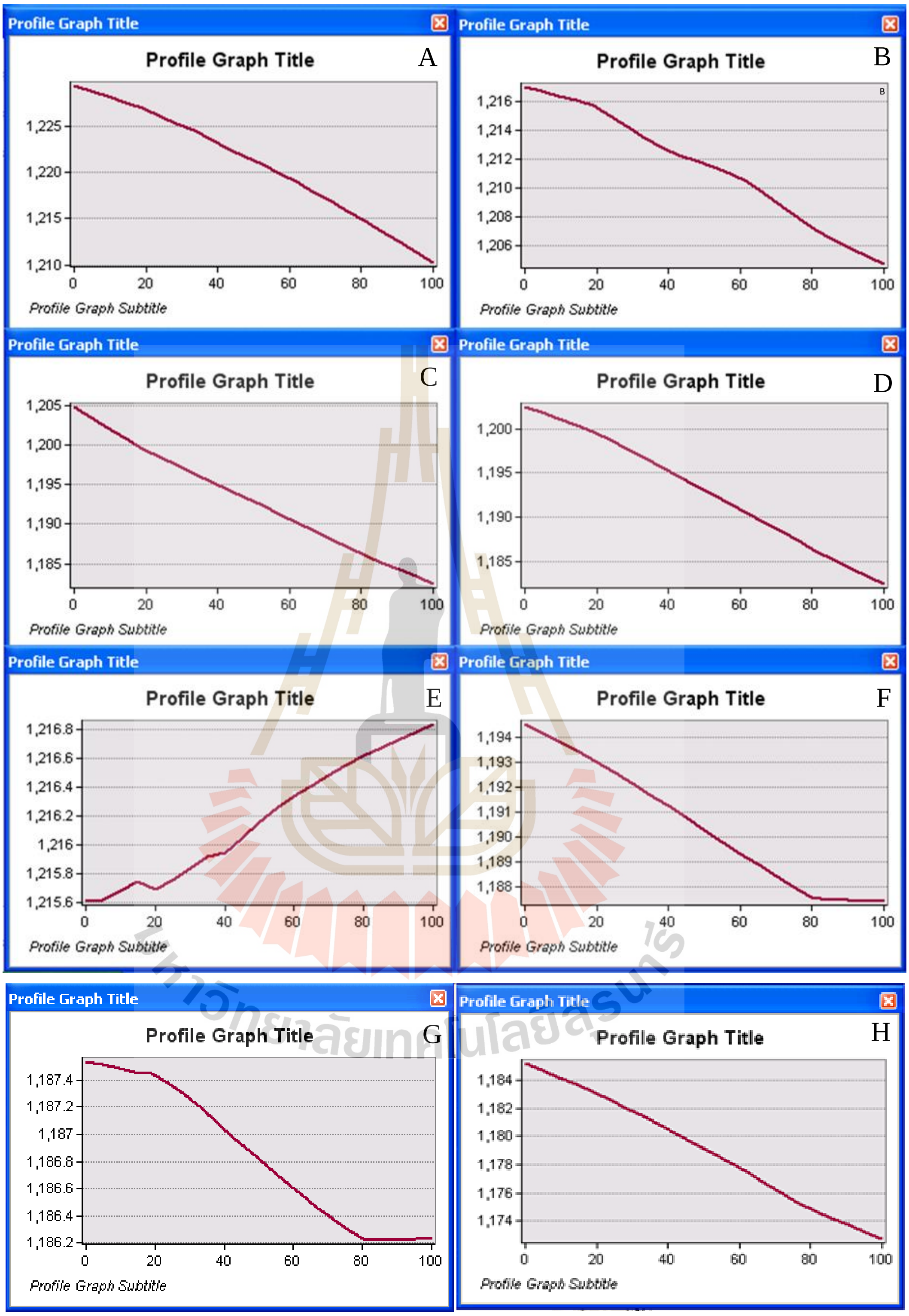

Figure 4.4 Local slope of transect 7 (A), 8 (B), 9 (C), 10 (D), 11 (E), 12 (F), 13 (G), and 14 (H).

Table 4.1 Study species in 70 plots along 14 transect lines in the area at Khao Khiew in Khao Yai National Park.

Transect line	**Plots**	**Species**	**Height (m)**	**dbh (cm.)**
1	1	-	-	-
	2	-	-	-
	3	*Dacrydium elatum*	12.80	36.27
		Dacrydium elatum	12.59	43.59
	4	*Dacrydium elatum*	27.72	55.90
		Dacrydium elatum	11.28	38.18
	5	*Dacrydium elatum*	15.21	7.95
2	1	*Dacrydium elatum*	1.75	1.27
	2	*Dacrydium elatum*	11.41	41.04
		Dacrydium elatum	10.29	33.72
	3	*Podocarpus neriifolius*	2.10	1.20
	4	*Dacrydium elatum*	1.10	0.63
		Dacrydium elatum	29.72	51.29
	5	-	-	-
3	1	-	-	-
	2	*Podocarpus neriifolius*	10.00	19.72
	3	-	-	-
	4	-	-	-
	5	-	-	-
4	1	-	-	-
	2	*Dacrydium elatum*	5.00	7.95
	3	*Dacrydium elatum*	2.96	1.75
		Dacrydium elatum	2.86	1.59
		Dacrydium elatum	2.91	1.65
	4	*Podocarpus neriifolius*	3.53	3.34
		Podocarpus neriifolius	4.83	4.13
		Dacrydium elatum	6.89	4.77
		Dacrydium elatum	6.27	4.77
		Dacrydium elatum	4.18	3.50
		Dacrydium elatum	3.20	3.18
	5	*Dacrydium elatum*	3.08	1.75

Table 4.1 (Continued) Study species in 70 plots along 14 transect lines in the area at Khao Khiew in Khao Yai National Park.

Transect line	Plots	Species	Height (m)	dbh(cm.)
5	1	*Dacrycarpus imbricatus*	2.00	19.09
	2	*Dacrycarpus imbricatus*	2.50	2.07
	3	*Podocarpus neriifolius*	4.50	3.50
		Podocarpus neriifolius	10.90	5.72
		Podocarpus neriifolius	10.61	12.09
	4	-	-	-
	5	*Podocarpus neriifolius*	27.20	45.72
6	1	-	-	-
	2	*Nageia wallichiana*	5.29	20.32
		Nageia wallichiana	13.00	17.78
	3	-	-	-
	4	-	-	-
	5	-	-	-
7	1	*Dacrycarpus imbricatus*	3.62	19.09
		Dacrycarpus imbricatus	1.87	20.68
		Dacrycarpus imbricatus	3.02	25.45
		Dacrycarpus imbricatus	9.22	19.09
		Dacrycarpus imbricatus	17.14	20.68
	2	*Podocarpus neriifolius*	35.20	54.72
		Dacrycarpus imbricatus	38.82	59.81
		Podocarpus neriifolius	3.00	7.95
		Podocarpus neriifolius	11.53	23.86
		Podocarpus neriifolius	41.84	59.81
		Podocarpus neriifolius	27.63	62.04
		Dacrycarpus imbricatus	35.09	55.68
		Podocarpus neriifolius	11.52	50.90
	3	*Dacrycarpus imbricatus*	15.00	39.77
		Podocarpus neriifolius	14.00	26.67
		Dacrycarpus imbricatus	11.00	20.32
	4	*Dacrycarpus imbricatus*	8.52	25.40
		Dacrycarpus imbricatus	9.92	35.56
	5	*Podocarpus neriifolius*	11.52	25.45
		Dacrycarpus imbricatus	3.69	14.31
		Podocarpus neriifolius	23.52	19.09

Table 4.1 (Continued) Study species in 70 plots along 14 transect lines in the area at Khao Khiew in Khao Yai National Park.

Transect line	**Plots**	**Species**	**Height (m)**	**dbh(cm.)**
		Dacrycarpus imbricatus	15.62	20.00
	1	*Podocarpus neriifolius*	12.97	32.00
		Podocarpus neriifolius	14.58	35.00
	2	*Podocarpus neriifolius*	19.05	35.00
		Nageia wallichiana	29.30	15.90
8	3	*Podocarpus neriifolius*	17.00	25.45
		Dacrycarpus imbricatus	27.00	29.27
	4	*Nageia wallichiana*	26.50	22.90
		Nageia wallichiana	23.50	32.45
		Dacrycarpus imbricatus	4.52	6.68
	5	-	-	-
9	1	*Nageia wallichiana*	34.87	33.09
		Nageia wallichiana	30.77	34.36
		Podocarpus neriifolius	29.87	32.45
	2	*Nageia wallichiana*	49.32	54.72
	3	*Nageia wallichiana*	41.21	38.18
	4	*Nageia wallichiana*	3.50	5.40
		Nageia wallichiana	1.60	2.54
		Nageia wallichiana	1.60	5.09
		Nageia wallichiana	2.20	2.54
		Nageia wallichiana	2.50	3.18
		Nageia wallichiana	4.30	6.68
		Nageia wallichiana	4.50	3.18
		Nageia wallichiana	5.20	6.36
	5	*Podocarpus neriifolius*	7.00	8.50
		Podocarpus neriifolius	26.60	21.63
10	1	*Nageia wallichiana*	24.40	43.59
		Nageia wallichiana	18.44	20.67
	2	*Nageia wallichiana*	21.26	18.77
	3	*Nageia wallichiana*	21.36	18.27
		Podocarpus neriifolius	25.96	37.54
	4	*Podocarpus neriifolius*	44.82	64.90
		Podocarpus neriifolius	40.92	46.13

Table 4.1 (Continued) Study species in 70 plots along 14 transect lines in the area at Khao Khiew in Khao Yai National Park.

Transect line	Plots	Species	Height (m)	dbh(cm.)
		Nageia wallichiana	8.52	19.72
10	5	*Nageia wallichiana*	16.64	16.22
		Podocarpus neriifolius	10.22	6.68
		Podocarpus neriifolius	9.89	7.00
11	1	*Nageia wallichiana*	16.73	13.36
	2	*Nageia wallichiana*	16.18	19.40
	3	-	-	-
	4	*Nageia wallichiana*	17.50	28.90
		Nageia wallichiana	21.15	39.13
	4	*Nageia wallichiana*	17.50	28.90
		Nageia wallichiana	21.15	39.13
	5	*Podocarpus neriifolius*	4.50	3.18
12	1	-	-	-
	2	-	-	-
	3	-	-	-
	4	-	-	-
	5	*Dacrycarpus imbricatus*	3.50	11.00
		Dacrycarpus imbricatus	3.52	12.00
13	1	*Nageia wallichiana*	6.80	7.00
		Nageia wallichiana	6.00	4.00
		Dacrycarpus imbricatus	3.35	7.00
		Dacrycarpus imbricatus	10.61	7.00
		Dacrycarpus imbricatus	3.35	7.00
	2	*Nageia wallichiana*	16.50	9.00
	3	*Nageia wallichiana*	30.98	51.90
	4	*Nageia wallichiana*	12.72	34.00
	5	*Nageia wallichiana*	14.30	42.00
		Nageia wallichiana	18.12	26.09
14	1	*Nageia wallichiana*	37.00	31.50
		Dacrycarpus imbricatus	11.86	16.54
		Dacrycarpus imbricatus	15.64	53.45
	2	*Dacrycarpus imbricatus*	33.26	35.95

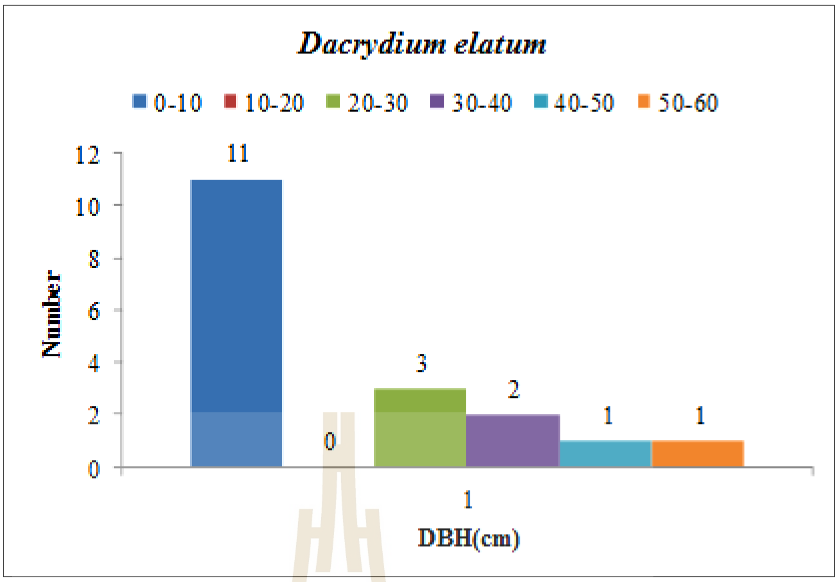

Figure 4.5 The diameter at breast height (dbh) of *Dacrydium elatum* found in Khao Khiew.

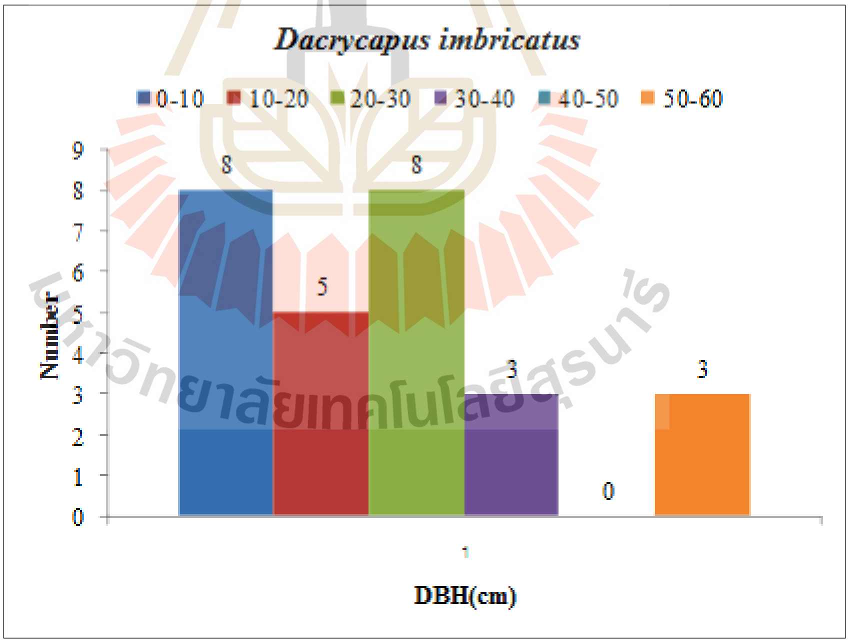

Figure 4.6 The diameter at breast height (dbh) of *Dacrycarpus imbricatus* found in Khao Khiew.

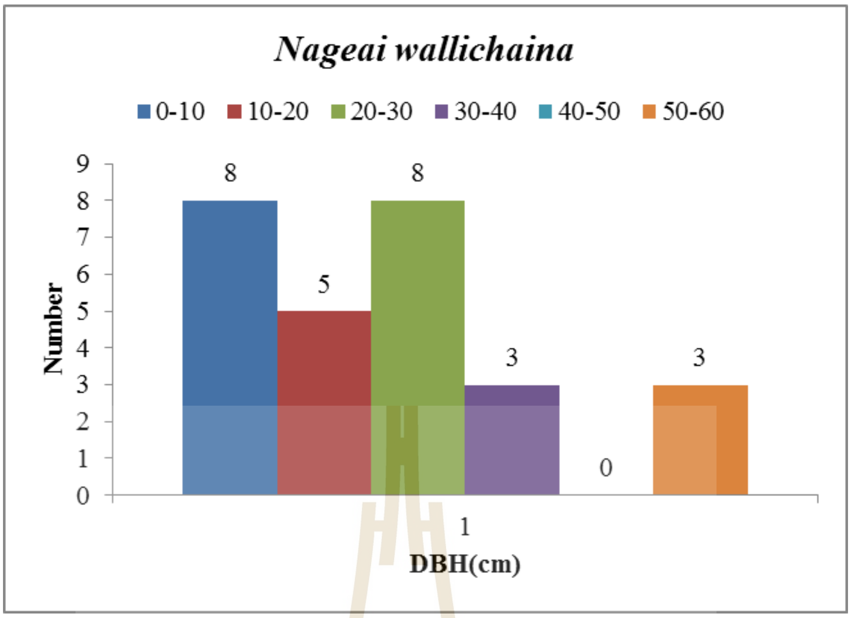

Figure 4.7 The diameter at breast height (dbh) of *Nageia wallichiana* found in Khao Khiew.

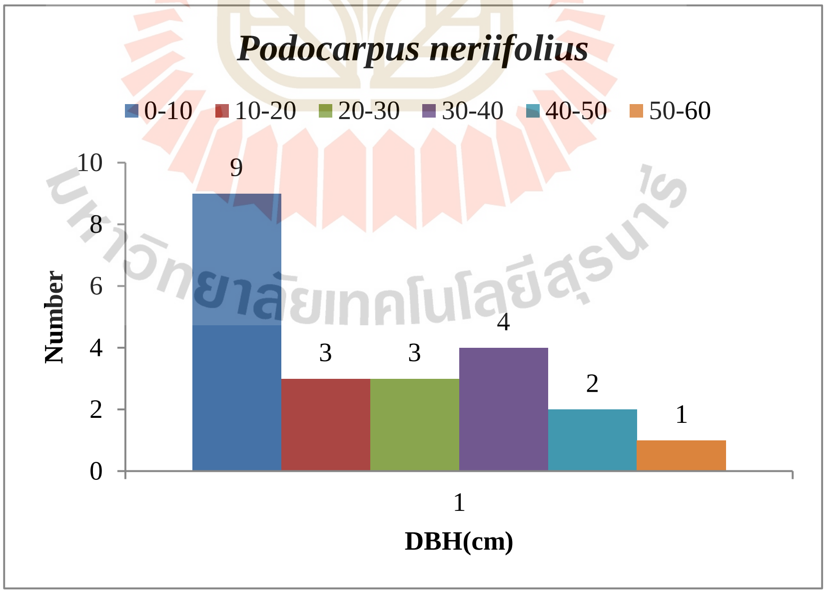

Figure 4.8 The diameter at breast height (dbh) of *Podocarpus neriifolius* found in Khao Khiew.

4.3 Seed germination and early seedling survival at Pha Diew Dai

Effects of competition with other plants and seed and seedling predation on seed germination and early seedling survival were tested with *Podocarpus neriifolius* germination in situ in a conifer-angiosperm forest at Pha Diew Dai. *P. neriifolius* was chosen because this species produces many seeds most years compared to the other three species. Seed germination and seedling success was sampled during August to October 2012. Unfortunately, very few seeds germinated and none of the seedlings survived until the end of the experiment. Therefore, the experiment was repeated from August to October in 2013 (Table 4.2). The seed germination was detected on 17th-18th August. Seed germination was detected in less than 50% of the subplots. By the 10th week, none of seedlings had survived. The subplots with cages showed a higher rate of germination than subplots without cages. In addition, it was found that cleared subplots showed seed germination and seedling germination more than uncleared subplot (Figures 4.9-4.14). This might be due to natural disturbance such as animals, flood, or weeds, etc. (Figures 4.15 and 4.16). Because of the low number of seeds germinating and lack of seedlings surviving until the end of the study, statistical analysis was not carried out.

Table 4.2 Seed germination of *Podocarpus neriifolius* during August - October 2013 (3 August 2013 to planted) at Khao Khiew in Khao Yai National Park.

Week 3August planted	Plot	Sub plot	Germination	Characteristics of subplot	Findings
17-18 August	1	1	None	Cleared without cage	-
		2	None	Not cleared with cage	-
		3	None	Not cleared without cage	-
		4	None	Not cleared with cage	-
	2	1	None	Not cleared with cage	-
		2	None	Cleared with cage	-
		3	None	Not cleared with cage	-
		4	None	Cleared with cage	-
	3	1	None	Cleared with cage	-
		2	None	Clear without cage	-
		3	None	Not cleared without cage	-
		4	None	Not cleared with cage	-
	4	1	None	Not cleared without cage	-
		2	None	Not cleared with cage	-
		3	None	Cleared with cage	-
		4	None	Cleared without cage	-
	5	1	None	Cleared with cage	-
		2	None	Cleared without cage	-
		3	None	Not cleared without cage	-
		4	None	Not cleared with cage	-
	6	1	None	Cleared with cage	-
		2	None	Cleared without cage	-
		3	None	Not cleared without cage	-
		4	None	Not cleared with cage	-

Table 4.2 (Continued) Seed germination of *Podocarpus neriifolius* during August - October 2013 at Khao Khiew in Khao Yai National Park.

Week	Plot	Sub plot	Germination	Characteristics of subplot	Findings
31 August - 1 September	1	1	None	Cleared without cage	-
		2	None	Not cleared with cage	-
		3	None	Not cleared without cage	-
		4	None	Not cleared with cage	-
	2	1	2	Not cleared with cage	The roots begin to grow
		2	None	Cleared with cage	-
		3	None	Not cleared with cage	-
		4	2	Cleared with cage	The roots begin to grow
	3	1	None	Cleared with cage	-
		2	None	Clear without cage	-
		3	None	Not cleared without cage	-
		4	None	Not cleared with cage	-
	4	1	None	Not cleared without cage	-
		2	None	Not cleared with cage	-
		3	None	Cleared with cage	-
		4	None	Cleared without cage	-
	5	1	1	Cleared with cage	The root begins to grow
		2	None	Cleared without cage	-
		3	None	Not cleared without cage	-
		4	1	Not cleared with cage	The root begin to grow
	6	1	Disturbance	Cleared with cage	Seeds eaten by an animal
		2	None	Cleared without cage	-
		3	None	Not cleared without cage	-
		4	None	Not cleared with cage	-

Table 4.2 (Continued) Seed germination of *Podocarpus neriifolius* during August - October 2013 at Khao Khiew in Khao Yai National Park.

Week	Plot	Sub plot	Germination	Characteristics of subplot	Findings
14-15 September	1	1	None	Cleared without cage	-
		2	None	Not cleared with cage	-
		3	1	Not cleared without cage	The root begins to grow
		4	2	Not cleared with cage	1) h=3.0 cm, 2) h=2.5 cm
	2	1	None	Not cleared with cage	
		2	5	Cleared with cage	1) h=3.5 cm, 2) h=3 cm, 3-5) the roots begin to grow
		3	None	Not cleared with cage	-
		4	2	Cleared with cage	1) h=1.5.cm, 2) h=2.5 cm, 2 leaves; some seeds became dry
	3	1	3	Cleared with cage	1) h=2.5 cm, 2) h=1.5 cm, 3) early seedling died
		2	None	Clear without cage	-
		3	1	Not cleared without cage	The root begins to grow
		4	3	Not cleared with cage	1) h=1.7 cm, 2) h=1.3 cm
	4	1	1	Not cleared without cage	h=1.7 cm, 2 leaves, seedling fell over and dried
		2	None	Not cleared with cage	-
		3	1	Cleared with cage	The root begins to grow
		4	1	Cleared without cage	The root begins to grow
	5	1	1	Cleared with cage	h=3 cm, seed coat not dropped from seed
		2	1	Cleared without cage	-
		3	1	Not cleared without cage	-
		4	1	Not cleared with cage	-
	6	1	5	Cleared with cage	1) h=4 cm, 2) h= 1.5cm, 3) h=1.7 cm, 4) h= 2.5 cm, seedling fell over and dried
		2	1	Cleared without cage	-
		3	1	Not cleared without cage	-
		4	1	Not cleared with cage	-

Table 4.2 (Continued) Seed germination of *Podocarpus neriifolius* during August - October 2013 at Khao Khiew in Khao Yai National Park.

Week	Plot	Sub plot	Germination	Characteristics of subplot	Findings
28-29 September	1	1	None	Cleared without cage	-
		2	None	Not cleared with cage	-
		3	Die	Not cleared without cage	h=2.8 cm, seedling fell over
		4	1	Not cleared with cage	The root begins to grow
	2	1	None	Not cleared with cage	-
		2	2 (3 die)	Cleared with cage	Two seedlings survive, h=1 and 1.2 cm
		3	None	Not cleared with cage	-
		4	1(1 dies)	Cleared with cage	h=1 cm and 1 died
	3	1	1(2 die)	Cleared with cage	h=6.5 cm, 2 leaves; 2 seedlings die
		2	None	Cleared without cage	-
		3	Die	Not cleared without cage	-
		4	1(2 die)	Not cleared with cage	The root begins to grow, 2 seedlings die
	4	1	1	Not cleared without cage	h=6.6 cm, 2 leaves
		2	None	Not cleared with cage	-
		3	1	Cleared with cage	Fallen seedling
		4	1	Cleared without cage	Fallen seedling
	5	1	1	Cleared with cage	h=1 cm
		2	1	Cleared without cage	h=1.2 cm
		3	1	Not cleared without cage	h=2 cm
		4	1	Not cleared with cage	h=1.5 cm
	6	1	3(2 die)	Cleared with cage	h=1.4 cm, fallen seedling
		2	1	Cleared without cage	h=1.5cm, fallen seedling
		3	1	Not cleared without cage	h=2.5cm
		4	Die	Not cleared with cage	h=4 cm, fallen seedling

Table 4.2 (Continued) Seed germination of *Podocarpus neriifolius* during August - October 2013 at Khao Khiew in Khao Yai National Park.

Week	Plot	Sub plot	Germination	Characteristics of subplot	Findings
12-14 October	1	1	0	Cleared without cage	No survival
		2	None	Not cleared with cage	No survival
		3	0	Not cleared without cage	No survival
		4	0	Not cleared with cage	No survival
	2	1	None	Not cleared with cage	No survival
		2	0	Cleared with cage	No survival
		3	None	Not cleared with cage	No survival
		4	None	Cleared with cage	No survival
	3	1	0	Cleared with cage	No survival
		2	None	Cleared without cage	No survival
		3	0	Not cleared without cage	No survival
		4	None	Not cleared with cage	No survival
	4	1	None	Not cleared without cage	No survival
		2	None	Not cleared with cage	No survival
		3	None	Cleared with cage	No survival
		4	0	Cleared without cage	No survival
	5	1	0	Cleared with cage	No survival
		2	None	Cleared without cage	No survival
		3	None	Not cleared without cage	No survival
		4	None	Not cleared with cage	No survival
	6	1	0	Cleared with cage	No survival
		2	0	Cleared without cage	No survival
		3	None	Not cleared without cage	No survival
		4	None	Not cleared with cage	No survival

Figure 4.9 Seed germination and early seedling survival of *Podocarpus neriifolius* at plot 1. A1-A2: not cleared, without cage, B1-B2: not cleared with cage. (Cage moved for photo, 14-15 September 2013).

Figure 4.10 Seed germination and early seedling survival of *Podocarpus neriifolius* at plot 2. A: cleared with cage (14 September 2013), B: cleared with cage (B and C: 12 October 2013), C: not cleared with cage, and D: not cleared without cage (14-15 September 2013).

Figure 4.11 Seed germination and early seedling survival of *Podocarpus neriifolius* at plot 3. A: cleared and no cage; arrows indicate seeds (17 August 2013), B: cleared without cage, C: not cleared without (B, C and D: 14 September 2013) cage, and D: not cleared with cage.

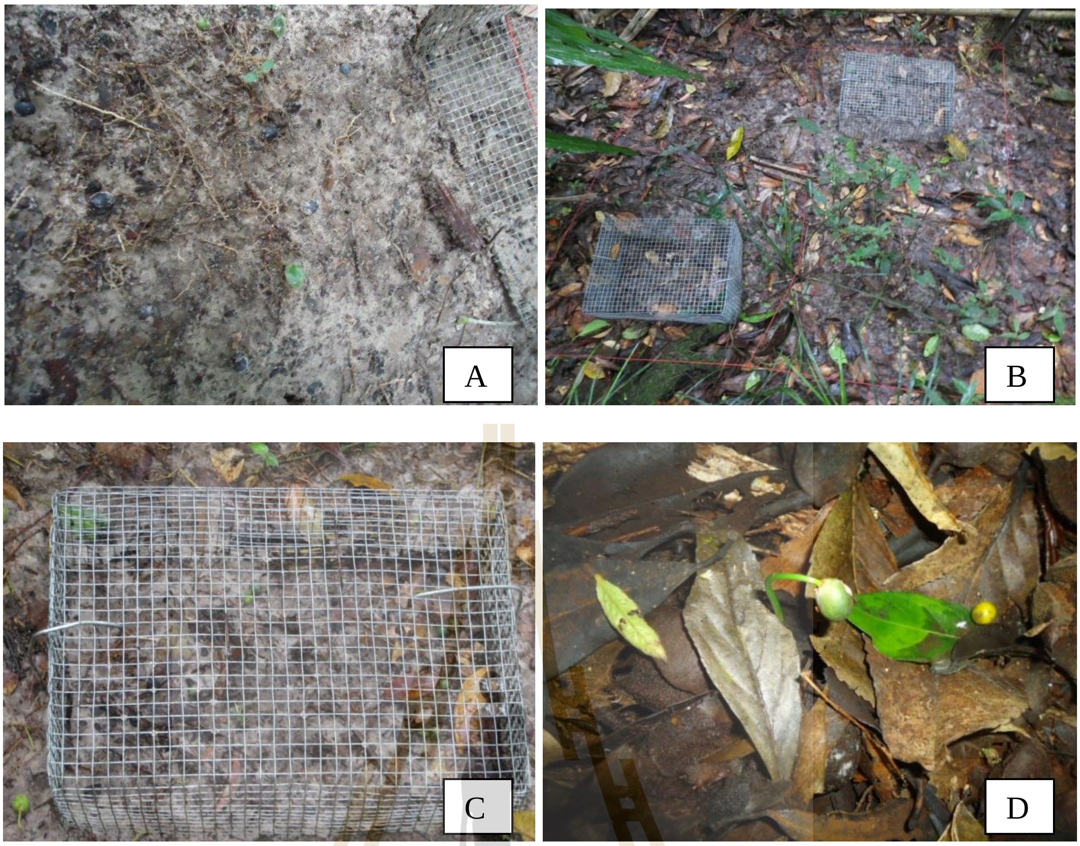

Figure 4.12 Seed germination and early seedling survival of *Podocarpus neriifolius* at plot 4. A: cleared and without cage (A, B and C: 12 October 2013), B: not cleared with cage, C: cleared and with cage, and D: not cleared with cage (28 September 20143).

Figure 4.13 Seed germination and early seedling survival of *Podocarpus neriifolius* at plot 5. A: not cleared without cage (12 October 2013), B: not cleared and with cage (17 August 2013), C: cleared without cage (17 August 2013), and D: cleared with cage (28 September 2013).

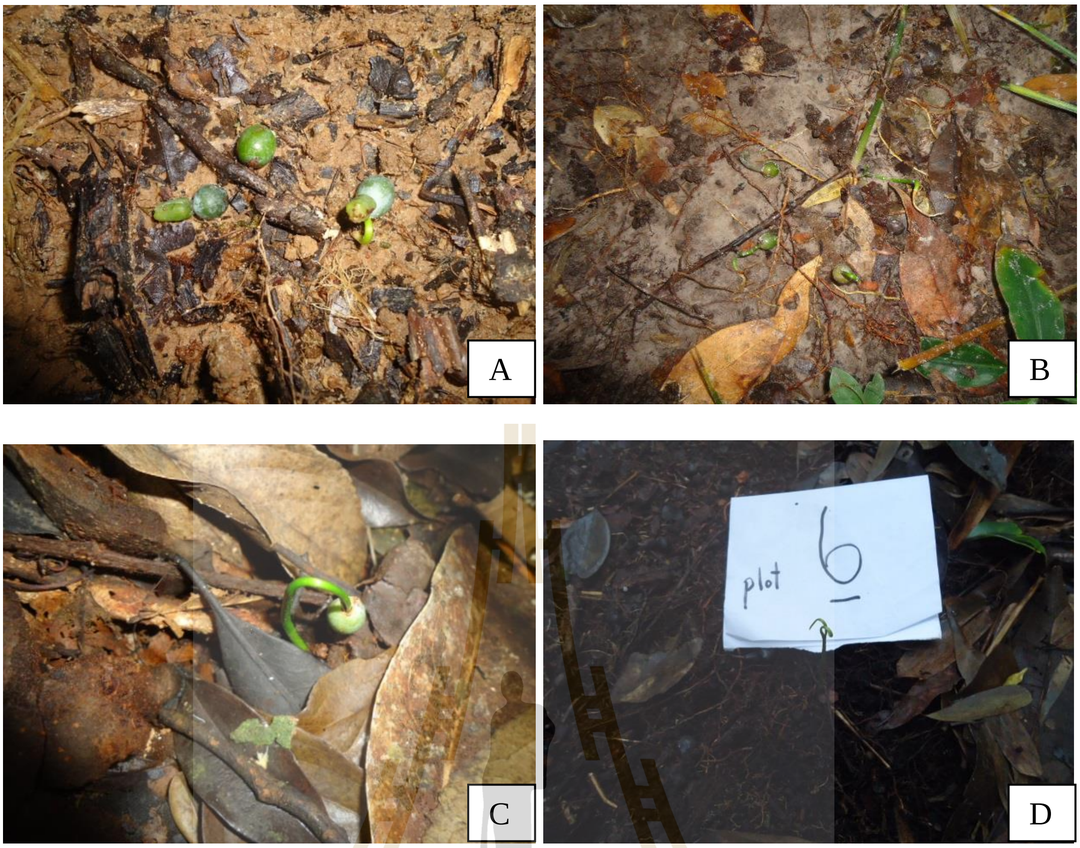

Figure 4.14 Seed germination and early seedling survival of *Podocarpus neriifolius* at plot 6. A: Cleared with cage (cage moved for photo) and B: cleared without cage (14 September 2013), C: not cleared with cage (29 September 2013), and D: not cleared and with cage (29 September 2013).

Figure 4.15 Animal disturbance by eating the seeds.

Figure 4.16 Flood disturbance.

4.4 Sapling survival of Podocarpaceae species

4.4.1 Sapling densities

The total number of *Podocarpus neriifolius* saplings present on systematically located plots was the highest for the Podocarpaceae species (Table 4.3), followed by *Nageia wallichiana*, *Dacrycarpus imbricatus*, and *Dacrydium elatum*, respectively. However, frequency (presence on number of plots) of *P. neriifolius* was comparable to *Nageia wallichiana*. In addition, *P. neriifolius* presented the highest in subjectively located plots, followed by *D. elatum* and *N. wallichiana*, but *D. imbricatus* was not found. These results suggest that *P. neriifolius* was most successful in the dispersal and early survival of podocarp saplings. Carswell et al. (2007) also reported that the density of the genus *Podocarpus* presented higher than other podocarp species.

4.4.2 Spatial correlations among sapling species

Two out of 6 pairwise comparisons were positive and significant. *P. neriifolius* and *N. wallichiana* showed positive correlations with *D. imbricatus* indicating that the distribution of these saplings was clustered and that regeneration conditions for these species were frequently similar (Table 4.4). In addition, there were negative correlations among saplings of *P. neriifolius*, *N. wallichiana* and *D. elatum*.

4.4.3 Candidate models predicting sapling occurrence

A series of models were tested to predict sapling occurrence in the 70 systematically placed plots. Each model used one or more of the following predictor variables: concentrations of soil nutrients, P, N, C, and H, soil depth, local slope, and percent canopy cover. Disturbance was not included as only 2 plots showed human disturbance.

For *P. neriifolius*, there was more support for a model that combined phosphorus with depth than for any of the components combined or alone (Table 4.5). Local slope received the best support of the single factor models for *P. neriifolius*. For *N. wallichiana*, depth alone received the best support for predicting its occurrence. The model with the best support for *D. imbricatus* was pH. However, the full model showed lowest support for these 3 podocarp species. In addition, *D. elatum* was found in only one plot from 70 plots, so it was too small of a sample size for AIC analysis.

Table 4.3 Mean densities (stems/ha) ± standard error of saplings (≥0.15 m and <1.35 m) of four podocarp species at Khao Khiew in Khao Yai National Park, Thailand.

Species	Saplings		
	Density (stems/ha)	% Frequency (plots on grid)	% Frequency (subjective samples)
Podocarpus neriifolius	465.89 ± 67.37^{a}	28.57^{a}	73.33^{a}
Nageia wallichiana	386.35 ± 41.41^{ab}	28.57^{a}	13.33^{c}
Dacrycarpus imbricatus	306.35 ± 54.09^{ab}	15.71^{b}	0.00^{d}
Dacrydium elatum	22.75 ± 0.64^{b}	1.42^{c}	46.66^{b}

Also given are the frequencies of plots on the grid in which saplings occurred (70 plots). The frequencies of plots in which saplings occurred in subjectively placed transects are also given (15 plots). $P<0.05$.

Table 4.4 Spatial correlations among sapling species at Khao Khiew in Khao Yai National Park, Thailand.

	Podocarpus neriifolius	*Nagaia Wallichaina*	*Dacrycarpus imbricatus*
Nageia wallichiana	Negative correlation $\chi^2 = 0.252$ $P = 0.615$		
Dacrycarpus imbricatus	Positive correlation $\chi^2 = 8.953$ $P = 0.003$	Positive correlation $\chi^2 = 7.670$ $P = 0.006$	
Dacrydium elatum	Negative correlation $\chi^2 = 0.004$ $P = 0.949$	Negative correlation $\chi^2 = 3.084$ $P = 0.079$	Negative correlation $\chi^2 = 1.452$ $P = 0.228$

These were assessed using Chi-square contingency tables and the direction of the correlation is given along with the Chi-square statistic and probability (P) value. P<0.05 was considered as position correlation.

Table 4.5 Comparison of candidate models predicting the occurrence of saplings of three canopy species at Khao Khiew in Khao Yai National Park, Thailand.

Model	*Podocarpus neriifolious*	*Nageia Wallichaina*	*Dacrycarpus imbricatus*
Depth+P	**0.00**	2.08	4.91
N+Depth+P+H	**0.21**	5.95	7.24
Depth+H	**0.76**	**1.90**	4.02
Local slope+H	**0.82**	3.76	3.77
N+Depth+P	**1.02**	3.48	7.30
Local slope	**1.19**	**1.62**	2.23
Local slope+N	**1.59**	2.56	4.55
Depth+H+pH	**1.83**	3.91	3.01
H	**1.99**	2.14	**1.88**
Local slope+C	**2.00**	2.40	4.55
Local slope+P	2.03	2.29	4.54
N+Local slope+P	2.33	3.31	6.93
N+Local slope+pH	2.71	4.58	3.38
Canopy+H	2.92	4.20	4.12

Values shown are Δ_i, the difference in AIC_c between the best model (model with smallest value of AIC_c) and the *i*th model. The best model has a Δ_i value of 0.
All models with $\Delta_i \leq 2$ have substantial support (sensu Burnham and Anderson, 2002) and are shown in bold. AIC_c = Akaike's Information Criterion. N = 70 for all species.

Table 4.5 (Continued) Comparison of candidate models predicting the occurrence of saplings of three canopy species at Khao Khiew in Khao Yai National Park, Thailand.

Model	*Podocarpus neriifolius*	*Nageia Wallichaina*	*Dacrycarpus imbricatus*
Local slope+H+pH	2.95	5.26	3.21
Local slope+pH	3.15	2.99	**1.44**
P+N	3.17	2.19	5.11
P	3.39	**1.59**	2.83
C	3.81	**0.60**	2.89
N	3.92	**0.89**	2.88
Syzygium gratum	4.02	**0.34**	**0.44**
Depth	4.02	**0.00**	2.77
Null model	4.09	**0.26**	**0.67**
Depth+C	4.66	1.19	5.09
Depth+N	4.77	1.49	5.08
Depth+pH	5.22	1.92	**1.71**
pH	6.01	1.52	**0.00**
Full model	15.19	24.40	22.22

Values shown are Δ_i, the difference in AIC_c between the best model (model with smallest value of AIC_c) and the *i*th model. The best model has a Δ_i value of 0. All models with $\Delta_i \leq 2$ have substantial support (sensu Burnham and Anderson, 2002) and are shown in bold. AIC_c = Akaike's Information Criterion. N = 70 for all species.

The probability of seedling occurrence in relation to environmental factors was evaluated (Figure 4.17-4.19 and Table 4.6). *P. neriifolius* had a negative relationship between sapling occurrence and available soil P, which was similar to that of *P. ferruginea* reported by Carswell and others (2007). On the other hand, *N. wallichiana* and *D. imbricatus* showed a positive relationship between sapling occurrence and soil P (Figure 4.17A). Support for the nutrient influence on all species was derived from a strong positive relationship between sapling occurrence and soil N (Figure 4.17B), except for *D. imbricatus*. It was indicated that soil N is essential for the sapling occurrence of *P. neriifolius* and *N. wallichiana*. For *P. neriifolius* and *D. imbricatus*, their sapling occurrence increased with increasing pH (Figure 4.18A). pH received more support for *D. imbricatus* (Table 4.5). In addition, occurrences of *N. wallichiana* and *D. imbricatus* increased with increasing canopy cover (Figure 4.18B). All species occurrences increased with increasing local slope (Figure 4.19A). Canopy cover appeared not to be an influence on *P. neriifolius* sapling occurrence. It was assumed that canopy was related to local slope. At higher slope and open canopy, *P. neriifolius* species was found. Although the model relating sapling occurrence to local slope and canopy received less support than other models, it still received greater support than the null model (Table 4.5). Saplings of *P. neriifolius* and *N. wallichiana* occurred more frequently in high depth soil areas (Figure 4.19B).

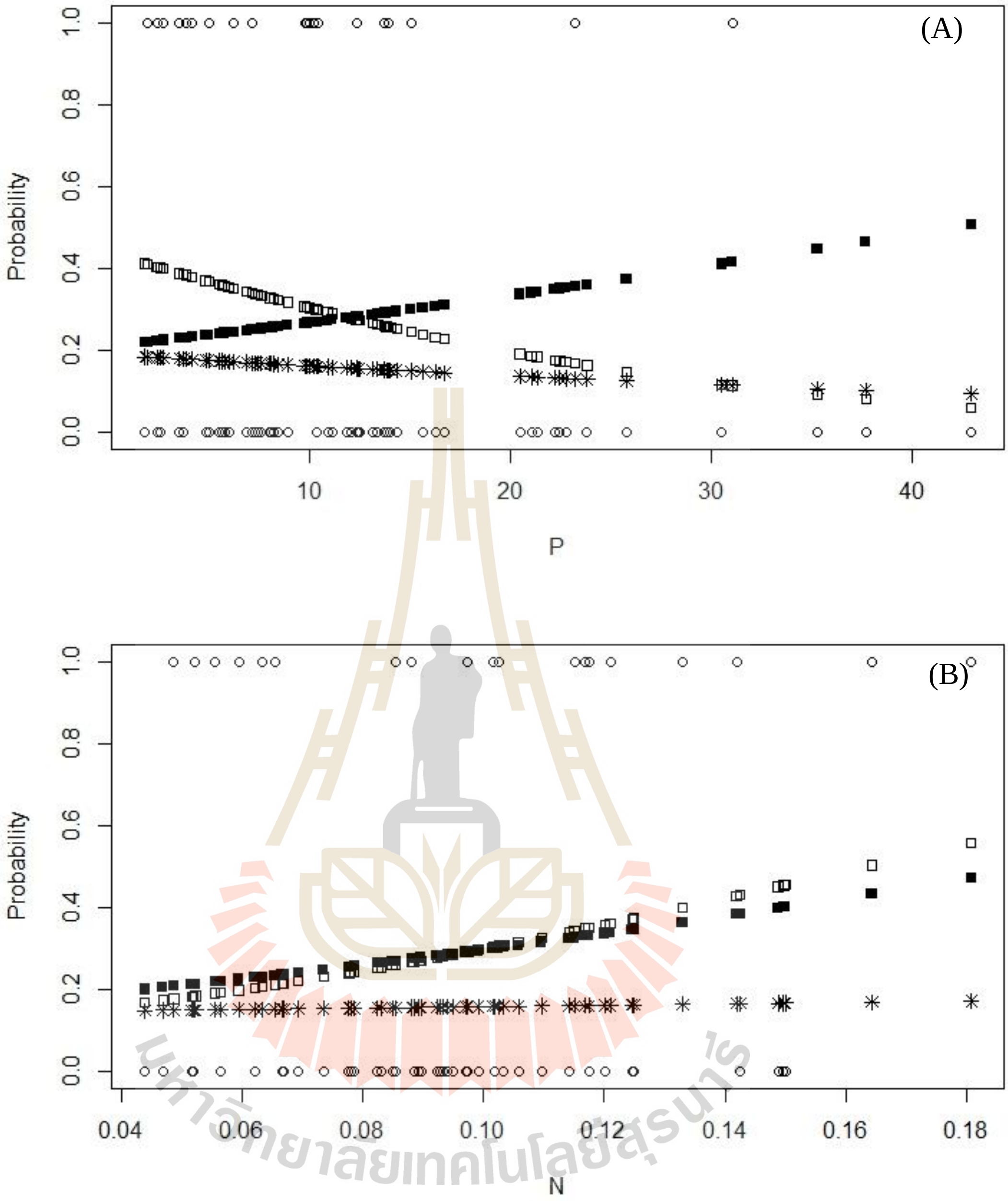

Figure 4.17 The probability of seedling occurrence in relation to soil P (A) and N (B) fitted to three conifer species at Khao Khiew in Khao Yai National Park, Thailand. Curves were fitted using binomial regression. (☐) *P. neriifolius*; (■) *N. wallichiana*; and (✳) *D. imbricatus*.

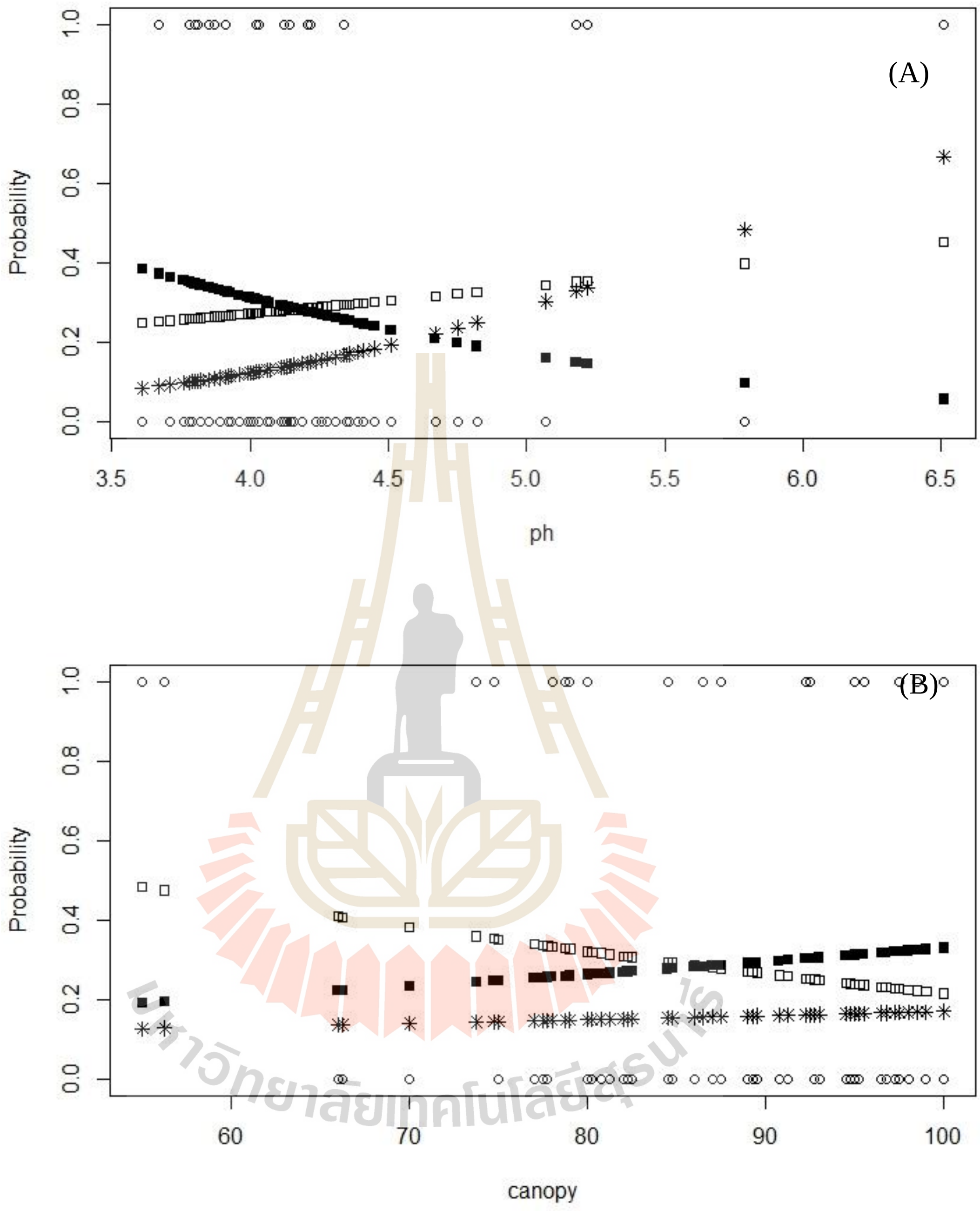

Figure 4.18 The probability of seedling occurrence in relation to soil pH (A) and % canopy cover (B) fitted to three conifer species at Khao Khiew in Khao Yai National Park, Thailand. Curves were fitted using binomial regression. (□) *P. neriifolius*; (■) *N. wallichiana*; and (✳) *D. imbricatus*.

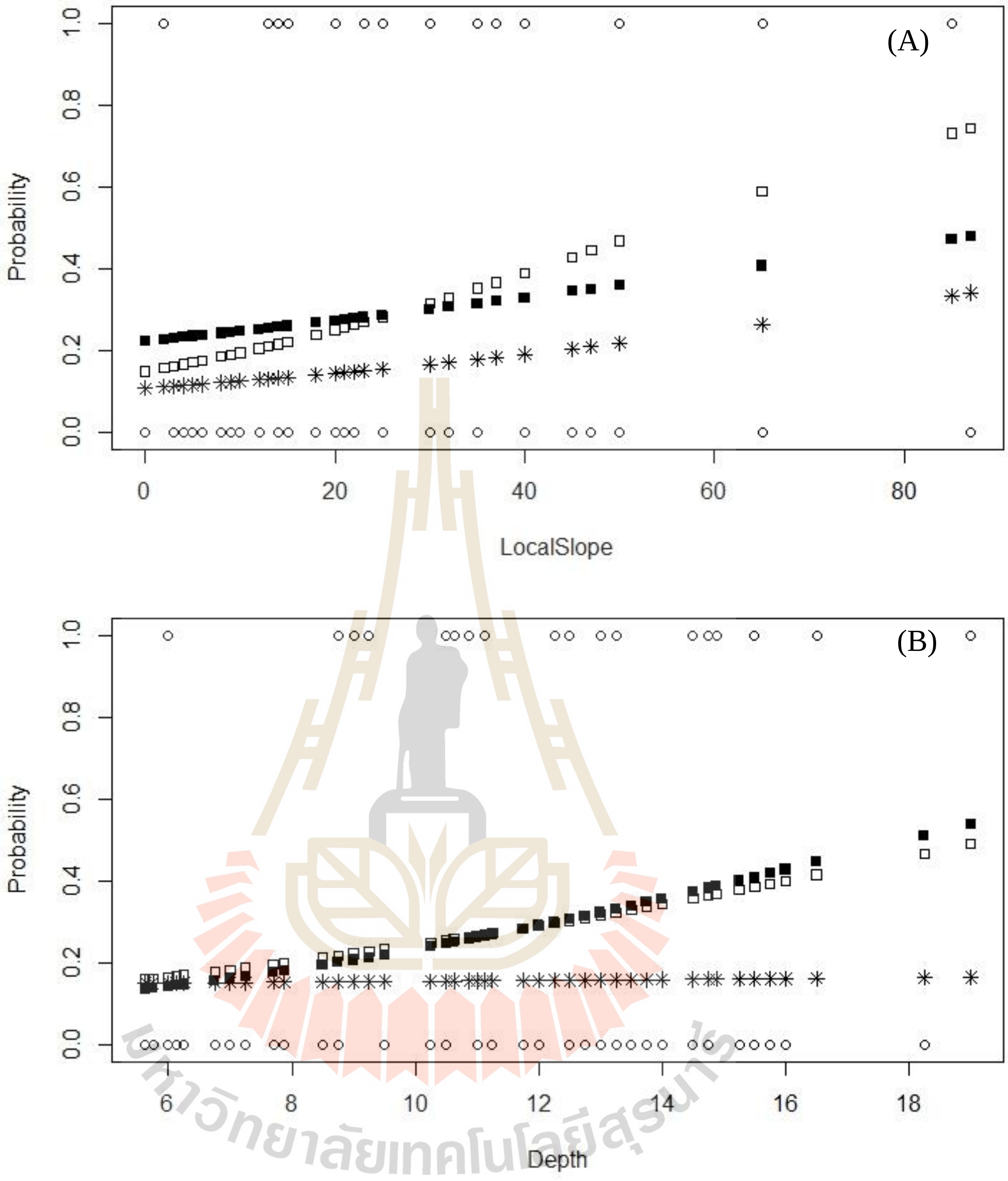

Figure 4.19 The probability of seedling occurrence in relation to local slope (A) and soil depth (B) fitted to three conifer species at Khao Khiew in Khao Yai National Park, Thailand. Curves were fitted using binomial regression. (☐) *P. neriifolius*; (■) *N. wallichiana*; and (✳) *D. imbricatus*.

Table 4.6 Comparison average slope values of the probability of three conifer species sapling occurrence in relation to continuous predictor variables at Khao Khiew in Khao Yai National Park, Thailand.

Species	**Slope**					
	P	**N**	**pH**	**Canopy**	**Local slope**	**Depth**
P. neriifolius	- 0.0098	+2.3529	+0.0945	-0.0048	+0.0068	+0.0016
N. wallichiana	+0.0056	+1.4117	-0.0409	+0.0011	+0.0034	+0.0170
D. imbricatus	-0.0024	0.0000	+0.9449	+0.0001	+ 0.0023	-0.0000

Pearson's correlations between continuous predictor variables at Khao Khiew in Khao Yai National Park, Thailand were calculated (Table 4.7). The regression and residuals versus fitted values plots between continuous predictor variables was also analysed (Appendix C). Soil C was positively correlated with soil H and N, while it showed negative correlation with soil pH. It was uncorrelated with local slope, canopy cover, depth and soil P. Canopy was uncorrelated with depth, soil H, local slope, soil N, soil P and soil pH. Depth showed positive correlation with soil P and negative correlation with soil pH. Soil P was correlated negatively with soil H and local slope. In addition, soil H had a positive correlation with local slope and soil N. Some of the predictor variables in the candidate models are correlated (Table 4.7). This indicates that some of the variables had some influences on sapling occurrence despite correlations between them.

Table 4.7 Pearson's correlations between continuous predictor variables at Khao Khiew in Khao Yai National Park, Thailand.

	pH	Canopy cover (%)	Depth	P	C	H	N
Canopy cover (%)	0.024						
Depth	**-0.316**	0.188					
P	**-0.355**	0.134	**0.398**				
C	**-0.329**	0.079	0.189	0.048			
H	0.078	0.088	-0.139	**-0.280**	**0.795**		
N	**-0.327**	0.040	0.211	-0.016	**0.933**	**0.733**	
Local slope	-0.008	0.031	0.024	**-0.276**	0.187	**0.250**	0.108

N = 70, degrees of freedom = 68, critical r for 0.05 level of significance = 0.250 (Carswell et al., 2007). All of the correlations in bold are significant.

Analysis of variance between classes of soil particle size and continuous predictor variables at Khao Khiew in Khao Yai National Park, Thailand was determined. Soil particle size is most strongly correlated with soil pH followed by soil P, soil H and soil depth (Table 4.8). It indicated that soil particle size is lowest at the highest values of pH, P, and H, which are deepest soil. Analysis of variance was also carried out between classes of local slope (flat, low slope, and high slope). Flat plots were defined as having a slope of 10 degrees or less, low slope plots with a slope greater than 10 up to 45 degrees, and high slope plots with a slope greater than 45 degrees. Classes of local slope were correlated most significantly with soil H and P (Table 4.9). These variables all tend to be higher where there is flat area while soil P is lower and H is higher when the slope is higher.

Table 4.8 Analysis of variance between classes of soil particle size and continuous predictor variables at Khao Khiew in Khao Yai National Park, Thailand.

	Soil particle size						
	1	2	3	4	5	*F*	*P*
pH	0.090	0.672	0.0899	0.0367	0.0409	6.771	**0.0001**
Canopy cover (%)	141.047	165.244	127.0832	59.9353	62.1395	1.346	0.2623
Depth	9.107	6.650	1.8489	7.4747	12.8646	5.122	**0.0012**
P	75.410	53.975	5.6099	84.3861	11.8996	6.483	**0.0002**
C	3.243	1.786	0.7903	1.6595	1.2563	2.251	0.0730
H	0.040	0.022	0.0053	0.0241	0.0261	5.743	**0.0005**
N	0.002	0.001	0.0006	0.0008	0.0006	1.887	0.1234

P-values for variables that varied significantly ($P < 0.05$) with soil particle size are shown in bold. $N = 70$.
1: clay loam, 2: clay, 3: silt clay loam, 4: silt loam, and 5: loam

Table 4.9 Analysis of variance between classes of local slope and continuous predictor variables at Khao Khiew in Khao Yai National Park, Thailand.

	Local slope				
	Flat	Low slope	High slope	*F*	*P*
pH	0.086	0.289	0.054	1.348	0.2666
Canopy cover (%)	104.178	111.005	55.625	0.34	0.7129
Depth	13.966	9.688	5.449	2.295	0.1086
P	124.270	60.319	22.071	6.494	**0.0026**
C	1.909	1.907	2.875	0.979	0.3810
H	0.032	0.027	0.048	4.754	**0.0117**
N	0.001	0.001	0.001	0.918	0.4043

P-values for variables that varied significantly ($P < 0.05$) with soil particle size are shown in bold. *N* = 70.

CHAPTER V

DISCUSSION AND CONCLUSION

Prior to this study, plants of Podocarpaceae at many places in Thailand including Nam Nao National Park, Phetchabun province was explored. *Podocarpus neriifolius* was the only one species of Podocarpaceae found and very few trees were observed. At Phu Hin Rong Kla National Park, *Pinus* was found but not Podocarpaceae, which was similar to Doi Luang, Chiang Mai. At Thung raya - Na sak Wildlife Sanctuary, Ranong province, two species were found in the wild, which were *Podocarpus neriifolius* and *Nageia wallichiana*. At Phu Luang, Loei province, three species of Podocarpaceae were found, namely *Podocarpus neriifolius*, *Dacrydium elatum* and *Podocarpus polystachyus*. Khao Yai National Park at Mo Singto was also explored and found only one tree of *Podocarpus neriifolius*. There was no Podocarpaceae found at Haew Suwat waterfall. At Pha Kluai Mai, *Dacrycarpus imbricatus* was the only species of Podocarpaceae found near the stream, with about 3-4 large trees, which were insufficient in number to use in research. However, at Pha Diew Dai, Khao Kiew, at Khao Yai National Park, species of Podocarpaceae found were *Podocarpus neriifolius*, *Nageia wallichiana*, *Dacrycarpus imbricatus*, and *Dacrydium elatum*. So we decided to do the research at Pha Diew Dai.

There were four species of Podocarpaceae at Khao Khiew in Khao Yai National Park used for study in this thesis, which were *D. imbricatus*, *P. neriifolius*, *N. wallichiana*, and *D. elatum*. The total area of research was 70 plots (20 hectares).

It was found that the density of *P. neriifolius* in the study area was the highest and the lowest was that of *D. elatum*. From subjective samples, seedlings of *D. elatum* were increased, but only in the top ridge and cliff in areas with much light (canopy 0%), suggesting that the seedlings of *D. elatum* prefer the light more than under the canopy. This may be due to the seeds of this species needing light to germinate more than the other three species. On the other hand, seedlings of the other three species usually grow under the canopy. Carswell et al. (2007) reported that the density of the genus *Podocarpus* presented higher than other podocarp species. However, it was found that the densities of podocarp species were lower than those in a conifer-angiosperm forest in central North Island, New Zealand (Carswell et al., 2007).

The effects of competition with other plants and seed and seedling predation on seed germination and early seedling survival were studied, which were tested with *P. neriifolius* germination in situ in a conifer-angiosperm forest at Pha Diew Dai. *P. neriifolius* produces many seeds most years compared to the other three species. From two planting experiments in 2012 and 2013, the first year of germination was so small because that year was a year of flooding rains so many of the seeds sown became rotten. No seedlings had survived at all. For the second year of study, the mesh size of the cage was reduced from the size of 1 cm used in the first year to 0.5 cm for better protection from the animals. The cage was also held in place by spikes to prevent movement or washing away by water. Germination was better than before. From a check every two weeks, there were found signs of eating seeds in the shell only. Near the plot, small rodents (mice) were observed in the subplot that did not have the cage covered. In addition, some subplots showed signs of flooding and soil erosion by water, causing rotten, dried, and black seeds. From observing 5 times, the level of germination at week 4 was low. At weeks 5 to 6, germination was higher indicating that the age of the seeds before germination is approximately 3-6 weeks. During October, the cold air caused dehydration and drying out of seedlings because of lack of water, so the growth was unlikely. The seedling was washed and damaged. However, finally there was no survival at all due to the unusual weather in 2013 was unusual. The relationship of all 4 species was analysed. The relationship between *P. neriifolius* and *N. wallichiana* was positive, and between *N. wallichiana* and *D. imbricatus* was positive as well. This indicated that if *P. neriifolius* were found, *N. wallichiana* might be found as well. Likewise, if *N. wallichiana* were found, *D. imbricatus* might be found too. Three species may be found in the same plot. There were some significant, positive correlations between saplings of these species.

Candidate models were developed for predicting the influence of environmental factors on seedling regeneration; these focused on the roles of soil nutrients, local slope, canopy openness, and soil particle size. It was found that the most support for models of each species was different and variable. A positive relationship was found between soil nitrogen (N), local slope, soil depth and sapling occurrence of all species surveyed. The relationship of soil nitrogen (N) combined with soil depth had most support in explaining the occurrence of *P. neriifolius* saplings. In contrast, *P. neriifolius* sapling occurrence declined with increasing soil phosphorus (P). *D. imbricatus* also declined with increasing soil P, while *N. wallichiana* increased. From Table 4.5, the best model for saplings of *P. neriifolius* was local slope. The substantial support factors with delta values less than or equal to 2 included N + depth + P + H, depth + H, local slope + H, N + depth + P, local slope, local slope + N, H, local slope + C. This meant that depth + P were important factors for saplings of Podocapaceae. In addition, full model showed highest delta value suggesting all the factors indicated lowest support for these 3 podocarp species. For saplings of *N. wallichiana*, the depth of the soil and phosphorus, and the depth of the soil was very important for prediction of seedling occurrence. The substantial support factors were the null model, *Syzygium gratum*, C, depth + C, depth + N, pH, P, N, depth + pH, while the model with the least support was the full model. pH was the best model for saplings of *D. imbricatus*. Substantial support factors were *S. gratum*, null model, local slope, pH, depth + P and H, indicating that pH was an important factor for the saplings. For all three species, the model with the least support was the full model. Figure 4.17A showed that higher levels of phosphorus were not essential for the saplings of *P. neriifolius*, but it was important for saplings of *N. wallichiana* which was consistent with Table 4.5. The level of P did not have an important effect on saplings of *D. imbricatus*. Figure 4.17B showed that soil nitrogen was important to saplings of *P. neriifolius* and *N.wallichiana*, but had little effect on saplings of *D. imbricatus*, in accordance with Table 4.5. Figure 4.18A showed that *P. neriifolius* and *D. imbricatus* saplings occurred more often in plots with a higher pH soil value, whereas *N. wallichiana* seemed to prefer soil with lower pH. Figure 4.18B showed that the canopy was important to saplings of *N. wallichiana* and *D. imbricatus*, but not for *P. neriifolius*. Areas with high percentages of canopy will show fewer saplings of *P. neriifolius*. Figure 4.19A showed that for all three species, sapling occurrence increased with higher local slope. Local slope was important to saplings of all three species. Figure 4.19B showed that saplings of *P. neriifolius* and *N. wallichiana* were more likely found in deeper soils, but soil depth appeared unimportant for *D. imbricatus*.

From Table 4.7, soil carbon was positively correlated with nitrogen and hydrogen indicating that the three factors were correlated. Soil C was positively correlated with soil H and N while it showed negative correlation with soil pH. It was uncorrelated with local slope, canopy cover, depth and soil P. Canopy was uncorrelated with depth, soil H, local slope, soil N, soil P and soil pH. Soil P was correlated negatively with soil H and local slope. In addition, soil H had a positive correlation with local slope and soil N.

In the analysis of variance of soil particle size with continuous variables, Table 4.8 showed that variation of soil particle size was correlated with soil pH, depth, P and H. In analysis of the relationship of local slope with the independent variables, Table 4.9 showed that the local slope correlated with soil P and H. The Pearson's correlation between continuous values of slope and P was negative, indicating a lower level of soil P in higher slopes. Burns and Leathwick (1996) studied a conifer-angiosperm forest in New Zealand and found that the podocarps occurred on ridges where P concentration was lower. Therefore, this previously study is consistent with our study. Saplings of podocarp species had a preference for ridges rather than gullies (Carswell et al., 2007). Coomes et al. (2005) reported that seedlings and adult podocarps (particularly *P. ferruginea* and *D. cupressinum*) occur in low P environments and/or near ridges. Carswell et al. (2003 and 2005) also reported that *P. ferruginea* seedlings respond positively to increasing N concentration and negatively to high concentrations of P. Given that podocarp seedlings were found on soils with low soil P, but high soil N concentrations, soil nutrient status should be taken into account during management.

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APPENDICES

APPENDIX A

SOME CHARACTERISTICS OF SOIL SAMPLES

Table 1A Humidity, pH and temperature of soil samples from 70 plots.

Transect line	Plot	Humidity (%)	pH	Temperature (ºC)
1	1	35.75	3.80	20.50
	2	26.62	4.34	20.25
	3	41.32	4.07	20.25
	4	43.01	4.24	20.50
	5	43.12	3.85	20.00
2	1	35.43	4.02	22.00
	2	41.48	3.85	21.25
	3	55.45	3.78	20.00
	4	33.68	3.91	20.75
	5	45.38	4.15	21.50
3	1	37.08	4.24	20.10
	2	36.74	4.03	20.20
	3	39.94	4.39	20.20
	4	30.79	4.41	20.40
	5	30.50	4.75	20.10
4	1	34.72	5.18	20.25
	2	37.85	4.45	20.50
	3	28.62	4.82	20.25
	4	32.12	4.22	20.25
	5	37.40	4.15	20.13
5	1	60.39	4.67	20.61
	2	54.60	5.79	20.16
	3	45.66	5.07	20.28
	4	47.72	6.51	20.29
	5	44.23	5.22	20.23
6	1	33.45	4.06	20.25
	2	29.30	4.26	20.50
	3	29.25	4.28	20.13
	4	27.40	4.36	20.00
	5	37.41	3.99	20.75
7	1	28.66	3.96	20.60
	2	31.22	4.01	20.91
	3	37.01	3.67	20.72
	4	38.90	4.03	20.93
	5	40.21	4.51	20.50
8	1	43.84	4.12	20.85
	2	36.01	3.81	21.15
	3	58.50	3.92	20.45
	4	42.56	3.82	20.88
	5	37.35	3.71	20.25

Table 1A (Continued) Humidity, pH and temperature of soil samples from 70 plots.

Transect line	Plot	Humidity (%)	pH	Temperature (ºC)
9	1	32.40	4.03	20.22
	2	41.57	3.79	20.26
	3	56.36	4.13	20.45
	4	33.73	3.87	20.22
	5	28.68	4.11	20.16
10	1	30.21	4.35	20.30
	2	39.95	4.14	20.80
	3	34.92	3.61	20.60
	4	28.43	3.78	20.60
	5	77.38	3.89	21.00
11	1	67.18	4.22	20.80
	2	44.90	4.03	20.60
	3	23.93	4.15	20.60
	4	54.02	4.19	20.70
	5	55.39	4.24	20.80
12	1	43.17	4.36	20.14
	2	46.51	4.03	20.17
	3	57.93	3.93	20.35
	4	41.34	4.16	20.43
	5	27.63	3.82	20.41
13	1	29.23	3.76	20.20
	2	36.14	4.03	20.10
	3	33.31	4.12	20.10
	4	36.12	4.31	20.10
	5	45.57	4.02	20.30
14	1	30.87	4.21	20.30
	2	43.20	4.00	20.30
	3	57.87	4.01	20.50
	4	38.21	3.82	20.20
	5	54.85	4.07	20.00

APPENDIX B

TYPE OF SOIL TEXTURE

CALCULATED BY TRIANGLE

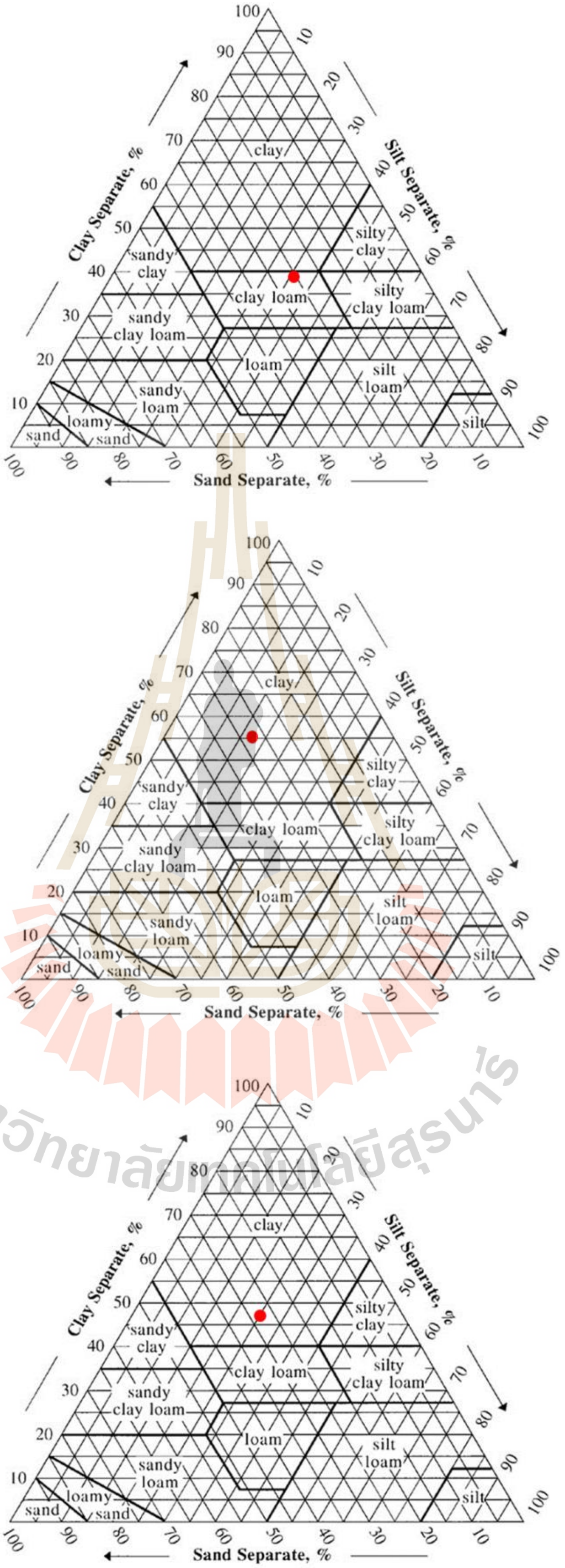


Figure 1B Soil texture of plot 1, 2, and 3 of transect 1.

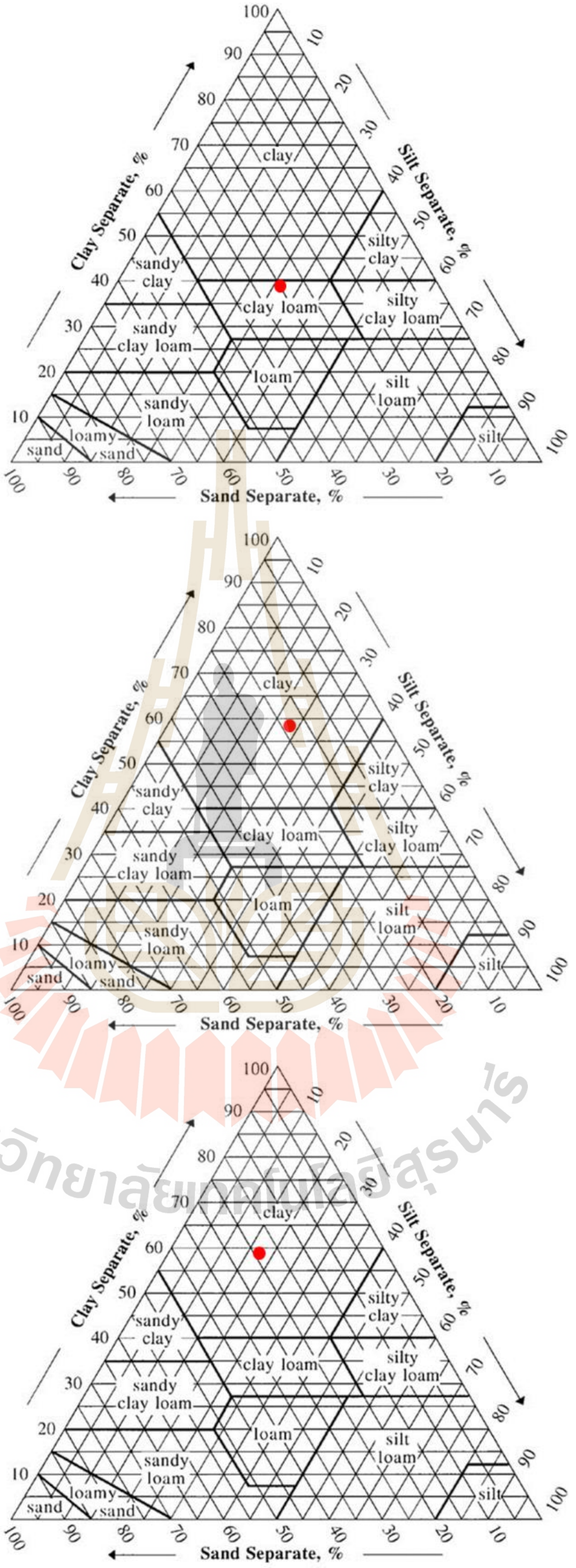


Figure 2B Soil texture of plot 4, 5 of transect 1, and plot 1 of transect 2.

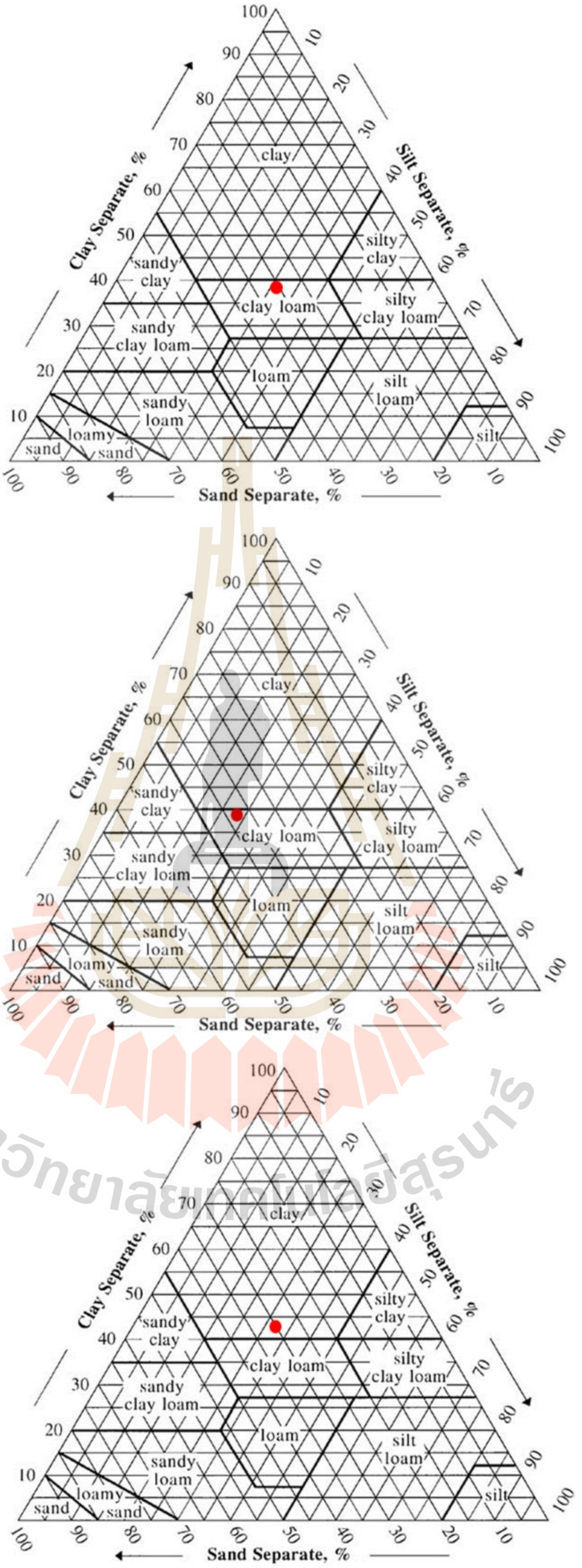


Figure 3B Soil texture of plot 2, 3, and 4 of transect 2.

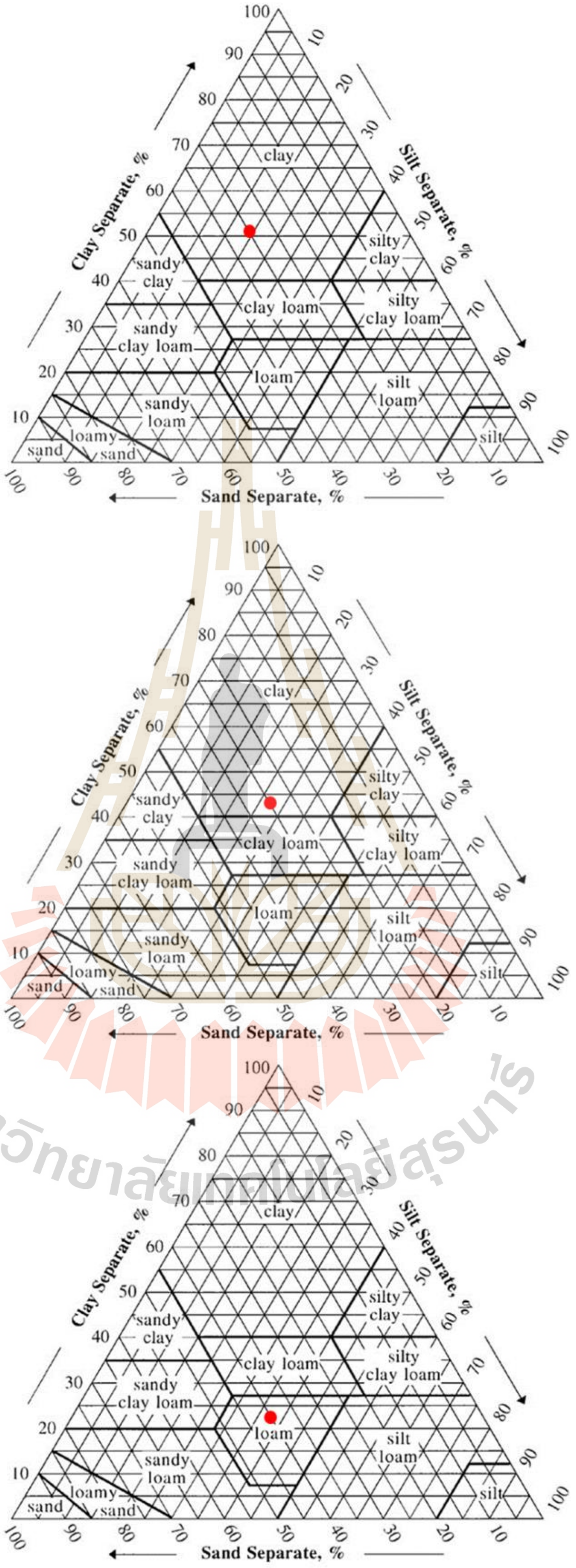


Figure 4B Soil texture of plot 5 of transect 2, plot 1 and plot 2 of transect 3.

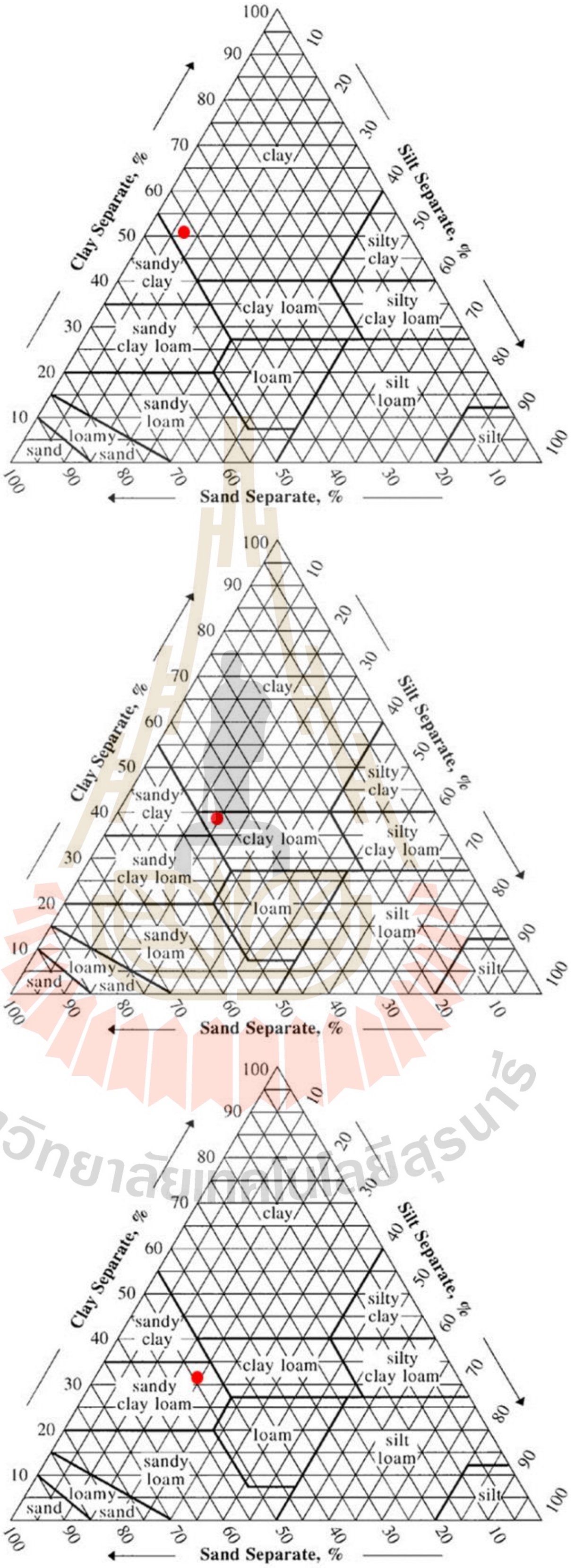


Figure 5B Soil texture of plot 3, 4, and 5 of transect 3.

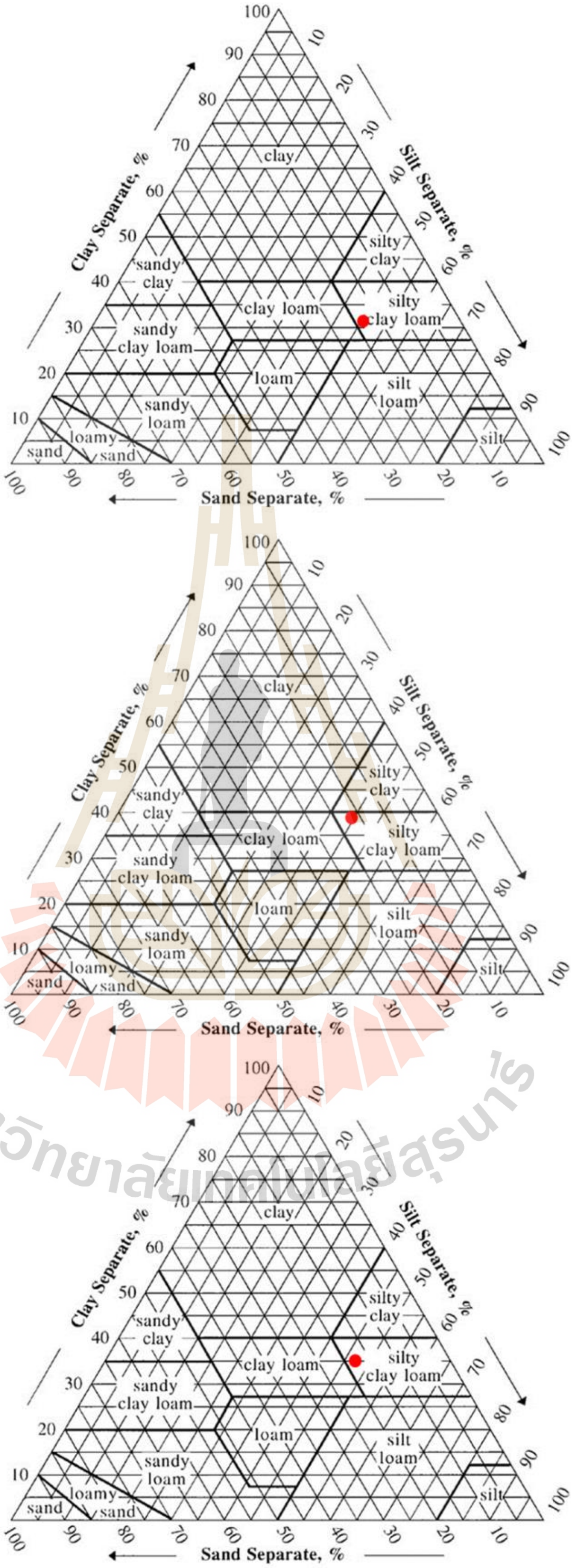


Figure 6B Soil texture of plot 1, 2, and 3 of transect 4.

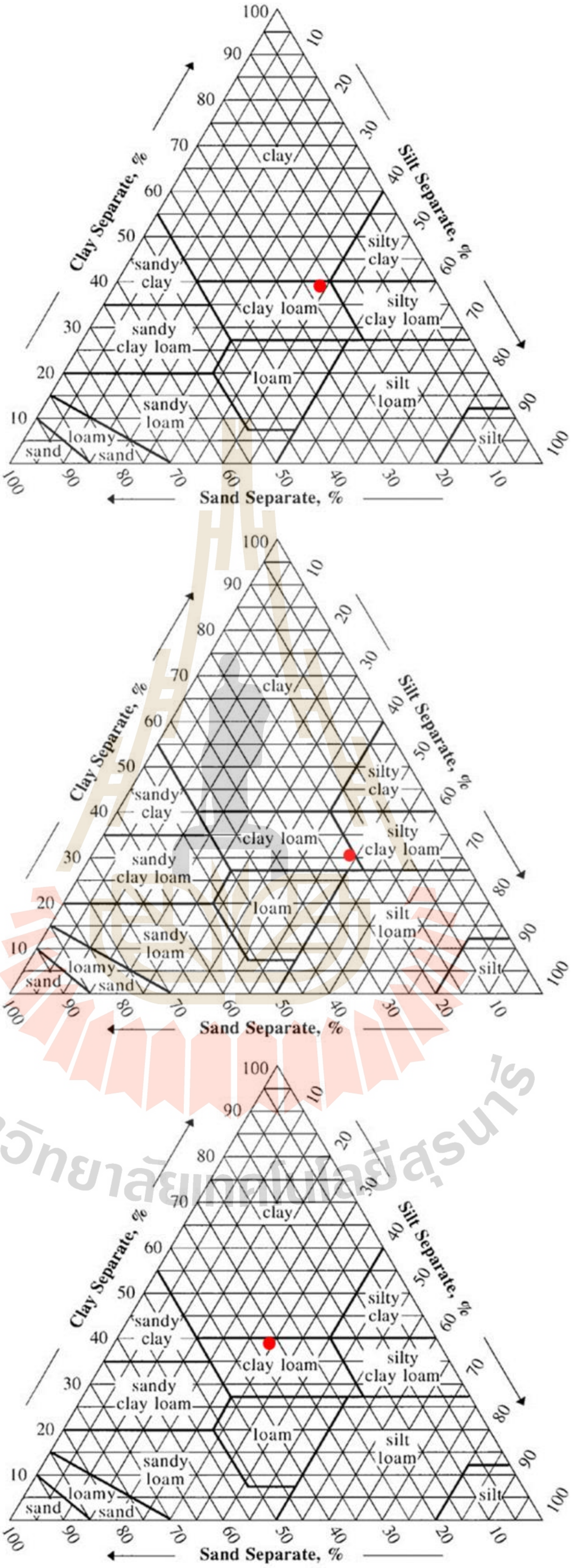


Figure 7B Soil texture of plot 4 and 5 of transect 4, and plot 1 of transect 5.

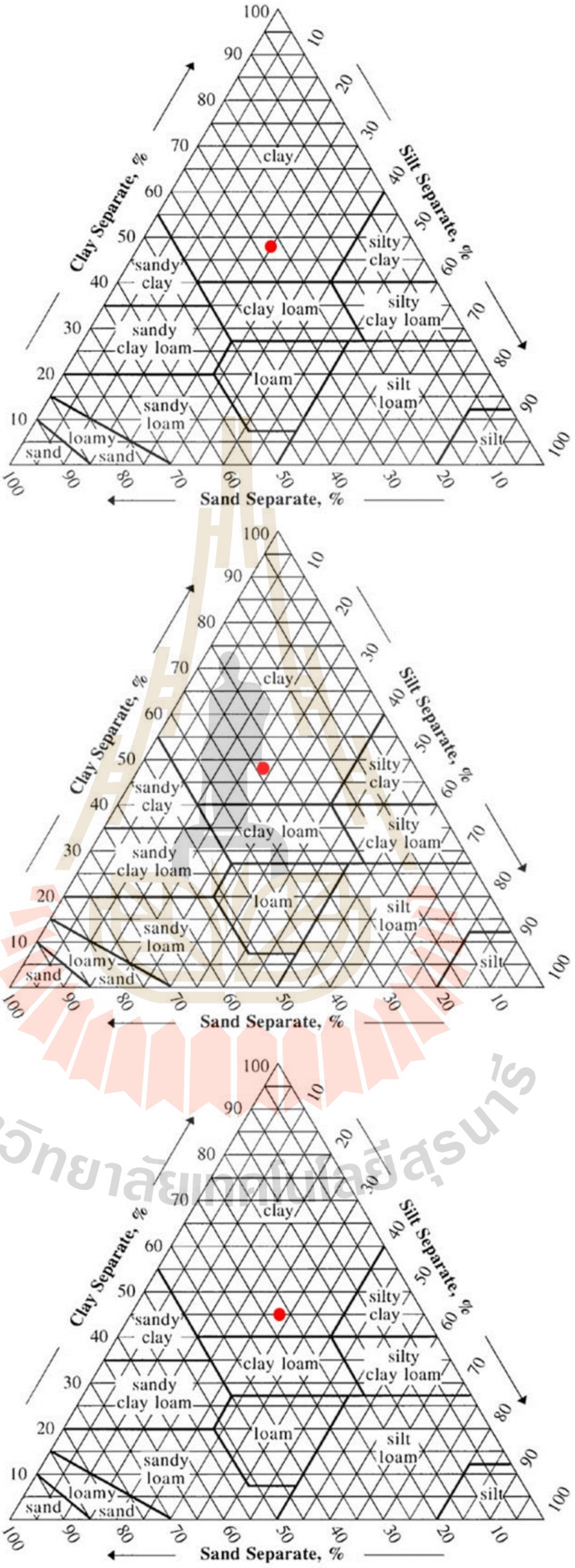


Figure 8B Soil texture of plot 2, 3, and 4 of transect 5.

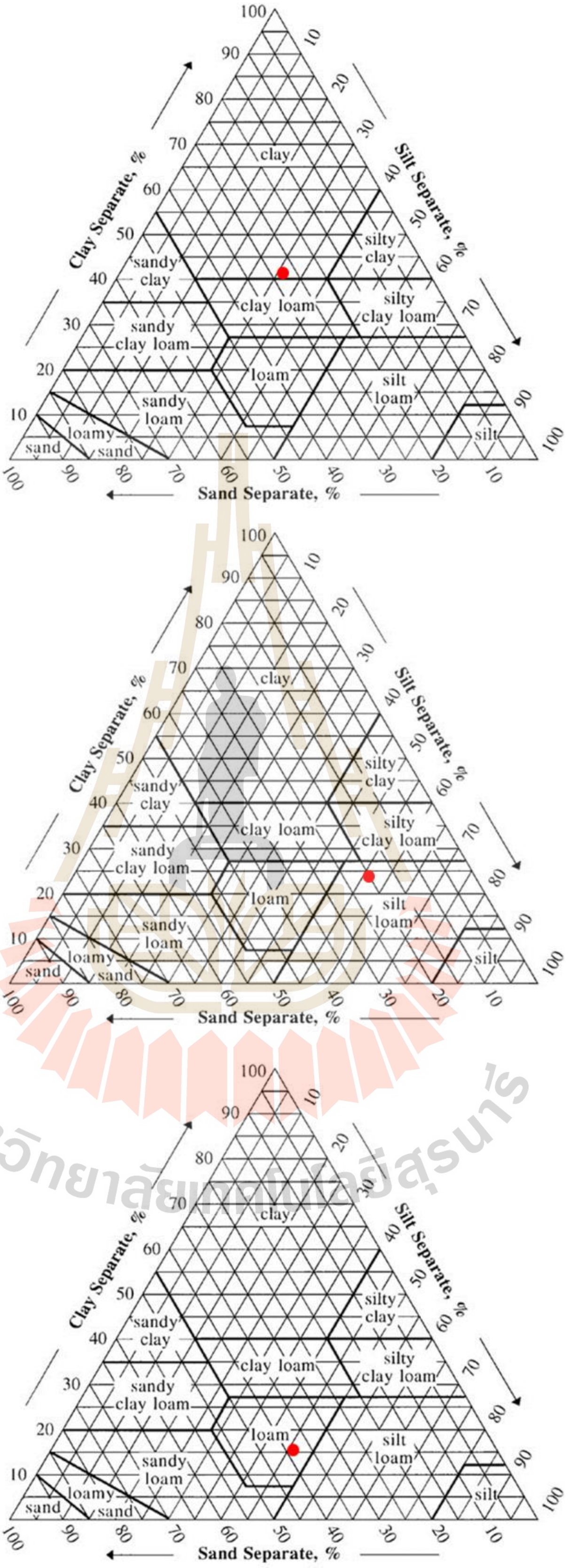


Figure 9B Soil texture of plot 5 of transect 5, and plot 1 and 2 of transect 6.

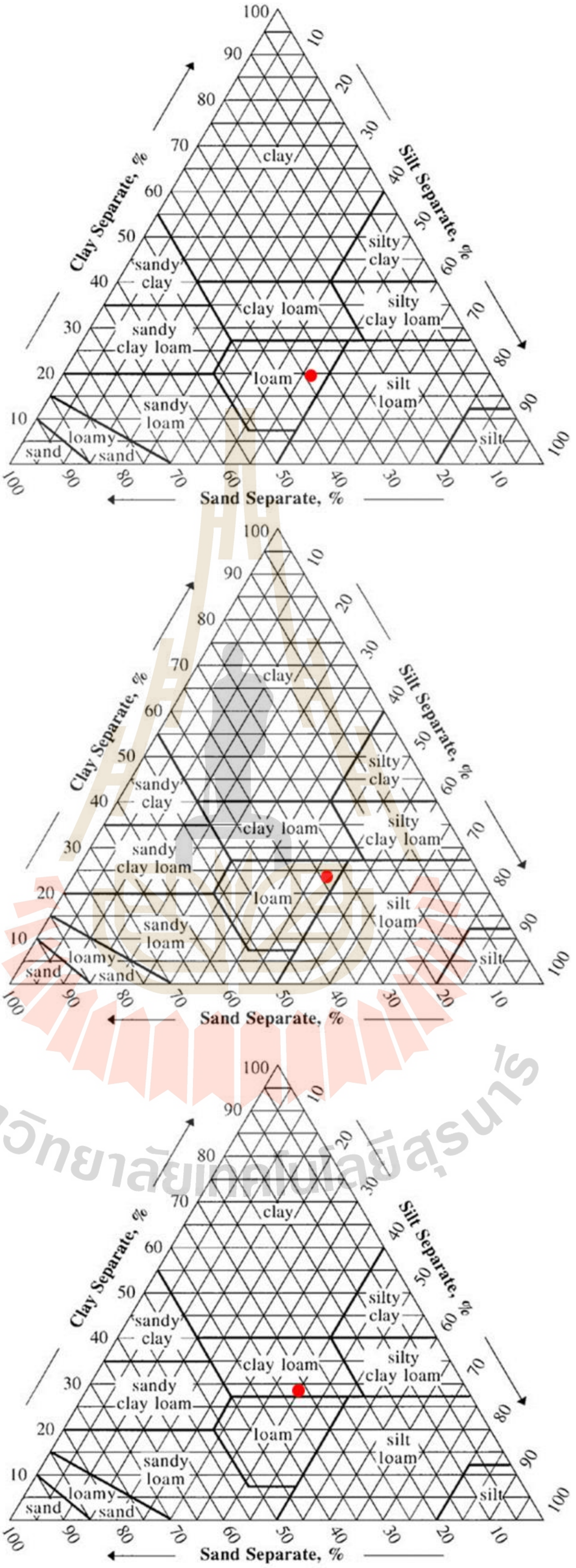


Figure 10B Soil texture of plot 3, 4, and 5 of transect 6.

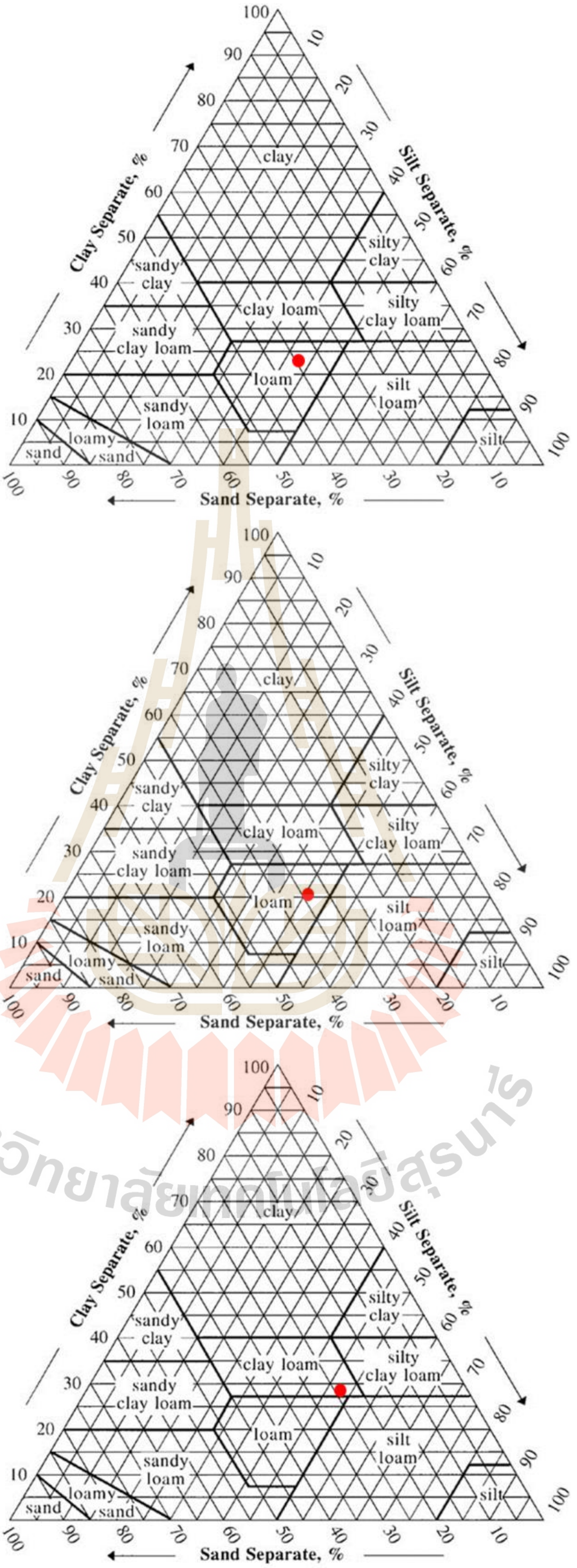


Figure 11B Soil texture of plot 1, 2, and 3 of transect 7.

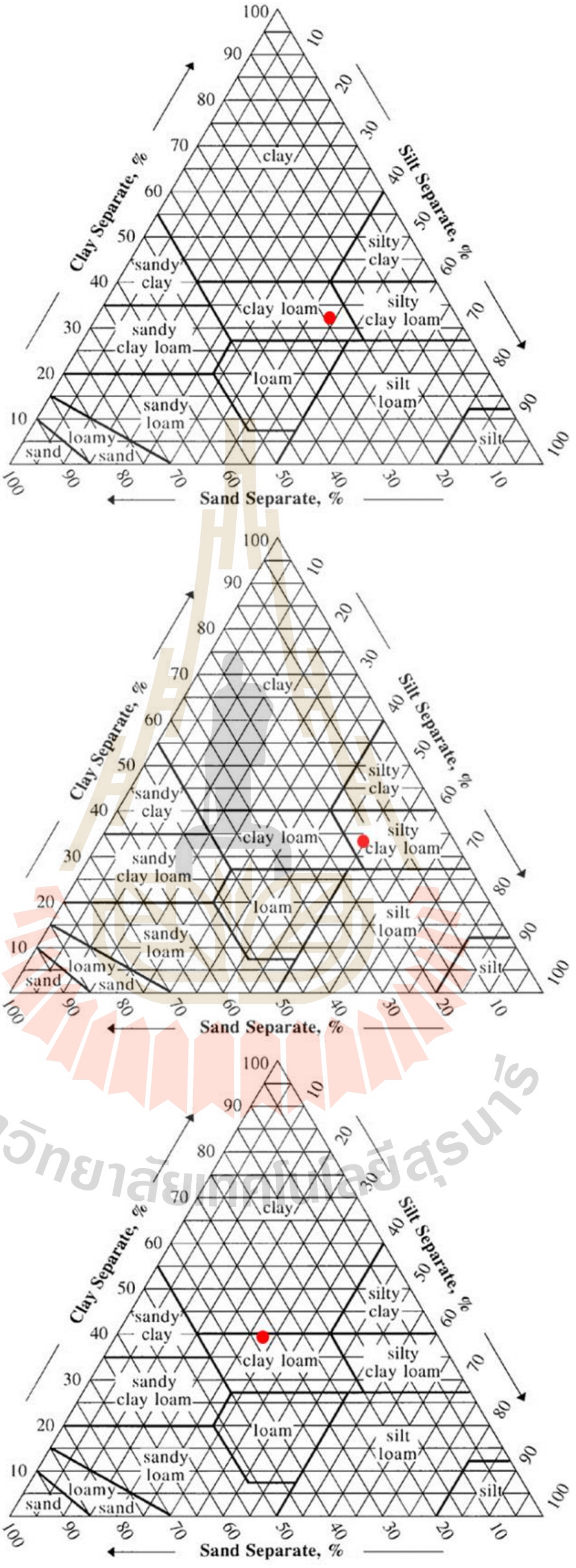


Figure 12B Soil texture of plot 4 and 5 of transect 7, and plot 1 of transect 8.

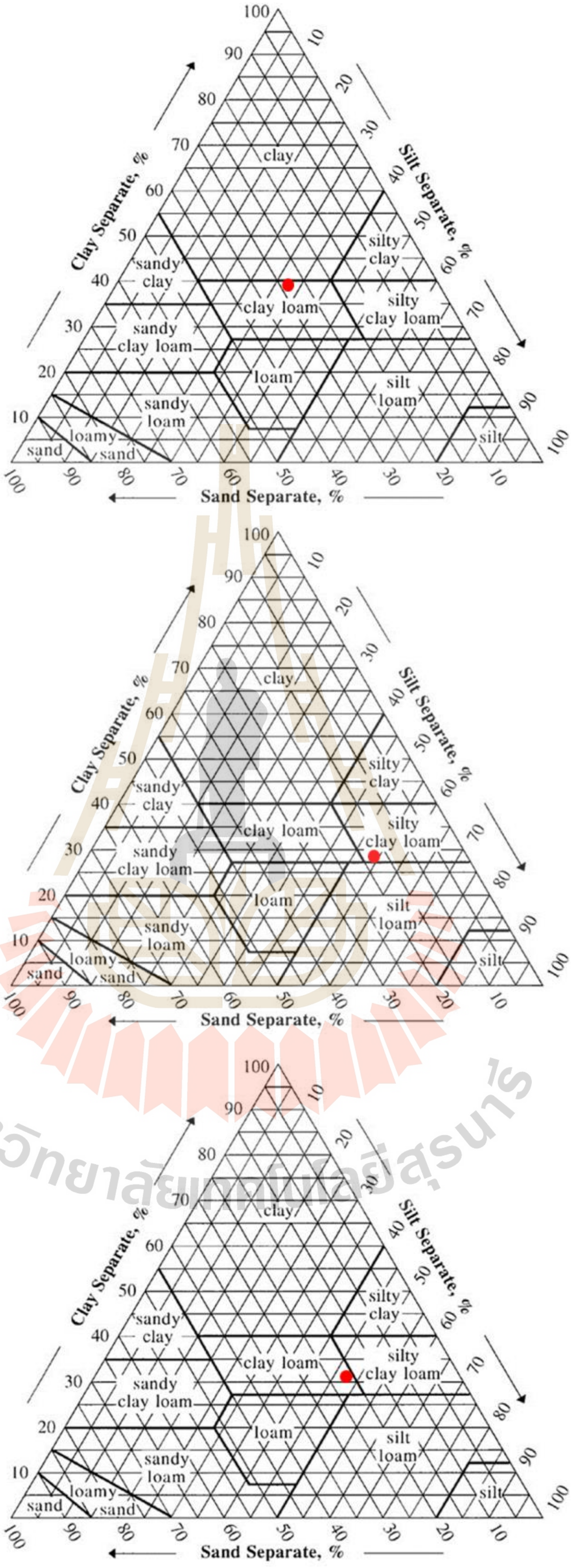


Figure 13B Soil texture of plot 2, 3, and 4 of transect 8.

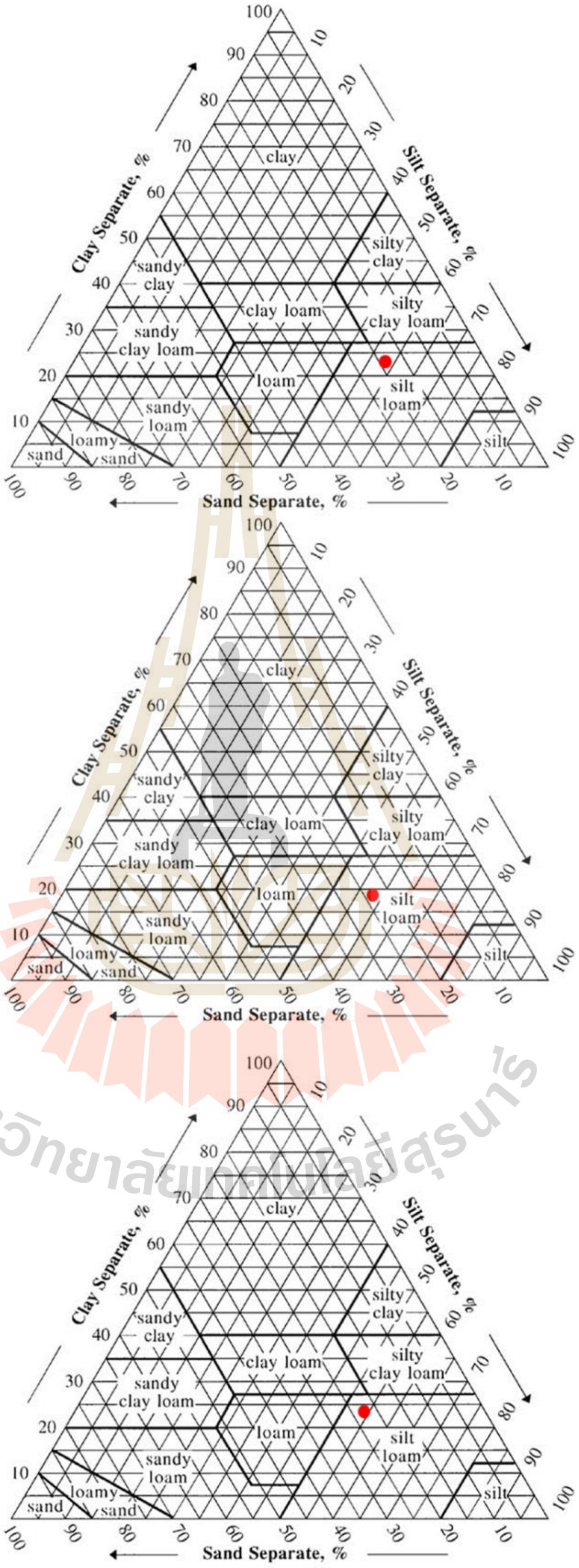


Figure 14B Soil texture of plot 5 of transect 8, plot 1, and plot 2 of transect 9.

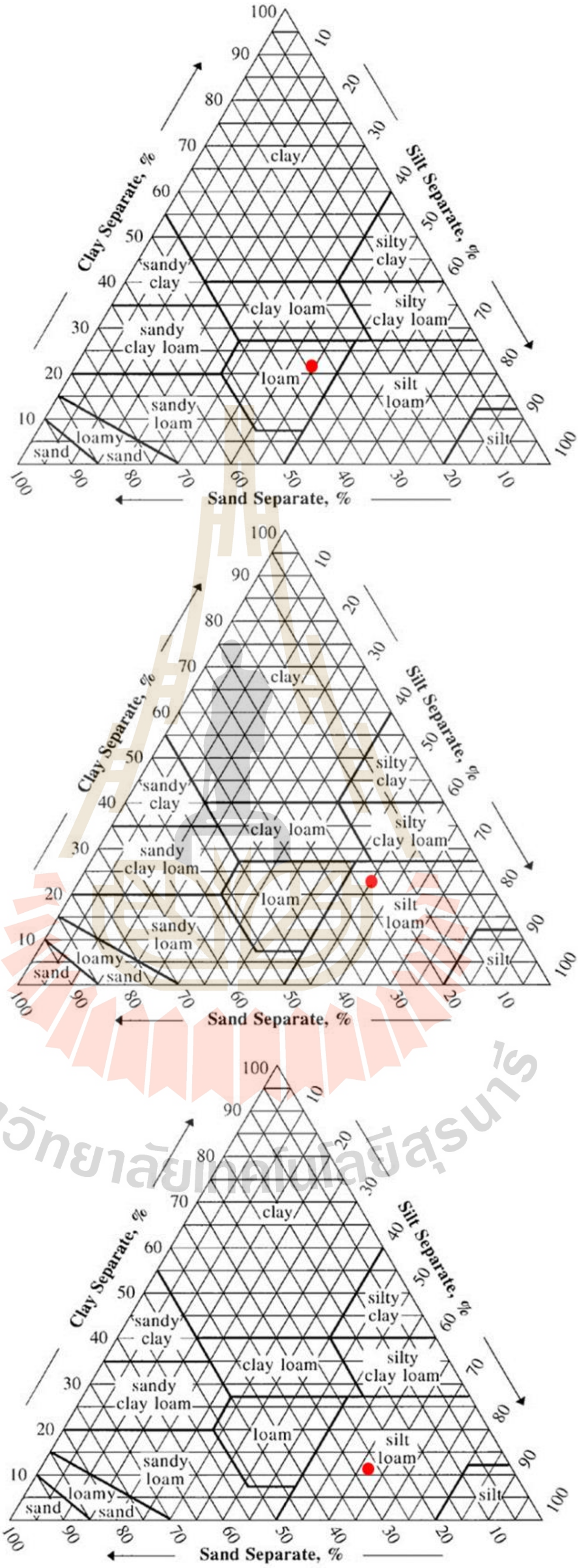


Figure 15B Soil texture of plot 3, 4, and 5 of transect 9.

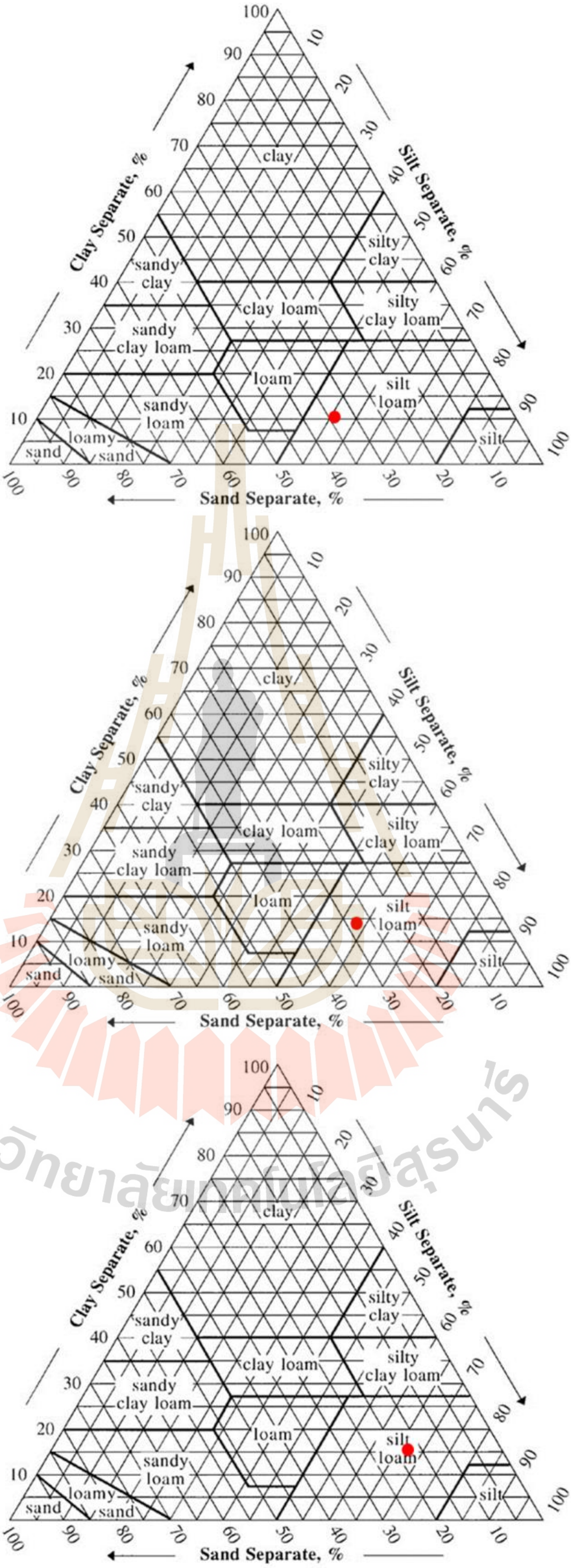


Figure 16B Soil texture of plot 1, 2 and 3 of transect 10.

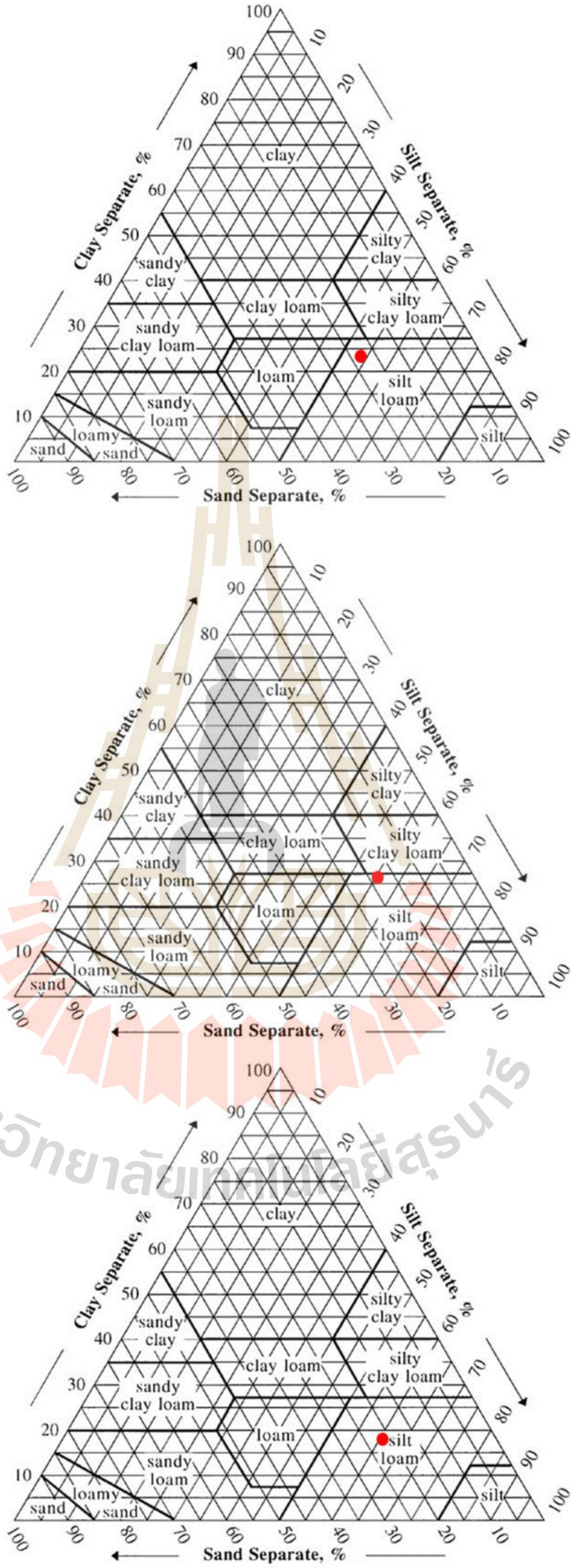


Figure 17B Soil texture of plot 4, 5 of transect 10, and plot 1 of transect 11.

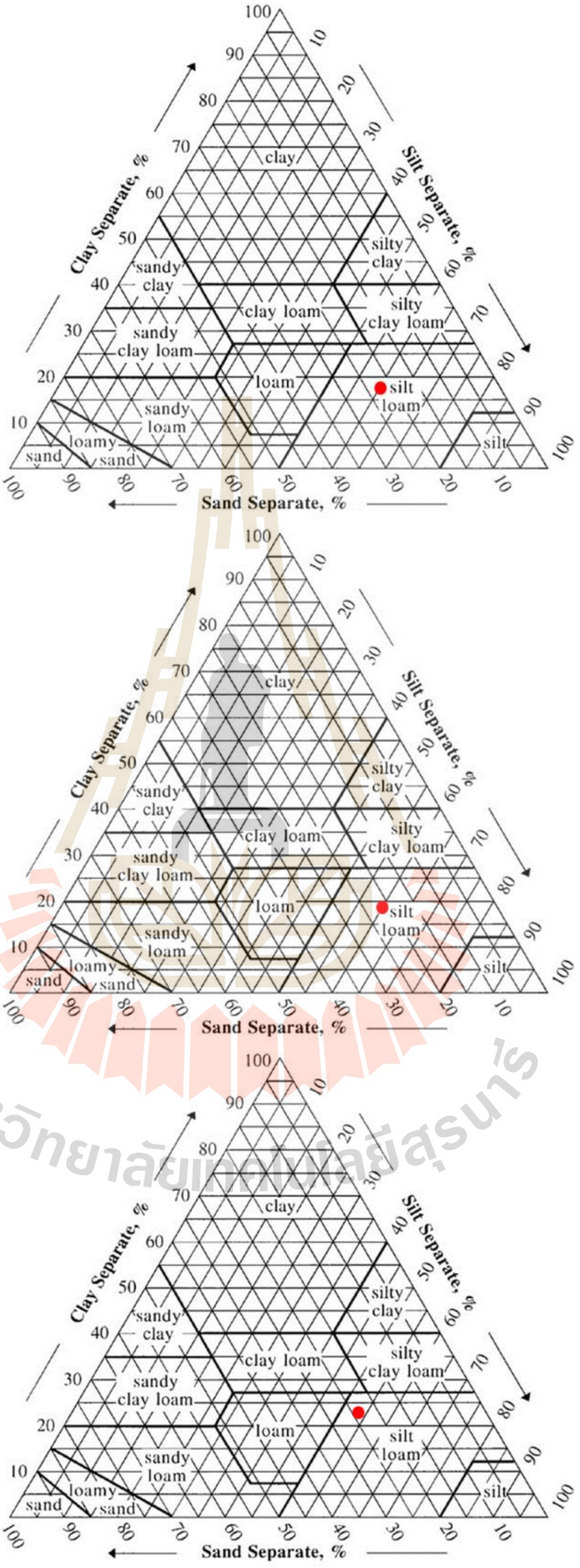


Figure 18B Soil texture of plot 2, 3, and 4 of transect 11.

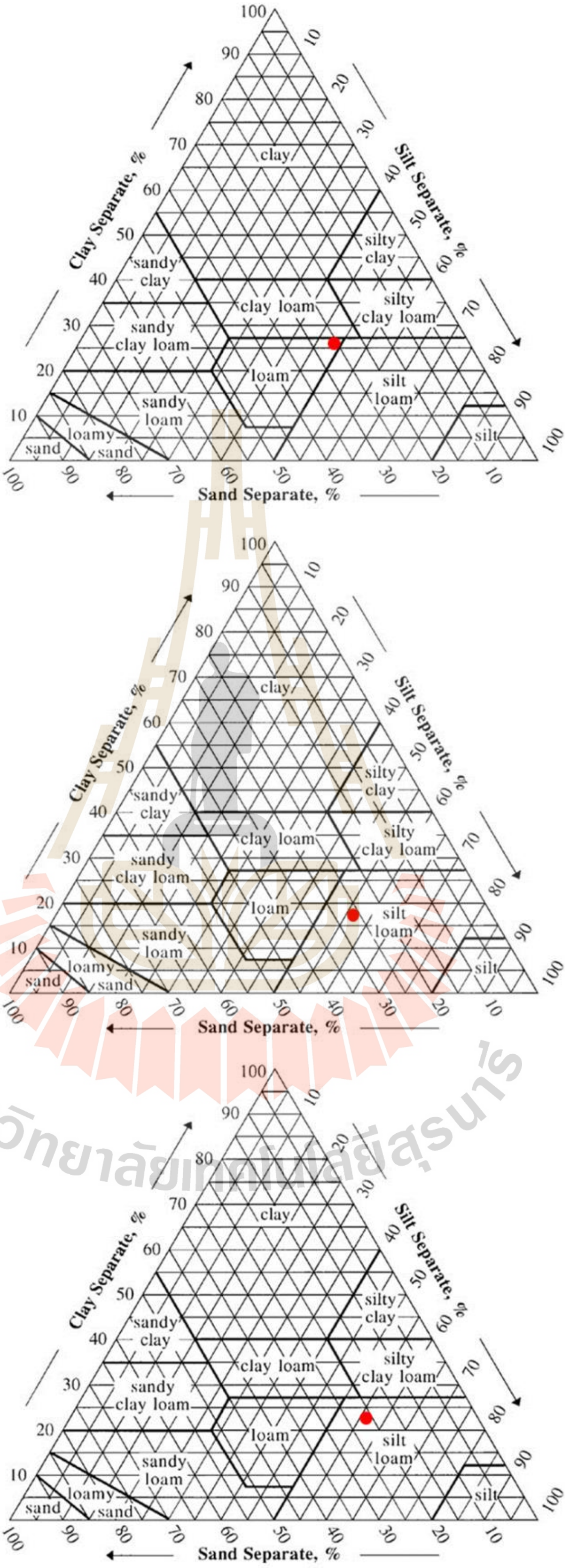


Figure 19B Soil texture of plot 5 of transect 11, plot 1, and 2 of transect 12.

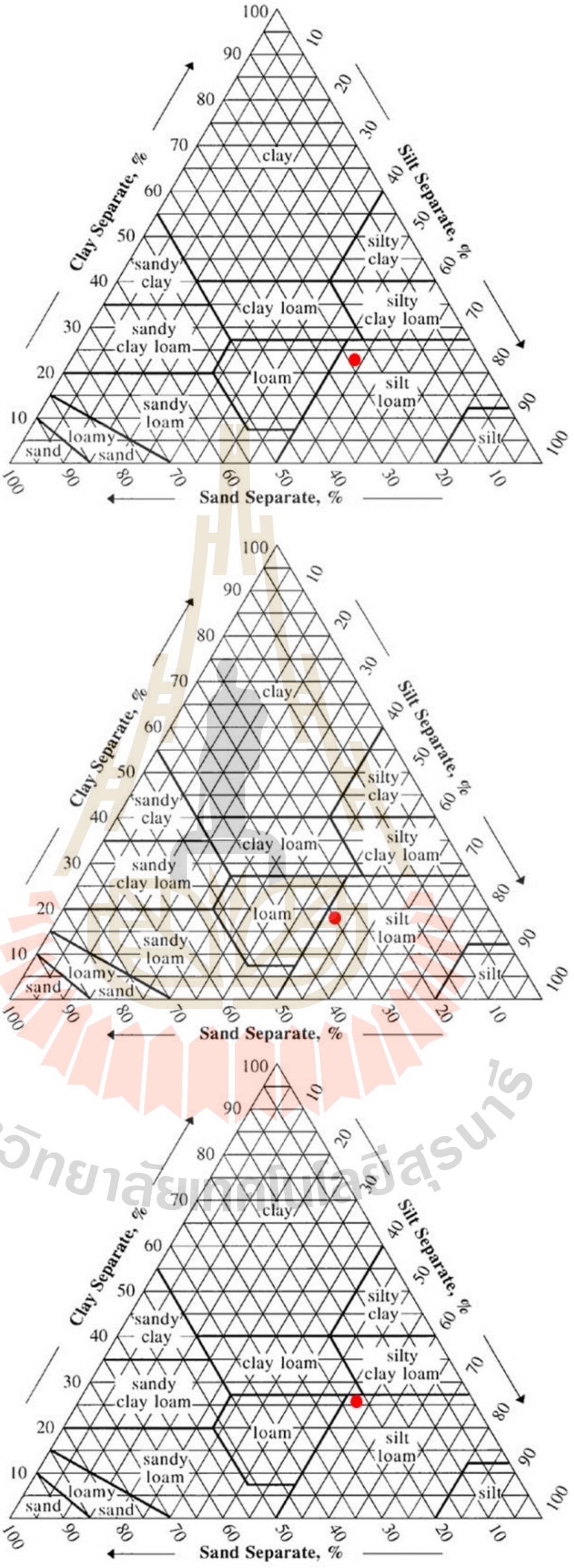


Figure 20B Soil texture of plot 3, 4, and 5 of transect 12.

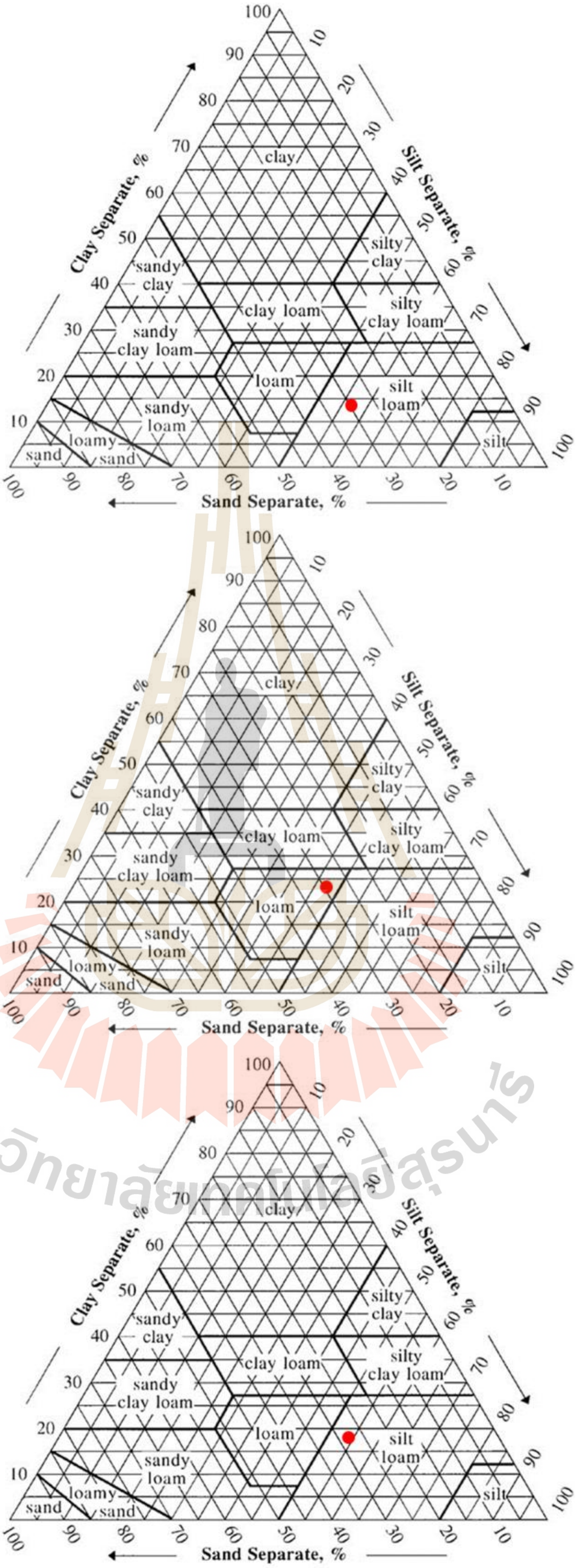


Figure 21B Soil texture of plot 1, 2, and 3 of transect 13.

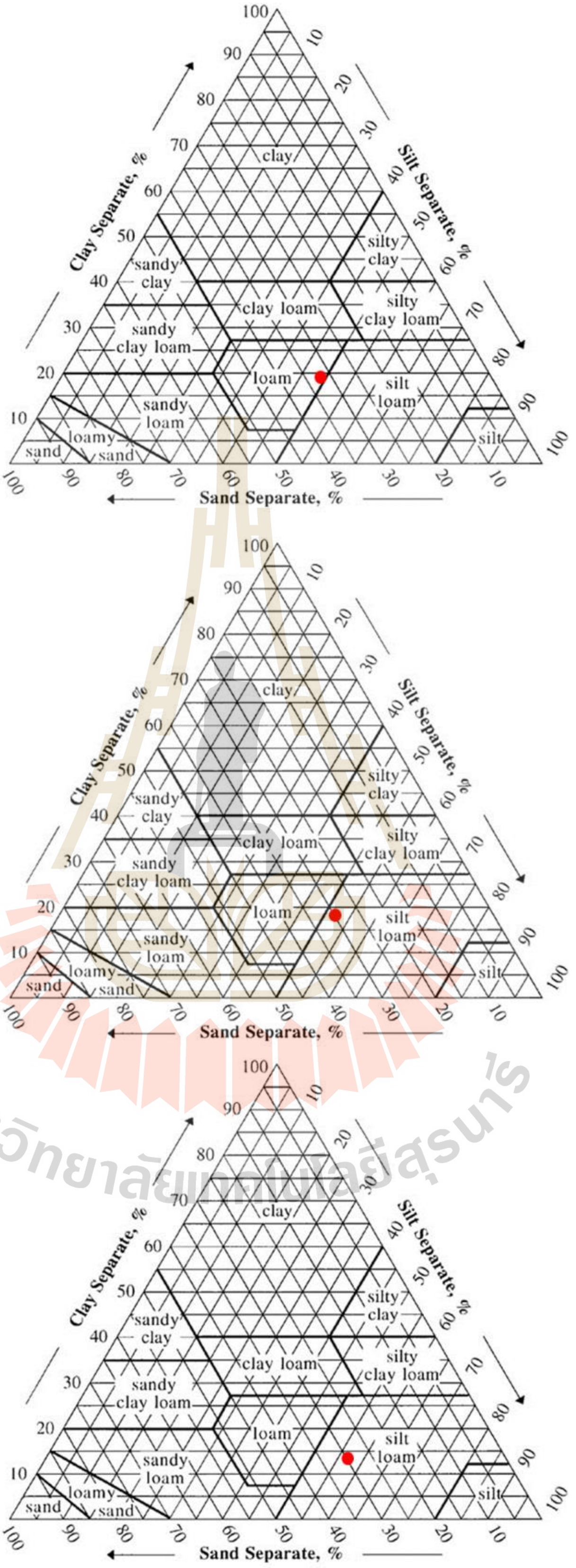


Figure 22B Soil texture of plot 4, 5 of transect 13 and plot 1 of transect 14.

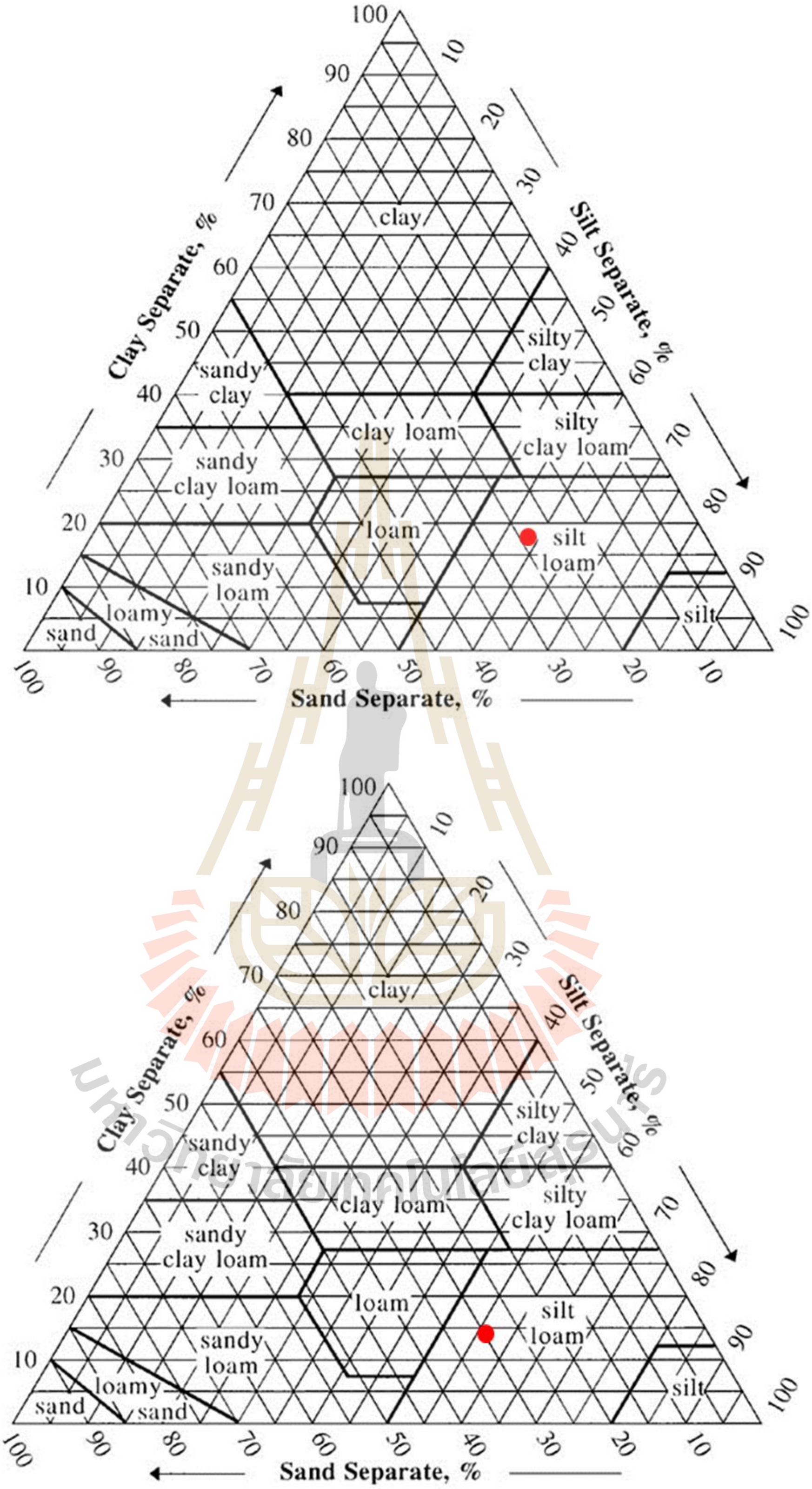
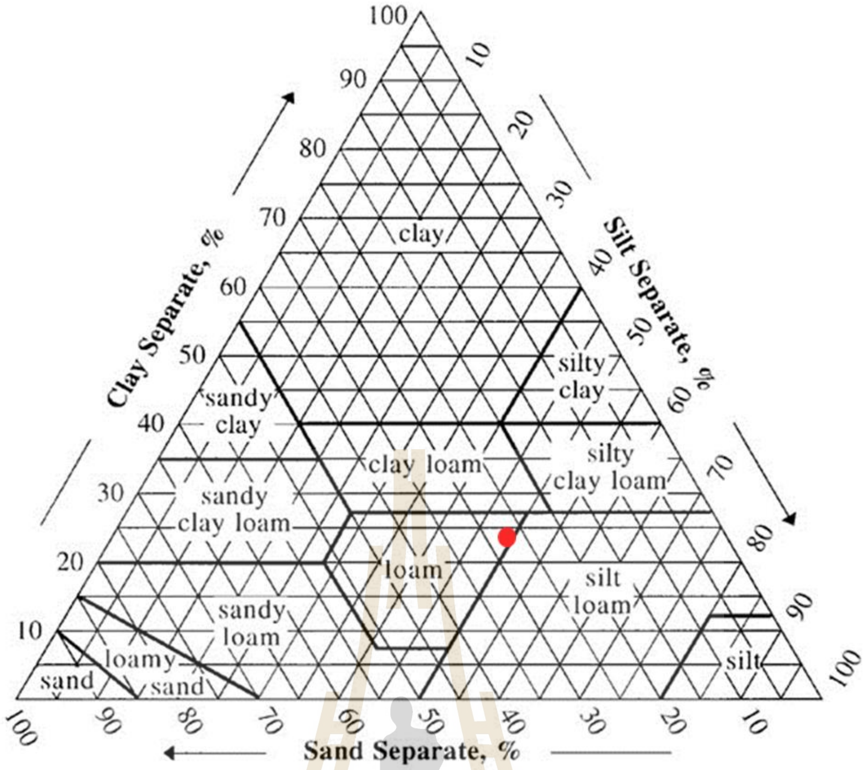


Figure 23B Soil texture of plot 2 and 3 of transect 14.



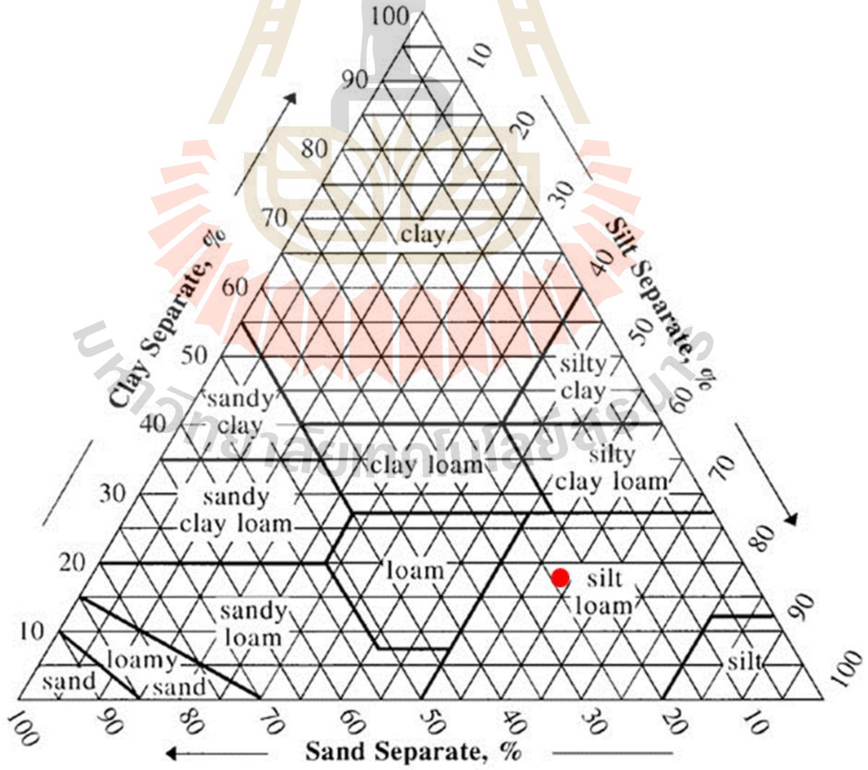


Figure 24B Soil texture of plot 4 and 5 of transect 14.

APPENDIX C

CORRELATION PLOTS

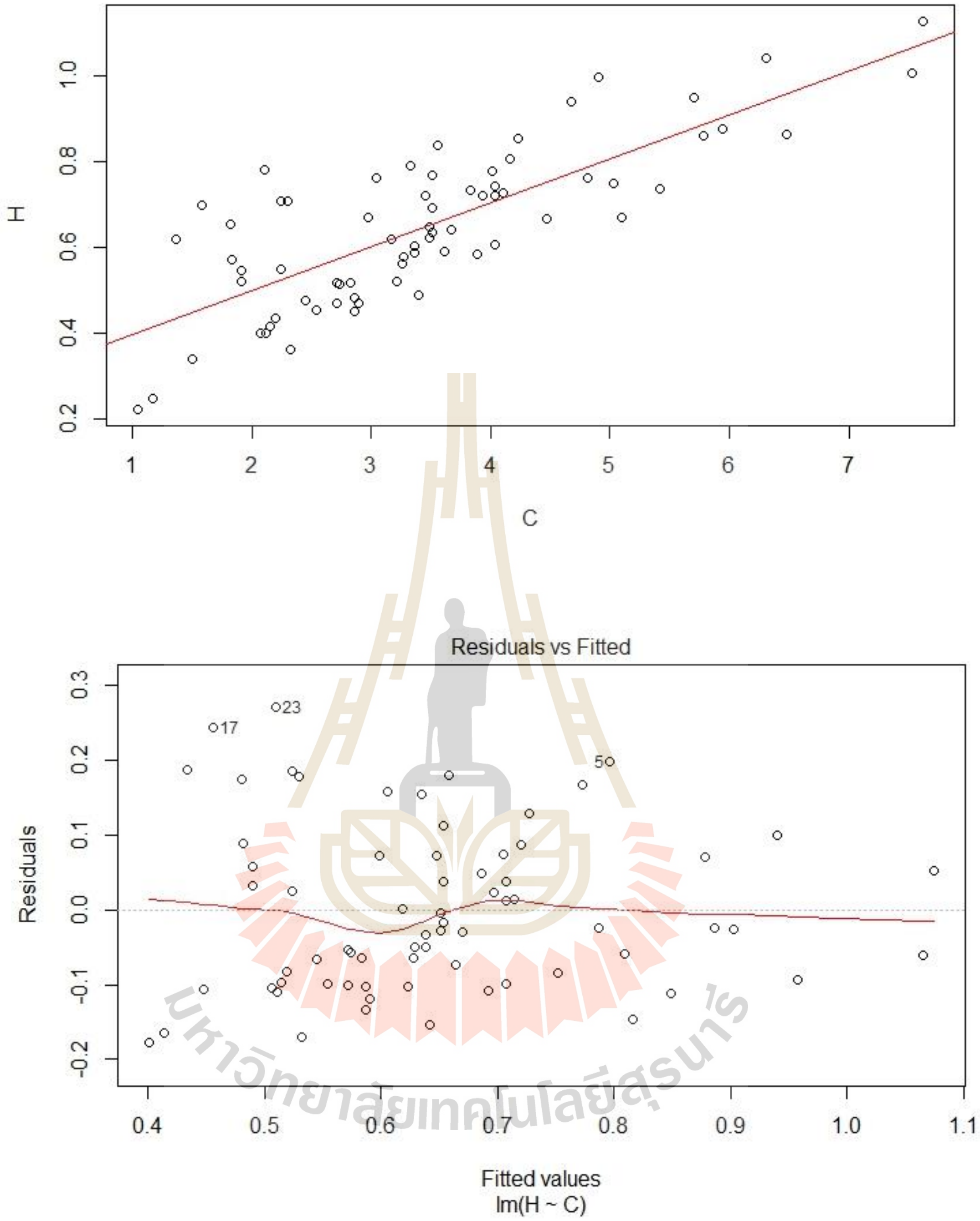


Figure 1C The regression and residuals versus fitted values plots between soil C and H in Khao Khiew in Khao Yai National Park, Thailand.

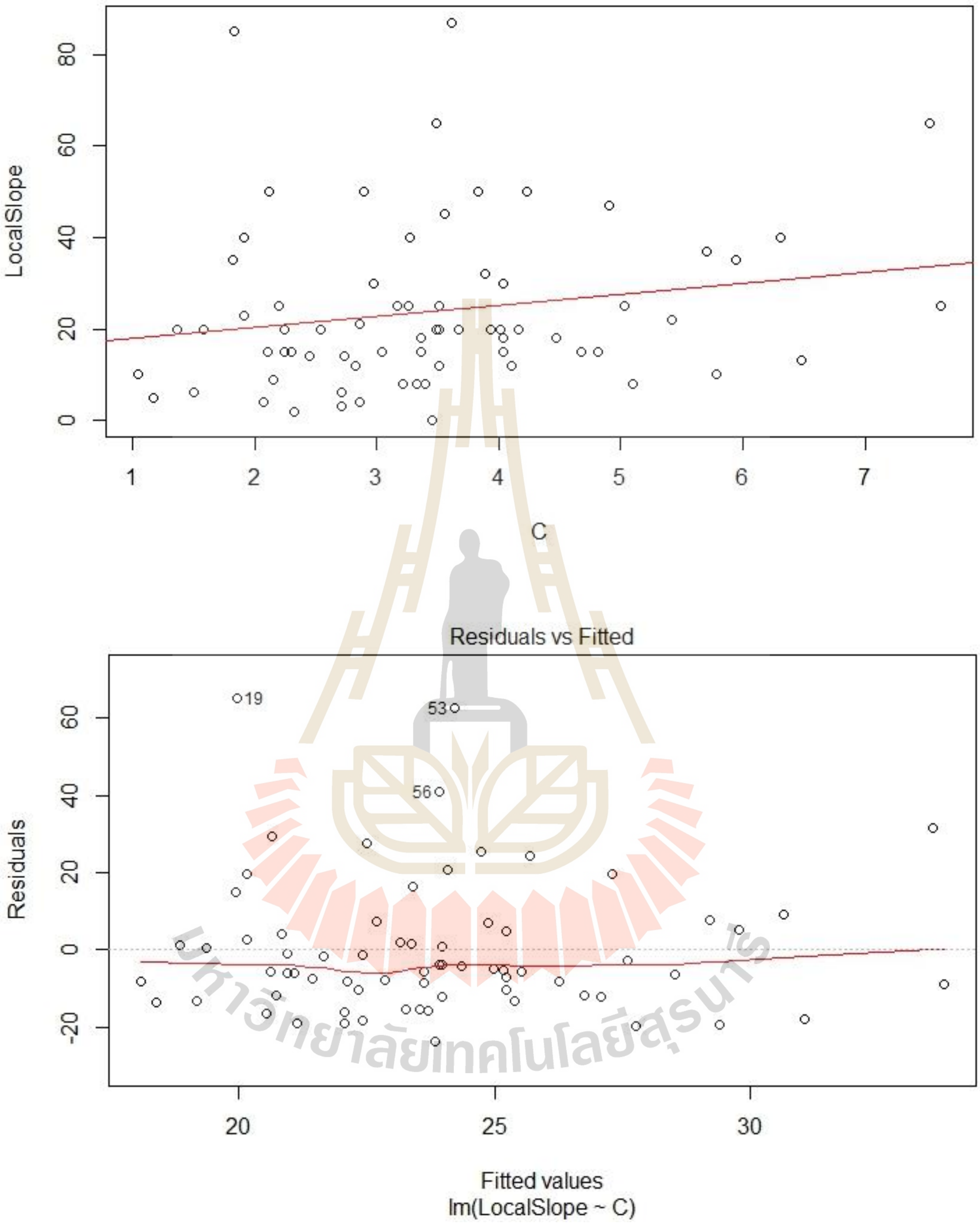


Figure 2C The regression and residuals versus fitted values plots between soil C and local slope in Khao Khiew in Khao Yai National Park, Thailand.

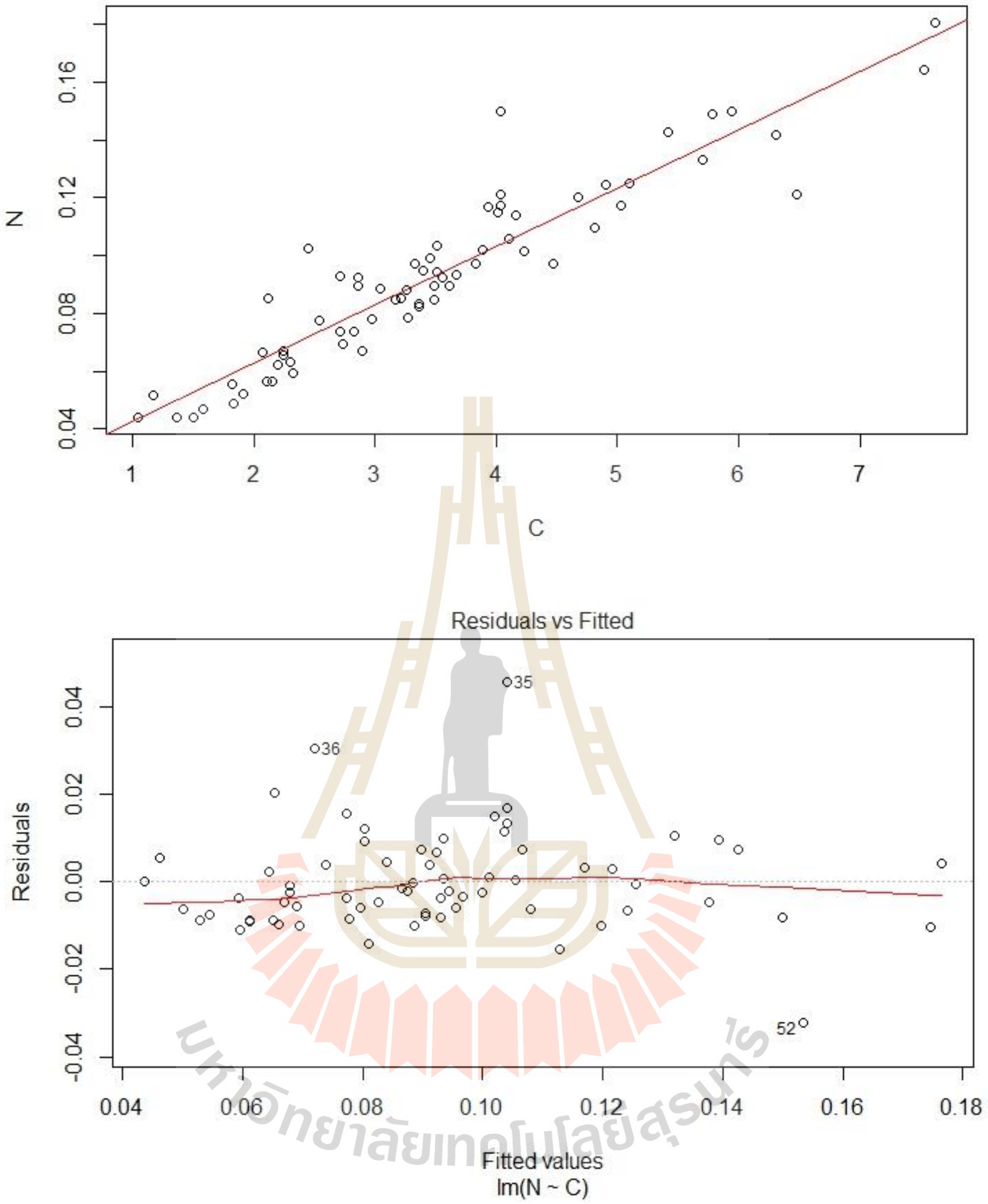


Figure 3C The regression and residuals versus fitted values plots between soil C and N in Khao Khiew in Khao Yai National Park, Thailand.

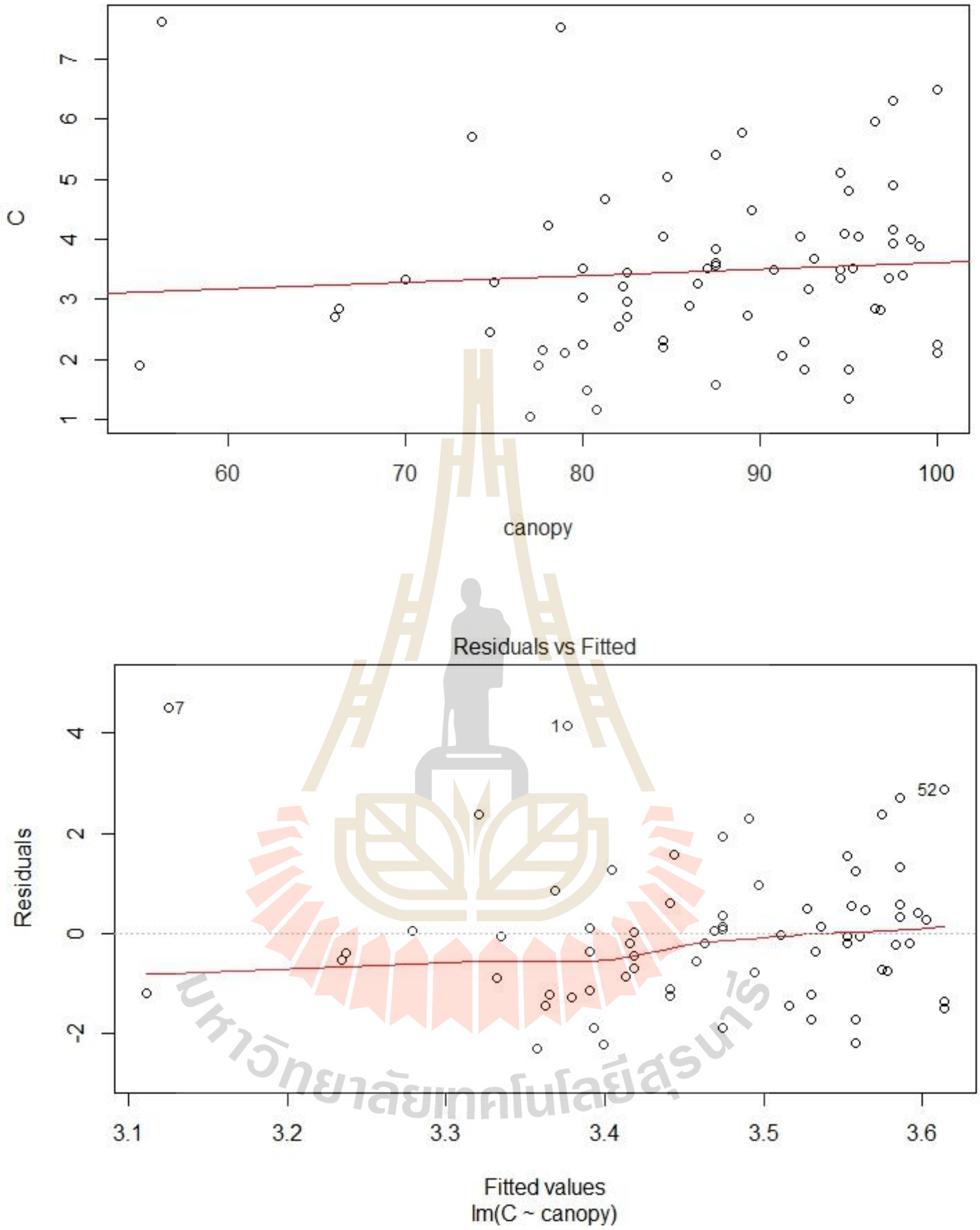


Figure 4C The regression and residuals versus fitted values plots between % canopy cover and soil C in Khao Khiew in Khao Yai National Park, Thailand.

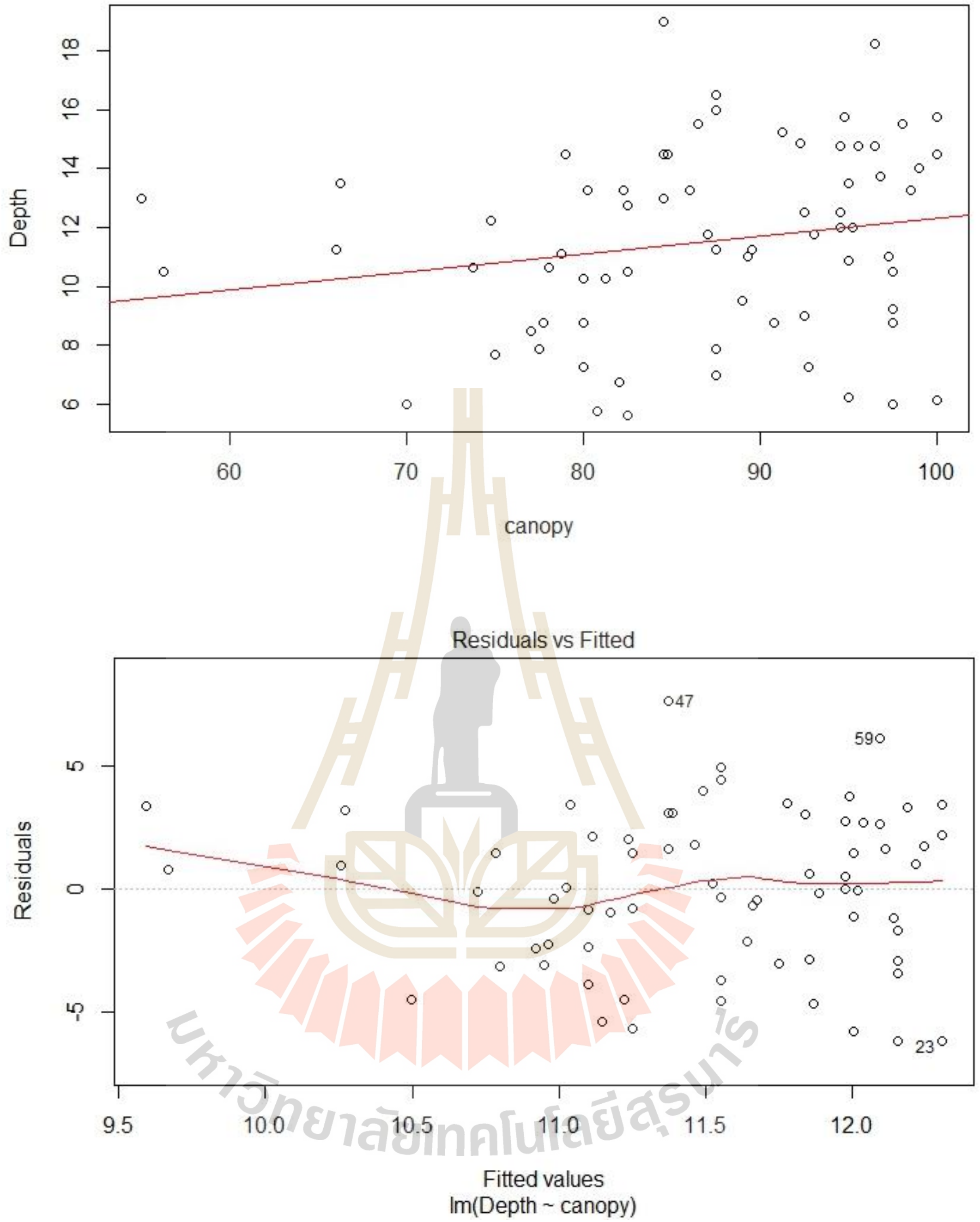


Figure 5C The regression and residuals versus fitted values plots between % canopy cover soil and depth in Khao Khiew in Khao Yai National Park, Thailand.

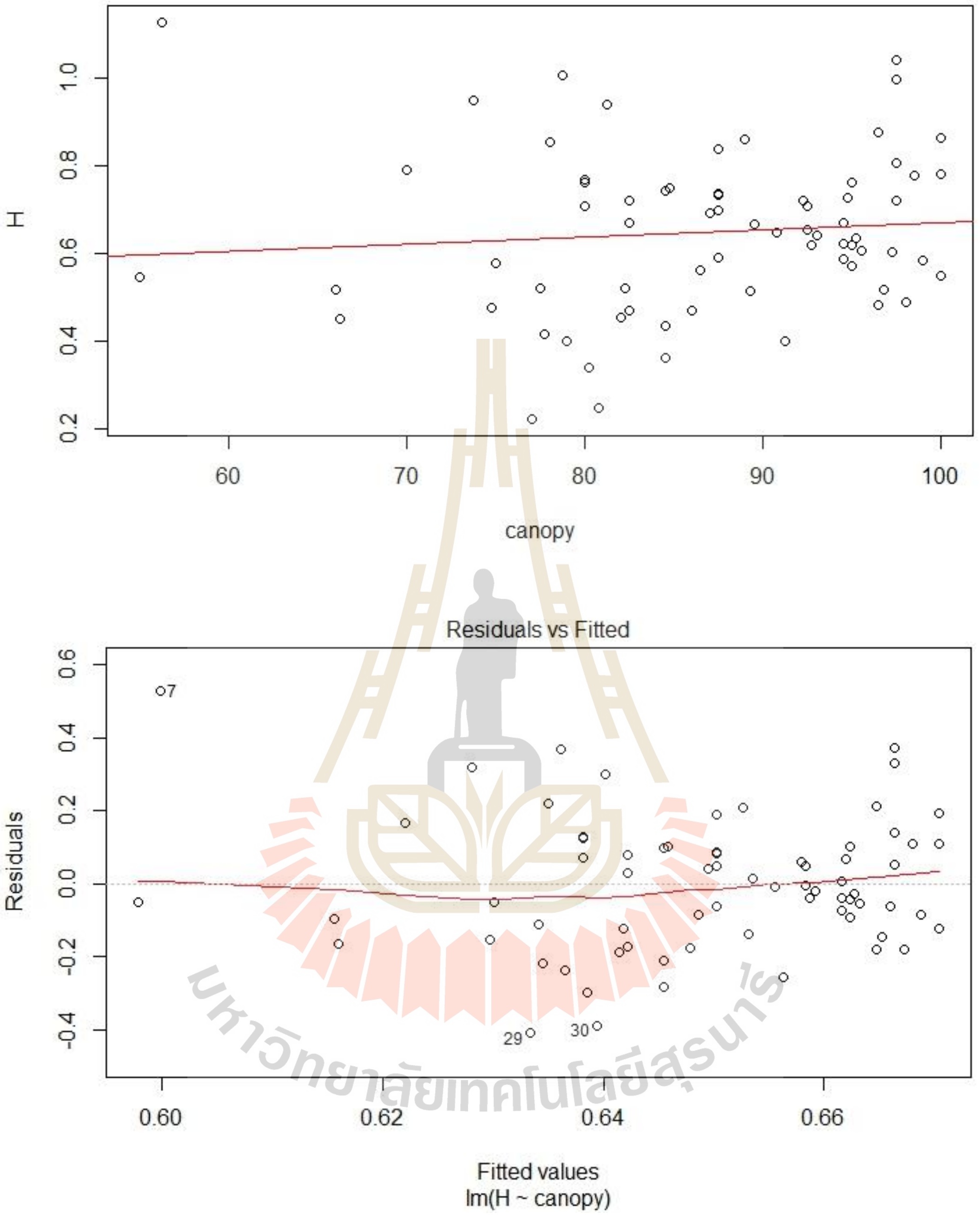


Figure 6C The regression and residuals versus fitted values plots between % canopy cover and soil H in Khao Khiew in Khao Yai National Park, Thailand.

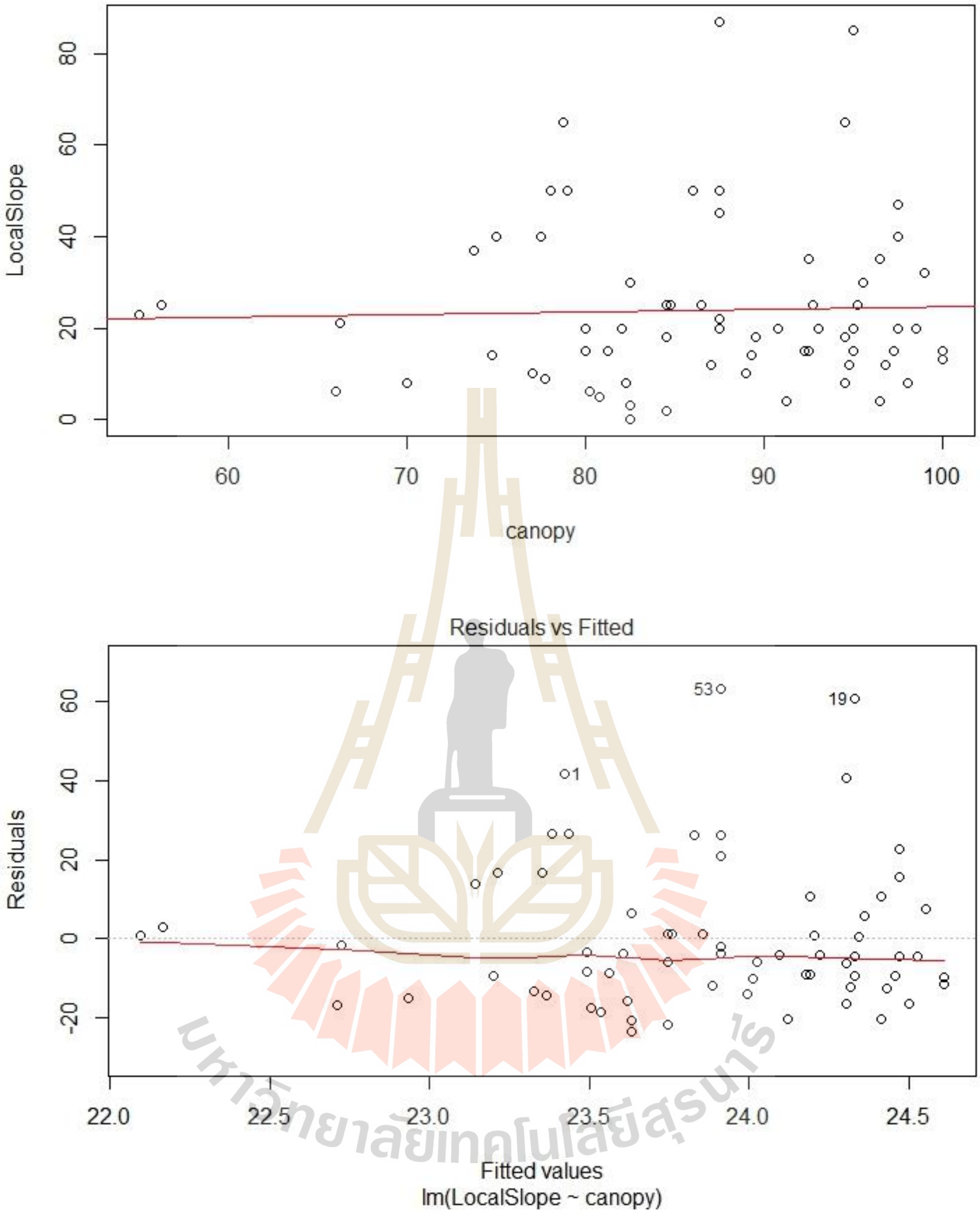


Figure 7C The regression and residuals versus fitted values plots between % canopy cover and local slope in Khao Khiew in Khao Yai National Park, Thailand.

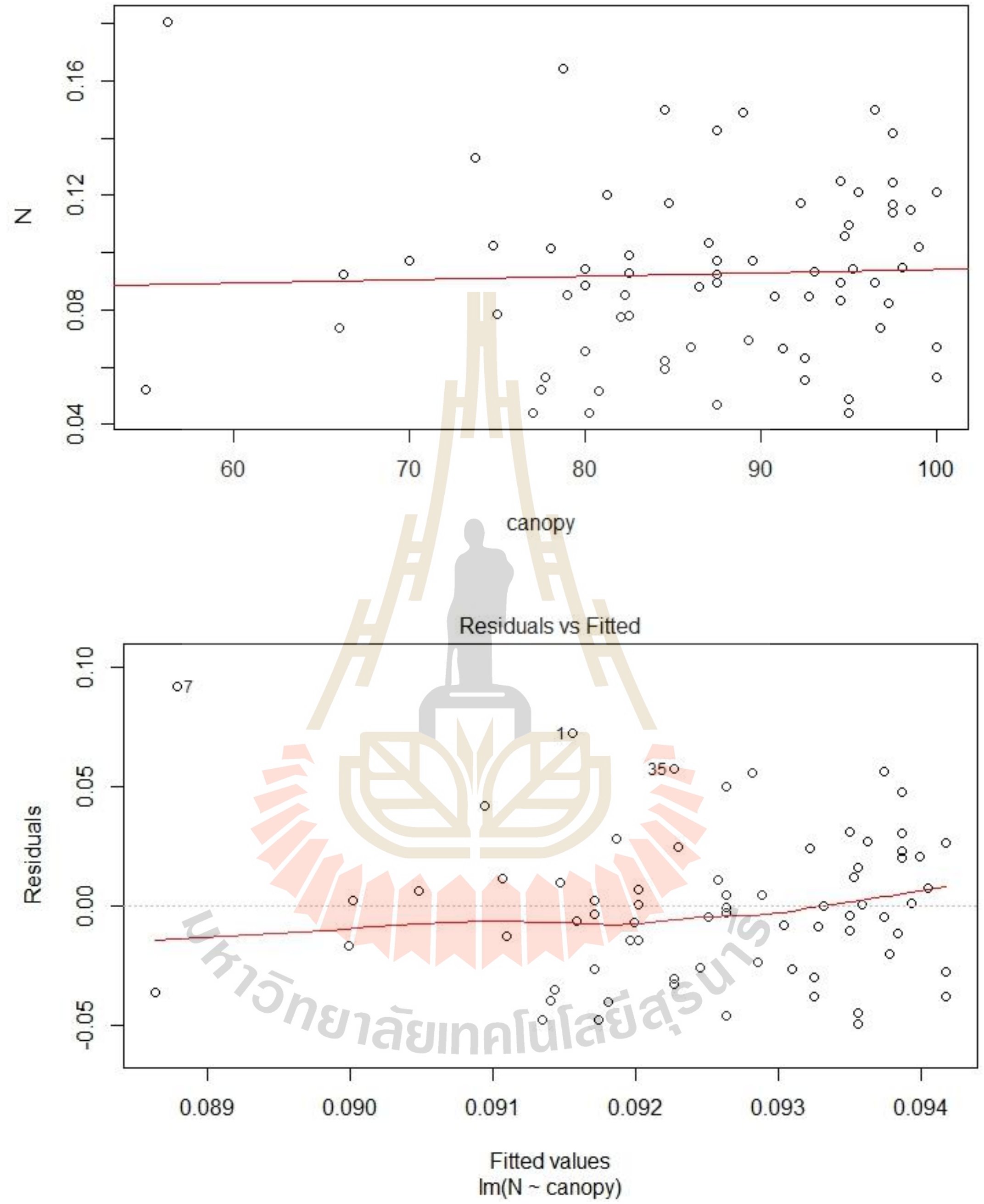


Figure 8C The regression and residuals versus fitted values plots between % canopy cover and soil N in Khao Khiew in Khao Yai National Park, Thailand.

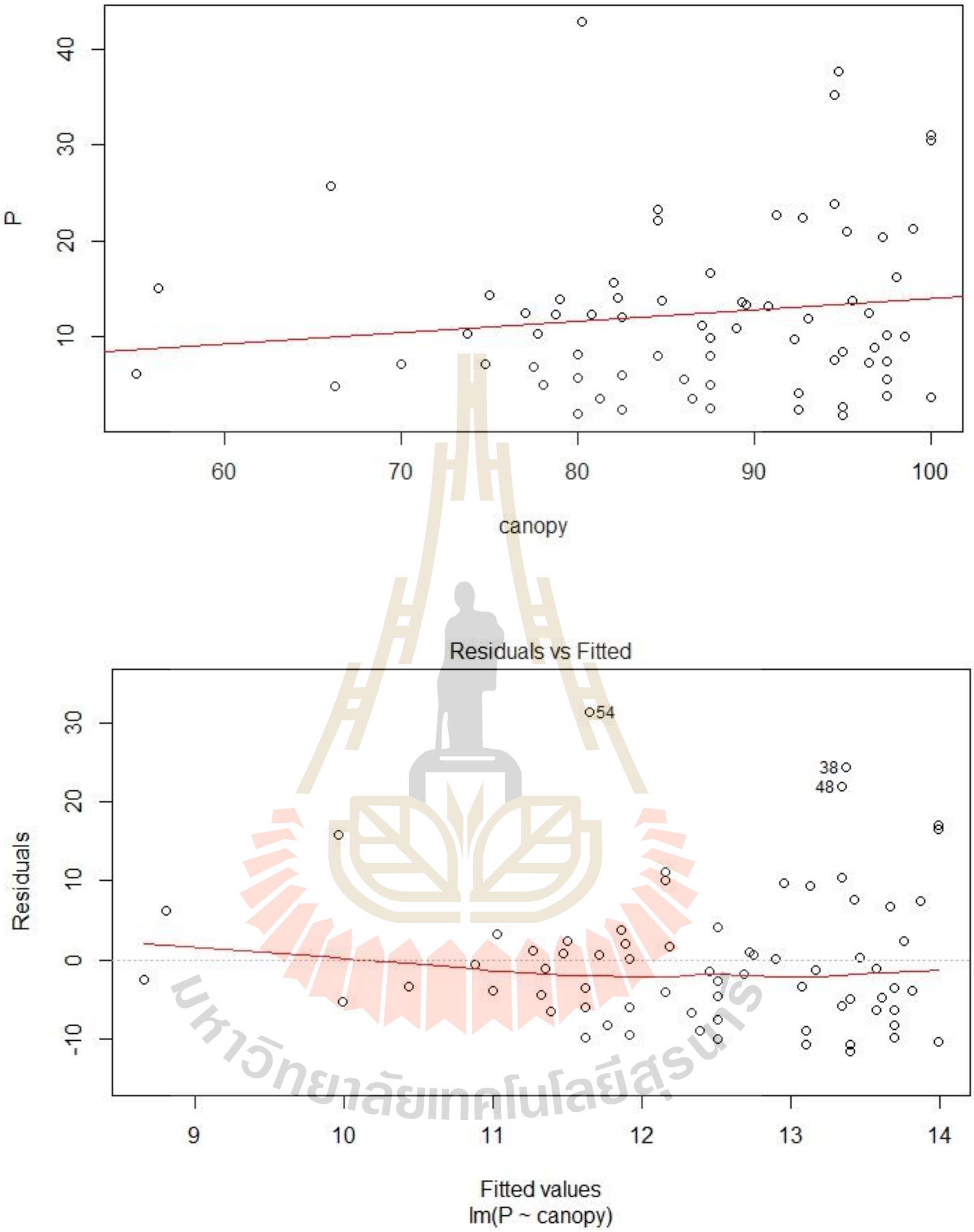


Figure 9C The regression and residuals versus fitted values plots between % canopy cover and soil P in Khao Khiew in Khao Yai National Park, Thailand.

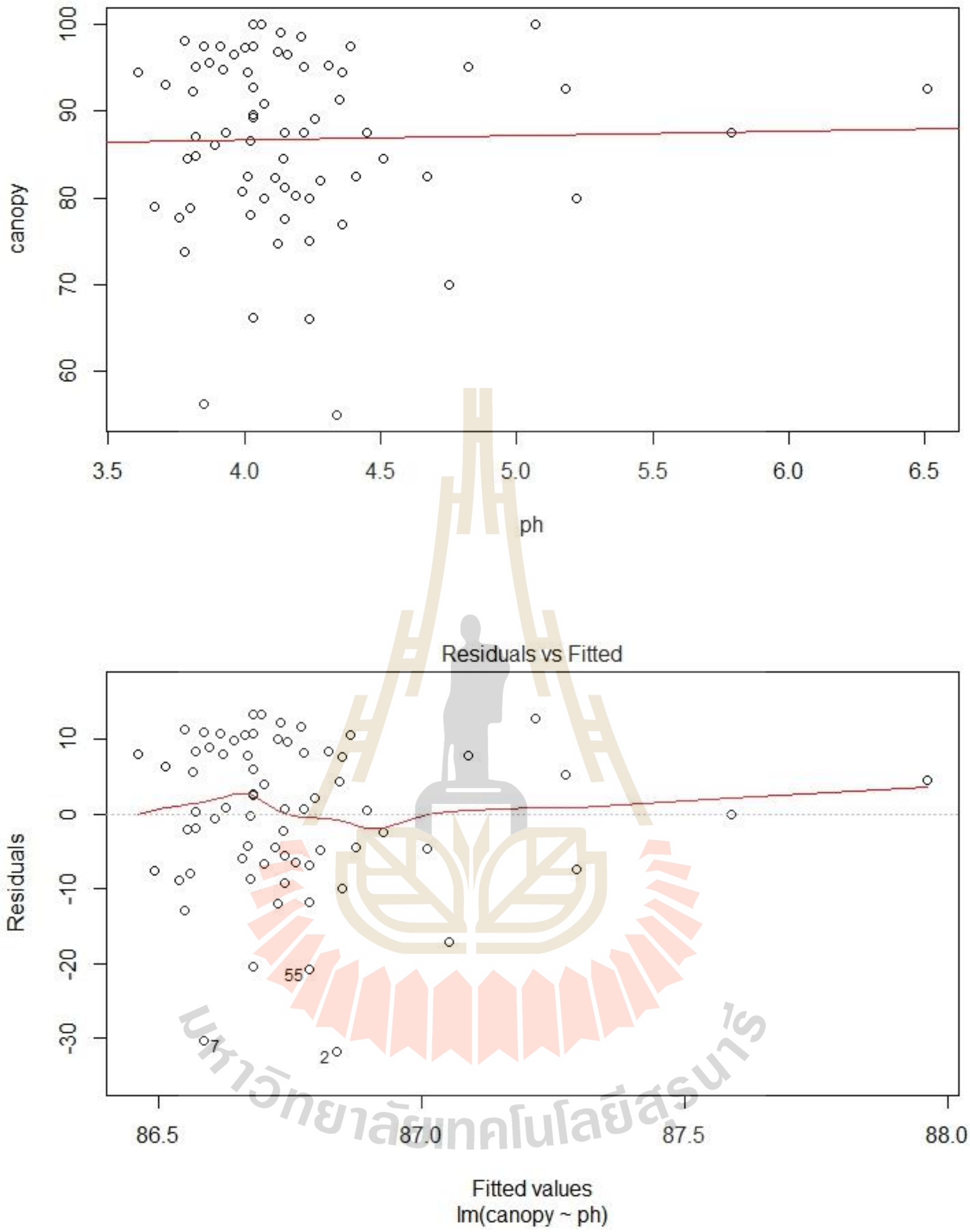


Figure 10C The regression and residuals versus fitted values plots between soil pH and % canopy cover in Khao Khiew in Khao Yai National Park, Thailand.

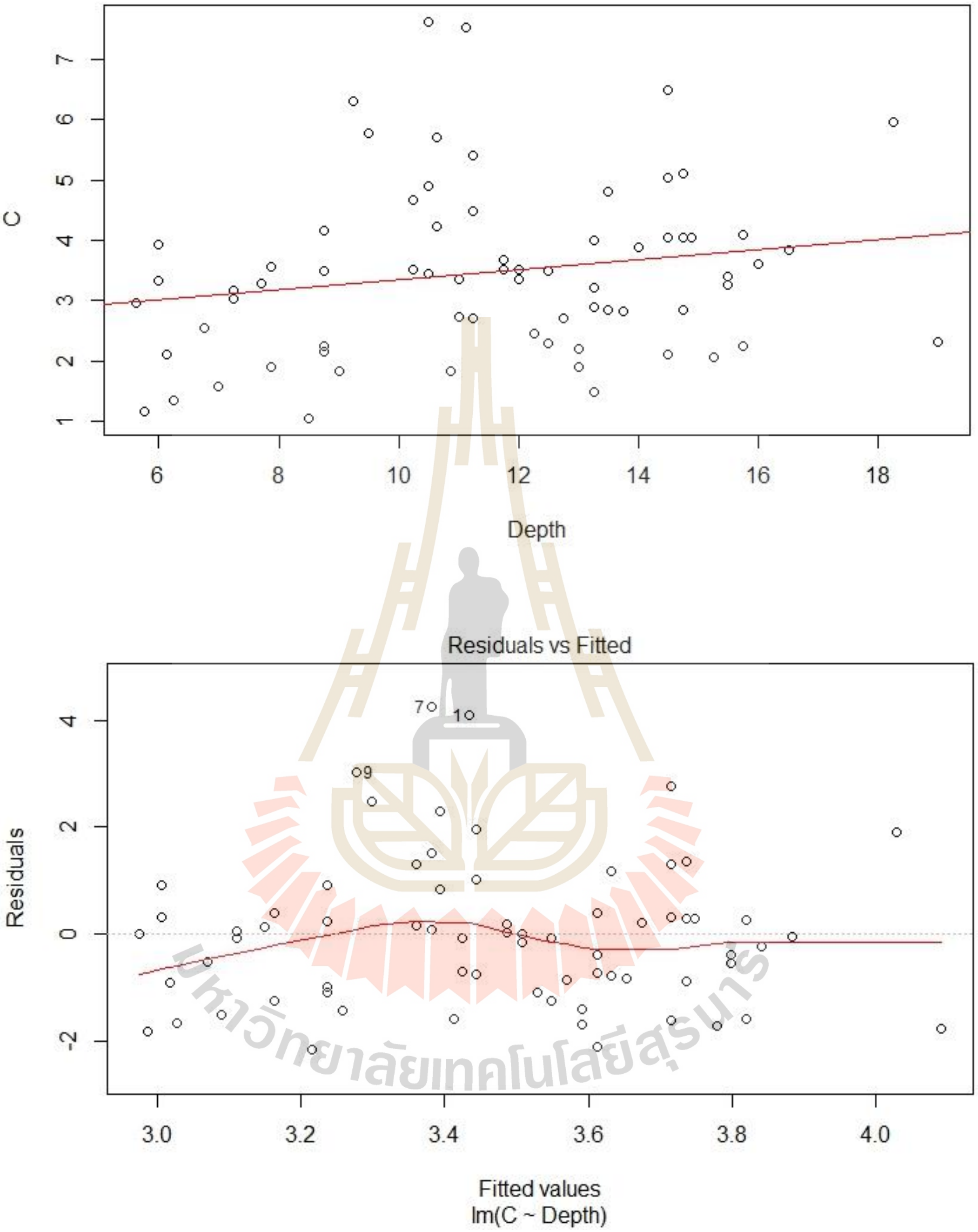


Figure 11C The regression and residuals versus fitted values plots between depth and soil C in Khao Khiew in Khao Yai National Park, Thailand.

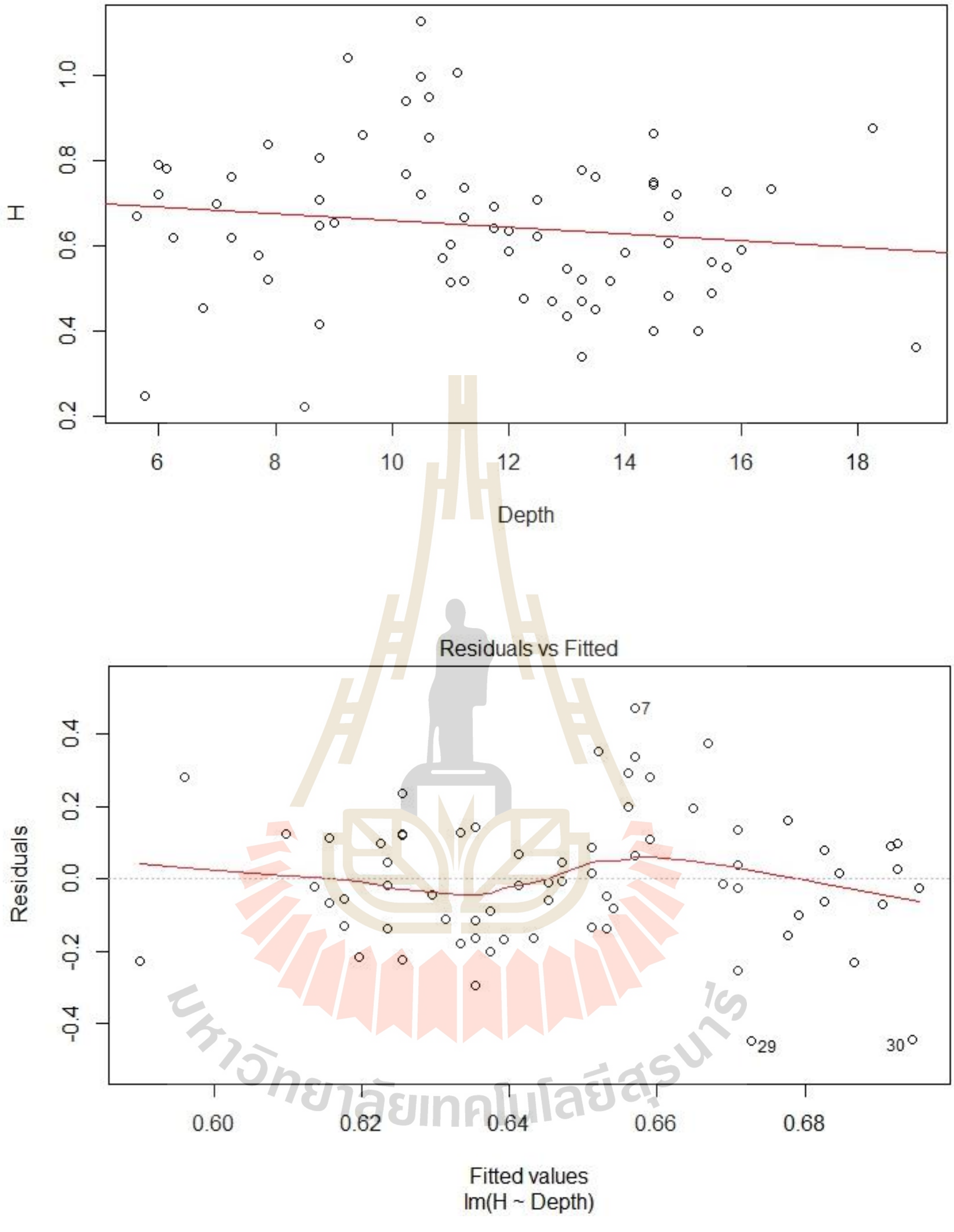


Figure 12C The regression and residuals versus fitted values plots between depth and soil H in Khao Khiew in Khao Yai National Park, Thailand.

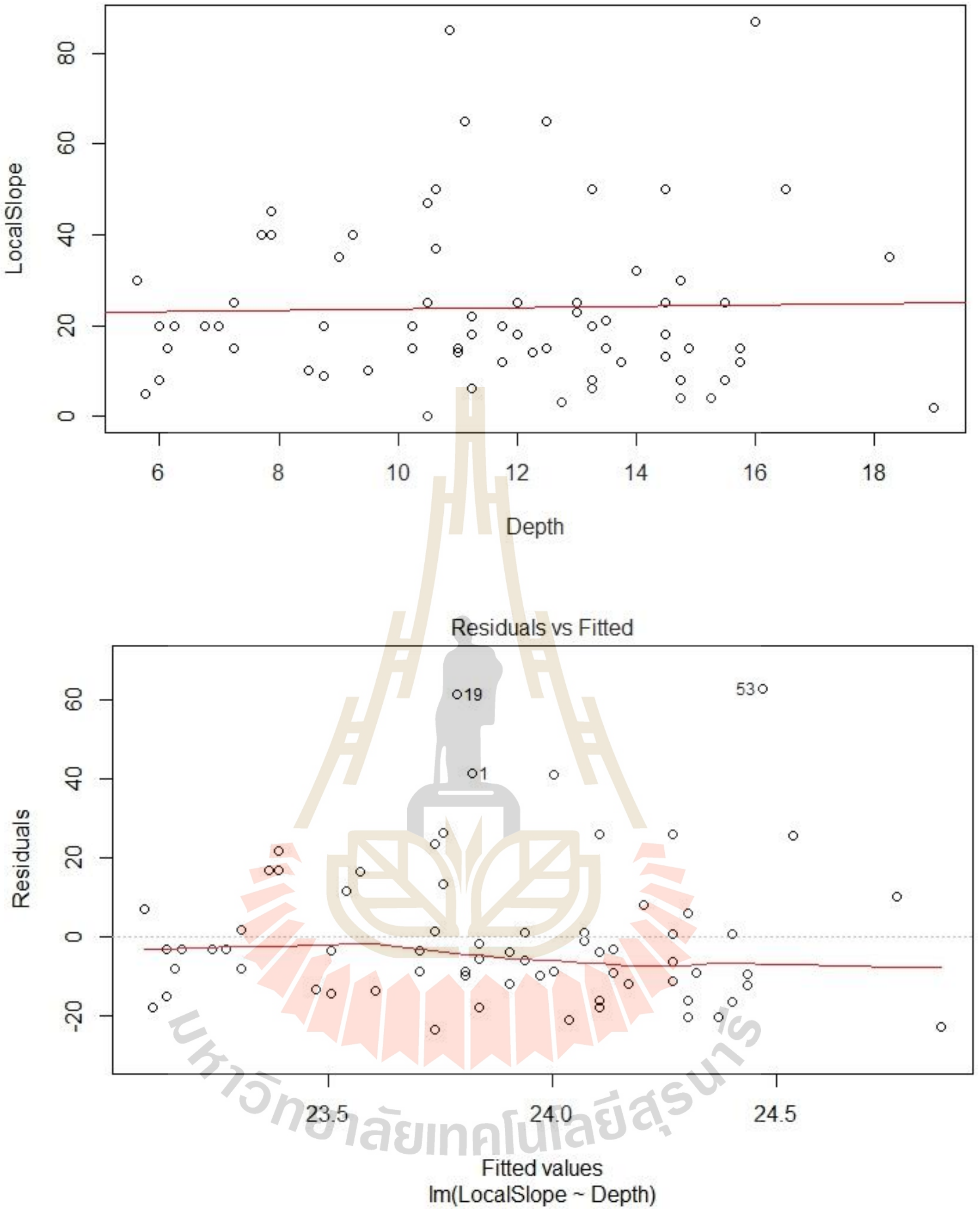


Figure 13C The regression and residuals versus fitted values plots between soil depth and local slope in Khao Khiew in Khao Yai National Park, Thailand.

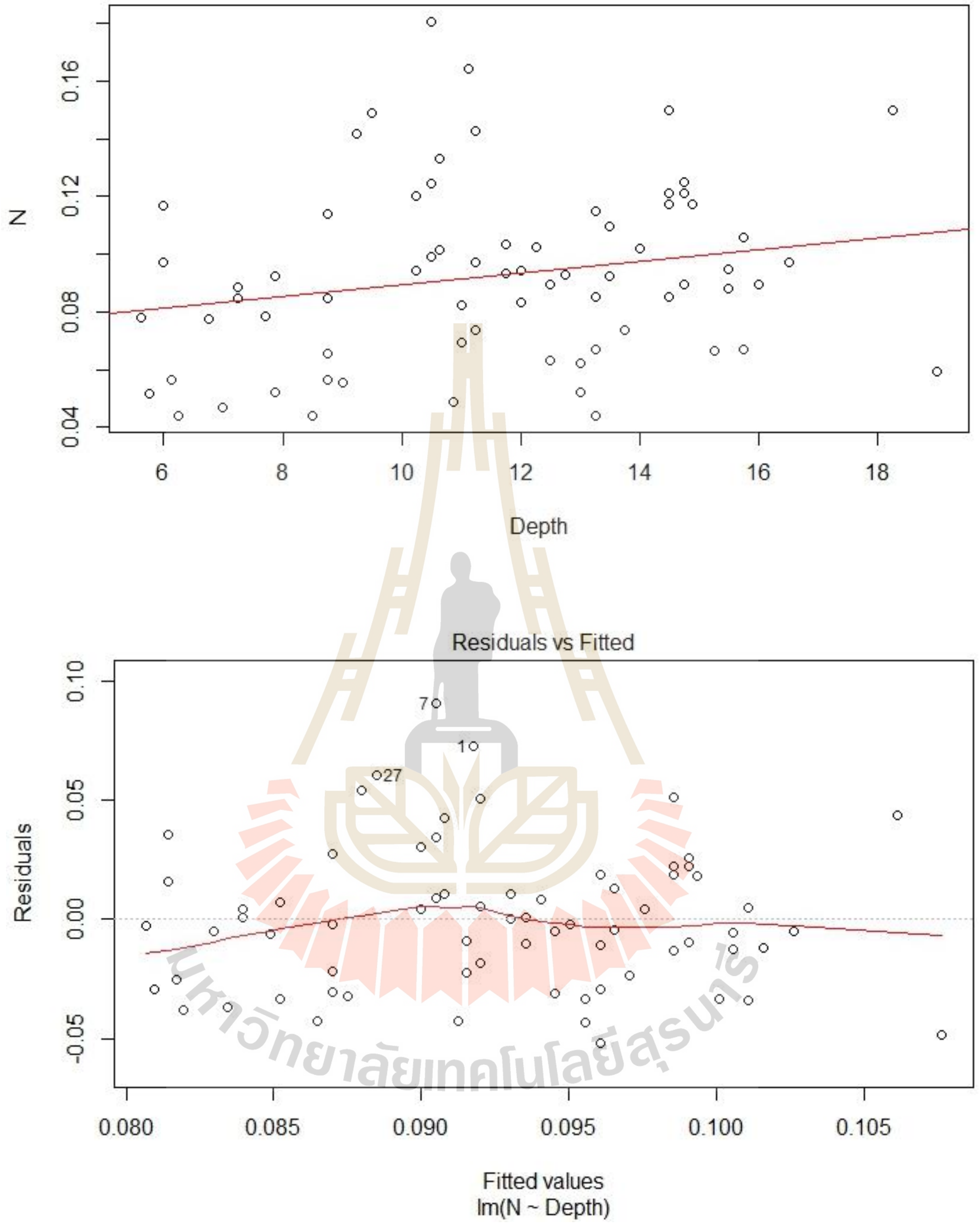


Figure 14C The regression and residuals versus fitted values plots between soil depth and N in Khao Khiew in Khao Yai National Park, Thailand.

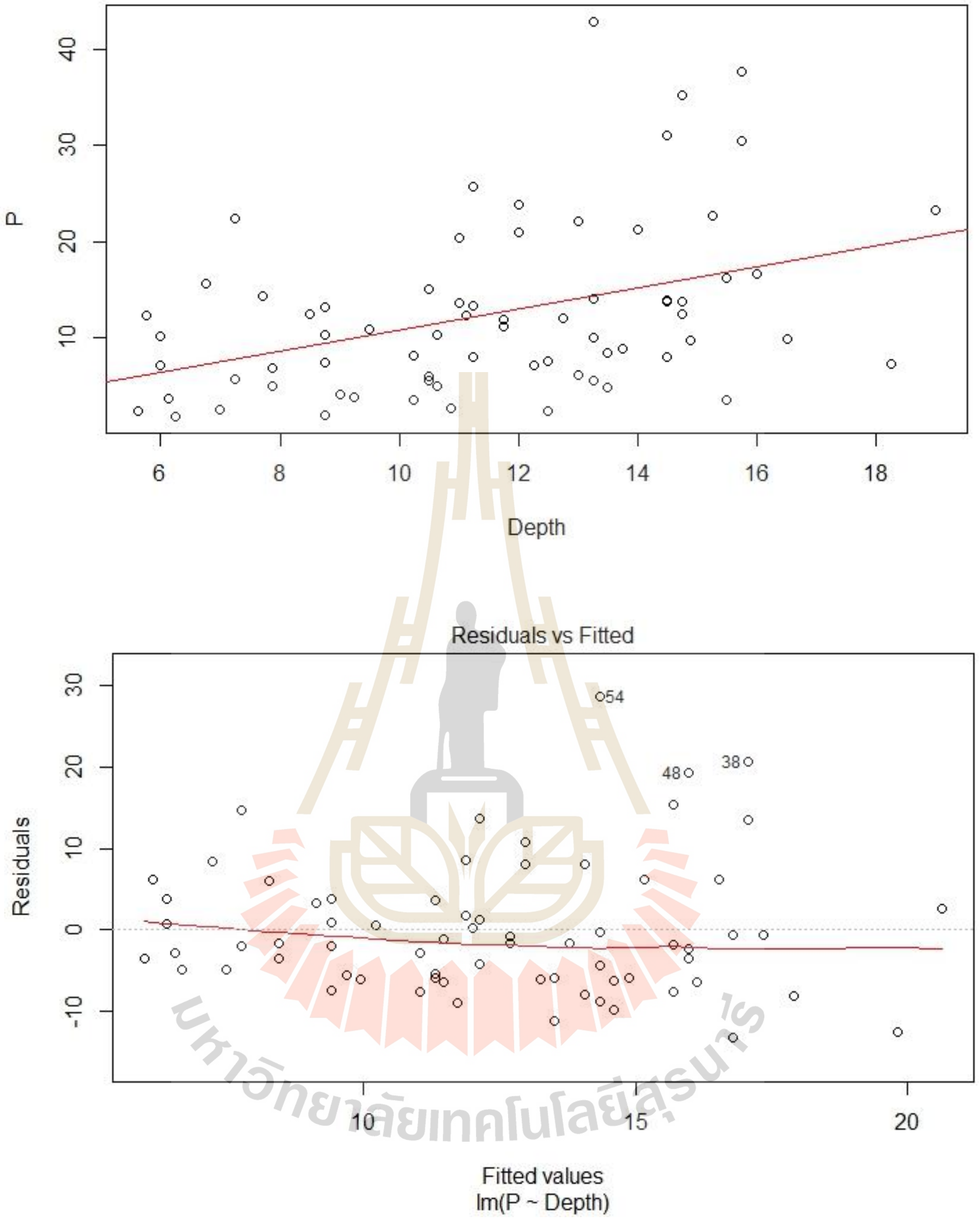


Figure 15C The regression and residuals versus fitted values plots between soil depth and P in Khao Khiew in Khao Yai National Park, Thailand.

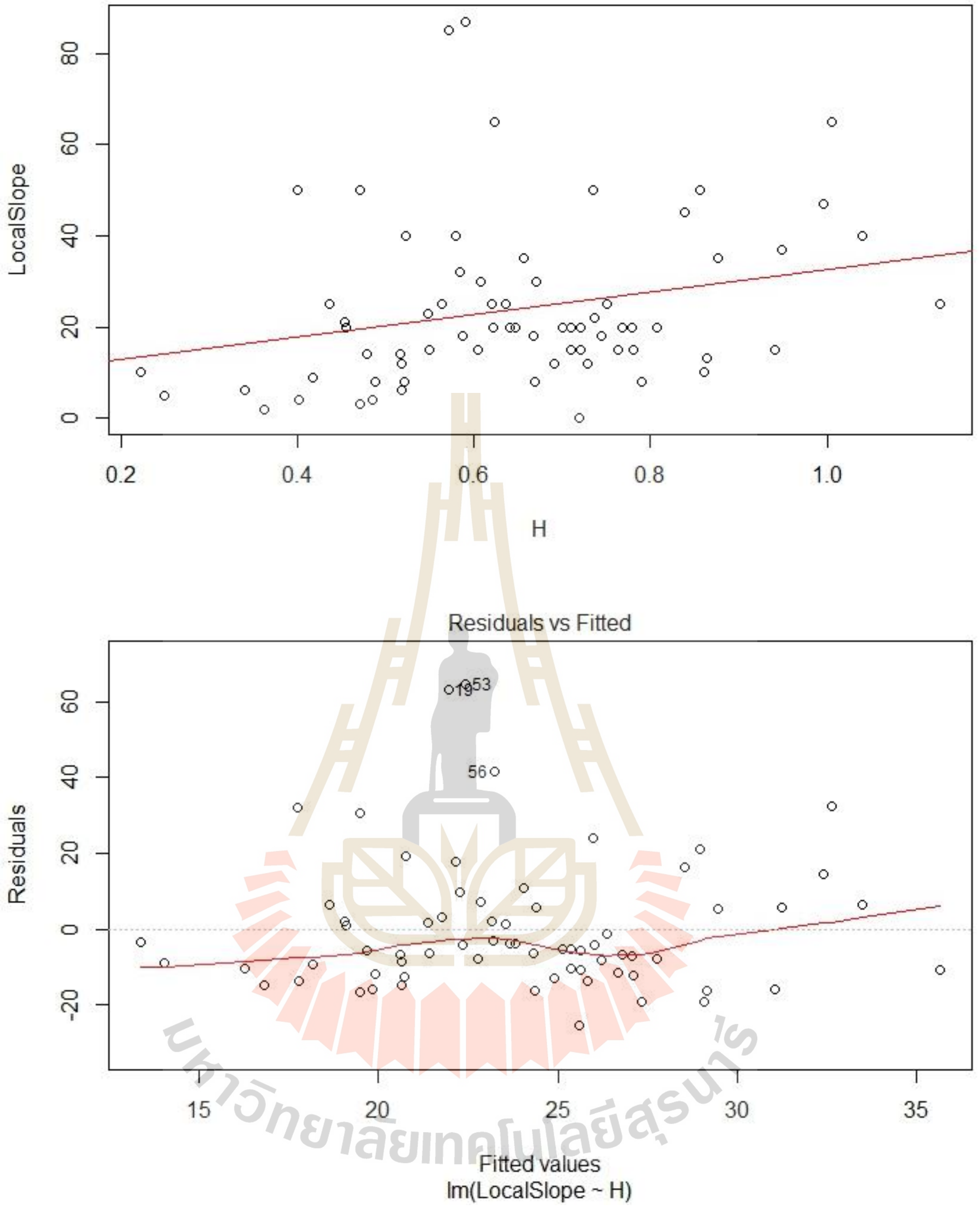


Figure 16C The regression and residuals versus fitted values plots between soil H and local slope in Khao Khiew in Khao Yai National Park, Thailand.

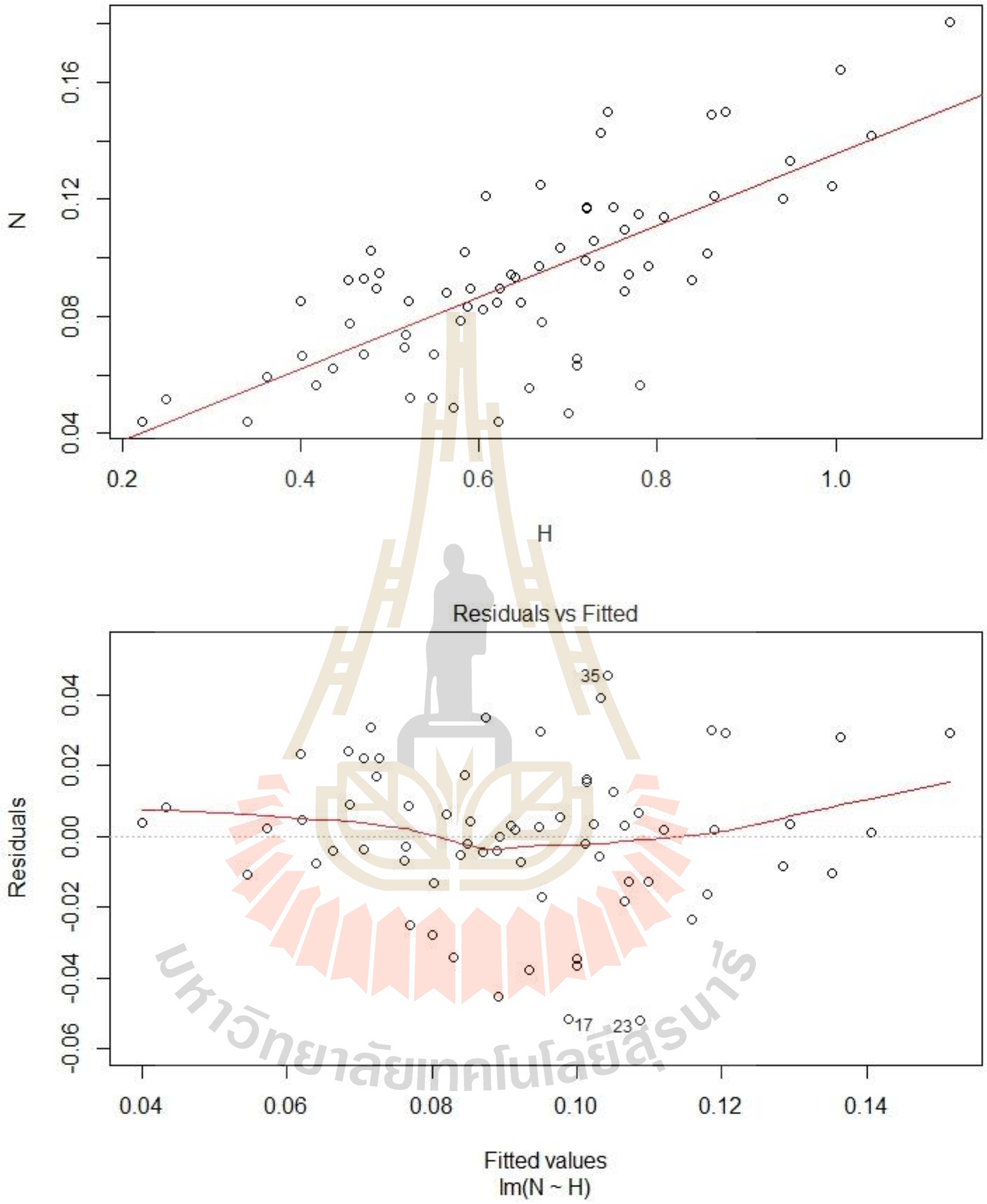


Figure 17C The regression and residuals versus fitted values plots between soil H and N in Khao Khiew in Khao Yai National Park, Thailand.

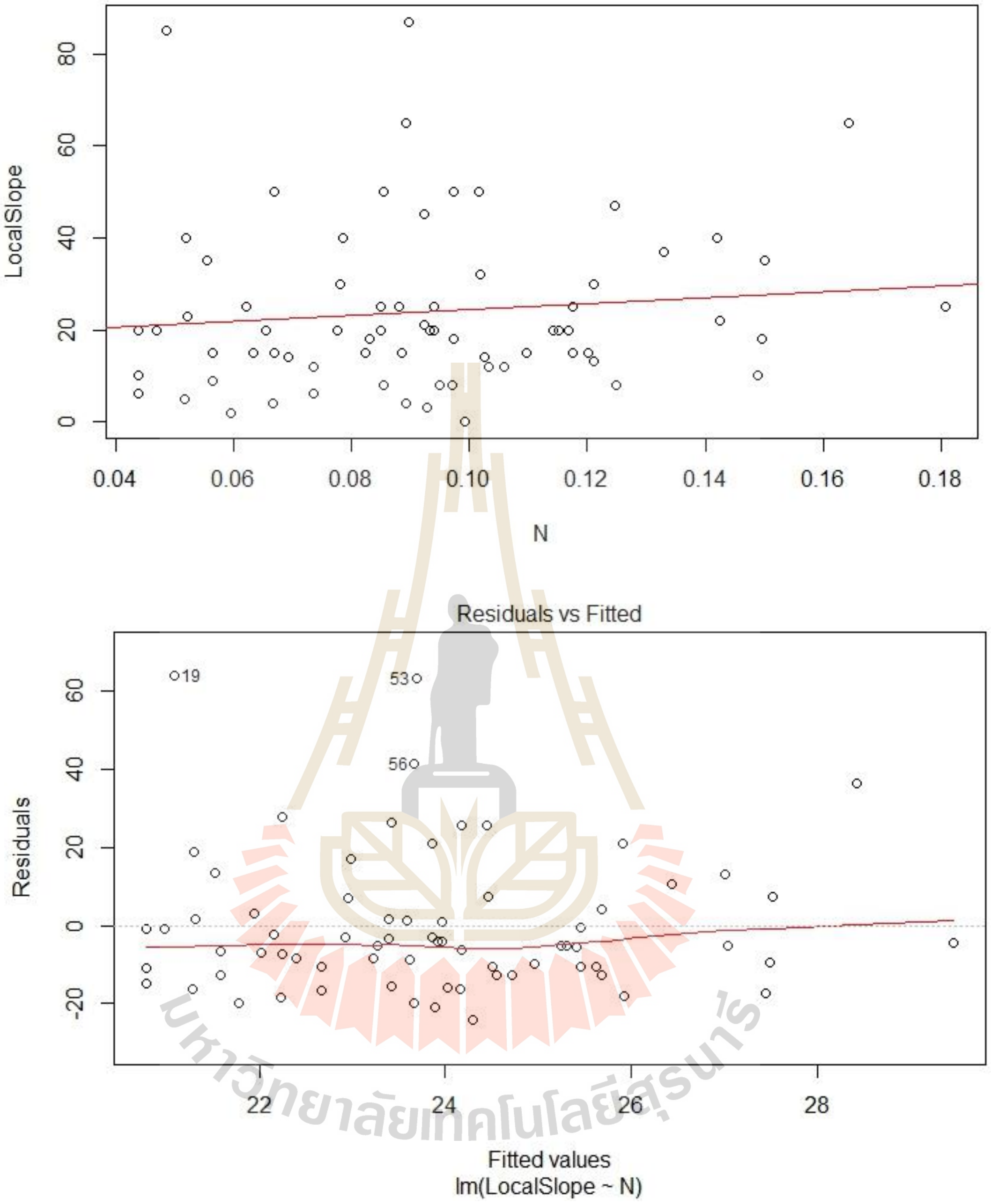


Figure 18C The regression and residuals versus fitted values plots between soil N and local slope in Khao Khiew in Khao Yai National Park, Thailand.

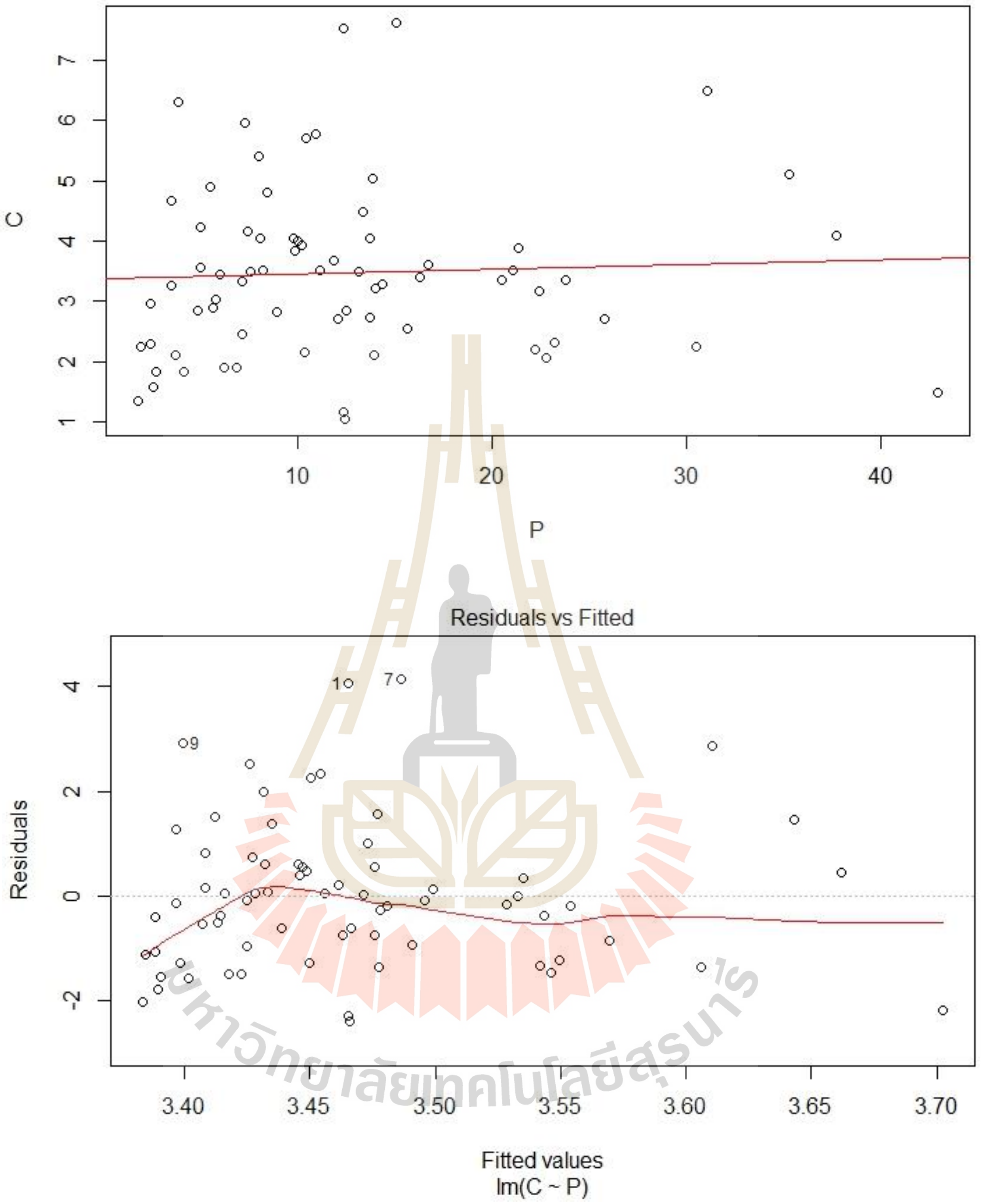


Figure 19C The regression and residuals versus fitted values plots between soil P and C in Khao Khiew in Khao Yai National Park, Thailand.

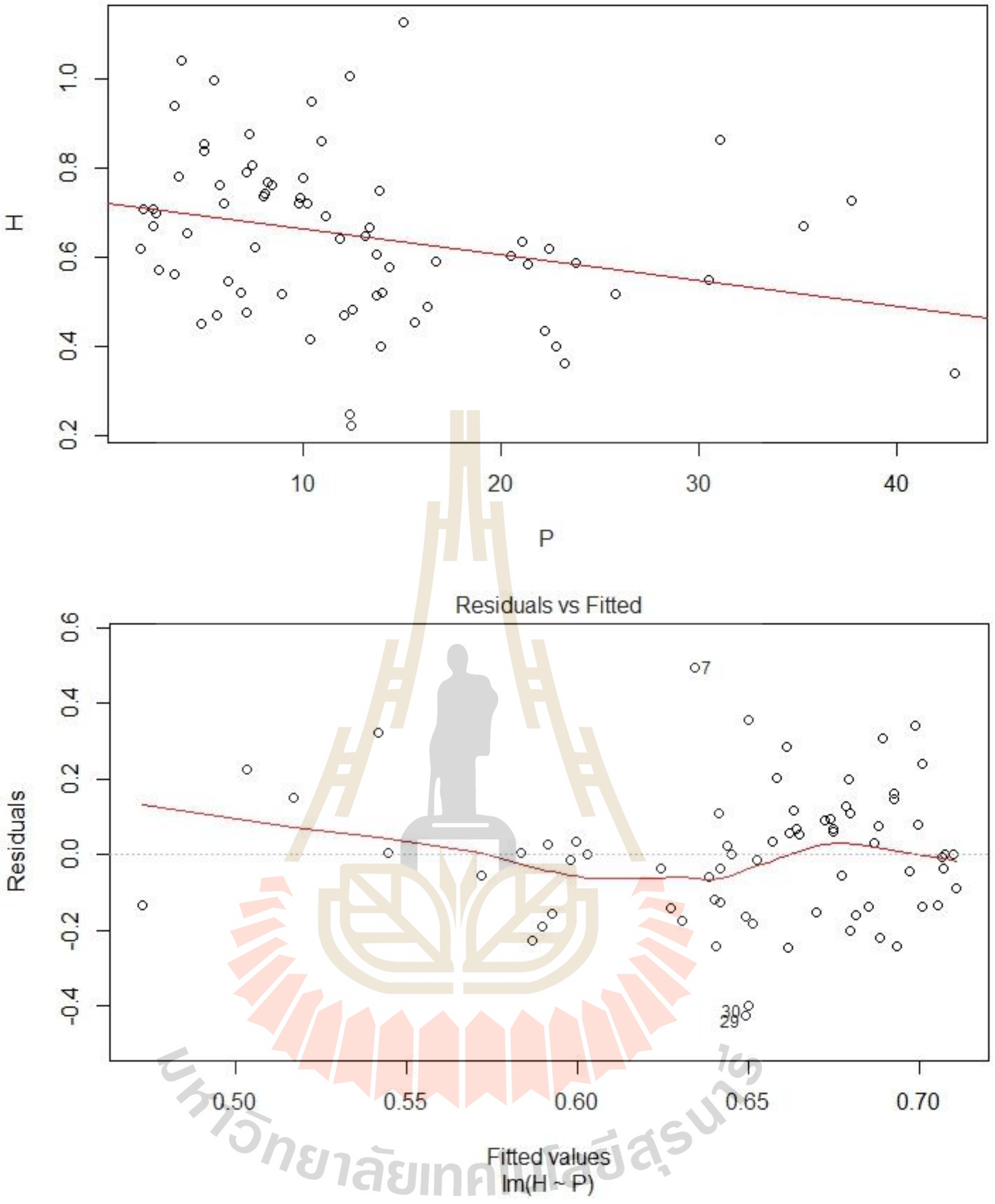


Figure 20C The regression and residuals versus fitted values plots between soil P and H in Khao Khiew in Khao Yai National Park, Thailand.

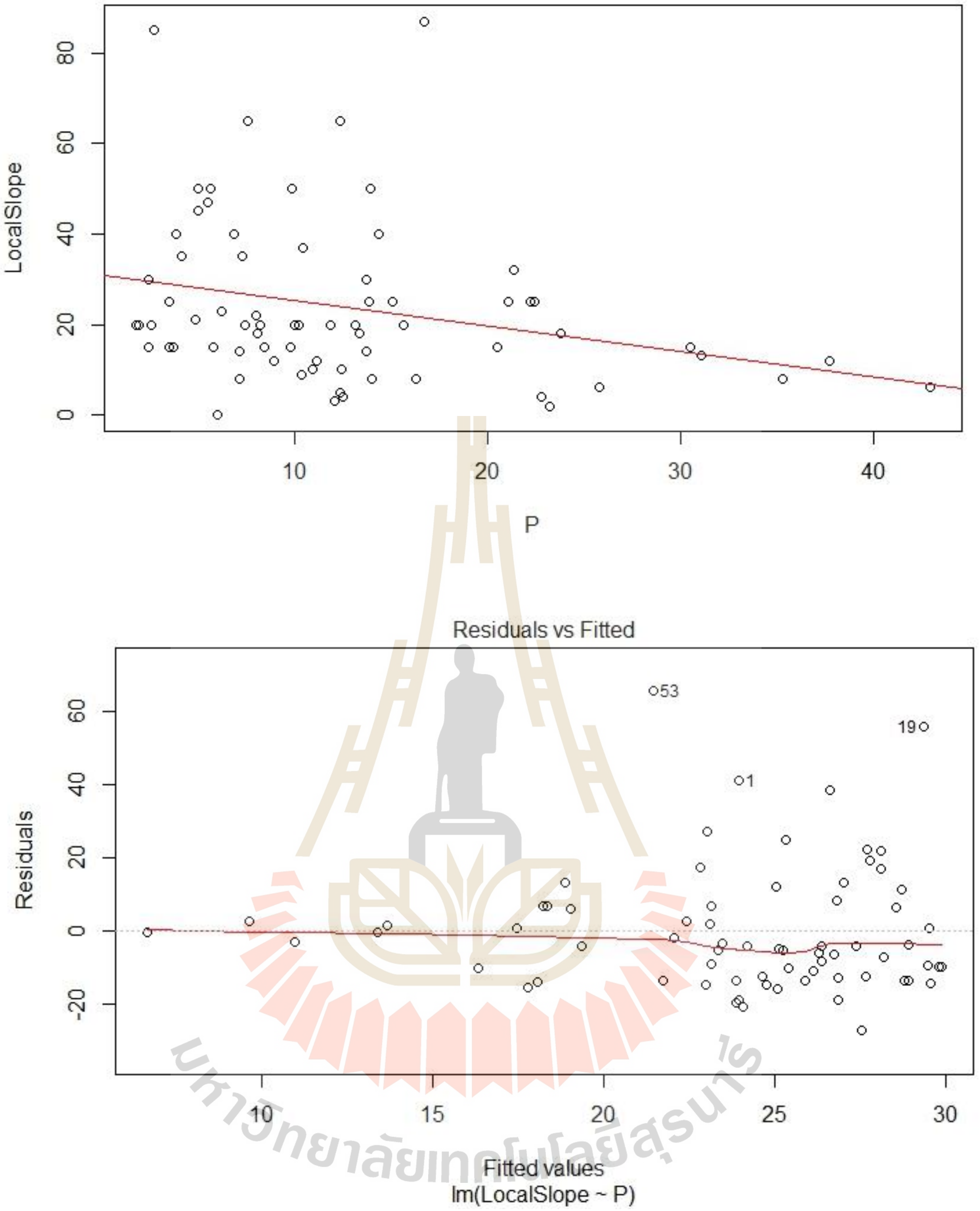


Figure 21C The regression and residuals versus fitted values plots between soil P and local slope in Khao Khiew in Khao Yai National Park, Thailand.

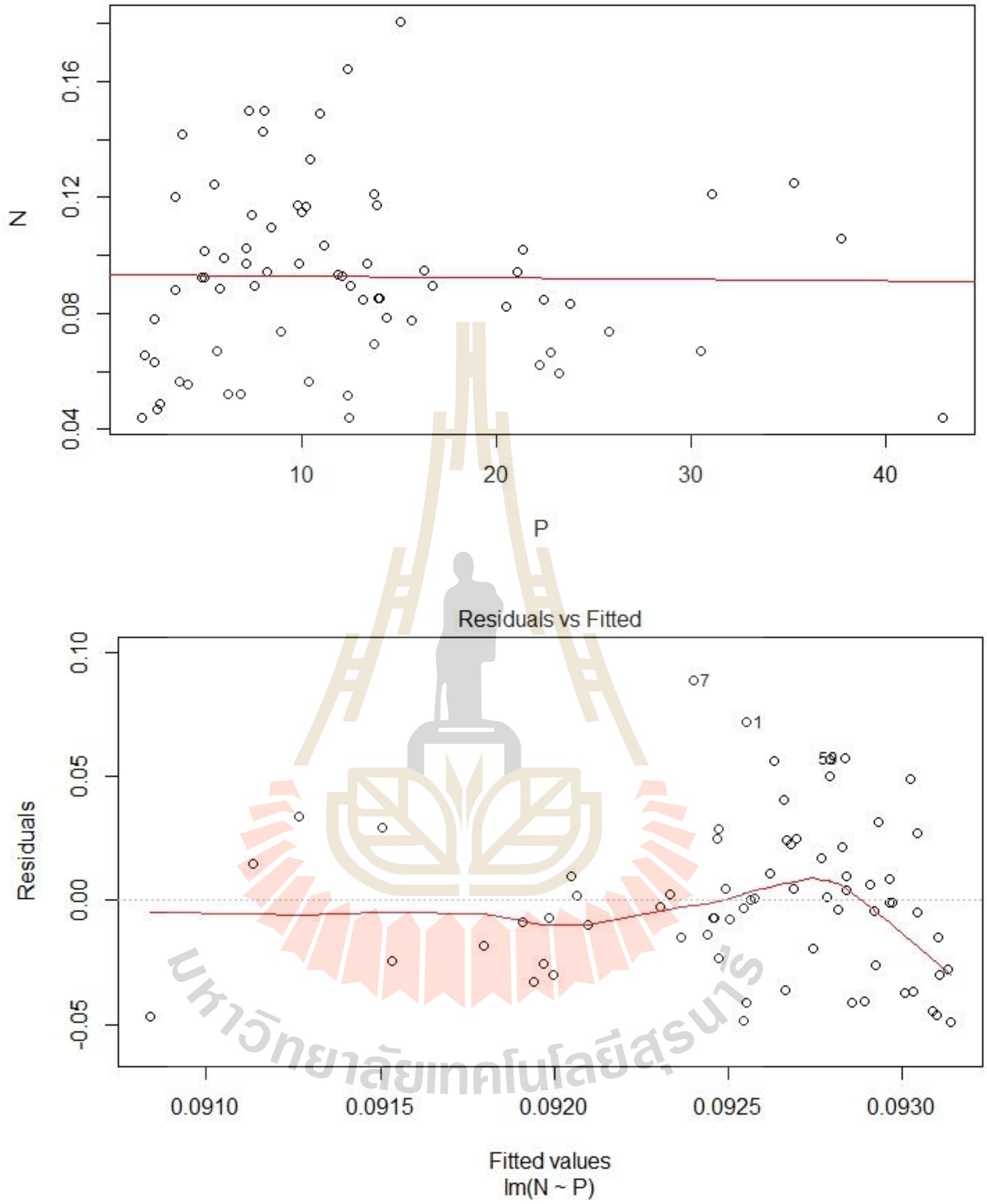


Figure 22C The regression and residuals versus fitted values plots between soil P and N in Khao Khiew in Khao Yai National Park, Thailand.

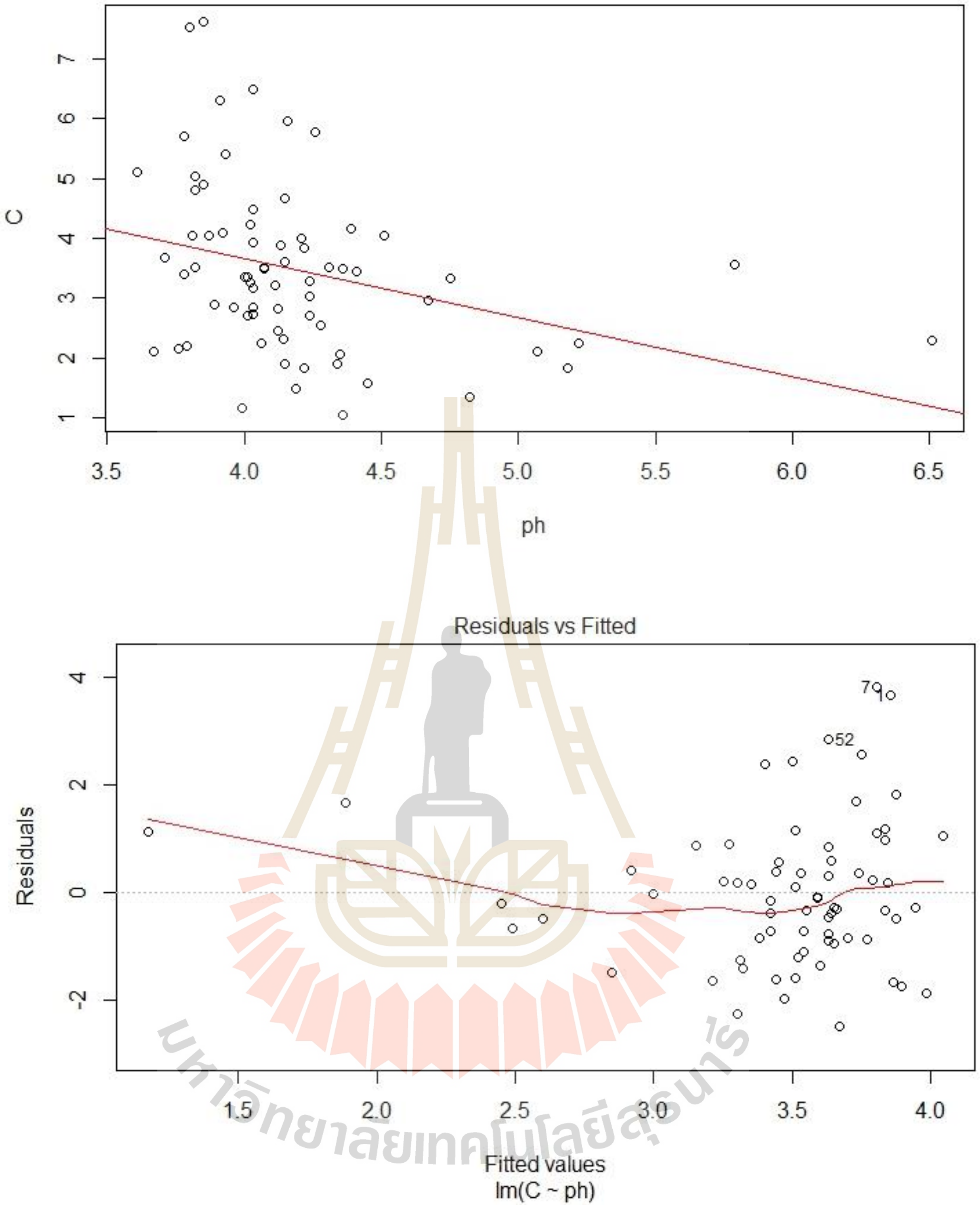


Figure 23C The regression and residuals versus fitted values plots between soil pH and C in Khao Khiew in Khao Yai National Park, Thailand.

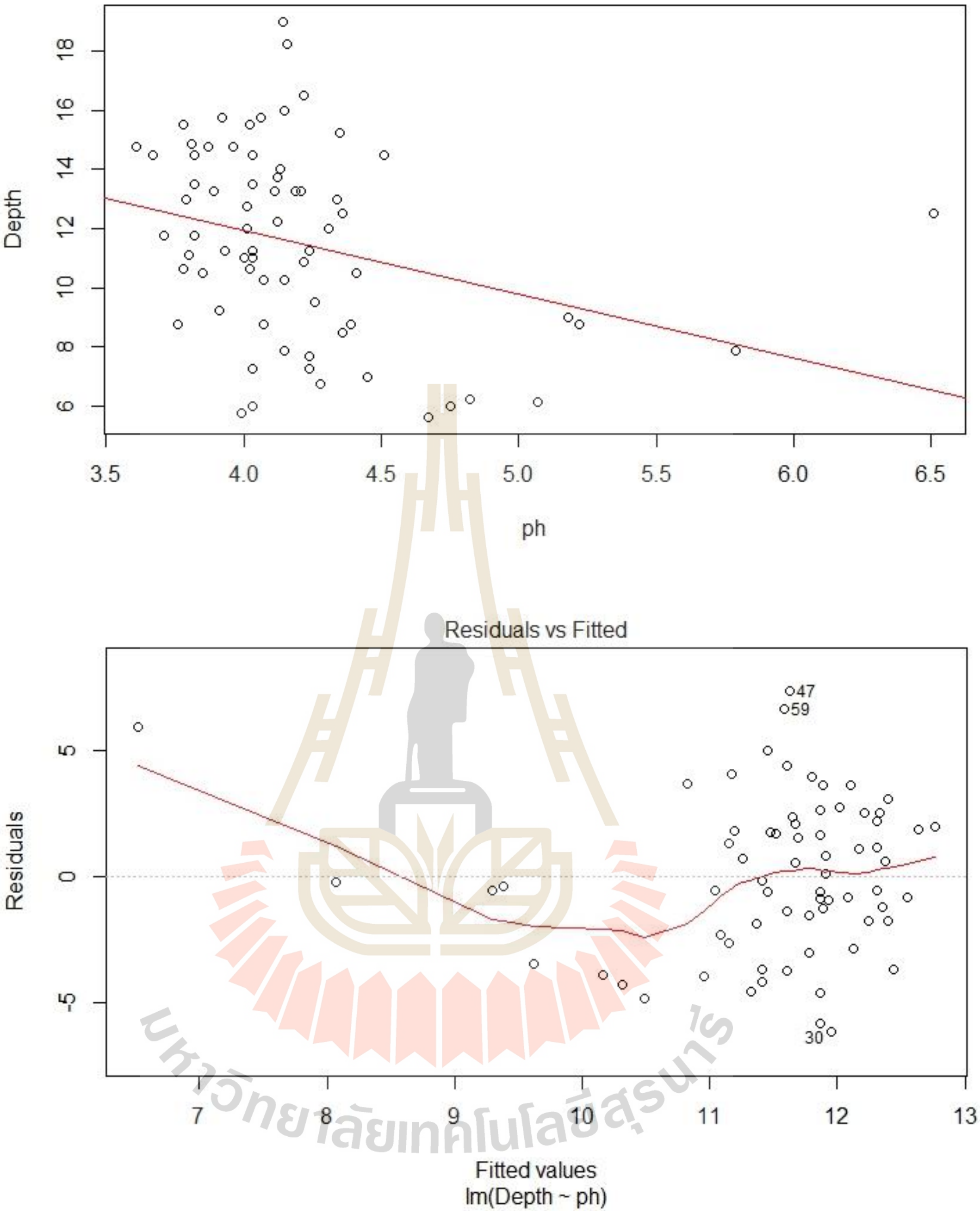
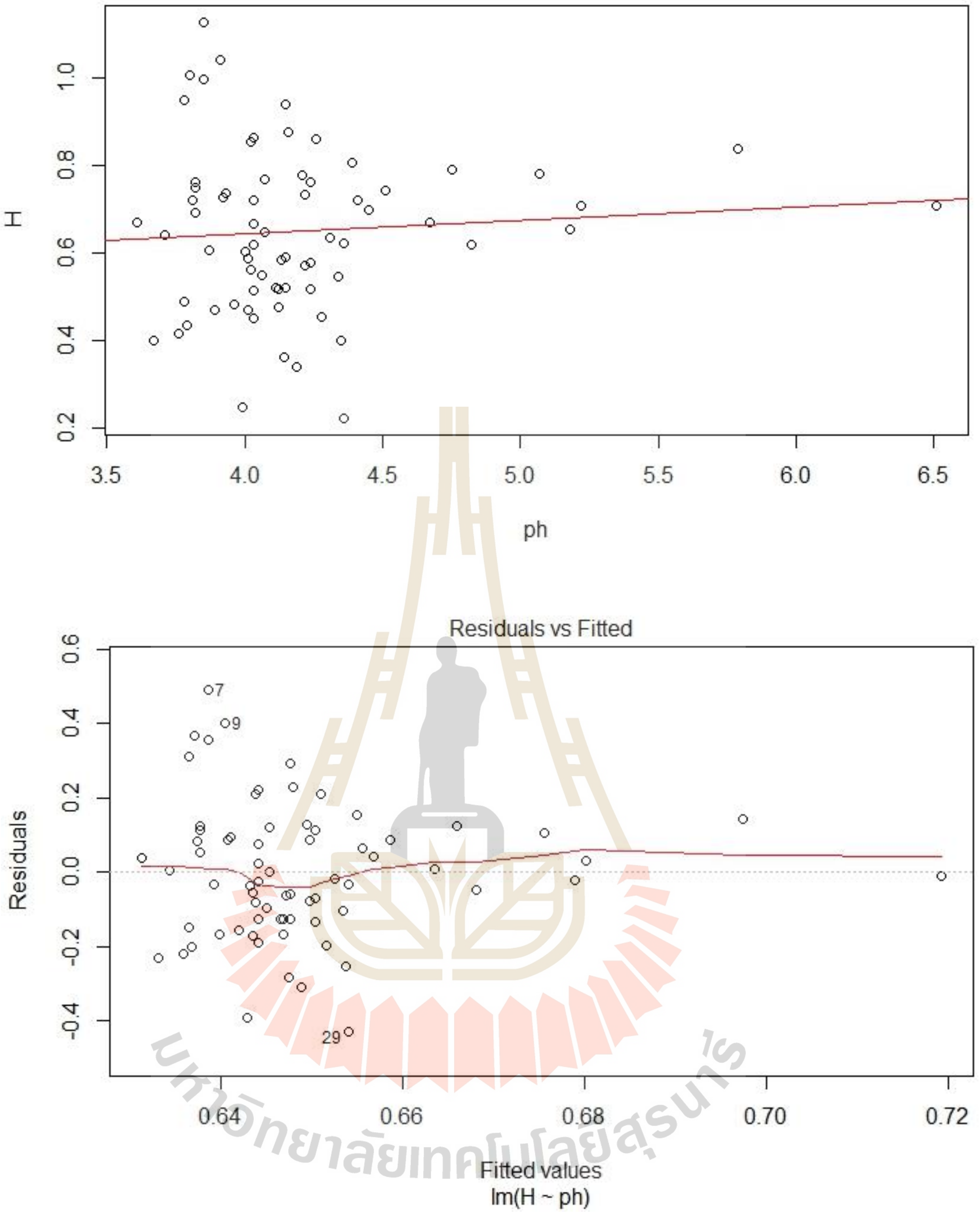


Figure 24C The regression and residuals versus fitted values plots between soil pH and depth in Khao Khiew in Khao Yai National Park, Thailand.



igure 25C 'he regression and residuals versus fitted values plots between soil H and H in Khao Khiew in Khao Yai National Park, Thailand.

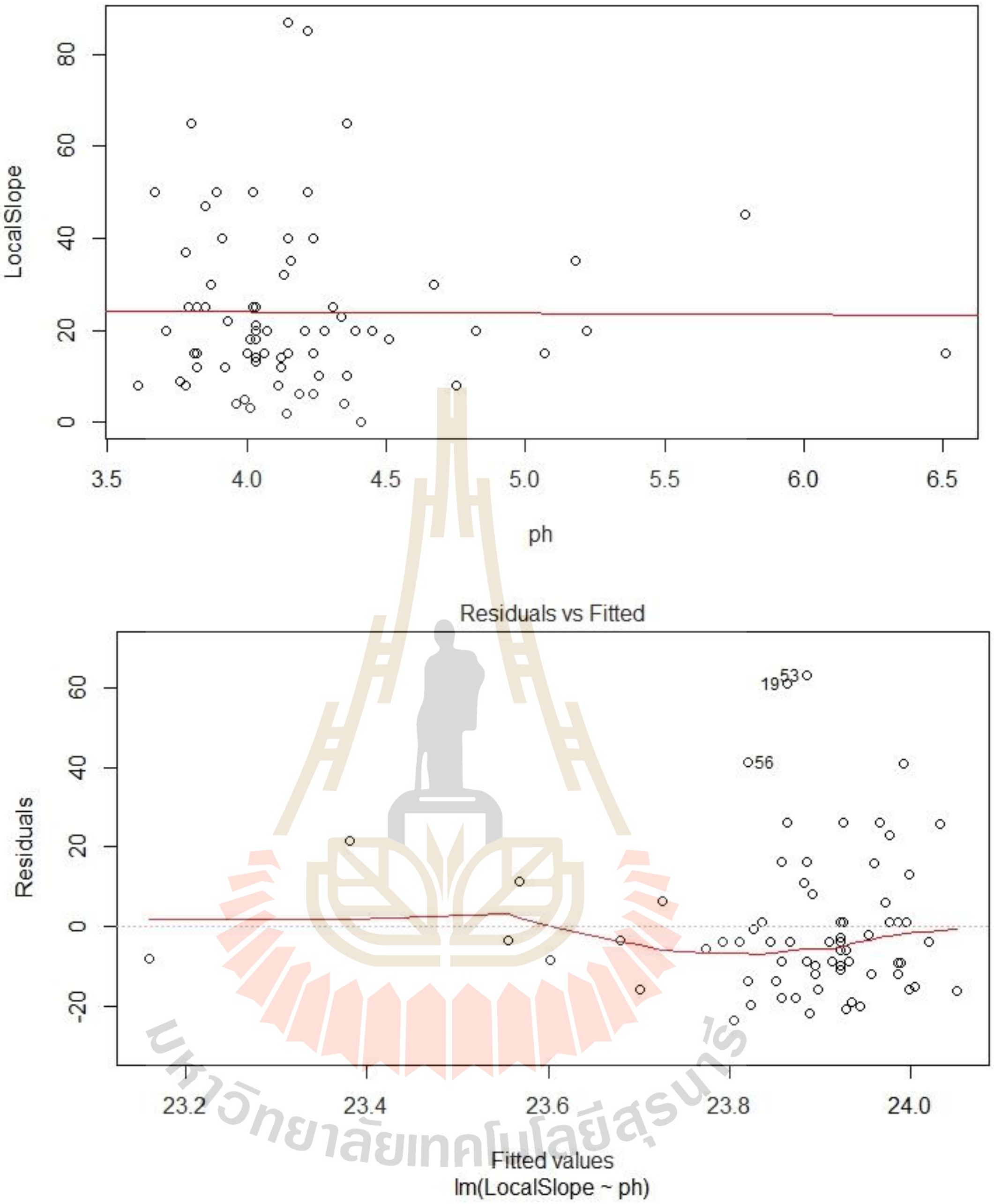


Figure 26C The regression and residuals versus fitted values plots between soil pH and local slope in Khao Khiew in Khao Yai National Park, Thailand.

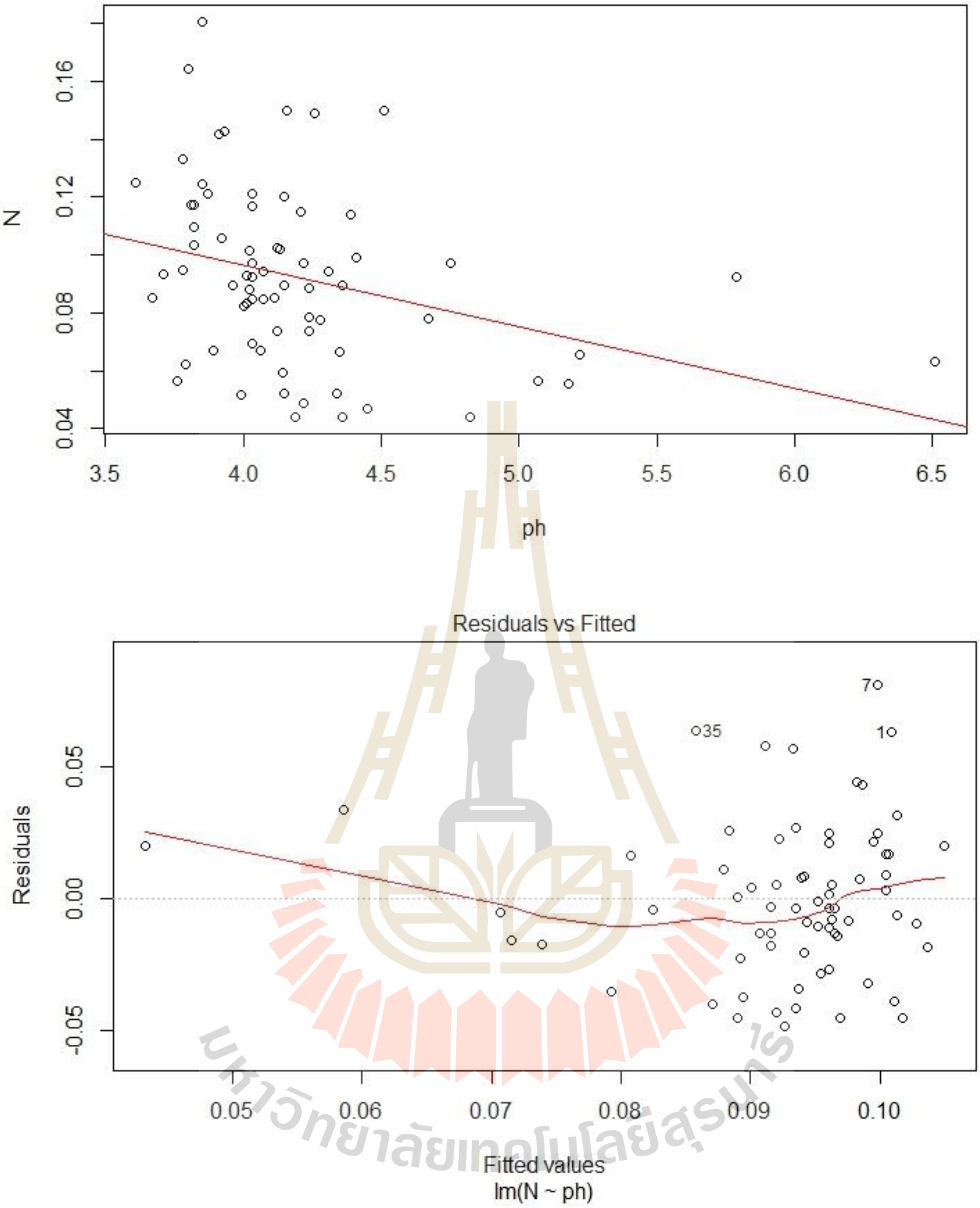


Figure 27C The regression and residuals versus fitted values plots between soil pH and N in Khao Khiew in Khao Yai National Park, Thailand.

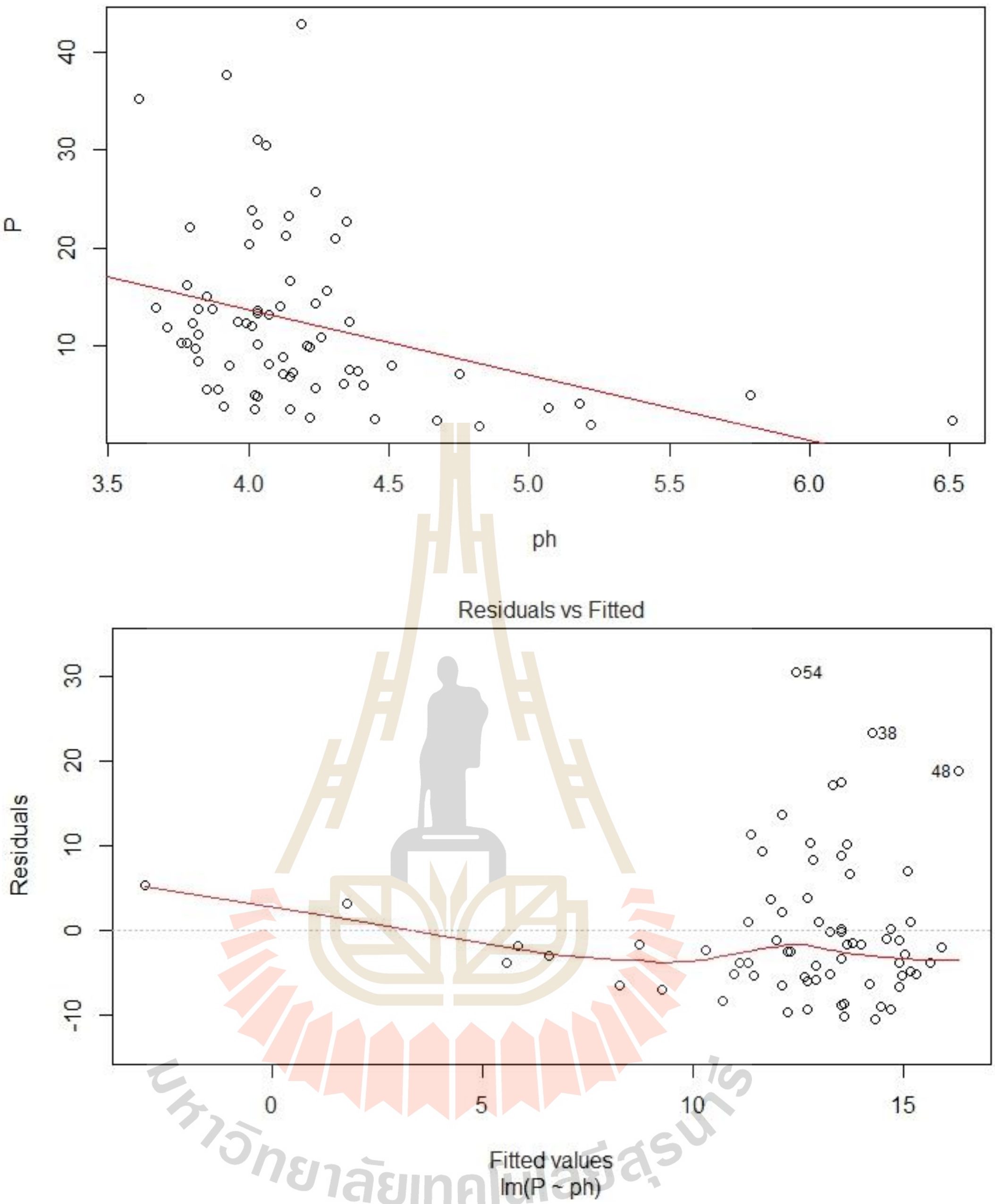


Figure 28C The regression and residuals versus fitted values plots between soil pH and P in Khao Khiew in Khao Yai National Park, Thailand.

APPENDIX D

DATA FOR AIC ANALYSIS

Table 1D Raw data for AIC analysis.

Transect line	Plot	Pne	Nwa	Dim	Del	pH	Canopy	Depth	Sgr	P	C	H	N	Soil particle	Local slope
1	1	1	1	1	0	3.80	78.75	11.13	1	12.29	7.53	1.01	0.16	1	65
	2	1	1	1	0	4.34	55.00	13.00	0	6.18	1.91	0.55	0.05	2	23
	3	0	0	0	0	4.07	80.00	10.25	0	8.16	3.51	0.77	0.09	2	20
	4	0	0	1	0	4.24	75.00	7.70	1	14.31	3.27	0.58	0.08	1	40
	5	0	0	0	0	3.85	97.50	10.50	1	5.47	4.91	1.00	0.12	2	47
2	1	1	0	0	0	4.02	78.00	10.63	1	4.95	4.23	0.86	0.10	2	50
	2	1	0	0	0	3.85	56.25	10.50	0	15.02	7.62	1.13	0.18	1	25
	3	1	0	0	0	3.78	73.75	10.63	0	10.36	5.70	0.95	0.13	1	37
	4	1	0	0	0	3.91	97.50	9.25	0	3.82	6.31	1.04	0.14	2	40
	5	0	0	0	0	4.15	81.25	10.25	0	3.48	4.67	0.94	0.12	2	15
3	1	0	0	0	0	4.24	80.00	7.25	0	5.72	3.04	0.76	0.09	2	15
	2	1	1	1	0	4.03	97.50	6.00	0	10.18	3.93	0.72	0.12	5	20
	3	0	0	0	0	4.39	97.50	8.75	1	7.38	4.16	0.81	0.11	2	20
	4	0	0	0	0	4.41	82.50	10.50	0	5.93	3.45	0.72	0.10	1	0
	5	0	0	0	0	4.75	70.00	6.00	0	7.11	3.33	0.79	0.10	3	8
4	1	1	1	1	0	5.18	92.50	9.00	1	4.11	1.82	0.66	0.06	3	35
	2	0	0	0	1	4.45	87.50	7.00	0	2.52	1.59	0.70	0.05	3	20
	3	0	0	0	0	4.82	95.00	6.25	1	1.76	1.36	0.62	0.04	3	20
	4	1	0	0	0	4.22	95.00	10.88	1	2.69	1.83	0.57	0.05	1	85
	5	0	0	0	0	4.15	77.50	7.88	1	6.84	1.91	0.52	0.05	1	40

Table 1D (Continued) Raw data for AIC analysis.

Transect line	Plot	Pne	Nwa	Dim	Del	pH	Canopy	Depth	Sgr	P	C	H	N	Soil particle	Local slope
5	1	0	0	0	0	4.67	82.50	5.63	1	2.38	2.97	0.67	0.08	1	30
	2	0	0	0	0	5.79	87.50	7.88	0	4.94	3.56	0.84	0.09	2	45
	3	0	0	1	0	5.07	100.00	6.13	0	3.67	2.11	0.78	0.06	2	15
	4	1	0	1	0	6.51	92.50	12.50	0	2.36	2.30	0.71	0.06	2	15
	5	1	0	0	0	5.22	80.00	8.75	0	1.88	2.25	0.71	0.07	2	20
6	1	0	0	0	0	4.06	100.00	15.75	0	30.50	2.24	0.55	0.07	2	15
	2	0	0	0	0	4.26	89.00	9.50	0	10.86	5.78	0.86	0.15	4	10
	3	0	0	0	0	4.28	82.00	6.75	0	15.62	2.54	0.45	0.08	5	20
	4	0	0	0	0	4.36	77.00	8.50	0	12.39	1.05	0.22	0.04	5	10
	5	0	0	0	0	3.99	80.75	5.75	0	12.29	1.17	0.25	0.05	5	5
7	1	0	0	0	0	3.96	96.50	14.75	0	12.44	2.85	0.48	0.09	1	4
	2	0	0	0	0	4.01	82.50	12.75	0	12.05	2.71	0.47	0.09	5	3
	3	1	0	0	0	3.67	79.00	14.50	1	13.92	2.11	0.40	0.09	5	50
	4	0	1	0	0	4.03	66.25	13.50	1	4.79	2.86	0.45	0.09	1	21
	5	0	1	0	0	4.51	84.50	14.50	0	8.01	4.04	0.74	0.15	1	18
8	1	1	0	0	0	4.12	74.75	12.25	1	7.11	2.45	0.48	0.10	5	14
	2	1	0	1	0	3.81	92.25	14.88	1	9.72	4.04	0.72	0.12	1	15
	3	0	1	1	0	3.92	94.75	15.75	1	37.70	4.10	0.73	0.11	1	12
	4	0	1	0	0	3.82	84.75	14.50	1	13.80	5.03	0.75	0.12	5	25
	5	0	0	0	0	3.71	93.00	11.75	0	11.82	3.67	0.64	0.09	1	20

Table 1D (Continued) Raw data for AIC analysis.

Transect line	Plot	Pne	Nwa	Dim	Del	pH	Canopy	Depth	Sgr	P	C	H	N	Soil particle	Local slope
9	1	0	0	0	0	4.03	89.50	11.25	0	13.36	4.47	0.67	0.10	4	18
	2	0	0	0	0	3.79	84.50	13.00	0	22.19	2.20	0.44	0.06	4	25
	3	0	1	0	0	4.13	99.00	14.00	0	21.30	3.88	0.58	0.10	4	32
	4	1	1	1	0	3.87	95.50	14.75	1	13.71	4.03	0.61	0.12	5	30
	5	0	0	0	0	4.11	82.25	13.25	0	14.00	3.21	0.52	0.09	4	8
10	1	0	0	0	0	4.35	91.25	15.25	0	22.74	2.07	0.40	0.07	4	4
	2	1	0	0	0	4.14	84.50	19.00	1	23.21	2.32	0.36	0.06	4	2
	3	0	0	0	0	3.61	94.50	14.75	0	35.28	5.10	0.67	0.12	4	8
	4	0	0	0	0	3.78	98.00	15.50	0	16.23	3.40	0.49	0.10	4	8
	5	0	0	0	0	3.89	86.00	13.25	0	5.60	2.90	0.47	0.07	4	50
11	1	1	1	1	0	4.22	87.50	16.50	0	9.83	3.83	0.73	0.10	4	50
	2	1	1	0	0	4.03	100.00	14.50	0	31.03	6.48	0.86	0.12	4	13
	3	0	1	0	0	4.15	87.50	16.00	0	16.68	3.61	0.59	0.09	4	87
	4	0	0	0	0	4.19	80.25	13.25	0	42.94	1.50	0.34	0.04	4	6
	5	0	0	0	0	4.24	66.00	11.25	0	25.77	2.71	0.52	0.07	4	6
12	1	0	0	0	0	4.36	94.50	12.50	0	7.56	3.48	0.62	0.09	5	65
	2	0	1	0	0	4.03	92.75	7.25	1	22.44	3.16	0.62	0.08	4	25
	3	0	0	0	0	3.93	87.50	11.25	1	7.98	5.41	0.74	0.14	4	22
	4	0	0	0	0	4.16	96.50	18.25	0	7.24	5.95	0.88	0.15	4	35
	5	0	1	0	0	3.82	87.00	11.75	0	11.09	3.51	0.69	0.10	4	12

Table 1D (Continued) Raw data for AIC analysis.

Transect line	Plot	Pne	Nwa	Dim	Del	pH	Canopy	Depth	Sgr	P	C	H	N	Soil particle	Local slope
13	1	0	1	0	0	3.76	77.75	8.75	1	10.29	2.16	0.42	0.06	4	9
	2	0	1	0	0	4.03	89.25	11.00	0	13.68	2.73	0.52	0.07	4	14
	3	0	1	0	0	4.12	96.75	13.75	1	8.88	2.82	0.52	0.07	5	12
	4	0	1	0	0	4.31	95.25	12.00	0	21.02	3.51	0.64	0.09	4	25
	5	1	0	0	0	4.02	86.50	15.50	0	3.48	3.26	0.56	0.09	5	25
14	1	1	0	0	0	4.21	98.50	13.25	0	9.97	4.01	0.78	0.12	4	20
	2	0	0	0	0	4.00	97.25	11.00	0	20.45	3.36	0.60	0.08	4	15
	3	0	0	0	0	4.01	94.50	12.00	0	23.80	3.36	0.59	0.08	4	18
	4	0	1	0	0	3.82	95.00	13.50	0	8.41	4.81	0.76	0.11	4	15
	5	0	0	0	0	4.07	90.75	8.75	0	13.11	3.49	0.65	0.08	5	20

Note: Pne, *Podocarpus neriifolius*: Nwa, *Nagiea wallichiana* : Dim, *Dacrycarpus imbricatus*: Del, *Dacrydium elatum* : Sgr, *Syzygium gratum*: P, Phosphorus: C, Carbon: H, Hydrogen: N, Nitrogen.

CURRICULUM VITAE

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