DISSERTATION

SOIL AND PLANT RELATIONSHIPS ALONG AN ALTITUDINAL GRADIENT IN DOI INTHANON NATIONAL PARK, NORTHERN THAILAND

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DISSERTATION

SOIL AND PLANT RELATIONSHIPS ALONG AN ALTITUDINAL GRADIENT IN DOI INTHANON NATIONAL PARK, NORTHERN THAILAND

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A study on soil and plant relationships along an altitudinal gradient was conducted in Doi Inthanon National Park, Chiangmai, Thailand. The purpose of the study was to elucidate the changing of community characteristic patterns from lowland to mountain vegetation in tropical monsoon climatic zone in mainland Southeast Asia by using floristic composition and species abundance data collected from 45 plots set at different altitudes and in different forest types. The other purpose was to investigate on how soil properties determine forest community distribution along an altitudinal gradient.

The results showed that forest community classification by cluster analysis suggested 45 sample stands to be classified floristically into three forest zones along an altitudinal gradient included lowland, transition and montane forest zones and could be clustered into six forest community groups. Tree density and basal area increased with rising altitude. Diversity of trees sharply increased from the lowland zone to an altitude of 1,800 m asl and gradually decreased at an altitude above 1,800 m asl as shown by species diversity and species richness indices. In contrast, evenness indices were not greatly different along the altitudinal gradient. The results of soil and plant relationships investigation showed that almost all soil properties in the six classified forest community groups were significantly different. Therefore, the study of relationships between forest community and other factors can be concluded that the influence of altitude was a main factor effecting plant distribution and soil physical and chemical properties also determined the characteristics of forest communities.

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SOIL AND PLANT RELATIONSHIPS ALONG AN ALTITUDINAL GRADIENT IN DOI INTHANON NATIONAL PARK, NORTHERN THAILAND

INTRODUCTION

Tropical forest is an important ecosystem in the world because of it's recognition in high biodiversity, greatest in the number of species and being the most important genetic pool of plants as compared to other terrestrial plant communities. In addition, tropical forest affects the global climate. Currently, people in tropical zone destroyed the tropical forest and changed them into other landuses. It is a main cause of sharp decease in tropical forest area during the last few decades. On the other hand, the knowledge of tropical forest ecology, especially the structure and function as well as the environmental factors determining the distribution of various important tree species is rather little accumulated. Thailand is a tropical country, which located on 6° N latitude to 20° N and 98° E to 105° E longitude. It's physiography ranges from the sea level to the summit of the country at Doi Inthanon. The formation of vegetation in Thailand varies from aquatic community, lowland forest up to montane forest. The territory of Thailand is usually divided into five regions according to their physiographic character (Samapudhi, 1957) as Northwest Highland, Chao Phraya Plains, Korat Plateau, Chanta Buri Region, and Peninsular Region. Northern Thailand or the Northwest Highland is characterized by hilly and mountainous landscapes. Correspondingly, it supports various types of vegetation and high species richness. The area is of phytogeographical interest as it harbors a great number of plant species of the East Himalayan and East Asiatic elements, particularly in the montane vegetation zone on the high mountains.

Ecological studies on forest formation of the Northwest Highland particularly Doi Inthanon were initiated by Ogawa *et al.* (1961) followed by Robbins and Smitinand (1966) and Faculty of Forestry (1992). However, Santisuk (1988) presented an account of forest vegetation of northern Thailand, which also included the forest formation of Doi Inthanon, and Pengklai (1996) reported the significance of plant species richness of this area. These studies are mainly focused on the broad perspective of the forest especially some ecological characteristics of each forest type but there are relatively few studies on soils in each forest type of Doi Inthanon.

Studies in respect to soils in Doi Inthanon are very scanty and there are only some details on soil type (Pendelton, 1962). Only soil properties in some forest type such as in deciduous dipterocarp forest (Sukwong *et al.*, 1976; 1977) and other forest types have been investigated by Kunaporn (1984). However, his study had detailed only on soil properties but did not mention on the relationships between soil and tree community. Particularly, the quantitative aspects of the tree species diversity and distribution associated with soil factors along the altitudinal gradients also have not yet been fully investigated.

Doi Inthanon was assigned as a National Park of Thailand and Doi Inthanon itself has been named the "summit of Thailand". It covers an area of 482.4 km^2 and it's altitude ranges from 400 m at the entrance of the National Park up to 2,565 m at the summit. This great difference in altitude is a main cause to form various forest types, such as deciduous dipterocarp forest at 400-1,000 m, mixed deciduous forest at 400-800 m, dry evergreen forest at 400-800 m, pine-deciduous dipterocarp forest at 800-1,200 m, pine-oak forest at 1,000-1,400 m, and montane forest at 1,000-2,565 m (Santisuk, 1988 and Faculty of Forestry, 1992). These forest types represent a majority of the terrestrial forest formations in Thailand. The geology of Doi Inthanon is the basement complex composed of gneiss, granite, and limestone, which are the principal groups of parent materials in most part of the country except the peninsular region. Moreover, it is an important watershed area of the northern region of the country. From these unique characteristics together with the well protective forest preserved in this area, Doi Inthanon is greatly considered to be the best area for study the forest communities in association with soil factor along the altitudinal gradients.

It is well known that soils have the paramount effects on plant distribution, growth and development causing their responses, tolerances, requirements and adaptations to the particularly soil environments. Meanwhile, soil itself is modified accordingly to several factors included the topographic conditions or relief and varied continuously with altitudes. Altitudinal gradients significantly affect on plant distribution as reflected by the zonation difference of forest type by them. Each type has it's own species composition and association, which suggest their preference to that specific environment. Therefore, within the altitudinal ranges, plant distribution and soil change should have more or less close relationship. To elucidate these relationships is of prime importance in order to understand and gain more knowledge on the zonation of forest vegetations in Doi Inthanon as well as in northern region of Thailand and in other similar regions or environmental conditions. There are several approaches in studying this kind of relationships. The present study will base on continuum concept which involving the quantitative gradients analyses of soils and plants along the altitude by using the ecological methods in classification and ordination. This study will not only to provide the detail of plant distribution in relation to soil properties but also to gain more knowledge on site requirement on each important tree species in each forest type. It is considered to be beneficial to forest management as well as to the conservation of watershed, protected areas and gene pool of the plant and for the application to rehabilitate the degraded forests of the country.

Objectives

1. To study the structure, species composition and tree species diversity in forms of association and resemblance functions of the main forest types in Doi Inthanon.

2. To study various soil properties including physical, chemical, mineralogical and charge characteristic underneath the main forest types in Doi Inthanon.

3. To determine the similarity and dissimilarity of soil properties among the main forest types in Doi Inthanon.

4. To determine which soil properties are the determinants of the species distribution and species diversity of the main forest types in Doi Inthanon.

5. To determine relationships between vegetation grouping by cluster analysis and soil properties of the main forest types in Doi Inthanon. All these detailed studies are performed along the altitudinal gradients of the area.

6. To quantitatively compile a database for further researches and provide the basic information for the management of the natural resource, genetic, species diversity and nature conservations and for the improvement of the degraded forest.

LITERATURE REVIEWS

General Characteristics of Forests in the Northern Thailand

The forests in northern Thailand were divided into two main categories, evergreen and deciduous by Santisuk (1988). The ecological distribution of the forest types in this region is fundamentally governed by two factors of paramount importance, the availability of moisture in the soil and elevation. Inevitably, these two parameters are interrelated closely with other environmental factors such as geology, bioclimatology, human activity etc. According to Santisuk (1988), evergreen forest type is further divided into seasonal rain forest and montane forest. Their characteristics are described briefly as follow:

Evergreen Forest

Seasonal Rain Forest

This is a closed, high rain forest of an evergreen type with the evergreen trees predominating in the main canopy in addition to some scattered isolated deciduous trees. The nomenclature of this vegetation included "dry evergreen forest", "semi evergreen forest' and "tropical semi evergreen forest" (Whitmore, 1984 and Bunyavejchewin, 1986). Physiognomically, the forest always exhibits a green nature at any time of the year. The deciduous species, represented by isolate scattered individuals among the tree predominantly evergreen trees of the main canopy, shed their leaves in part or in total for only a brief period (usually less than two-weeks) and soon replace by new flushes of leaves and or flowers. The inclusion of deciduous trees in seasonal forest is likely depended on the moisture condition of the soil. Santisuk (1988) suggested that "seasonal evergreen forest" in the North occupy the sheltered moist valleys of low hill ranges up to approximately 900 m asl, gentle to moderate moist foothills or depressions of the peneplain. The forest developed on both calcareous and non-calcareous soil types, frequently on granitic loamy soil, which is usually deep and moisture-retaining capacity is relatively high. Along the larger watercourses in the open valley basins, this forest usually forms a narrow strip of gallery forest characterized by magnificent lofty stand of some evergreen dipterocarps, such as *Dipterocarpus turbinatus*, *Dipterocarpus alatus* and *Hopea odorata*.

Montane Forest

One of the most important features of tropical mountains is the altitude, where the tropical lowland forest is replaced with montane ones. The replacements of lowland components with the montane components in the mountains in the northern region, Santisuk (1988) proposed that montane forest gradually commences at an elevation of approximately 700 m asl. The typical lower montane vegetation types (lower montane rain forest, lower montane oak forest and lower montane pine-oak forest) dominated by montane components often occur at approximately 1,000 m asl. Lower montane vegetation is replaced by upper montane vegetation at higher elevations, above approximately 1,800 m asl. The boundary line between lower montane vegetation and lowland vegetation (seasonal rain forest, tropical mixed deciduous forest and deciduous dipterocarp forest) has not been exactly described yet.

Lower Montane Forest

Lower montane vegetation prevalent in the mountains of the northern region of Thailand can be classified on the basis of physiognomical and structural characteristics as well as floristic composition into three types as: lower montane rain forest, lower montane oak forest and lower montane pine-oak forest (Santisuk, 1988).

Lower Montane Rain Forest

This community characterizes as a high, dense, continuous closed-canopy forest similar to seasonal rain forest in the lowland forest zone. According to Santisuk (1988) suggestion, the floristic composition of this forest type dominant with families Fagaceae, Lauraceae, Magnoliaceae and Theaceae are represented. The lower montane rain forest distributed along the moist valley slopes and valley basins at altitude approximately 1,000-1,800 m, where the average annual rainfall ranges between 1,300-2,000 mm, and the weather is constantly high humidity. This forest is often found on red granitic or brown-black calcareous soil types with conspicuous accumulation of organic matters. The lower montane rain forest is structurally three-tree layered and rather poor in undergrowth and woody lianas. On the other hand, this forest type occurred on the drier valley slope and ridges at elevation from 1,000-1,400 m, show drier than at higher elevation (1,400-1,800 m). The moist soil and rich enough in organic matter support the development of plant community to be high and dense forest.

Lower Montane Oak Forest

Lower montane oak forest is the most common type of the vegetation in the mountainous area above 1,000 m asl. This vegetation type is usually dense, possessing trees of the families Facaceae, Theaceae, Magnoliaceae, Lauraceae Betureaceae etc. in varying size and height (12-20 m) on the unmarked layers. The crowns of canopy tree more or less touch and branches of tall trees exposed to the prevalent cool breeze are usually festooned with "beard lichens". Epiphytic orchids and ferns are also commonly occurred on the branches of giant trees. The graminoid species are poorly developed on the forest floor, whilst shrubs and forbs are successfully dominated by temperate or montane species (Santisuk, 1988).

Lower Montane Pine-Oak Forest

This forest type is similar to lower montane forest, however it dominant species is pine (*Pinus kesiya*). Santisuk (1988) proposed that the lower montane pine-oak forest might be a severe destruction stage of lower montane oak forest, which regularly or periodically interfered with by biotic (burning, cutting, grazing) or edaphic (e.g. soil erosion) factors. Lower montane pine-oak forest is best developed on the ridges, moderate to steep slopes at elevations from 1,000-1,400 m where soils are excessively eroded and become too xeric to support the growth of other broad-leaved trees. Regular or periodical burning in the dry season is a common as fire can readily sweep over the forest floor where dry needle leaves are thickly accumulated.

Upper Montane Forest

Upper montane forest occurred in the montane vegetation zone of northern Thailand can be classified into two distinct types included upper montane rain forest and upper montane scrub. The occurrence of upper montane forest is coincident with the mist belt prevailing and usually at elevation above 1,800 m asl, however the lower limit of upper montane rain forest may vary from 1,700-1,800 m due to exposition. The change of the two forest types is rather gradual and can be expected at the lower limit of the frequent cloud cover. Furthermore, the change from lower montane rain forest into upper montane scrub is abrupt because of the remarkable contrast in edaphic condition between these vegetation types (Santisuk, 1988).

Upper Montane Rain Forest

This sub forest type distributes only on a peak of the mountains that higher than 1,800 m asl, and is once luxuriant in the moist and rich in organic matter soils at elevation 1,800-2,565 m asl. On Doi Inthanon, the upper montane rain forest imperceptibly change into lower montane rain forest below the cloud belt, and it is very difficult to separates the boundary between the two forest types. Upper montane rain forest is tall, dense and forms a single storey. The crowns are typically dome shaped supported by the crooked branches on which, epiphytic flowering plants are luxuriantly developed. The majority of oaks, commonly found in lower montane rain forest, are not found in upper montane rain forest (Santisuk, 1988).

Upper Montane Scrub

This is a unique vegetation type in Thailand. The distinction of upper montane rain forest from upper montane scrub is clearly justified. Smitinand (1966) recognizes this vegetation as an open hill evergreen forest at 1,900-2,200 m asl. It occurs along the crests of exposed barren areas of the limestone massive only in Doi Chiang Dao. Herbaceous plants and many low shrubs thriving in the mossy cracks or crevices of limestone rocks overwhelmingly dominate upper montane scrub. The harsh environment, i.e. frequent clouds, occasional showers, heavy dews, regular cold winds and barren, extremely exposed ground surfaces, favor the typical sub-alpine plant and alpine at this altitude (Santisuk, 1988).

Deciduous Forest

Tropical Mixed Deciduous Forest

This is the most important deciduous vegetation in northern region of Thailand developing either on acidic or basic soil groups, but best development represent on soils derived from limestone, and the fertile alluvium soils. The soils derived from sandstone and quartzites appear to be unsuitable for tropical mixed deciduous forest in general. This forest is most widely developed below 800 m asl and prefers deep loamy soils or clay loam with more or less accumulation of organic matter. The forest is affected by seasonal drought during the long spell of dry season. The canopy strata of this forest are evenly mixed with almost all-deciduous tree species without any single-species dominance. Dominant stands of teak (*Tectona grandis*) are occasionally found on the fertile alluvium soils of the valley plains (Santisuk, 1988).

Tropical mixed deciduous forest and deciduous dipterocarp forest often alternately distribute in mosaics or in transitions in accordance with topographic or edaphic sequence, especially in the hilly areas. Ogawa *et al.* (1961) recognized this forest as tall deciduous forest as influenced by Credner's classification (Credner, 1935). This forest is divided into various subtypes mainly based on terrain and floristic composition: "upper mixed forest" "lower mixed forest" "moist upper mixed forest" "dry upper mixed forest" and "lower mixed deciduous" (Champion, 1936; RFD 1962; Neal, 1967 and Smitinand, 1977). Bamboo is usually found as undergrowth of this forest type. A healthy stand of teak is always found in deep, well-drained soil, non-lateritic, preferably calcareous parent material (Kaosaard, 1981).

Deciduous Dipterocarp Forest

This is the most xeric type of the natural vegetation of Thailand. It occurs in alternation with tropical mixed deciduous forest. Obviously, edaphic factor and forest fire plays important roles in determining the development and distribution of this deciduous vegetation type. Almost all canopy tree species shed their leaves during the cool, dry season (December-January), and form new flushes of leaves accompanied by bloom before the onset of the rainy season (April-May). The degree of deciduousness and the period of leaflessness of the trees in the deciduous dipterocarp forest vary considerably with the soil moisture content.

This forest type bears several names in the publications; savanna forest (Ogawa *et al.*, 1961), dipterocarp deciduous forest (RFD, 1962) lowland deciduous dipterocarp forest (Robbins and Smitinand, 1966), deciduous dipterocarp forest (Kutintara, 1975; Bunyavejchewin, 1983a) and dry deciduous dipterocarp forest (Stott, 1975; Smitinand, 1977; Smitinand *et al.*, 1978). The name deciduous dipterocarp forest is preferable, because it designates the overwhelming deciduous dipterocarp tree species; *Dipterocarpus intricatus*, *D. obtusifolius*, *D. tuberculatus*, *Shorea obtusa*, and *S. siamensis* in every forest tree stratum. Nevertheless, *Dipterocarpus intricatus* does not occur in northern Thailand, it is restricted to this forest on the Korat Plateau (Smitinand *et al.*, 1978). This forest occupies the dry to extremely dry habitats, on the slope of foothills, on hill sides, along the ridges, and running up slopes to approximately 600-800 m asl, and more common at elevations below 600 m asl. The soils are poorer than in other forest types being characteristically acidic, shallow, gravelly to sandy, or lateritic with levels of stoniness and are subject to annual burning, slope erosion, and extreme leaching. Rock outcrops are locally common. This forest has an open canopy and a conspicuous layer of graminoid, including dwarf bamboo as an undergrowth plant.

Pine-Deciduous Dipterocarp Forest

This vegetation type is notable by the inclusion of two native pine species, *Pinus merkusii* and *P. kesiya*. Santisuk (1988) suggested that this forest might be readily promoted by man-induced fire in the cool dry season (December-Febuary). *P. merkusii* accompanied by some Facaceous and Theaceous trees species, makes it's infiltration into deciduous diptercarp forest generally at altitude of approximately 550 m asl and is more abundant from 800-1,200 m asl. The one of pine species, *P. kesiya* is locally found co-dominant with *P. merkusii.* In northern Thailand, *P. kesiya* is associated with lower montane oak forest, the overlapping zone between lower montane pine-oak forest and pine-deciduous dipterocarp forest. Beside the topographic and edaphic factors that limit the distribution of *P. kesiya* in pine-deciduous dipterocarp forest, frequent and severe fires in this forest (often caused by turpentine harvesting) are likely to favor *P. merkusii,* which is characteristically more resistant than *P. kesiya.*

In northern Thailand, pine-deciduous diptercarp forest is most extensively developed on the plateau-like rolling hill at elevation ranging from 800-1,200 m asl Pine-deciduous dipterocarp forest is three-layered and of an open nature, usually with prominent development of the graminoid layer. The upper or emergent stratum is composed of the majority of *P. merkusii* tree, and sporadic *P. kesiya* tree. *P. merkusii* is likely to be replaced by *P. kesiya* on the moderate to steep slopes of moister gullies. The middle or main canopy consists of large to medium-sized tree of deciduous dipterocarp species. The shrub layer consists of seedling and sapling of pines and deciduous dipterocarp species in addition to scattered shrubs and forbs. Graminoid undergrowth is well developed in intensive layer or often in closely spaced tufts. Herbaceous ground floras consist of many temperate genera and species (Santisuk, 1988).

Concept of Vegetation Study

Traditionally, most of ecological in aspect the vegetation studies have been based on two principle concepts. Firstly, Clements's concept (Clements, 1916; 1928), described plant communities as the clearly recognizable and definable entities which repeated themselves with great regularity over a given region of the earth's surface. Clements's view of the plant community is known as the organismic concept, in which the various species composing the vegetation at a point on the earth's surface were likened to the organs and parts of the body of an animal or human. Putting all the parts together made a kind of super-organism, which was thus the plant community and the organism could not function without it's entire organ present.

Many ecologists then developed this concept. The vegetation on the landscape is treated as made up of discrete unit of well-defined and integrated part. These can then be characterized into abstract classes reflecting the interaction of all components within each particular class (McIntosh, 1967; Whittaker, 1967; 1970; Gauch and Whittaker, 1972; Day and Monk, 1974). Each unit is separated from the others by a more or less distinct boundary called a transition zone or ecotone (Oosting, 1956; Spurr, 1964; Drew and Shanks, 1965). This concept has been called as the "community unit theory" or "association unit theory" (Whittaker, 1956; 1967; 1970; McIntosh, 1967).

Second theory, was described by Gleason (1917; 1926; 1936) that all plant species distributed as a continuum. He argued that plant species respond individually to variation in environmental factors and those factors vary continuously in both space and time. Consequently, the combination of plant species that found at any given point on the surface of the earth was unique. Every species has a different distribution or tolerance range and abundance over that range. For these reasons, Gleason' s view is known as individualistic concept. Interesting discussions of these early viewpoints on the nature of the plant community are found in Whittaker (1951).

Robotnov (1979) introduced the work of L.G. Ramenskii, a Russian ecologist, who has largely been ignored in western's literature. They made the point that Ramenskii published ideas on the continuum concept, and the plant community in the early decades of this century and that independently, he evolved theories that were very similar to those of Gleason in America. The main burden of this approach rests on the concept that each species has it's own range of environmental tolerance or amplitude of tolerance. And that, the vegetative community of any particular landscape, is the result of the joint occurrence of species due to overlapping of their amplitudes of tolerance (Ayyad and Dix, 1964; McIntosh, 1967; Whittaker, 1967; 1970; Beals, 1973)

The continuum concept leads to a new method of vegetational analysis called "vegetation ordination" by Curtis or "gradient analysis" by Whittaker (Curtis and McIntosh, 1951; Brown and Curtis, 1952; Bray and Curtis, 1957; Beals, 1965; 1973; McIntosh, 1967; Whittaker, 1956; 1967; 1970; Gauch *et al.*, 1974). Ordination is the process of arranging samples in relation to one or more gradients or axes of variation (Goodall, 1954). In more of mathematical sense, it is a summarization of the information content of a matrix, whose elements composed of distances or angles, defines the spatial relationship between ecological entities (Orloci, 1966). Two types of gradient analysis can be used: (1) direct gradient analysis or arrangement and study vegetation along the known magnitudes or indices of environmental gradient. And (2) indirect gradient analysis where the vegetative samples are compared and arranged in terms of their dissimilarity in species composition and/or other vegetative characteristics. It may or may not correlate with environmental gradients but if it does it then becomes an indirect gradient analysis (Whittaker, 1967).

Environments of plant community differ in many ways and each species in each community responds to the whole environmental complex not to separate factors because the environmental factors are arranged in the gradient patterns; for example, altitudinal gradient from the bottom to the summit of a mountain or soil moisture gradient from dry to wet. It is logically that the continuum concept and ordination techniques can be useful tools for these studies. The results of many ecological studies have been shown to support the validity of the technique. Shaukat and Qadir (1971) demonstrated that the individualistic hypothesis of species distribution and the continuum concepts could be readily applied to tropical vegetation.

Biodiversity Indices

Biodiversity indices are the numerical index, which can be used to characterize species abundance relationship in forest communities. Biodiversity is composed of two components. The first is the number of species in the community, which ecologists often refer to as species richness. The second component is species evenness or equitability, which refers to how the species abundances (e.g., the number of individuals, biomass, cover, etc). Over the years, many numbers of indices have been proposed for characterizing species richness and evenness and called richness indices and evenness indices. These indices attempting to combine both of them into a single value are what we refer to as diversity indices. Since diversity indices often attempting to incorporate both of these components into the single value, much debate and often confusion occur. In fact, Hurlbert (1971) suggested that diversity was probably best described because of the many semantic, conceptual, and technical problems associated with it's use. In spite of debates and numerous cautionary remarks put forth by many regarding their use, diversity indices have remained very popular among ecologists.

Ecological Studies on Forest Communities in Doi Inthanon

Ecological studies on forest communities in Doi Inthanon were firstly begun by Ogawa *et al.* (1961). They classified the forest in Doi Inthanon into five forest types; (1) tall deciduous, (2) savanna, (3) evergreen gallery, (4) subtropical evergreen forest and (5) temperate evergreen forest. Robbins and Smitinand (1966) studied forest communities in the same area as Ogawa *et al.* (1961), and subsequently replaced the forest type names as (1) mixed deciduous forest, (2) dry dipterocarp forest, (3) tropical evergreen forest, (4) ecotone and (5) hill evergreen forest. Faculty of Forestry (1992) reported six forest types in the area together with the vegetation map and area cover distribution of each forest types as 54.06, 0.98, 1.58, 12.83, 20.77, and 4.77 % for hill evergreen forest, dry evergreen forest, pine-oak forest, mixed deciduous forest, deciduous dipterocarp forest and pine-deciduous dipterocarp forest respectively.

Plant species diversity in Doi Inthanon was reported by Pengklai (1996) that there were 25 families, 71 genus, 121 species for ferns; 5 families, 5 genus, 11 species for gymnosperms; 25 families, 197 genus, 536 species for monocotyledons; and 97 families, 317 genus, 2,500 species for dicotyledon plants.

General Characteristics of Forest Soils in Thailand

Physiography and geology of Northwest Highland is divided into two sub regions comprising of the Northern Hills and Valleys and the Western Mountains

(Moormann and Rojanasoonthon, 1962). The Northern Hills and Valleys is a region of parallel N-S oriented ridge, alternating with elongated inter montane basins, which harbor four major rivers namely Ping, Wang, Yom and Nan rivers. The basins containing great thickness of lacustrine and fluviatile Cenozoic sediments mainly Miocene to basins is over 3,000 m and overlain by thick bed of Quaternary deposits. The Western Mountains sub region occupies a considerable part of northern Thailand. They are formed in widely variable rocks of igneous and sedimentary origin that more or less metamorphosed in places. The topography of the hills characterized with a high degree of relief. Older granite and gneiss are dominant igneous rocks. Sedimentary rocks are mainly shale, sandstone, and phillite (Moncharoen *et al.*, 1987). Doi Inthanon is located in this region (Moormann and Rojanasoonthon, 1962).

Soils of Northwest Highland vary with the topography. Block (1958) was the pioneer in studying of soil in Northern Thailand, mainly focused on the chemical properties of soil in deciduous dipterocarp forest and mixed deciduous forest at Prae province. Samaphudhi (1963) studied soil in some forest types including deciduous dipterocarp forest, mixed deciduous forest, dry evergreen forest, and tropical evergreen forest in some provinces. The fertilities of forest soils in Doi Chiangdoa were evaluated by Khemnark *et al.*, (1972). The soil and plant relationships in the deciduous dipterocarp forest type were studied by Kutintara (1975) in Hod district, Chiangmai. Bunyavejchewin (1983a, 1985) studied the floristic and soil properties in the dry dipterocarp and mixed deciduous forests, partly located in northern Thailand. In addition, Sakurai *et al.* (1998), Sahunalu *et al.* (1994), and Janmahasatein *et al.* (1996) also studied forest soils in another regions of Thailand.

Forest Communities and Environmental Gradients Studies

The studying of vegetation distribution pattern with environmental gradients could be analyzed by many ways. Factor analysis is one of the popular methods, which was used by Schnell *et al.* (1977) for studying in 76 community patterns with 19 environmental factors at Oklahoma. Goodall (1954) had developed factor analysis into principal component analysis. Marchand (1973) used the same method for an analysis of vegetation pattern in White Mountains, eastern California. In addition, correspondence analysis is one of the methods for studying ordination of vegetation distribution patterns, which was developed from reciprocal averaging (Hill, 1973b; Peet and Loucks, 1977). Furthermore, Lieberman *et al.* (1996), Johnston (1992), ter Steege *et al.* (1993) also used correspondence analysis for studying the relationships between tropical forest community and soil factors in Guyana.

The study of vegetation distribution pattern could be done by several methods. For example, Proctor *et al.* (1983) studied tropical rain forest along the altitudinal gradients in Gunung Mulu, Sarawak Malaysia by descriptive study, which is the original method to study vegetation ecology. Many ecologists popularly prefer to use this method such as Pendry and Proctor (1996) studied tropical rain forest along the altitudinal gradients in Bukit Belalong, Brunei. Edwards and Grubb (1977, 1982) made the sample plots and studied in montane rain forest, New Guinea. In addition, descriptive method was used in tropical rain forest at Gunung Silam, Malaysia (Proctor *et al.*, 1988). Tanner (1977) studied montane rain forest in Jamaica. This method was also used by Branson *et al.* (1970) in temperate zone at northeastern Montana, USA.

Polar ordination is an older kind of ordination technique for relating soils to vegetation distribution pattern, which was improved by Bray and Curtis (1951). This method was used widely in ecological study, i.e. Schmelz and Lindsey (1970) studied vegetation pattern in Indiana forest. Gemborys (1974) studied hardwood forest in Prince Edward County, Virginia. Nevertheless, this method was improved by the ecologist of Wisconsin University and widely used by Gittens (1965), Beals (1965) and Orloci (1966). In Thailand, Bunyavejchewin (1983a, 1985) and Kutintara (1975) used this method for dry dipterocarp and mixed deciduous forest classifications. The other methods were consequently improved and widely used by many ecologists as referred to below.

Forest community distribution along the environmental gradients may be divided into four types included topographic gradients, climatic gradients, edaphic gradients, and the combination of all of them. The studies of forest communities along environmental gradients, especially in relation to soil factors were carried out widely in temperate zone. On the other hand, this kind of study have been investigated very few in tropical zone, for example Day and Monk (1974) used principal component analysis to analyze patterns of temperate forest in Appalachian watershed, south USA. Parker (1989) studied forest compositional patterns in relation to environmental factors in Yoasemite National Park, California. TWINSPAN and DCA techniques were selected to classify and generate a composite axes. His study indicated that elevation and soil magnesium content were the significant variables to explain the forest distribution. Smith (1995) used TWINSPAN and CCA for studying the relationships between forest community and edaphic factors on upland northern hardwood forest, central Vermont, USA. The result suggested that the ecological forest type was a characteristic combination of physiography, and vegetation.

Graae and Heskjaer (1997) attempted to compare the understorey vegetation between untouched and managed deciduous forest in Denmark by using multivariate regression, DCA. They concluded that there were some differences between the two forest types, which might be caused by different of tree species composition, soil moisture and litter depth. Chen *et al.* (1997) studied the relations of soil properties to topography and vegetation in subtropical rain forest in southern Taiwan, and proposed that soil pH, available N, CEC, exchangeable Al, Ca, K and Mg influenced to the occupying vegetation. This suggestion was supported by the study of Hsieh *et al.* (1998)

However, some studies were carried out in tropical region such as Proctor *et al.* (1983) used descriptive method to studied tropical forest along the altitudinal gradients in Gunung Mulu, Sarawak, Malaysia. Ola-Adams and Hace (1987) found that natural forest community was significantly dependent on available phosphorus, soil acidity and texture. Lieberman *et al.* (1996) studied tropical forest along the altitudinal gradients from 30 m asl up to 2,600 m asl using detrended correspondence analysis in northern aspect of Volcan Bawa, Costa Rica. The study of Ogutu (1996) on plant communities in the Narok district, Kenya indicated that soil moisture content, carbon content, and nutrient availability of nitrogen and zinc influenced to vegetation patterns. Sabatier *et al.* (1997) investigated the influence of soil factors on the floristic and structural heterogeneity in Guianan rain forest. The result concluded that the forest community seems to be dependent on the soil and the topographical features that govern it. The correspondence analysis of the species by environmental variable matrices revealed that the first axis could be associated with the drainage mainly related to the thinness of the soil and the second with the hydromorphic conditions related to the topography.

STUDY SITES

Doi Inthanon was established as a National Park in 1972 (Faculty of Forestry, 1992) and Doi Inthanon itself has been called the “summit of the country”. It is a representative of the mountain complex forming part of the Thanon Thongchai Range, the southern extension of the Shan Hills of Myanmar, which is the southernmost of the Himalayan foothills. It is located at 18° 24’ N to 18° 40’N latitude and 98° 24’ E to 98° 42’ E longitude. The park covers an area of 482.4 km^2 and it’s altitude ranges from 400 m asl at the southern entrance of the park up to 2,565 m asl at the summit in the north of the park.

According to Pendelton’s reconnaissance geologic map (Pendelton, 1962), Doi Inthanon is huge granite massive, underlain by three major rock types found in the highlands of Thailand (Figure 1). From Ban Mae Hoi in the eastern part of the park to Pha Mawn in the central part of the park, it traverses the band of gneiss that connects in the northwest with Doi Suthep. This parent material produces the Sithammarat coarse sandy loams, which Pendelton (1962) described as miserably poor and of little agricultural value. At Pha Mawn there is a narrow pocket of clastic sediments, the Kanchanaburi series, consisting of shales, siliceous sandstone and in places, quartzites and slates. These parent materials produce poor soils, shallow and stony and have scant agricultural value. Doi Inthanon itself is a granitic massive generally giving rise to the Kuantan sandy loams of shallow coarse and stony soils.

According to the most recent preliminary study conducted by the Faculty of Forestry (1992), Doi Inthanon vegetation types are generally composed of 6 forest community types: dry dipterocarp (9.84 %), mixed deciduous (15.93 %), dry evergreen (0.75 %), pine-dipterocarp (7.49 %), pine-oak (1.21 %), and montane forests (41.50 %) (Figure 2).

The area has a monsoon climate with a strong alternation of wet and dry seasons. Based on this seasonality, Sternstein (1962) recognized seven rainfall regions in Thailand. Doi Inthanon falls in the center of the North Region. This region has a uniform monsoon climate with the heaviest rains coinciding with the moist southwest monsoon during August to September and the driest month in January, coinciding with the dry northeast monsoon. Three sets of meteorological data are available for Doi Inthanon National Park. First is from a radar station base of the Royal Thai Air Force located at the summit (2,565 m asl), second from the Royal Project Doi Inthanon Station located near the park headquarters (1,300 m asl) and the other from the meteorological station at Chiangmai City (310 m asl). The climatic data sets are shown in Figure 2 as pluviothermic graphs drawn according to Walter's method.

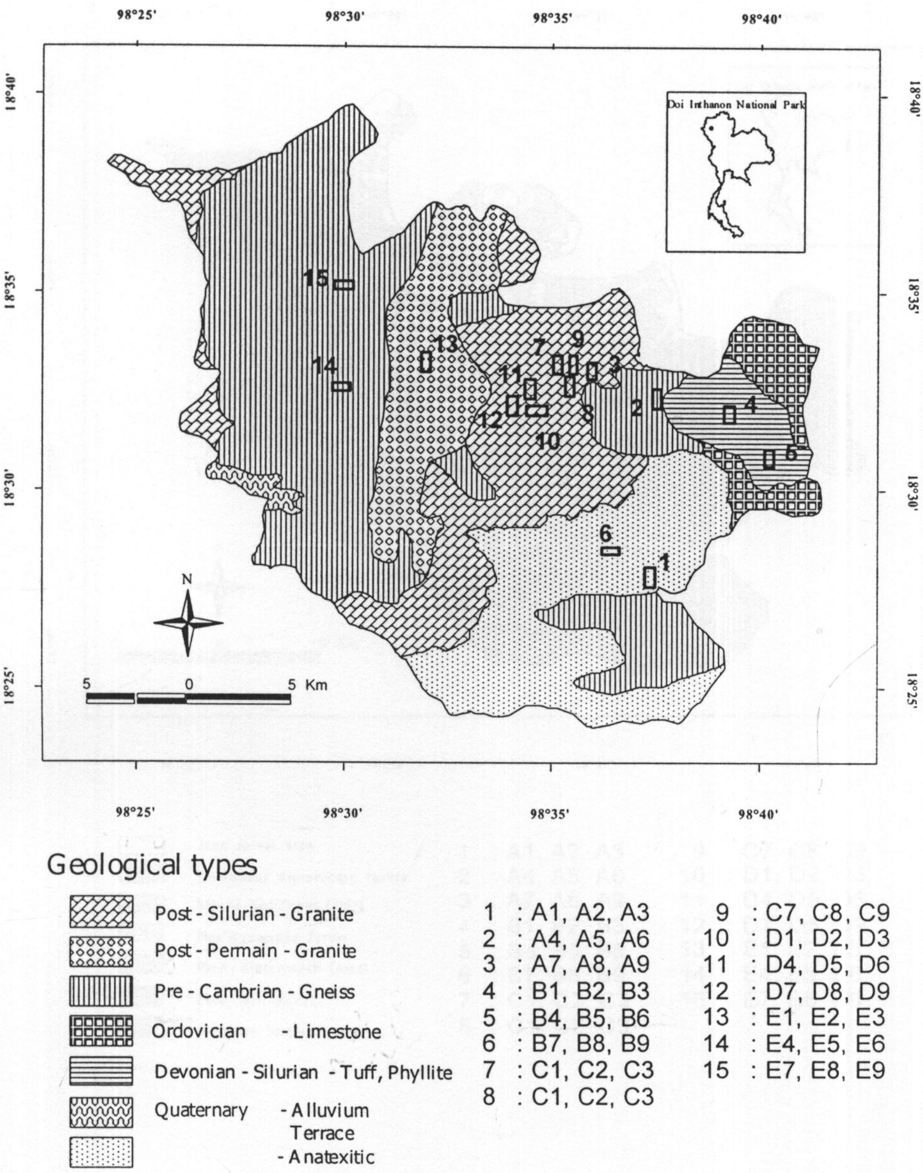

Figure 1 Geological map and location of study plots in Doi Inthanon National Park; A1 to A9: dry dipterocarp forest, B1 to B9: mixed deciduous forest, C1 to C9: pine-dipterocarp forest, D1 to D9: pine-oak forest, E1 to E9: montane forest.

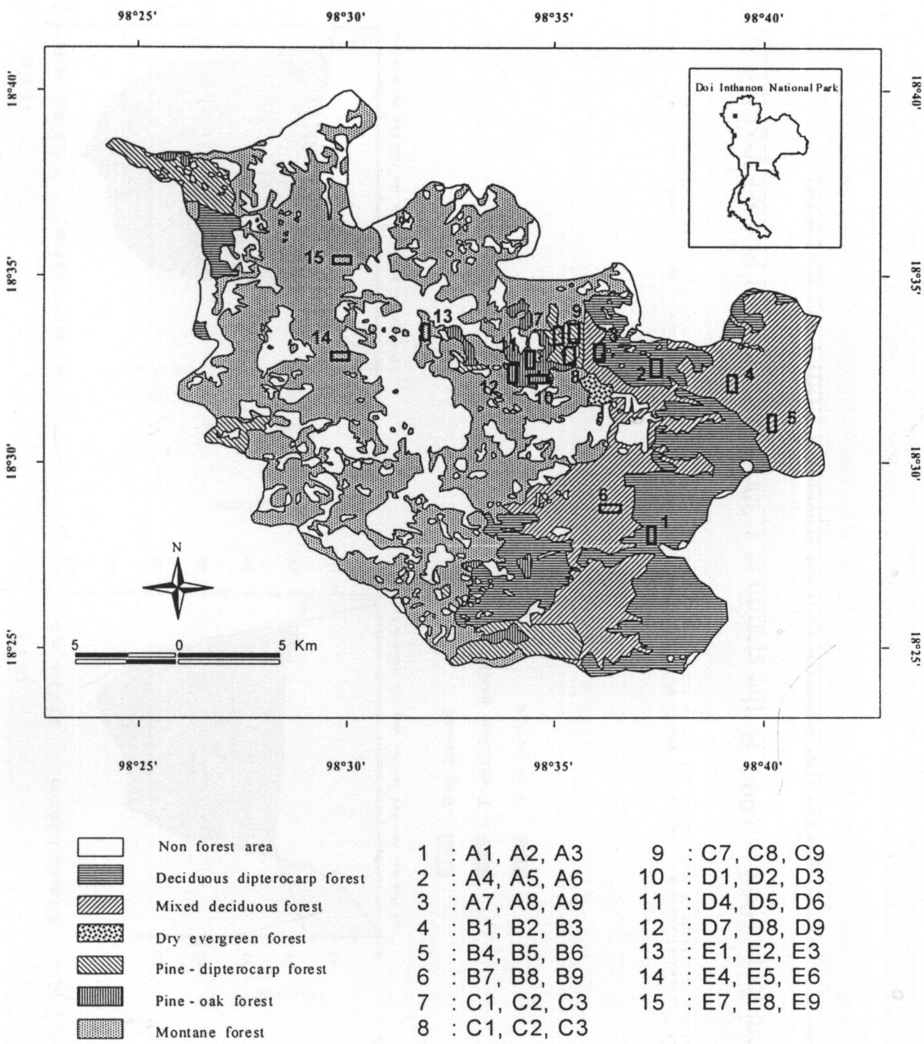

Figure 2 Vegetation map and location of study plots in Doi Inthanon National Park; A1 to A9: dry dipterocarp forest, B1 to B9: mixed deciduous forest, C1 to C9: pine-dipterocarp forest, D1 to D9: pine-oak forest, E1 to E9: montane forest.

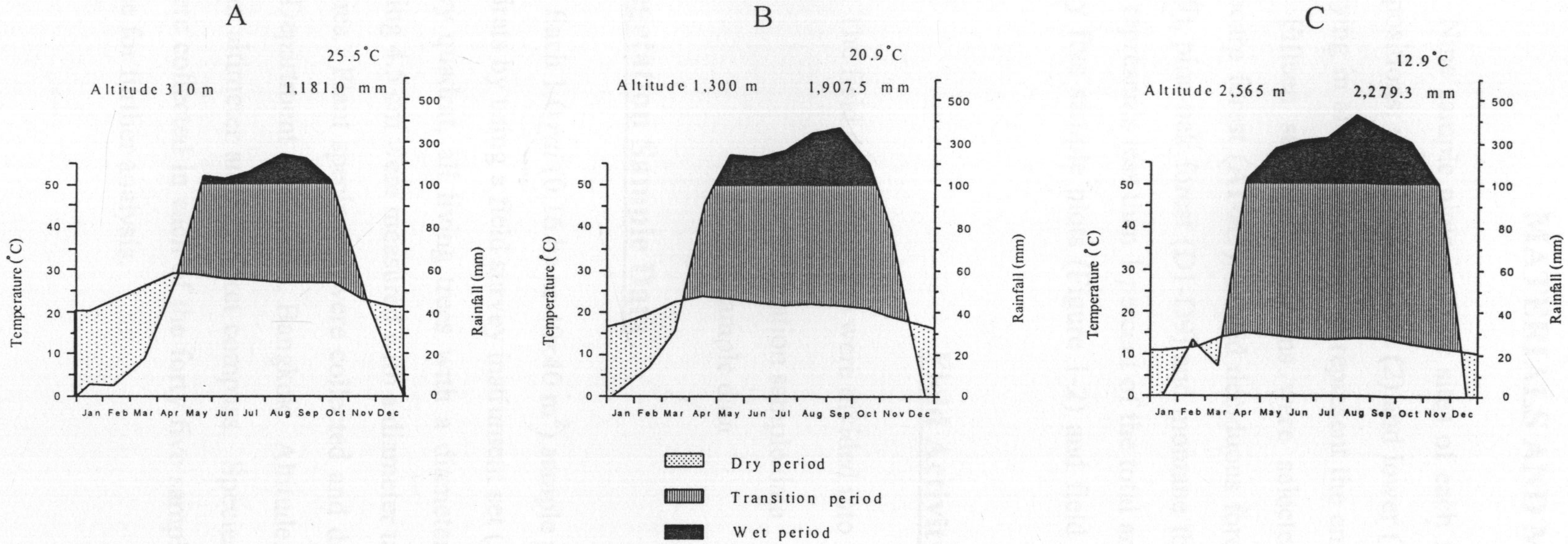

Figure 3 Walter's climatic diagram of three weather stations located in Doi Inthanon and in Chiangmai, Northern Thailand.

(A: the station at 310 m asl in Chiangmai from 1969 to 1999, B: the station at 1,300 m asl in Royal Project, Doi Inthanon station from 1982 to 1999, C: the station at 2,565 m asl on the summit of Doi Inthanon from 1993 to 1999)

MATERIALS AND METHODS

Nine sample plots in three sites of each forest type were delineated at three slope positions: upper (1), middle (2) and lower (3). Plots were deliberately selected by varying in altitude in order to represent the entire altitudinal gradient of the study area. Fifteen sampling locations were selected in five forest types: deciduous dipterocarp forest (A1-A9), mixed deciduous forest (B1-B9), pine-dipterocarp forest (C1-C9), pine-oak forest (D1-D9) and montane forest (E1-E9). Dry evergreen forest which represents less than 1 percent of the total area was omitted. These were a total of forty five sample plots (Figure 1-2) and field work was conducted in November 1999.

Field Activity

The field data collection were divided into two parts as follows:

1. Vegetation sample data
2. Soil sample data

1. Vegetation Sample Data

Each 1.0 *rai* (0.16 ha or 40x40 m^2) sample plot was divided into sixteen 10x10 m quadrats by using a field survey instrument set (field compass and measuring tape). In every quadrat, all living trees with a diameter at breast height (DBH) equal or exceeding 4.5 cm were measured with a diameter tape and as far as possible identified to species. Plant specimens were collected and dried for identification at the Royal Forest Department Herbarium, Bangkok. Altitude, slope and aspect were determined using an altimeter and a pocket compass. Species abundance and presence/absence data were collected in each of the forty five sample plots (stands) and entered into a database for further analysis.

2. Soil Sample Data

2.1 Soil Profile Description

Soil profiles of the sample plots on the middle slope topography of each sampling locations were carefully investigated and described following the keys of soil taxonomy (Soil Survey Staff, 1987).

2.2 Soil Sample Collection

According to the sampling method, there are fifteen transects from five forest vegetation types. There are three sample plots (stands) within transect. Soil samples collected from each sample plots (stands) in two layers were subsequently analyzed to evaluate physical, chemical, and mineralogical properties. Soil samples were collected by two methods as follows:

Soil cores (100 cc) were used to collect undisturbed soil samples at the depth of 0-5 cm. (surface soil) and 20-25 cm. (subsurface soil). The undisturbed soil samples were subsequently analyzed for their three-phase compositions and their water permeability by determining hydraulic conductivity (Ks) in the field laboratory at Doi Inthanon National Park, and they were taken to determine for pF-retention at the Department of Soil Science, Kochi University, Japan.

Soil samples for other laboratory analysis were also collected by using spades at the depth of 0-20 cm. (surface soil) and 20-40 cm. (subsurface soil). The disturbed soil samples were determined for soil reaction, cation exchange capacity, organic matter, total nitrogen, available phosphorus, exchangeable potassium, exchangeable calcium, and exchangeable magnesium at the Department of Silviculture as well as mineralogical and charge properties in soil at the Department of Soil Science, Kochi University, Japan.

Soil Analysis

All soil samples collected from the sample plots (stands) were analyzed as follows:

1. Physical Properties

Undisturbed 100 cc core samples were used for analyzing three characteristics as follows;

1). One hundred and eighty undisturbed 100 cc core samples from surface and subsurface soil layers of each sample plot (stands) were measured for three-phase distribution by the three-phase meter (Daiki). These soil samples were oven dried for determining three components of soils included: solid, liquid and gaseous and calculating some physical soil properties such as bulk density, particle density, porosity, and moisture content.

2). Another one hundred and eighty undisturbed 100 cc core samples from surface and subsurface soil layers of each sample plot were used for measuring water permeability by saturated hydraulic conductivity method following the study of Sakurai *et al.* (1998).

3). Twenty undisturbed 100 cc core samples from surface and subsurface soil layers of each middle sample plot (stand) of sampling site were measured for pF-moisture retention curve. Based on this method, the moisture content at various pF levels were subsequently obtained by soil column method (for pF 1.5), pressure plate method (for pF 2.0, 2.5 and 3.0), centrifugation method (for pF 4.2), air dry (for pF 5.5) and oven dry for 24 hour (for pF 7.0).

Ninety disturbed soil samples from surface and subsurface soil layers of each sample plots were determined for soil texture by the hydrometer method on air-dried soils that had been passed through a 2-mm soil sieve to remove small rocks, roots, pebbles, and debris followed by wet sieving to separate the sand fraction. Sand, silt, and clay were expressed as a percentage of oven dry weight.

Vertical distributions of soil hardness down to 60 cm in depth were evaluated in the field at center position of each sample plot by the fall-cone type soil penetrometer (Hasegawa type, H-60). The data set of hardness was gradually recorded the depth of penetrated per one drop of the penetrometer. Then, the data were converted to soil hardness at every depth of soil (Sakurai *et al.*, 1995). It's result can be depicted as Figure 4. Horizontal axis represents the penetrating depth (cm) per one drop of weight (term as one drop penetrability, ODP) and vertical axis does the cumulative depth (cm). In this study, soil hardness is classified using the value plotted on the horizontal axis as follows: very hard, ODP less than 0.5; hard, ODP between 0.5 and 1.0; moderate, ODP between 1.0 and 2.0; soft, ODP more than 2.0. The vertical distribution of soil hardness of forty five sample plots (stands) were obtained.

2. <u>Chemical Properties</u>

Using disturbed air-dried soil samples from surface and subsurface soil layers of each sample plot that had been passed through a 2-mm soil sieve to remove small rocks, roots, pebbles and debris, chemical soil properties were analyzed for:

The pH_{H2O} and electric conductivity were measured by using the water suspension at the soil to water ratio as 1:5. The pH_{KCl} were measured by using the 1 M KCl suspension at the soil to KCl solution ratio of 1:5. These suspensions were centrifuged and the supernatants were subsequently used for the analysis of exchangeable Al and H by titration method.

Exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) were extracted with 1 M ammonium acetate and their contents were measured by atomic absorption and flame emission spectrophotometers. After extraction of exchangeable cation, the residues were washed with 20 ml of deionized water, then twice with 30 ml of 99 % ethanol to remove the access salt. Ammonium ions were replaced with sodium ions three times by the addition of 30 ml 10 % NaCl using reciprocal shaking for 1 h following with centrifugation. The ammonium ion was determined as cation exchange capacity (CEC) by Kjeldahl distillation and titration method.

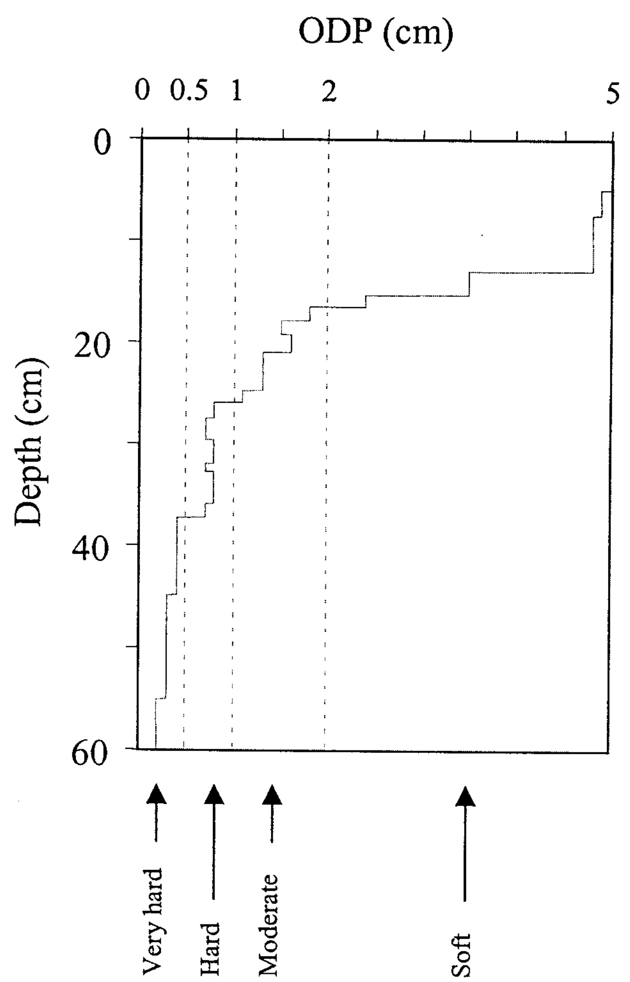

Figure 4 One drop penetrability (ODP) and definition of soil hardness (Sakurai *et al.*, 1995).

Available phosphorus content was evaluated by Bray II method (Alexander and Robertson, 1970). Total carbon and nitrogen contents were measured by CN-corder (Yanaco Model. mt-700).

3. Mineralogical and Charge Properties

Clay fraction of ten soil samples from surface and subsurface soil layers of each middle sample plot (stand) of sampling site of each forest type were collected after the analysis of soil texture and saturated with K and Mg ions and analyzed by X-ray diffraction method (Shimadzu XRD1000IV) to identify the clay minerals.

Ninety disturbed soil samples from surface and subsurface soil layers of all sample plot (stand) were analyzed for zero point of charge (ZPC) and the remaining charge at ZPC by the modified salt titration method (Sakurai *et at.*, 1988).

Data Analysis

All vegetation and soil data were analyzed as follows:

1. Structural Characteristics

The studies were carried out by adopting the quantitative ecological methods as follows:

1.1 The Importance Value Index (IVI)

The importance value index (IVI) (Cottam, 1949) of each species were determined by:

IVI = % relative density + % relative frequency + % relative dominance

where,

$$\% \text{ relative density} = \frac{\text{density of}}{\text{total tree density}} \times 100,$$

$$\% \text{ relative frequency} = \frac{\text{frequency of species i}}{\text{total frequency of all species}} \times 100,$$

$$\% \text{ relative dominance} = \frac{\text{total basal area of species i}}{\text{total basal area of all species}} \times 100,$$

i = 1, 2, 3, 4,…,N,

N = total number of species.

The relative density was determined from all standing trees of DBH equal to and greater than 4.5 cm in the whole plot of 40X40 m^2. The relative frequency was determined from sixteen 10X10 m^2 subplots set by regularly subdividing the 40X40 m^2 plot. The relative dominance was obtained from the basal area at breast height calculated as $\pi D^2/4$ of each tree in the whole plot (where, D=DBH cm).

1.2 Species Diversity Indices

1. The Shannon-Wiener index of species diversity, H (Shannon and Weaver, 1949) is adopted as:

$$H = -\sum_{i=1}^{s} p_i \log_2 p_i$$

where, p_i = proportion of the number of individuals of species i to total number of individuals of all species (i=1,2,.,s),

S = total number of species in the sampling area.

2. <u>The Fisher's index of species diversity, (α)</u> (Fisher *et al.*, 1943)

$$N = \frac{\alpha X}{1-X} \qquad \text{.........................(1)}$$

or

$$S = -\alpha \ln(1-X) \qquad \text{.........................(2)}$$

$$\alpha = \frac{N(1-X)}{X}$$

where, N = number of individuals in the sampling area,

α = the Fisher's index of diversity,

S = number of species

X = constant value calculated from trail and error method from (2)/(1) or

$$\frac{S}{N} = [\frac{(1-X)}{X}][-\ln(1-X)]$$

ln = natural logarithm.

3. <u>The Hill 's index of species diversity</u> (Hill, 1973a) were determined by following formulas:

$$N_0 = S$$

$$N_1 = e^H$$

$$N_2 = \frac{1}{C}$$

where, H = Shannon-Wiener index of species diversity from (1),

e = exponential value,

$$C = \sum_{i=1}^{s} (p_i)^2$$ = concentration of dominance or Simpson's diversity index (λ) (Simpson, 1949)

5. The richness index, (R) in forms of richness index 1 (R_1) (Margalef, 1958) and richness index 2 (R_2) or Menhinick's index (Menhinich, 1964) were used:

$$R_1 = \frac{s-1}{\ln (n)}$$

$$R_2 = \frac{s}{\sqrt{n}}$$

where, S = total number of all species,

n = total number of individuals of all species,

ln = natural logarithm.

6. The evenness index, (E) in forms of evenness index of Hurlbert (E_1) (Hurlbert, 1971), evenness index of Sheldon (E_2) (Sheldon, 1969), evenness index of Heip (E_3) (Heip, 1974) evenness index of Hill (E_4) (Hill, 1973a) and evenness index of modified Hill's ratio (E_5) (Hill, 1973a) were used:

$$E_1 = \frac{H}{\ln S}$$

$$E_2 = \frac{e^H}{S} = \frac{N_1}{N_0}$$

$$E_3 = \frac{(e^H-1)}{(S-1)} = \frac{(N_1-1)}{(N_0-1)}$$

$$E_4 = \frac{1}{C\ e^H} = \frac{N_2}{N_1}$$

$$E_5 = \frac{1}{(C-1)\ (e^H-1)} = \frac{(N_2-1)}{(N_1-1)}$$

where, E = species evenness,

H = Shanon-Weiner's index of species diversity,

S = total number of all species.

2. Forest Community Classification

The abundance and presence/absence data of all forty five sample stands were used for forest community classification by cluster analysis and two-way indicator species (TWINSPAN) analysis.

3. Forest Community Ordination

Two methods of forest community ordination were used: (1) detrended correspondence analysis (DCA) and (2) canonical correspondence analysis (CCA). The results from ordination are scores of axis, which is subsequently plotted into the diagram for an ease of interpretation.

3.1 Vegetation Data Ordination

The vegetation data were subsequently analyzed by using detrented correspondence analysis (DCA) (Hill and Gauch, 1980). The PC-OR program (McCune and Mefford, 1999) was applied to analyze the data in terms of multivariate technique. The species abundance matrix consisting of the parceled important value index (IVIs) of the species having IVI value more than 2.0 in all of stands were included. This matrix were standardized by an equation, $Xij = (Pij)^{0.2}$ before entering into analysis procedure.

The same vegetation data set was used again for analyzing by the canonical correspondance analysis method (CCA). The DCA and CCA diagrams were then compared in order to select the one which is suitable for further description of the vegetation classification.

3.2 Soil Data Ordination

The data of soil properties were selected for analyzing by ordination method DCA and CCA, the same technique as in community data analysis. The DCA and CCA scores were then plotted for classifying the sample stands based on soil properties of sample plots.

4. Soil and Plant Relationships

1. The matrix of environmental variable in each sampling plot was initially included the soil properties in surface (0-5 cm) and subsurface (20-25 cm) soil layers. The correlation between the scores of plant ordination axes (DCA and CCA) was applied using non-parametric Spearman's rank test. The significant correlated variables were then used to explain the distribution of woody plant along the altitudinal gradients particularly for Doi Inthanon National Park.

2. Stepwise multiple regression analysis was applied for creating the community distribution model. The important environment factors showing the significant correlation among the scores of the axis of DCA and CCA were finally obtained.

RESULTS

Floristic Characteristics

Floristic Composition

A total of 306 tree species with a DBH equal to or exceeding 4.5 cm in 161 genera and 73 families were identified in the 45 forest stands. The number of species in each stand (0.16 ha) varied from 10 to 44 (mean = 27). The number of trees varied from 37 to 365 trees/stand (mean = 175). In total, 7,819 tree individuals were encountered in the whole 45 stands of 5 forest types in Doi Inthanon National Park.

The number of species representing the most important families is shown in Figure 5 and their relative basal area in Figure 6. The relative basal area of the most abundant species in the 45 sample stands is shown in Figure 7.

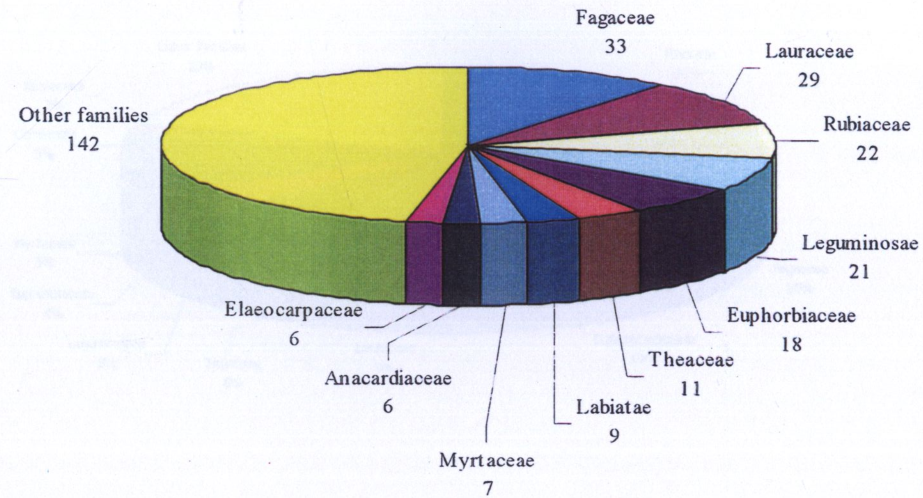

Figure 5 Number of tree species belonging to the 10 most important families and other families found in the 45 stands.

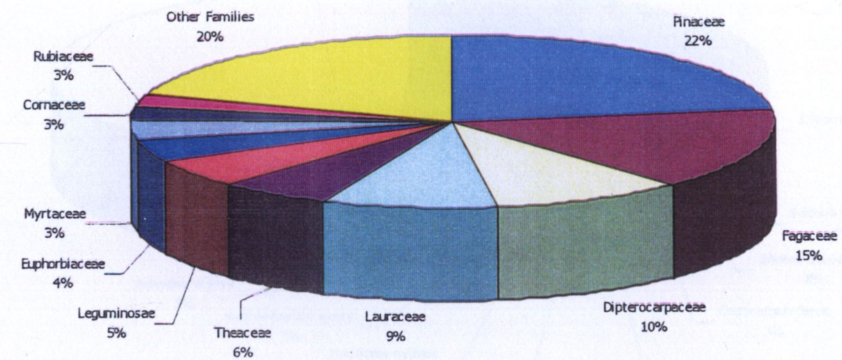

Figure 6 Relative basal area (%) of the 10 most important families and other families found in the 45 stands.

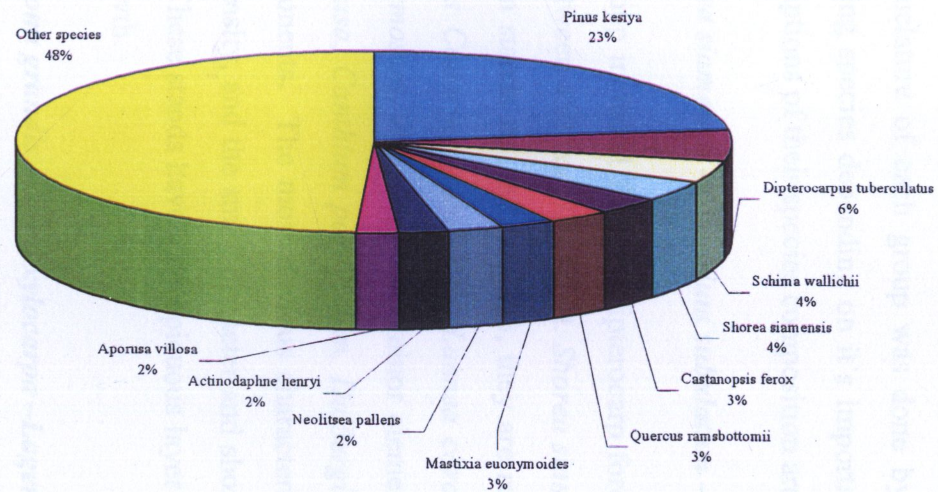

Figure 7 Relative basal area (%) of the 10 most important tree species and other species found in the 45 stands.

Forest Community Classification

Cluster analysis demonstrated that the 45 forest stands in Doi Inthanon National Park could be classified into six forest groups along the altitudinal gradient by using an arbitrary criterion of Sorensen's distance of 6.40 (Figure 8). The result of cluster analysis of forest community groups was supported by TWINSPAN classification (Figure 9). Species composition of each group is summarized in Table 1. The nomenclature of each group was done by using the various numbers of important leading species depending on it's importance value index in forest group and brief descriptions of their species composition are as follows:

Group I: Shorea siamensis - Canarium subulatum - Shorea obtusa

This group included five dry dipterocarp forest stands (A1, A2, A3, A5, and A6) located between 450 and 720 m asl. *Shorea siamensis* is the dominant species in every stand. In stands A1, A2, and A3, they are represented by other co-dominant species such *as Canarium subulatum, Lannea coromandelica, Terminalia triptera, Cratoxylum formosum*, and some other minor elements. In stands A5 and A6, there are *Shorea obtusa, Canthium parvifolium, Dalbergia dongnaiensis* and a few more minority components. The most obvious characteristics of this group are an open canopy, low density, and the small diameter and short stature of most trees as shown in Figure 10. These stands have a conspicuous layer of graminoid, dwarf bamboo, or other undergrowth.

Group II: Tectona grandis – Xylia xylocarpa –Lagerstroemia calyculata – Millettia leucantha

Nine stands of mixed deciduous forest are clustered in this group including B1, B2, B3, B4, B5, B6, B7, B8, and B9. This group can be further divided into two sub-groups, one with *Tectona grandis* as the dominant species, the other without it's presence. The canopy strata of this forest are evenly mixed among almost deciduous tree species, lacking any single-species dominance (Figure 11). One of the sub-groups, features *Tectona grandis* and *Xylia kerrii* as the dominant tree species, mixed with other species such as *Millettia leucantha*, *Dalbergia oliveri*, *Strychnos nux-vomica* and *Grewia eriocarpa*. These sub-group species are represented in stands B1, B2, B3, B5, and B6. Other sub-groups represented by stands B4, B7, B8, and B9 are characterized by the complete absence of *Tectona grandis*. The dominant species are represented by *Millettia leucantha*, *Lagerstroemia calyculata* and *Pterocarpus macrocarpus* mixed with other species such as *Dalbergia dongnaiensis*, *Cratoxylum formosum*, *Garuga pinnata* and *Cananga latifolia*. This group is clearly associated with bamboo in every stand.

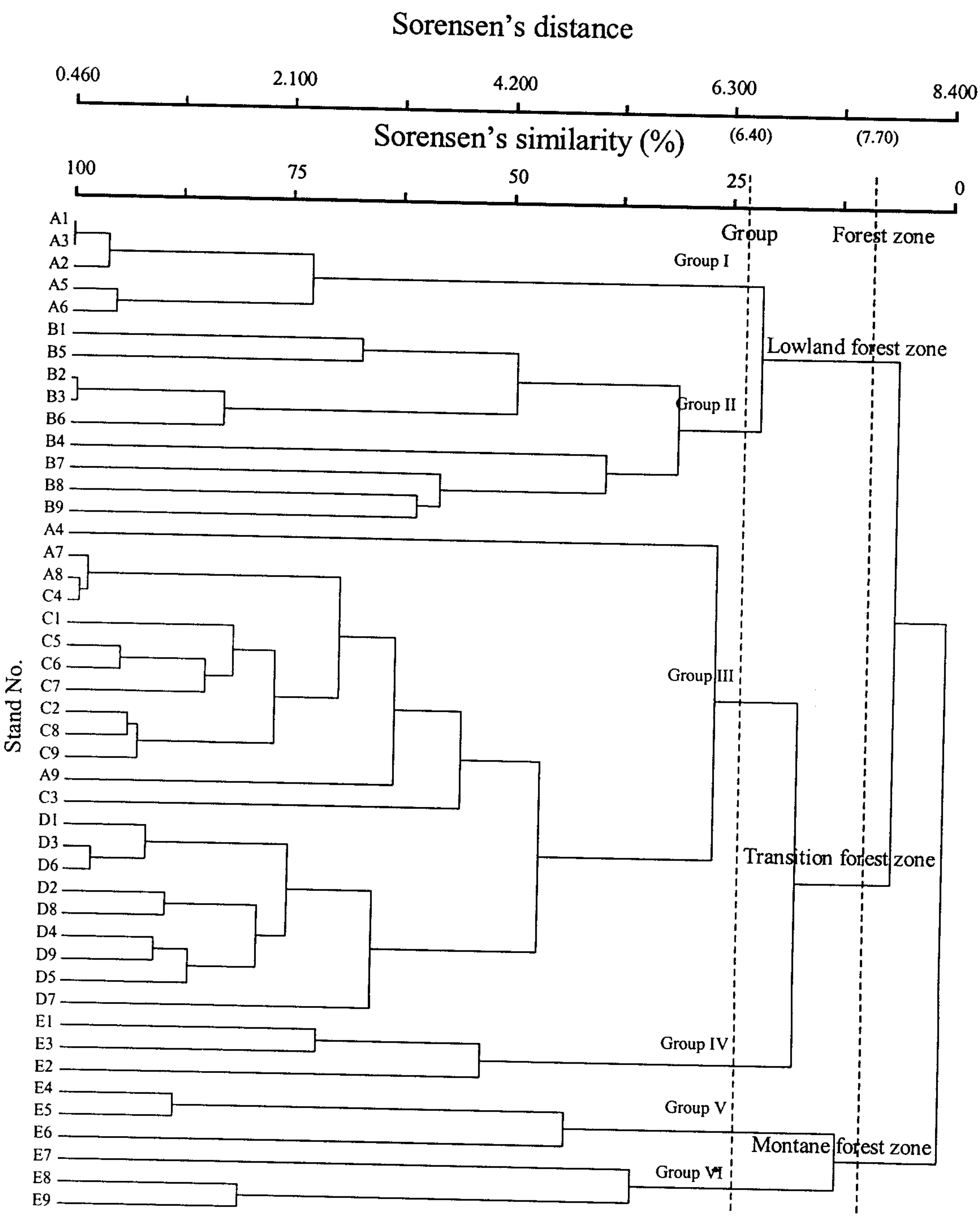

Figure 8 Dendrogram obtained by cluster analysis based on Sorensen's distance using importance value index. Five clusters obtained by truncating the dendrogram at 6.40 distance were named forest groups I, II, III, IV, V, and VI. These forest groups formed three clusters named lowland, transition, and montane forest zones at 7.70 distance.

Species Names	Stand Names	
	BBBBBBBBAAABAAAACAACCCCCCCCCDDDDDDDDDEEEEEEEEE	
	231564782569134977845791238456289137123789456	
Lannea coromandelica	-------152-144--------------1---2---1---------	000000
Terminalia triptera	-----212----54--------------------------------	000000
Lagerstroemia macrocarpa	--------3-4---------------1-------------------	000000
Holarrhena pubescens	------33--------------------------------------	000000
Terminalia sp.	-------11--4---1--1---------------------------	000000
Hymenodictyxon excelsum	-----31-1--3----------------------------------	000000
Garuga pinnata	------3-1-11-2--------------------------------	000000
Ochna integerrima	------------23--------------------------------	000000
Cananga latifolia	------3---------------------------------------	000000
Gargenia obtusifolia	--------2-1--3--------------------------------	000000
Sindora siamensis	------------23--------------------------------	000000
Bridelia retusa	-------2---2-------1--------------------------	000000
Morinda coreia	--------22--1---------------------------------	000000
Lagerstroemia calyculata	--1-33544--4----------------------------------	000001
Cratoxylum formosum	---2-2225--444---2----11-2--------------------	000001
Canarium subulatum	1---131-321145-121-1-----1----1----2----------	000001
Pterocarpus macrocarpus	1--23-2311-432------1--1----------------------	000001
Vitex pinata	-1--23-12---52-----1---2----------------------	000001
Canthium parvifolium	----1----343----------------------------------	000001
Mitragyna brunonis	--11-112-22222--------------------------------	000001
Bombax ceiba	---112--32112---------------------------------	000001
Spondias pinata	----12-21--11---------------------------------	000001
Lagerstroemia villosa	--1----3--------------------------------------	000001
Gmelina arborea	---1---3--------------------------------------	000001
Anogeisus acuminata	1--21-15--------------------------------------	000010
Zizyphus oenoplia	-1-1-4--	000010
Cassia fistula	--1-1-11-2------------------------------------	000010
Schleichera oleosa	---11--2---1----------------------------------	000010
Vitex canescens	---11-2---------------------------------------	000010
Millettia brandissiana	---2-2-------1--------------------------------	000010
Tectona grandis	554351--	000011
Xylia xylocarpa	443252-3132423--------------------------------	000011
Millettia leucantha	-232332-3--13---------------------------------	000011
Strychnos nux-vomica	34-------211--11------------------------------	000011
Antidesma acidum	---3--------2---------------------------------	000011
Careya sphaerica	----2--2------------1-------------------------	000011
Shorea siamensis	----3---555-551-23-2--4-543-------------------	00010
Dalbergia dongnaiensis	--11-1112432-----------2423---------1---------	00010
Antidesma ghaesembilla	1------232-3--1-3-1----111--------------------	00010
Adenanthera pavonina	------12--------------------12----------------	00010
Litsea glutinosa	-------2----1---------------------2------1----	00011
Albizia odoratissima	---------13-111-3--11---233---------1---------	0010
Grewia eriocarpa	23-------212-1-2-2-1-1-213--------------------	0010
Terminalia chebula	11-------2---111--2-1-------------------------	0010
Albizia lebbeck	-1----1---1-----1-----3--2--------------------	0010
Gardenia sootepensis	--------11-1-1-222-2-2---11-------------------	0010
Shorea obtusa	---------51---5325-32--1----------------------	0011
Vitex peduncularis	-1--1----2-1---213211-122-31--1--1------------	010000
Symplocos racemosa	--------------111-3---31----------------------	010000
Mangifera caloneura	--------2-----2-2211---2-1--------------------	010000
Artocarpus lakoocha	-------------1------------3---1---------------	010000
Lophopetalum wallichii	--------1--------3---1------------------------	010000
Dipterocarpus tuberculatus	--------------5555555534444-------------------	010000
Quercus ramsbottomii	---------------325554442421-------------------	010001
Gluta usitata	---------1-----134433423331---1-1--1----------	010001
Quercus kerrii	--------------354312-4232-321--23-------------	010001
Lithocarpus polystachyus	---------------111-----4352--1-1---3----------	010001
Craibiodendron stellatum	--------------1-12141223122-3-1---------------	010001
Bhesa robusta	---------------1---1223---4-------------------	010001

Figure 9 Result of TWINSPAN classification of forest communities in Doi Inthanon National Park, Northern Thailand.

Castanopsis argyrophylla	---------------32-----133-2------------------	010001
Symplocos sp.	---------------51-2--1-----------------------	010001
Syzygium cumini	--------------411----------------------------	010001
Quercus sp.	---------------1--------4--------------------	010001
Quercus kingiana	---------------21-2--------------------------	010001
Dalbergia rimosa	---------------31----------------------------	010001
Lagerstroemia speciosa	---------------3-----------------------------	010001
Vaccinium sprengelii	---------------2255425334-343111---1-----3---	010010
Aporusa villosa	-------------1-4555554425254552455555--------	010011
Wendlandia tinctoria	---------------33454354545555454523441-------	010011
Anneslea fragrans	--------------35245412212-332-213--3--1------	010011
Tristania rufescens	---------------1-45--532-123--135--1---------	010011
Tristaniopsis burmanica	----------------5--32---1--242---1-----------	010011
Phyllanthus emblica	----1-----1---22-12----1--1-1------1---------	010011
Dalbergia cultrata	---22-----11---2212323-1122332-42-24---------	010100
Stereospermum neuranthum	---2----------2---1-----------1----12--------	010100
Callicarpa arborea	1-------------1---------1---------2----------	010100
Engelhardtia spicata	1----------------------1-----------211-------	010100
Pinus kesiya	---------------141-34545332545555555---------	010101
Buchanania lanzan	--------11-----2-121----1122223-4-2----------	010101
Cratoxylum cochinchinensis	----------------2------1-3--3------4---------	010101
Schima wallichii	-------1---------1-112-23313244-435534--1----	010110
Helicia nilagirica	-----------------------133-22-52-13-553------	010110
Styrax benzoides	-----------2------------2-311432214352-------	010110
Dalbergia velutina	------------------------------1-5412------	010110
Terminalia gymnanthera	-----------------------1-2---42222-342------	010110
Eurya acuminata	--------------------------11-1-14-2423------	010110
Glochidion sphaerogynum	---------------1---------2-11111-1-4-21------	010110
Savravia napaulensis	-----------------------------2----14-------	010110
Diospyros glandulosa	---------------------------------322------	010110
Lithocarpus ceriferus	---------------------------------2-3------	010110
Lithocarpus dealbatus	---------------------------------2-3------	010110
Lithocarpus elegans	--------------------------243555333342------	010111
Castanopsis tribuloides	--------------------------2--2431224-2------	010111
Viburnum inopinatum	------------------------1-3312343-3---------	010111
Castanopsis armata	---------------------111--1133-134---------	010111
Archidendron clypearia	--------------------------12-221--2-2-------	010111
Syzygium albiforum	------------------------1--1-2--13----------	010111
Castanopsis cerebrina	--------------------------11--23------------	010111
Dillenia parviflora	----------------------------1-2-22121-------	010111
Albizia chinensis	----------------1-----------22--1----------	010111
Dalbergia floribunda	---------------------------1----3----------	010111
Euonymus cochinchinensis	--------------------------2-2---1----------	010111
Lithocarpus annamensis	--------------------------------31---------	010111
Beilschmiedia sp.	------------------------------1-1-2---------	010111
Engelhardtia serrata	--------------------------1-1-2---2---------	010111
Rhus chinensis	---------------------------43-------1----21-	011
Castanopsis acuminatissima	---------------------------2112---2--2--2--1	011
Helicia atteneuta	-----------------------------------3--1----	011
Ilex umbellulata	----------------1--------2---1-111-------2---	011
Castanopsis calathiformis	------------------------------1-2-2222-----5	10
Phoebe lanceolata	--------------------------1--11-13211-2----3	10
Symplocos cochinchinensis	-------------------------------1---213----12	10
Unidentified	------------------------11----1-21-------2-1	10
Sarcosperma arboreum	-----21-------------------------2--------3--	110
Syzygium angkae	-------------------------------1--2224--233	111000
Lindera sp.	---------------------------------21----1--3	111000
Eurya nitida	-----------------------------------2--1---2	111000
Mallotus khasianus	--541	111001
Ostodes paniculata	--54-	111001
Aidia yunnanensis	---------------------------------11----344	111001
Syzygium balsamea	-----------------------------------1----234	111001
Cryptocarya dencifolia	--343	111001
Drypetes indica	--4--	111001
Litsea lancifolia	--42-	111001
Tarenna disperma	--4	111001
Mangleitia garrettii	--321	111001
Lindera metacafaena	--4	111001
Litsea beusekomii	--33-	111001

Figure 9 (continued)

```
Symplocos hookerii          ------------------------------------------231  111001
Calophyllum polyanthum      ------------------------------------------321  111001
Quercus glabricupula        ------------------------------------1-1---221  111001
Walsura trijuga             ------------------------------------------132  111001
Camellia oleifera           ------------------------------------------123  111001
Drypetes sp.                -------------------------------------------3-  111001
Litsea chatacea             ------------------------------------------23-  111001
Cryptocarya sp.             -------------------------------------------3-  111001
Nyssa javanica              -------------------------------------------22  111001
Rapanea yunnanensis         ----------------------------------------45--4  111010
Litsea dubele               ---------------------------------------55321-  111010
Lithocarpus aggregatus      ------------------------2----------1---253343  111010
Quercus lenticellata        ---------------------------------------154-13  111010
Acer laurinum               ----------------------------------------22512  111010
Ilex triflora               ---------------------------------------2-3--4  111010
Mastixia euonymoides        ---------------------------------------2--333  111010
Neolitsea pallens           ---------------------------------------355---  111011
Symplocos longifolia        ---------------------------------------244---  111011
Myrsine semiserrata         ----------------------------------------51---  111011
Helicia formosana           ---------------------------------------432---  111011
Actinodaphne henryi         ---------------------------------1-----5----1  111011
Ardisia rubro-glandulosa    ---------------------------------------4-----  111011
Beilschmiedia roxberghiana  ---------------------------------------4-----  111011
Schefflera hypoleucoides    -----------------------------------------4---  111011
Glocidion acuminatum        ---------------------------------------32----  111011
Camellia siamensis          ---------------------------------------132---  111011
Beilschmiedia globularia    ----------------------------------------31---  111011
Gomphandra quadrifolia      ----------------------------------------22---  111011
Pavetta aspera              ----------------------------------------22---  111011
Castanopsis ferox           -------------------------------------5--35---  1111
Chionanthus ramiflorus      ---------------------------222----------441--  1111
Myrica esculenta            ------------------------------------11-1-3---  1111

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                                            0111111    000111
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Figure 9 (continued)

Table 1 Relative basal area of the leading dominant tree species in each group clustered by Sorensen' s similarity coefficient.

	Zones						
	Lowland		Transition			Montane	
	Group						
	I	II	III		IV	V	VI
			Sub group				
			I	II			
Altitudinal range (m asl)	450-720	490-730	980-1120		1340-1440	1650-1710	2220-2320
No. of plot in group	5	9	22		3	3	3
Leading species	Average relative basal area (%)						
Shorea siamensis	49.87	-	1.56	-	-	-	-
Canarium subulatum	6.81	2.10	-	-	-	-	-
Lannea coromandelica	4.97	-	-	-	-	-	-
Dalbergia dongnaiensis	4.48	2.12	-	-	-	-	-
Terminalia triptera	4.17	1.11	-	-	-	-	-
Cratoxylum formosum	3.64	2.27	-	-	-	-	-
Millettia leucantha	3.10	8.07	-	-	-	-	-
Lagerstroemia calyculata	3.01	10.89	-	-	-	-	-
Shorea obtusa	2.53	-	0.58	-	-	-	-
Vitex pinnata	2.30	1.15	-	-	-	-	-
Pterocarpus macrocarpus	1.78	4.48	-	-	-	-	-
Lagerstroemia macrocarpa	1.31	-	-	-	-	-	-
Bombax ceiba	1.31	-	-	-	-	-	-
Tectona grandis	-	17.58	-	-	-	-	-
Xylia xylocarpa	-	13.86	-	-	-	-	-
Anogeisus acuminata	-	4.26	-	-	-	-	-
Zollingeria acuminata	-	2.57	-	-	-	-	-
Antidesma acidum	-	2.36	-	-	-	-	-
Cordia sp.	-	1.96	-	-	-	-	-
Grewia eriocarpa	-	1.73	-	-	-	-	-
Terminalia sp.	-	1.61	-	-	-	-	-
Garuga pinnata	-	1.28	-	-	-	-	-
Dalbergia nigrescens	-	1.27	-	-	-	-	-
Spondias pinnata	-	1.22	-	-	-	-	-
Gmelina arborea	-	1.17	-	-	-	-	-
Pinus kesiya	-	-	19.39	57.98	-	-	-
Dipterocarpus tuberculatus	-	-	11.83	-	-	-	-
Quercus ramsbottomii	-	-	6.16	-	-	-	-
Schima wallichii	-	-	1.08	7.86	17.63	-	-
Aporusa villosa	-	-	1.50	4.92	-	-	-
Wendlandia tinctoria	-	-	1.69	2.49	-	-	-

Table 1 (continued)

	Zones						
	Lowland		Transition			Montane	
	Group						
	I	II	III		IV	V	VI
			Sub group				
			I	II			
Altitudinal range (m asl)	450-720	490-730	980-1120		1340-1440	1650-1710	2220-2320
No. of plot in group	5	9	22		3	3	3
Leading species	Average relative basal area (%)						
Tristania rufescens	-	-	1.74	1.26	-	-	-
Lithocarpus elegans	-	-	-	4.99	2.59	-	-
Gluta usitata	-	-	2.08	-	-	-	-
Quercus kerrii	-	-	1.60	-	-	-	-
Anneslea fragrans	-	-	1.10	-	-	-	-
Dalbergia fusca	-	-	-	1.70	-	-	-
Lithocarpus polystachyus	-	-	1.19	-	-	-	-
Buchanania lanzan	-	-	-	1.26	-	-	-
Castanopsis armata	-	-	-	1.47	-	-	-
Syzygium angkae	-	-	-	-	10.67	-	-
Castanopsis tribuloides	-	-	-	1.10	9.66	-	-
Helicia nilagirica	-	-	-	-	6.70	-	-
Castanopsis ferox	-	-	-	-	6.01	-	14.39
Lithocarpus triboides	-	-	-	-	5.29	-	-
Castanopsis calathiformis	-	-	-	-	4.53	3.35	-
Ternstroemia gymnanthera	-	-	-	1.14	3.94	-	-
Xantolis sp.	-	-	-	-	2.89	-	-
Stereospermum neuranthum	-	-	-	-	2.77	-	-
Lindera missneri	-	-	-	-	2.48	-	-
Artocarpus chaplasha	-	-	-	-	2.22	-	-
Lithocarpus dealbatus	-	-	-	-	2.22	-	-
Quercus glabricupula	-	-	-	-	1.51	-	-
Cinnamomum glaucescens	-	-	-	-	1.39	-	-
Homalium ceylanicum	-	-	-	-	1.31	-	-
Protium serratum	-	-	-	-	1.22	-	-
Elaeocarpus floribundus	-	-	-	-	1.10	-	-
Styrax benzoides	-	-	-	-	1.08	-	-
Mastixia euonymoides	-	-	-	-	-	16.58	-
Mangleitia garrettii	-	-	-	-	-	10.73	-
Drypetes indica	-	-	-	-	-	9.29	-
Quercus lenticellata	-	-	-	-	-	7.77	2.14

Table 1 (continued)

	Zones						
	Lowland		Transition			Montane	
	Group						
	I	II	III		IV	V	VI
			Sub group				
			I	II			
Altitudinal range (m asl)	450-720	490-730	980-1120		1340-1440	1650-1710	2220-2320
No. of plot in group	5	9	22		3	3	3
Leading species	Average relative basal area (%)						
Calophyllum polyanthum	-	-	-	-	-	6.62	-
Nyssa javanica	-	-	-	-	-	5.97	-
Cryptocarya dencifolia	-	-	-	-	-	3.88	-
Aidia yunnanensis	-	-	-	-	-	3.29	-
Lithocarpus aggregatus	-	-	-	-	-	2.51	1.79
Ostodes paniculata	-	-	-	-	-	2.39	-
Acer laurinum	-	-	-	-	-	2.10	4.25
Lindera sp.	-	-	-	-	-	2.04	-
Lindera metacafaena	-	-	-	-	-	1.89	-
Ilex triflora	-	-	-	-	-	1.67	1.03
Syzygium balsamea	-	-	-	-	-	1.60	-
Tarenna disperma	-	-	-	-	-	1.53	-
Litsea sp1.	-	-	-	-	-	1.39	-
Rapanea yunnanensis	-	-	-	-	-	1.31	2.60
Chionanthus ramiflorus	-	-	-	-	-	1.02	4.36
Neolitsea pallens	-	-	-	-	-	-	14.46
Actinodaphne henryi	-	-	-	-	-	-	13.95
Beilschmiedia globularia	-	-	-	-	-	-	11.55
Litsea dubele	-	-	-	-	-	-	5.83
Camellia siamensis	-	-	-	-	-	-	4.84
Beilschmiedia roxberghiana	-	-	-	-	-	-	3.46
Glochidion acuminatum	-	-	-	-	-	-	2.70
Syzygium angkae	-	-	-	-	-	-	2.22
Symplocos longifolia	-	-	-	-	-	-	1.33
Helicia formosana	-	-	-	-	-	-	1.29

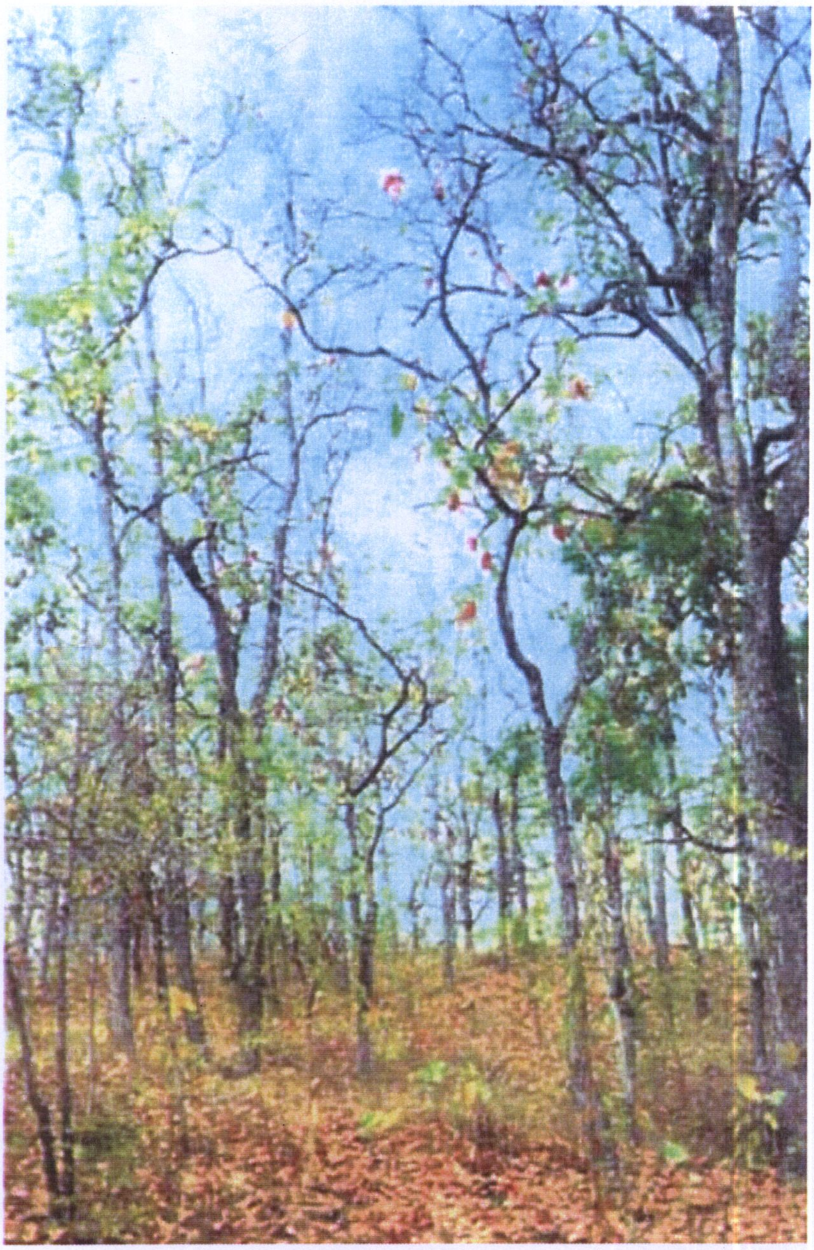


Figure 10 The stand characteristics of forest community group I.

Figure 11 The stand characteristics of forest community group II.

Group III: Pinus kesiya – Dipterocarpus tuberculatus – Aporusa villosa – Wendlandia tinctoria – Schima wallichii – Helicia nilagirica

Pinus kesiya is the dominant species in this group. It is the main canopy tree species. The stands having *Pinus kesiya* as a dominant tree can be classified into two sub-groups: 1) those also including *Dipterocarpus tuberculatus*, *Quercus ramsbottomii* (C1, C2, C3, C4, C5, C6, C7, C8, C9) (Figure 12) those also including *Schima wallichii*, *Aporusa villosa*, and *Wendlandia tinctoria* (D1, D2, D3, D4, D5, D6, D7, D8, D9) (Figure 13). Sub-group 1 occurs in drier habitats than sub-group 2. During the dry season, soils of this sub-group are often very dry and if so, some species shed their leaves. Normally this group is restricted to the upper slopes or on mountain ridges at altitudes between 850 and 1,150 m asl. Furthermore stand A7, A8, and A9 are clearly associated with sub-group 1 because there are many similar tree species in other stands of this sub-group which are dominated by *Dipterocarpus tuberculatus* and *Quercus ramsbottomii*. However, stand A4 might be separated into other group. Unfortunately, it could not be clustered into a new group because A4 had been randomly collected for only one plot.

Group IV: Schima wallichii – Castanopsis ferox – Castanopsis tribuloides – Helicia nilagirica

This group is represented by three stands located between 1,340 and 1,440 m asl (E1, E2, and E3). Stands of this group are characterized by tall and closeed canopy (Figure 14). The canopy trees of this group are those belonging to the family Fagaceae, such as Castanopsis ferox and Castanopsis tribuloides, well mixed with Schima wallichii. Those species with lower statures, especially Helicia nilagirica, Ternstroemia gymnanthera, Syzygium angkae and Wendlendia tinctoria, are the main co-dominant trees.

Figure 12 The stand characteristics of forest community group III (sub group 1).

Figure 13 The stand characteristics of forest community group III (sub group 2).

Figure 14 The stand characteristics of forest community group IV.

Group V: Mastixia euonymoides – Castanopsis calathiformis – Drypetes indica

This group is located between 1,650 and 1,710 m asl. The essential characteristics of these stands are high density and canopies are tall and close (Figure 15). In stands on the lower and middle slopes (E4 and E5), *Mastixia euonymoides* is the dominant canopy tree mixed with other species such as *Manglietia garrettii*, *Lithocarpus aggregatus* and *Calophyllum polyanthum*. In the sub-canopy layer, *Drypetes indica*, *Mallotus khasianus*, *Ostodes paniculata* are abundant. In contrast, in stands on the upper slopes (E6), *Castanopsis calathiformis* is dominant, mixed with *Quercus lenticellata*, *Tarenna disperma*, and *Lindera metacafaena*. This group may be considered cloud forest and mosses grow abundantly on tree trunks.

Group VI: Neolitsea pallens – Actinodaphne henryi – Rapanea yunnanensis

This group occurs at the highest altitudes in Doi Inthanon National Park, located between 2,220 and 2,320 m asl. The characteristics of the canopy layer are the same as those of group V however, the dominant trees are different. In this case, *Neolitsea pallens*, *Castanopsis ferox* and *Quercus lenticellata* are the main canopy trees mixed with *Rapanea yunnanensis*, *Symplocos longifolia* in the sub-canopy (Figure 16).

Figure 15 The stand characteristics of forest community group V.

Figure 16 The stand characteristics of forest community group VI.

Forest Zones

If Sorensen's distance is arbitrarily set at 7.70 (Figure 8) then the forest stands can be divided into three forest zones: lowland, transitional and montane forest zone. The lowland forest zone is a combination of groups I and II and is located between the altitudes of 400 and 850 m asl. The forests distributed in this zone are deciduous forest and low density (Table 2). The transitional forest zone which is composed of groups III and IV, occurs in a band between the altitudes of 850 and 1,400 m asl. The characteristic of forest in this zone has changed to be an evergreen forest and density of tree gradually increases with altitude. Groups V and VI are therefore considered to be a montane forest zone, occurring between the altitudes of 1,400 and 2,500 m asl. The forest of this zone is tall, dense and forms a single storey. The crowns are typically dome-shaped supported by the crooked branches on which epiphytic flowering plants are luxuriantly developed. The result from Table 2 shows that the basal area of tree is significantly different among the forest zones while tree density of lowland zone is clearly lower than transitional and montane zones. Diversity indices are significantly different between lowland and montane zones however, these indices of transition zone are intermediate between these zones. Whilst, Fisher's(α), richness (R1 and R2) and eveness (E1, E3 and E5) indices are not significantly different among the forest zones.

Table 2 Community characteristics (mean ± S.D.) with the different superscripts a, b, c to compare zones by using a nonparametric rank test (Kruskal-Wallis' method at $p < 0.05$). ns indicates non-significantly difference of different groups of forest trees as classified by cluster analysis. (N1, N2 = Hill's diversity indices, H = Shannon-Wiener's index, λ = Simpson's index, α = Fisher's index, R1, R2 = Margalef & Menhinick's richness indices, E1, E3 and E5 = Pielou's evenness indices).

Zone	Lowland forest zone	Transition forest zone	Montane forest zone
No. of plots/area (ha)	14 / 2.24	25 / 4.0	6 / 0.96
Mean no. of trees (indiv./0.16 ha)	112.64 ± 54.35^{b}	196.92 ± 66.83^{a}	236.50 ± 76.74^{a}
Basal area (m^2/ha)	15.33 ± 4.52^{c}	35.18 ± 10.46^{b}	66.36 ± 18.63^{a}
Density (stem/ha)	$704. \pm 340^{b}$	1231 ± 418^{a}	1478 ± 437^{a}
Diversity indices:			
N1	10.70 ± 4.82^{b}	14.97 ± 4.45^{ab}	17.16 ± 6.68^{a}
N2	7.67 ± 4.58^{b}	10.64 ± 3.46^{ab}	12.98 ± 6.32^{a}
H	2.27 ± 0.49^{b}	2.65 ± 0.38^{ab}	2.78 ± 0.39^{a}
λ	0.17 ± 0.10^{a}	0.11 ± 0.06^{ab}	0.09 ± 0.03^{b}
α	8.43 ± 2.98^{ns}	10.37 ± 4.16^{ns}	12.39 ± 9.56^{ns}
Richness indices:			
Mean no. of species (/ 0.16 ha)	21.1 ± 6.1^{b}	29.6 ± 8.7^{ab}	30.3 ± 10.9^{a}
R1	4.34 ± 1.09^{ns}	5.48 ± 1.59^{ns}	5.39 ± 1.94^{ns}
R2	2.08 ± 0.53^{ns}	2.18 ± 0.63^{ns}	1.99 ± 0.69^{ns}
Evenness indices:			
E1	0.75 ± 0.12^{ns}	0.79 ± 0.08^{ns}	0.83 ± 0.06^{ns}
E3	0.47 ± 0.17^{ns}	0.49 ± 0.11^{ns}	0.56 ± 0.12^{ns}
E5	0.64 ± 0.14^{ns}	0.69 ± 0.11^{ns}	0.73 ± 0.17^{ns}

Forest Structure and Species Diversity

Forest communities in Doi Inthanon National Park vary greatly in species composition as shown by the classification above. The number of trees and species richness, diversity, and evenness indices of each group are shown in Table 3. Forest stands of group II show the lowest tree density and basal area. Stands of group V are highest in tree density, and stands of group VI in basal area. The mean number of species of group II shows the lowest and increases in order by following groups VI, I, III, IV and V. Diversity indices of all stands as determined by N1, N2 and H indicate that group I has significantly lower diversity than the other groups followed in order of N1 and N2 by groups VI, II, III, IV and V, and H by groups II, VI, III, IV and V. Moreover, Fisher's index is associated with other indices. This index of group V is the highest diversity and decreases in order by groups IV, III, II, I and VI. The Simpson's index is an inversion value comparing with the others, the result from Table 3 shows that group I is the highest value determined to the lowest diversity followed in order by groups II, VI, III, IV and V. Richness value trends are closely related to diversity indices therefore, group VI clearly shows the lowest richness increased in order of R1 by groups II, I, III, IV and V, and R2 by groups I, III, II, V and IV however, evenness values are not. Evenness value, such as E1 and E3 indicate that forest stands of group I are significantly lower in evenness than those of other groups, while E5 demonstrates no significant difference among all groups.

Table 3 Community characteristics (mean ± S.D.) with the different superscripts a, b, c to compare groups by using a nonparametric rank test (Kruskal-Wallis' method at $p < 0.05$). ns indicates non-significantly difference of different groups of forest trees as classified by cluster analysis. (N1, N2 = Hill's diversity indices, H = Shannon-Wiener's index, λ = Simpson's index, α = Fisher's index, R1, R2 = Margalef & Menhinick's richness indices, E1, E3 and E5 = Pielou's evenness indices).

Zone	Lowland forest zone		Transition forest zone		Montane forest zone	
Group	I	II	III	IV	V	VI
No. of plots/area (ha)	5 / 0.80	9 / 1.44	22 / 3.52	3 / 0.48	3 / 0.48	3 / 0.48
Mean no. of trees (indiv./0.16 ha)	168.0 ± 12.9^{ab}	81.9 ± 30.0^{b}	198.7 ± 66^{a}	184.0 ± 86.8^{ab}	244.0 ± 70.9^{a}	228.3 ± 83.5^{a}
Basal area (m^2/ha)	16.36 ± 5.35^{bc}	14.75 ± 4.23^{c}	34.47 ± 10.89^{abc}	40.38 ± 4.63^{bc}	64.15 ± 20.03^{a}	68.58 ± 13.69^{a}
Density (stem/ha)	1050 ± 268^{ab}	511 ± 187^{b}	1241 ± 412^{a}	1150 ± 542^{ab}	1529 ± 443^{a}	1427 ± 521^{a}
Diversity indices:						
N1	6.44 ± 3.39^{c}	11.88 ± 5.70^{bc}	14.58 ± 4.53^{abc}	17.84 ± 2.76^{ab}	22.63 ± 4.45^{a}	11.69 ± 1.39^{bc}
N2	4.98 ± 0.92^{b}	10.10 ± 6.38^{ab}	10.40 ± 3.33^{a}	12.40 ± 4.67^{a}	16.60 ± 7.44^{a}	9.35 ± 2.23^{ab}
H	1.70 ± 0.69^{b}	2.34 ± 0.60^{ab}	2.62 ± 0.39^{a}	2.87 ± 0.15^{a}	3.11 ± 0.21^{a}	2.45 ± 0.12^{ab}
λ	0.21 ± 0.04^{a}	0.16 ± 0.13^{abc}	0.11 ± 0.06^{bc}	0.09 ± 0.03^{bc}	0.07 ± 0.04^{b}	0.11 ± 0.03^{abc}
α	7.49 ± 1.29^{bc}	8.95 ± 3.58^{abc}	9.76 ± 4.07^{abc}	14.82 ± 0.24^{ab}	19.20 ± 9.43^{a}	5.57 ± 0.52^{b}
Richness indices:						
Mean no. of species (/ 0.16 ha)	23.4 ± 3.9^{ab}	19.8 ± 6.9^{b}	28.6 ± 8.4^{a}	37.3 ± 8.1^{a}	40.0 ± 2.0^{a}	20.7 ± 3.5^{ab}
R1	4.39 ± 0.62^{bc}	4.31 ± 1.32^{bc}	5.27 ± 1.55^{ab}	7.04 ± 0.84^{a}	7.14 ± 0.29^{a}	3.64 ± 0.39^{c}
R2	1.82 ± 0.21^{ab}	2.22 ± 0.61^{ab}	2.09 ± 0.62^{ab}	2.85 ± 0.17^{a}	2.61 ± 0.33^{ab}	1.39 ± 0.04^{b}
Evenness indices:						
E1	0.54 ± 0.21^{b}	0.79 ± 0.13^{a}	0.79 ± 0.08^{a}	0.80 ± 0.10^{a}	0.84 ± 0.07^{a}	0.81 ± 0.06^{a}
E3	0.24 ± 0.14^{b}	0.55 ± 0.18^{a}	0.49 ± 0.10^{a}	0.49 ± 0.21^{a}	0.56 ± 0.14^{a}	0.56 ± 0.12^{a}
E5	1.40 ± 1.63^{ns}	0.77 ± 0.23^{ns}	0.69 ± 0.10^{ns}	0.66 ± 0.16^{ns}	0.69 ± 0.22^{ns}	0.77 ± 0.14^{ns}

Total tree basal area, tree density as well as average basal area along the altitudinal gradient display the increasing trend with altitude, and can be all explained by the cubic polynomial form (Figure 17). Compared to basal area, density exhibits relatively little variation with altitude. The co-occurrence of low basal area per individual, low total basal area and low tree density are remarkable at low altitude. Therefore, longer drought period (Figure 3) or sometimes a sporadic disturbance by humans as a usual case for most forests of deciduous types or located in lower altitude where close to human settlement (e.g. forest fire, tree cutting and firewood extraction) may be more or less the main factors affecting species composition and the physiognomy of these forest stands.

The results from Figure 18 show that number of species, diversity indices such as N1, N2, Shannon-Wiener's and Simpson's indices as well as richness index (R1) can be well described their explicit trends by the cubic polynomial forms with altitude, but by the quadratic polynomial forms with altitude for N1 and N2. The trends of these indices along the altitudinal gradient show gradually increasing species diversity from 450 m asl reaching a maximum at around 1,800 m asl and then decreasing species diversity at altitude upward above that. However, Simpson's index trend is the inverse of the others and is also followed the quadratic polynomial form while evenness (E5) values are not clearly differentiated along the altitudinal gradient (Figure 18).

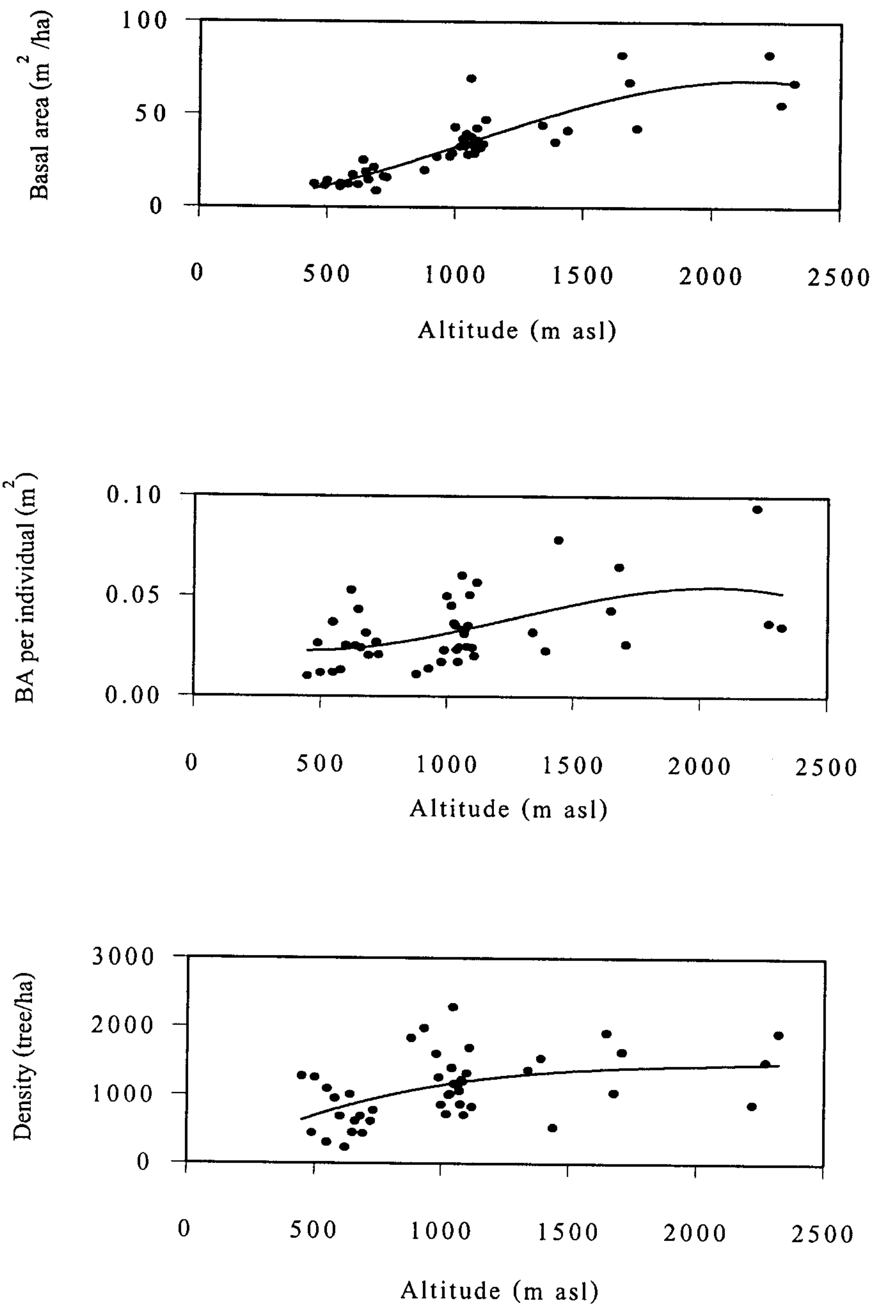


Figure 17 Stand structure of forest along the altitudinal gradient in Doi Inthanon National Park.

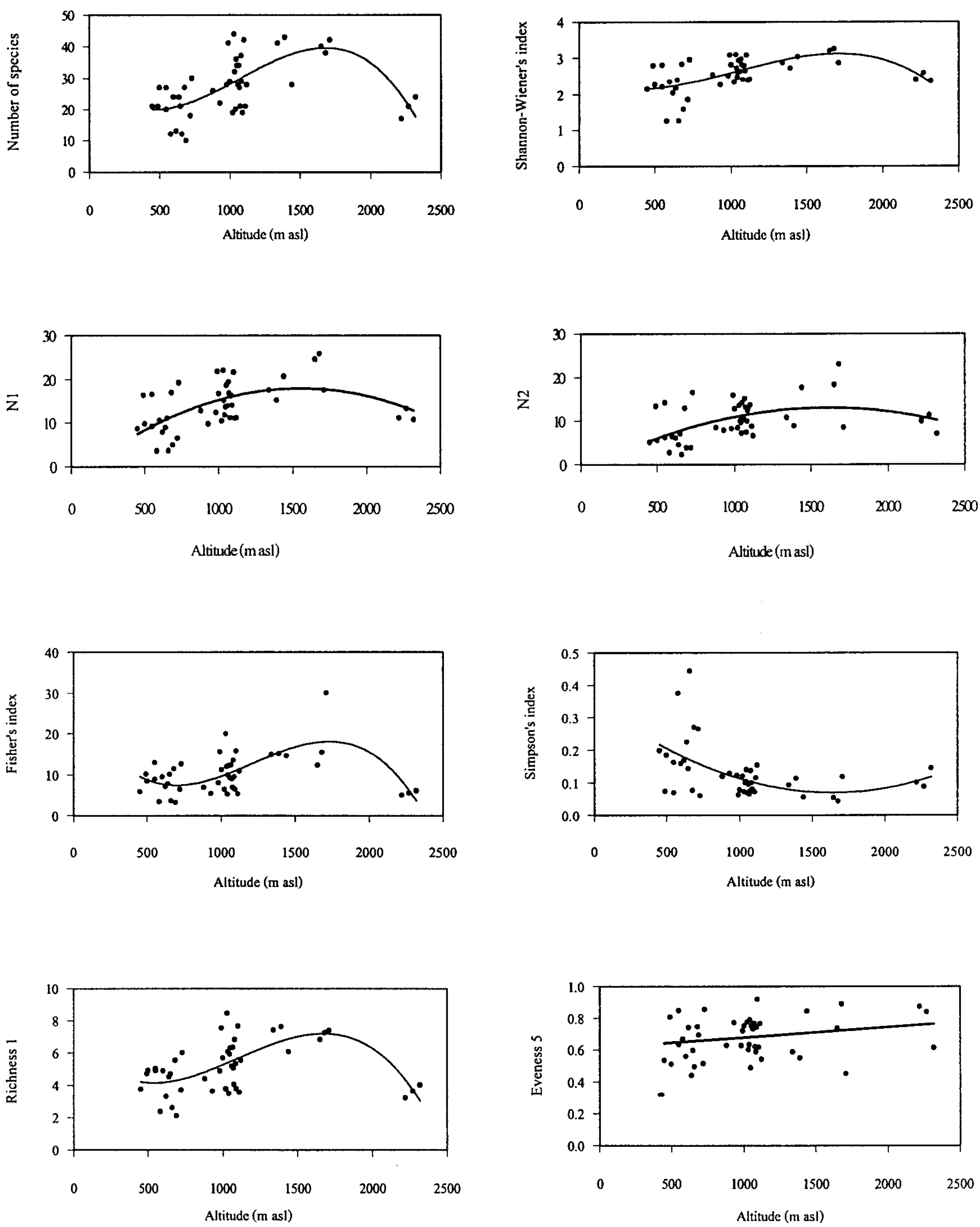


Figure 18 Species richness and diversity of tree species along the altitudinal gradient in Doi Inthanon National Park.

Soil Characteristics

Soil Morphology

The major morphological characteristics of the fifteen soil profiles are shown in Table 4. Soil profiles in the middle plot of each study site have been described fully in Appendix B. The photographs of all soil profile are shown in Figure 19-23.

According to soil profiles studied, it is summarized as follows: The soil profiles in deciduous dipterocarp forest (Figure 19) at altitude about 400-800 m asl were deep, varying from 0.8 to 2.0 m in effective soil depth having moderate to well drainage characteristics. The surface color of P-A2 and P-A5 were very dark grayish brown with hue of 10YR, however P-A8 showed a rather red color with hue of 7.5YR. The subsoil colors in the P-A2, P-A5 and P-A8 were yellowish brown. Soil textures were predominantly sandy loam to heavy clay, especially more clayey at the deeper part. Most of the profiles had a moderate fine subangular blocky structure except the C-horizon of P-A2 and P-A5, where massive texture was found. Consistency of soils in deciduous dipterocarp forest was friable and firm in P-A2 and P-A8, and hard in P-A5.

The profiles of soils in mixed deciduous forest (Figure 20) at the altitude about 400-700 m asl were deep varying from 1.3 to 2.0 m and moderate to well drained. The surface color was black to very dark brown with hue of 10YR and 7.5YR. The subsurface soil color showed dark grayish brown and rather similar color throughout the profile. Soil texture was predominantly clay loam to heavy clay especially at the deeper part where clay accumulation is conspicuous. Most of the profiles had a moderate fine subangular blocky structure. Consistency of soils in mixed deciduous forest was friable in P-B2, but firm in P-B5 and P-B8.

Table 4 Morphologic descriptions in abbreviated form of the soil profiles.

Profile	Depth (cm)	Color Hue	Color Value/Chroma	Texture	Structure	Consistence Moist	Consistence Wet	Boundary	Cutans, other
P-A2									
A	0-8	10YR	3/2	SL	mvf sbk	fr	ns np	cs	-
B	8-25	7.5YR	5/6	SL	mvf sbk	fr	ns np	cs	-
BC	25-41	7.5YR	5/6	SCL	svf sbk	fr	ns np	cs	-
C	41-65+	7.5YR	5/6	SCL	Massive	-	-	-	-
P-A5									
A	0-3/5	10YR	3/2	L	sc sbk	h	ns, sp	aw	-
B	3/5-20/25	10YR	6/3, 5/6	C	sc sbk	eh	s, p	cs	-
BC	20/25-40	10YR	6/6	C	sc sbk	eh	s, p	ab	-
C	40-75+	10YR	6/4	SCL	Massive	-	ss, sp	-	-
P-A8									
A	0-5	7.5YR	4/3	L	svf sbk	fr	ss, np	as	-
AB	5-13	5YR	4/6	CL, C	svf sbk	fr	s, p	as	-
BA	13-25	2.5YR	5/8	C	sf sbk	fr, fi	vs, p	cs	-
Bt1	25-45	2.5YR	5/8	C	sf sbk	fi	vs, p	gs	-
Bt2	45-60+	2.5YR	5/8	C	sf sbk	fi	vs, vp	-	-

Table 4 (continued).

Profile	Depth	Color		Texture	Structure	Consistence		Boundary	Cutans, other
	(cm)	Hue	Value/Chroma			Moist	Wet		
P-B2									
A	0-14	7.5YR	3/2	CL	wvf sbk	fr	ss, ss	cs	-
B	14-28	7.5YR	3/3	C	wvf sbk	fr	s, p	gi	-
BC	28-40	7.5YR	3/4	C	wvf sbk	fr	s, p	ci	-
C	40-75+	7.5YR	4/6	C	Massive	-	s, p	-	-
P-B5									
A	0-10	10YR	2/3	C	svf sbk	fr	ss, p	cs	-
AB	10-25	7.5YR	3/4	C	svf sbk	fr	vs, p	gb	-
BA	25-40	7.5YR	3/4	C	sf sbk	fi	vs, vp	as	-
B	40-85+	5YR	4/8	C	sf sbk	fi	vs, vp	-	-
P-B8									
A	0-20	10YR	2/1	C	svf sbk	fi	s, p	as	-
AB	14-27	10YR	4/3	C	sf sbk	fi	s, p	cs	-
BA	27-40	10YR	5/4	C	sf sbk	fi	vs, vp	cs	-
B	40-70+	5YR	4/3	C	sf sbk	-	vs, vp	-	-

Table 4 (continued).

Profile	Depth (cm)	Color		Texture	Structure	Consistence		Boundary	Cutans, other
		Hue	Value/Chroma			Moist	Wet		
P-C2									
A	0-4	5YR	3/6	CL	svf sbk	fr	ss, p	aw	-
AB	4-10	5YR	3/6	C	svf sbk	fi	s, p	cw	-
BA	10-20	2.5YR	4/6	C	sf sbk	fi	vs, p	gs	-
Bt	20-50+	2.5YR	3/6	C	sf sbk	fi	vs, vp	-	c
P-C5									
A	0-3	10YR	2/3	L	svf sbk	fr	ss, p	as	-
AB	3-10	7.5YR	3/4	CL	svf sbk	fr	s, p	aw	-
BA	10-23	5YR	4/6	C	svf sbk	fi, fr	vs, p	cs	-
Bt1	23-43	5YR	4/6	C	sf sbk	fi	vs, p	gs	c
Bt2	43-90+	5YR	4/6	C	sf sbk	fi	vs, p	-	c
P-C8									
A	0-4	7.5YR	3/4	CL	mvf sbk	fr	s, p	as	-
AB	4-12	5YR	3/4	C	sf sbk	fr, fi	vs, vp	ci	-
BA	12-22	2.5YR	4/8	C	sf sbk	fi	vs, vp	gs	-
Bt	22-55+	2.5YR	5/8	C	sf sbk	fi	vs, vp	-	c

Table 4 (continued).

Profile	Depth (cm)	Color		Texture	Structure	Consistence		Boundary	Cutans, other
		Hue	Value/Chroma			Moist	Wet		
P-D2									
A	0-4	10YR	2/3	L	svf sbk	fr	ss, sp	as	-
AB	4-13	7.5YR	2/3	C	svf sbk	fr	s, p	as	-
BA	13-31	2.5YR	4/6	C	svf sbk	fr, fi	vs, vp	cb	-
Bt1	31-51	2.5YR	4/6	C	sf sbk	fi	vs, vp	cb	c
Bt2	51-71+	2.5YR	4/6	C	sf sbk	fi	vs, vp	-	c
P-D5									
A	0-4	7.5YR	2/3	L	mvf sbk	fr	ss, p	as	-
AB	4-13	5YR	3/4	C	mvf sbk	fr, fi	vs, vp	aw	-
BA	13-31	2.5YR	4/6	C	mf sbk	fr, fi	vs, vp	cb	-
Bt1	31-51	2.5YR	4/6	C	mf sbk	fr, fi	vs, vp	cs	c
Bt2	51-71	2.5YR	4/8	C	mf sbk	fi	vs, vp	cs	c
Bt3	71-95+	2.5YR	4/8	C	mf sbk	vfi	vs, vp	-	c
P-D8									
A	0-5	10YR	2/3	SL	mvf sbk	fr	ss, sp	as	-
AB	5-15	7.5YR	4/6	C	mvf sbk	fr, fi	s, p	as	-
BA	15-25/30	5YR	5/8	C	mf sbk	fr, fi	vs, vp	cb	-
Bt1	25/30-55+	5YR	5/8	C	mf sbk	fi	vs, vp	-	c

Table 4 (continued).

Profile	Depth (cm)	Color Hue	Color Value/Chroma	Texture	Structure	Consistence Moist	Consistence Wet	Boundary	Cutans, other
P-E2									
A	0-5	10YR	4/3	L	mf sbk	fr	ss, sp	as	-
AB	5-11/18	10YR	4/6	CL	mf sbk	fr	s, p	cb	-
BA	11/18-28	7.5YR	5/6	C	mf sbk	fr	s, p	gs	-
B	28-60+	7.5YR	6/8	C	mf sbk	fr	vs, vp	-	-
P-E5									
A	0-11	7.5YR	3/3	CL	wvf sbk, wvf gr	vfr	ss, vp	ab	-
AB	11-20	7.5YR	4/6	C	mvf sbk	fr, fi	s, p	cs	-
BA	20-33/38	7.5YR	5/8	C	mvf sbk	fr	vs, vp	cb	-
B	33/38-53	5YR	4/8	C	mf sbk	fi	vs, vp	cw	c
CB	53-83	5YR	5/8	C	Massive	-	vs, vp	cs	
C	83-100+	7.5YR	6/8	C	Massive	-	vs, vp	-	
P-E8									
A	0-6	10YR	3/1	CL, C	wvf sbk, wvf gr	fr, fi	ss, p	ab	-
BA	6-10/15	10YR	5/6	C	wvf sbk	fr	s, p	ab	-
B	10/15-70	10YR	6/8	C	wvf sbk	fr	vs, vp	-	-

Remarks: The symbols used in table are as follow:

Structure:

Shape: gr = granular; sbk = subangular blocky;

Grade: 1 = weak; 2 = moderate; 3 = strong

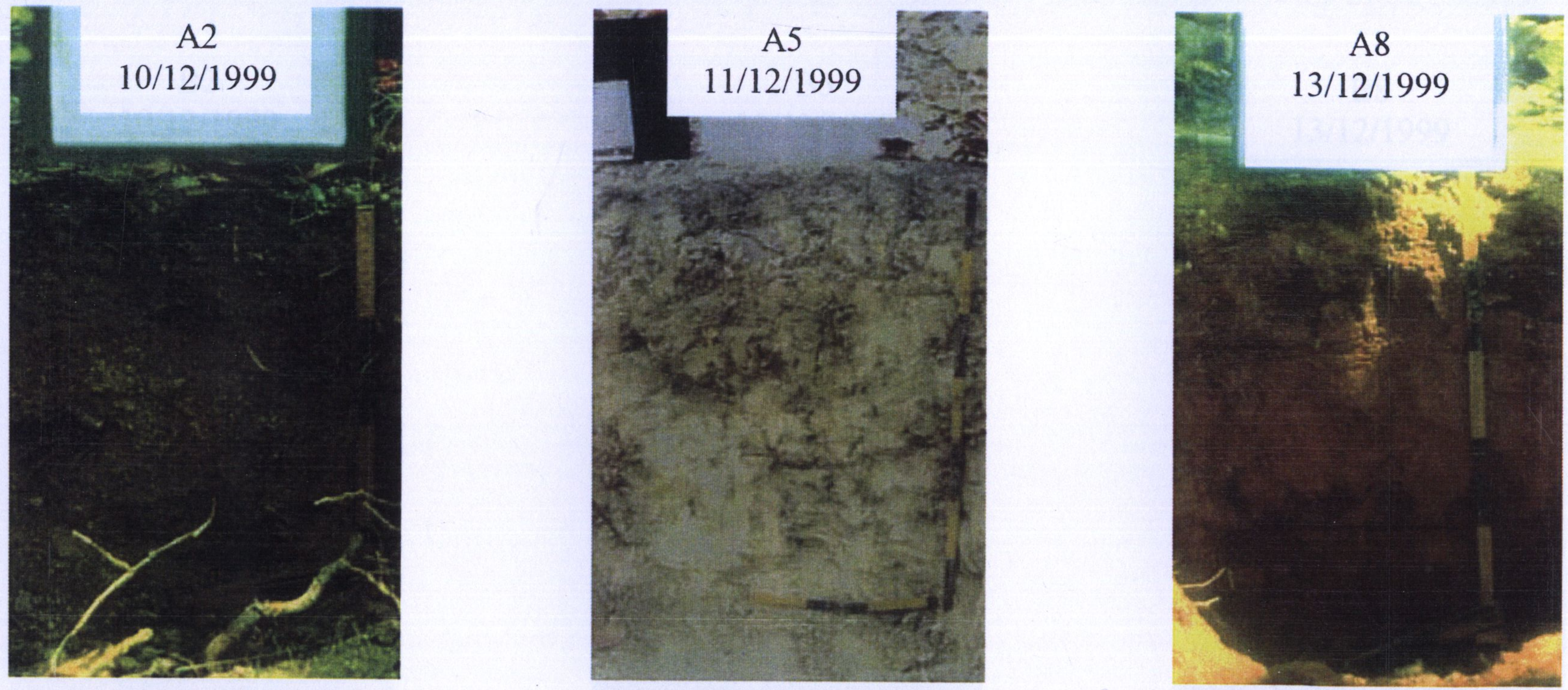
Size: vf = very fine; f = fine; m = medium; co = coarse

Texture: L = loam; CL = clay loam; SCL = sandy clay loam; SL = sandy loam; LS = loamy sand; C = clay

Other: c = cutan

Boundary: c = clear; g = gradual; a = abrupt; d = diffuse; s = smooth; w = wavy; i = irregular; b = broken

Consistency: eh = extremely hard; h = hard; sh = slightly hard; fi = firm; fr = friable; ss = slightly sticky; sp = slightly plastic; s = sticky; p = plastic; vs = very sticky; vp = very plastic



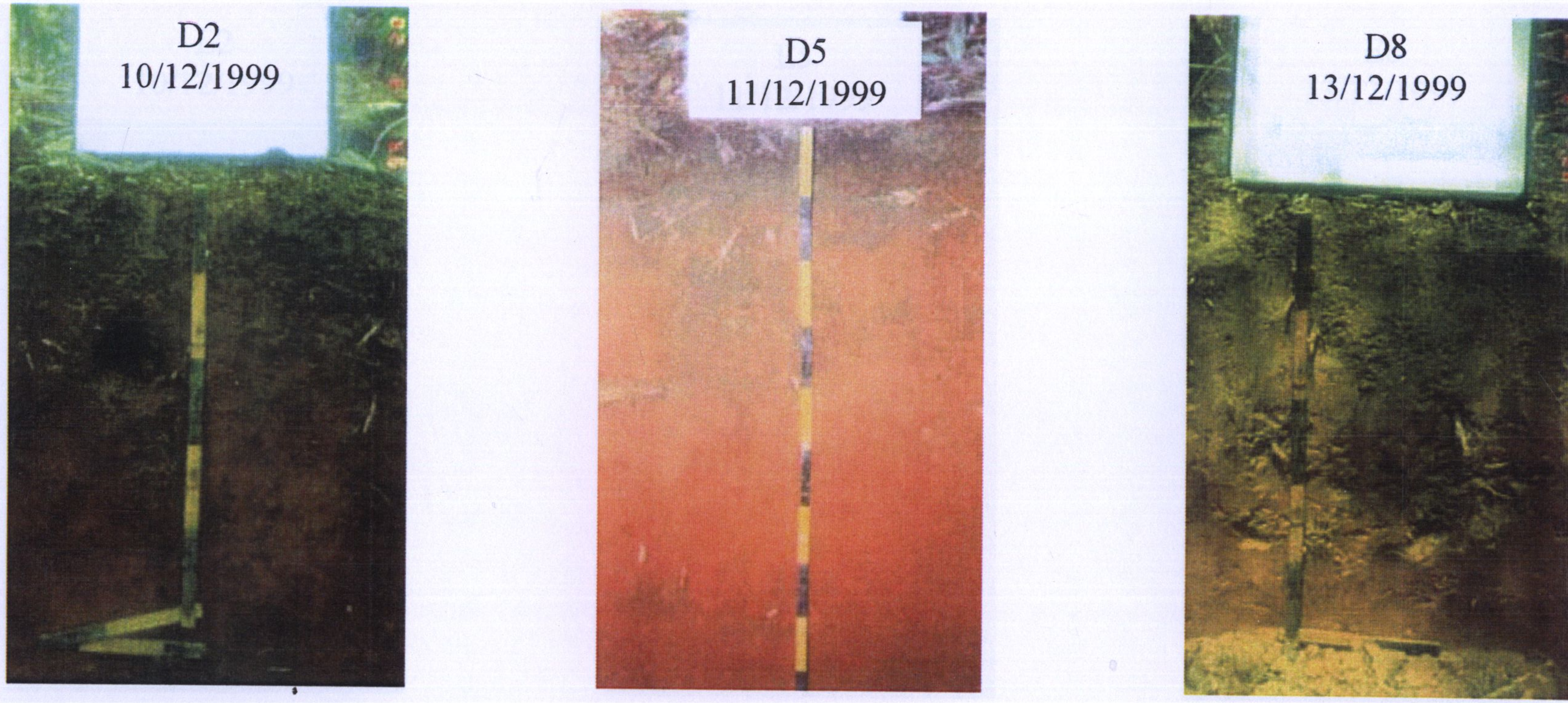
A2 **A5** **A8**

Figure 19 Soil profiles at the middle sample plot of each study site in deciduous dipterocarp forest, Doi Inthanon National Park, Northern Thailand.

B2 **B5** **B8**

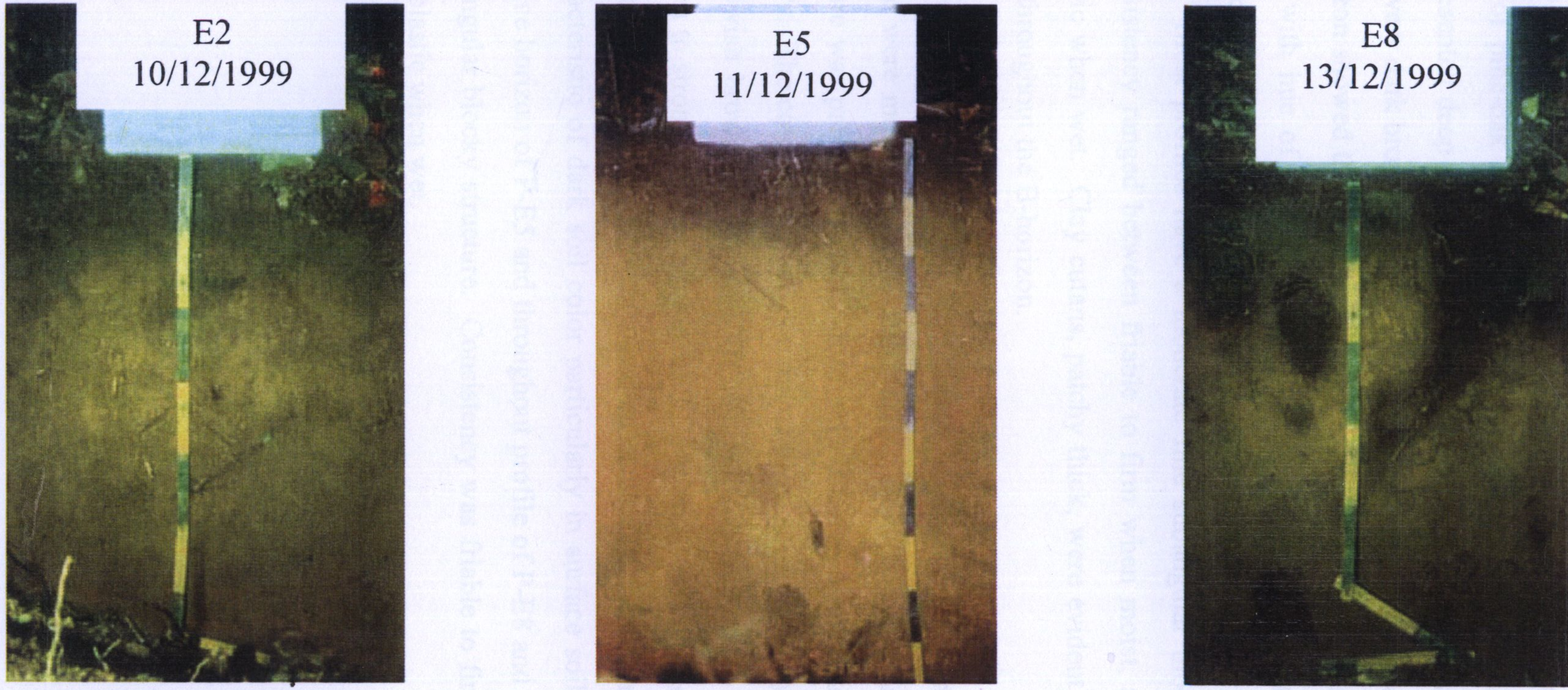
Figure 20 Soil profiles at the middle sample plot of each study site in mixed deciduous forest, Doi Inthanon National Park, Northern Thailand.

Figure 21 Soil profiles at the middle sample plot of each study site in pine-dipterocarp forest, Doi Inthanon National Park, Northern Thailand.



D2 **D5** **D8**

Figure 22 Soil profiles at the middle sample plot of each study site in pine-oak forest, Doi Inthanon National Park, Northern Thailand.



E2 **E5** **E8**

Figure 23 Soil profiles at the middle sample plot of each study site in montane forest, Doi Inthanon National Park, Northern Thailand.

The profiles of soils in pine-dipterocarp forest (Figure 21) were very similar to soil of pine-oak forest (Figure 22). These profiles at altitude of 900-1,300 m asl represented deep soil which were deeper than 2 m. The surface horizons were thin and very dark brown to dark yellowish brown color with hue of 10YR and 7.5YR. B-horizon showed the dominant characteristic of this group namely yellowish red color soil with hue of 5YR to 2.5YR and accumulation of clay. The soil texture was predominately loam to clay loam in surface horizon, and heavy clay in subsurface soil. Most profiles have a moderate fine subangular blocky structure throughout. Consistency ranged between friable to firm when moist, and very sticky and very plastic when wet. Clay cutans, patchy thick, were evident on surfaces and pores of soil throughout the B-horizon.

The profiles of soils in montane forest (Figure 23) at altitudes of 1,400-2,500 m asl were moderately and deep varying from 1 to 2 m and well drained. Surface texture was predominately loam to clay loam with larger amounts of clay in deeper layers. The color of surface horizon of these soils was very dark brown to very dark yellowish brown with hue of 10 YR, and the subsurface soil color was yellowish brown to strong brown with hue of 7.5 YR and 10 YR. The accumulation of organic matters in subsurface horizon was dominantly represented in this soil group causing a characteristic of dark soil color particularly in surface soil. Structure was weak in surface horizon of P-E5 and throughout profile of P-E8 and moderate in P-E2, having subangular blocky structure. Consistency was friable to firm when moist and sticky and plastic when wet.

Physical Soil Properties

Soil samples collected from each sample plot in two layers were analyzed to evaluate several physical properties. The average value within transect are shown in Table 5 for surface soils and Table 6 for subsurface soils.

According to physical soil properties, the soils showed different textural compositions in both horizons among the forest types that located on different altitudinal range varying from sandy loam to sandy clay loam on the surface soils and clay loam to clay in the subsurface soils. Soils along the transect T1 of DDF, the lowest altitude showed less clay content as compared to other sites. Silt compositions of MDF soils were found to be high variation in both of two horizons, however the least content was found in surface soils of MF and in subsurface soils of PDF. Soils of PDF located on the altitudes between 800 to 1200 m asl showed higher clay content than soils from other forest types. As to gravel contents, they were downwardly increased to subsurface soils of DDF except T3 transect, on the contrary subsurface soils of MF and others gradually decreased with soil depth. The highest gravel was found in soils of DDF and MDF.

Particle density of soils tended to decline gradually along the altitudinal gradient. Soil particle density in T3 transect of MDF was found to be the highest for both surface and subsurface soils, and the lowest was found in T3 of MF for surface soils and in T1 of PDF for subsurface soils. Parent material and content of organic matter mainly affects particle density. Soil parent materials in Doi Inthanon National Park are mainly derived from weathered granite and gneiss rocks, except some of the soils in MDF that are weathered from sedimentary rocks.

Table 5 The average value of surface soil physical properties along the transect in Doi Inthanon National Park.

Forest types	Transect	Altitude	Depth	Sand	Silt	Clay	Gravel	BD	PD	Porosity	MC	Ks
		(m)	(cm)	……………(%)……………				…..(g/cm^{-3})…..		……..(%)……..		(cm s^{-1})
DDF	T1	450-550	0-5	63.80	20.27	15.93	30.27	1.26	2.74	0.54	10.14	0.0092
DDF	T2	580-730	0-5	64.93	15.80	19.27	32.50	1.31	2.71	0.51	3.97	0.0035
DDF	T3	880-990	0-5	54.73	18.33	26.93	9.51	1.31	2.71	0.52	9.90	0.0046
MDF	T1	620-690	0-5	41.07	33.00	25.93	18.33	1.00	2.98	0.67	9.97	0.0067
MDF	T2	490-600	0-5	45.07	25.33	29.60	20.33	1.18	2.62	0.55	5.15	0.0055
MDF	T3	650-730	0-5	57.07	21.67	21.27	7.72	1.21	2.67	0.55	6.12	0.0030
PDF	T1	1000-1100	0-5	47.40	21.00	31.60	8.22	1.02	2.65	0.62	16.10	0.0100
PDF	T2	980-1080	0-5	57.73	19.67	22.60	5.87	1.13	2.74	0.59	12.82	0.0046
PDF	T3	1080-1100	0-5	49.40	17.00	33.60	3.80	1.12	2.65	0.58	16.03	0.0016
POF	T1	1020-1070	0-5	53.45	20.67	25.88	3.02	0.84	2.82	0.70	21.37	0.0109
POF	T2	1040-1120	0-5	54.79	19.33	25.88	5.40	0.69	2.58	0.73	31.41	0.0062
POF	T3	1040-1120	0-5	61.12	16.67	22.21	2.86	0.89	2.73	0.67	15.87	0.0105
MF	T1	1340-1440	0-5	61.68	17.00	21.32	2.88	0.89	2.63	0.66	25.15	0.0120
MF	T2	1650-1710	0-5	65.68	18.33	15.99	9.58	0.66	2.70	0.76	50.39	0.0134
MF	T3	2220-2320	0-5	72.01	17.00	10.99	2.96	0.58	2.37	0.76	55.12	0.0082

Table 6 The average value of subsurface soil physical properties along the transect in Doi Inthanon National Park.

Forest types	Transect	Altitude (m)	Depth (cm)	Sand	Silt	Clay	Gravel	BD	PD	Porosity	MC	Ks
				................(%)................				.....(g/cm^{-3}).....		........(%)........		(cm s^{-1})
DDF	T1	450-550	20-25	62.73	19.67	17.60	37.47	1.34	2.75	0.51	3.70	0.0077
DDF	T2	580-730	20-25	36.93	16.13	46.93	23.19	1.39	2.74	0.49	16.04	0.0005
DDF	T3	880-990	20-25	31.07	16.33	52.60	5.81	1.40	2.72	0.49	22.58	0.0000
MDF	T1	620-690	20-25	40.07	32.33	27.60	18.99	0.98	3.09	0.68	12.45	0.0092
MDF	T2	490-600	20-25	35.07	22.33	42.60	20.25	1.28	2.67	0.52	13.12	0.0020
MDF	T3	650-730	20-25	58.07	17.33	24.60	18.30	1.31	2.72	0.52	8.21	0.0018
PDF	T1	1000-1100	20-25	22.07	12.33	65.60	2.80	1.22	2.43	0.49	23.18	0.0008
PDF	T2	980-1080	20-25	32.40	13.67	53.93	6.82	1.37	2.86	0.52	18.74	0.0001
PDF	T3	1080-1100	20-25	24.73	13.00	62.27	1.73	1.23	2.66	0.54	27.22	0.0008
POF	T1	1020-1070	20-25	40.12	15.67	44.21	1.97	1.02	2.47	0.58	24.42	0.0088
POF	T2	1040-1120	20-25	28.12	14.00	57.88	3.58	1.16	2.74	0.58	25.07	0.0073
POF	T3	1040-1120	20-25	37.79	15.67	46.55	4.47	1.33	2.71	0.51	15.46	0.0013
MF	T1	1340-1440	20-25	45.68	14.00	40.32	1.62	1.04	2.79	0.63	18.29	0.0094
MF	T2	1650-1710	20-25	44.01	17.00	38.99	16.94	1.08	2.73	0.60	32.93	0.0054
MF	T3	2220-2320	20-25	58.01	24.67	17.32	3.29	0.61	2.72	0.78	61.17	0.0066

Bulk density of soils in five forest types decreased with increasing altitude, whilst the porosity of soil increased with altitude. However within forest type there was a similar particle density. The highest bulk density was found in soils of DDF for both surface and subsurface soils, and the lowest was occupied in soil of MF in both soils of MF both of surface and subsurface. Bulk density of soils in Doi Inthanon National Park was strongly associated with carbon content.

Field moisture content of soils increased with altitude. These soil samples collected within the same season, except soils of T1 transect in DDF were collected one day after rain, thus, soils in lowland forest, DDF and MDF, were rather low moisture content, however soil moisture content in other forests at upper 1,000 m asl were high content. While, soil moisture gradually increased following the increasing altitude up to the summit. The results also would be consistent with pF values that are shown in Figure 24. Characteristic curves of soil moisture showed the difference of water holding capacity between forest types in every pF level. Soils of POF and MF showed higher water holding capacity than soil of PDF and MDF, located in lower altitude for every level of pF. The lowest water holding capacities were found in soil of DDF for both soils of surface and subsurface horizons (Figure 24).

The analysis of soil hardness enabled us to seize the material distribution in the shallow part of soils where most of roots concentrated. In particular, gravel level or C horizon with abundant gravel can be easily discriminated without digging a soil pit and without disturbing the vegetation stand greatly (Sakurai *et al.*, 1995). If the gravel or packing layer is found in a shallow depth, tree root may suffer greatly from the physical hazard. The typical vertical distribution patterns of soil hardness around the soil pit are depicted for each site in Figures 25-39.

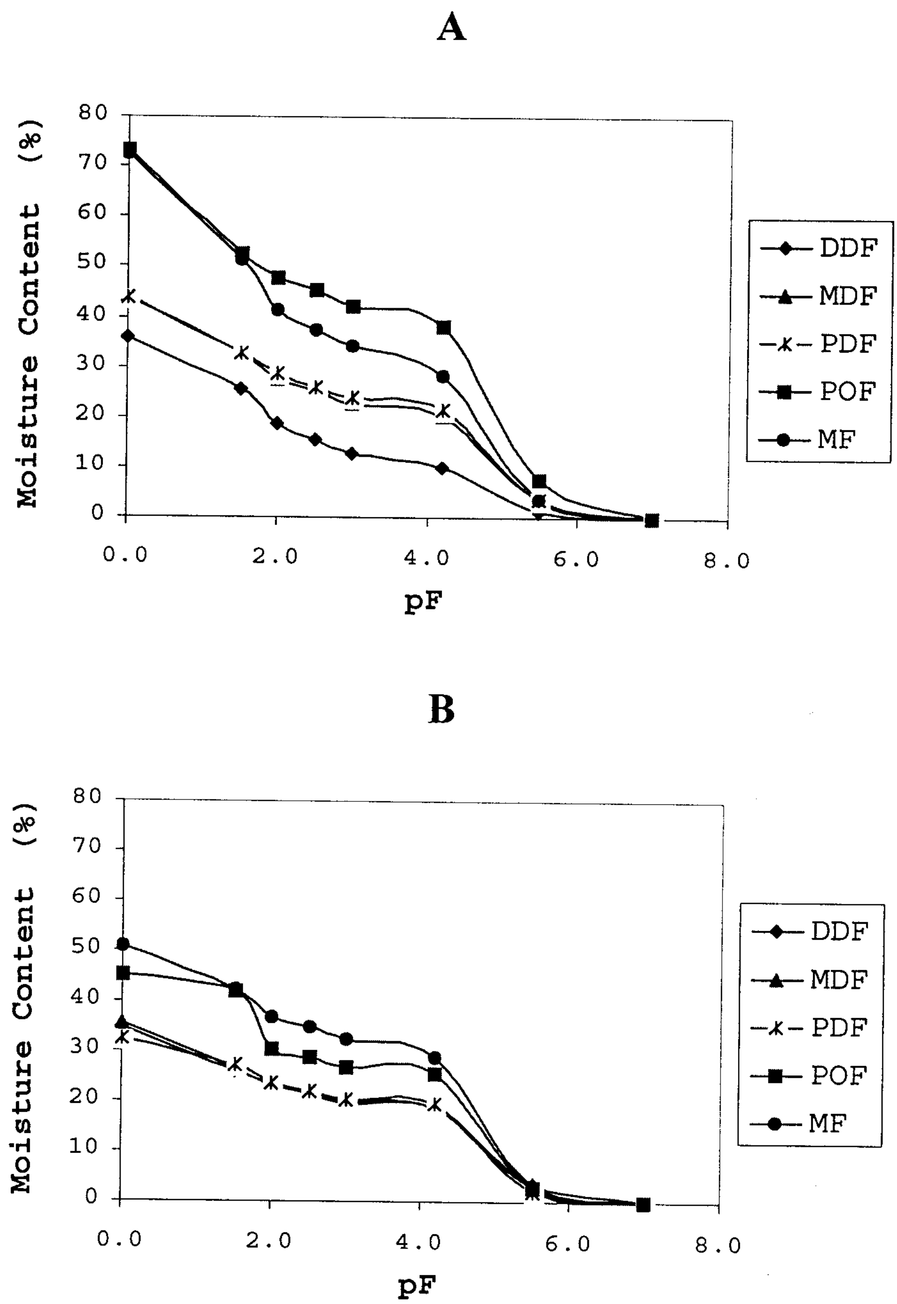


Figure 24. Soil moisture characteristic curves of surface soils and subsurface soils in five forest types along the altitudinal gradient.

A Surface soils

B Subsurface soils

Soil hardness in deciduous dipterocarp forest at the P-A1, P-A2, and P-A3 (Figure 25) was measured in the early rainy season unfortunately, there was rainy before determining soil hardness in the field. However, the hardness pattern indicated that P-A1 was moderate from the surface to 30 cm depth, and it was softer between 30 to 50 cm depths. Moreover, it became hard again, below 50 cm. At the P-A2, the soil was soft from surface to 10 cm depth, and become harder between 10 to 40 cm depths. The deeper part was extremely hard soil. The soil hardness of the P-A3 was moderately hard above 15 cm, become harder and extremely hard below that depth. At P-A4, P-A5, and P6 soils (Figure 26) they were hard to extremely hard throughout profiles. At P-A7, P-A8, and P-A9 (Figure 27), the soils throughout profile were extremely hard except for the depth of 0-5 cm in P-A9 when it was soft.

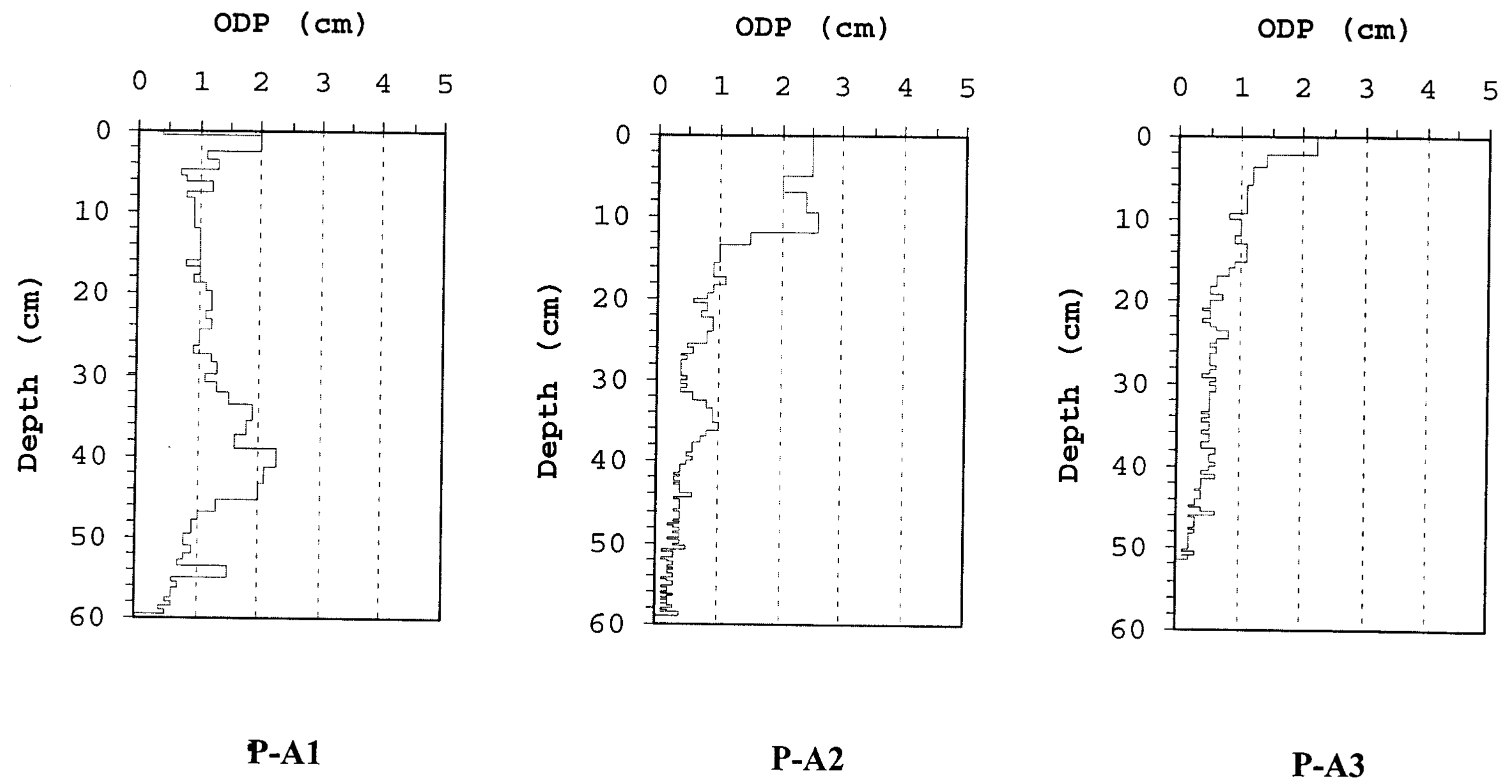


Figure 25 The typical patterns of soil hardness in soil profile of P-A1, P-A2, and P-A3 in deciduous dipterocarp forest.

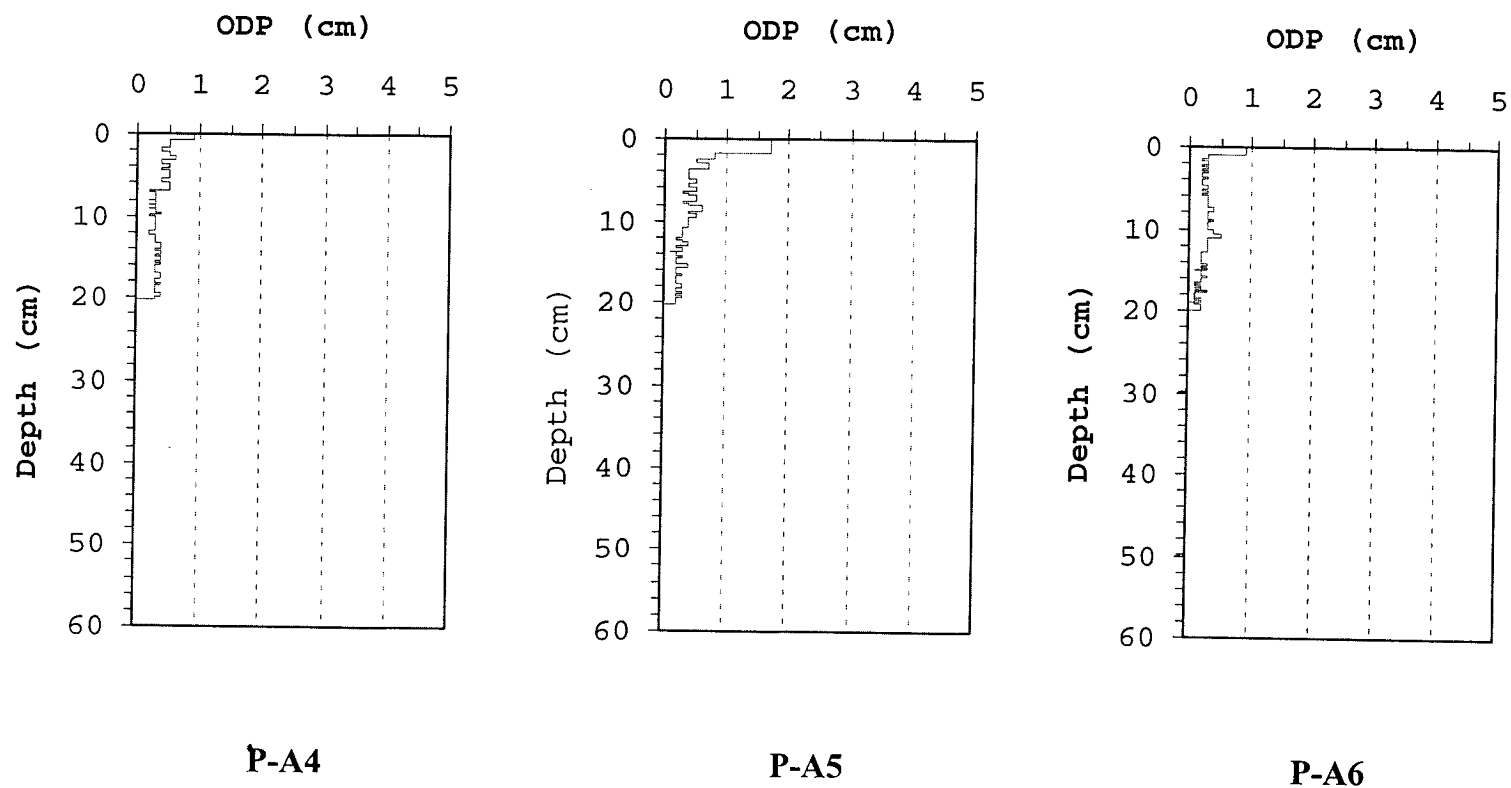


Figure 26 The typical patterns of soil hardness in soil profile of P-A4, P-A5, and P-A6 in deciduous dipterocarp forest.

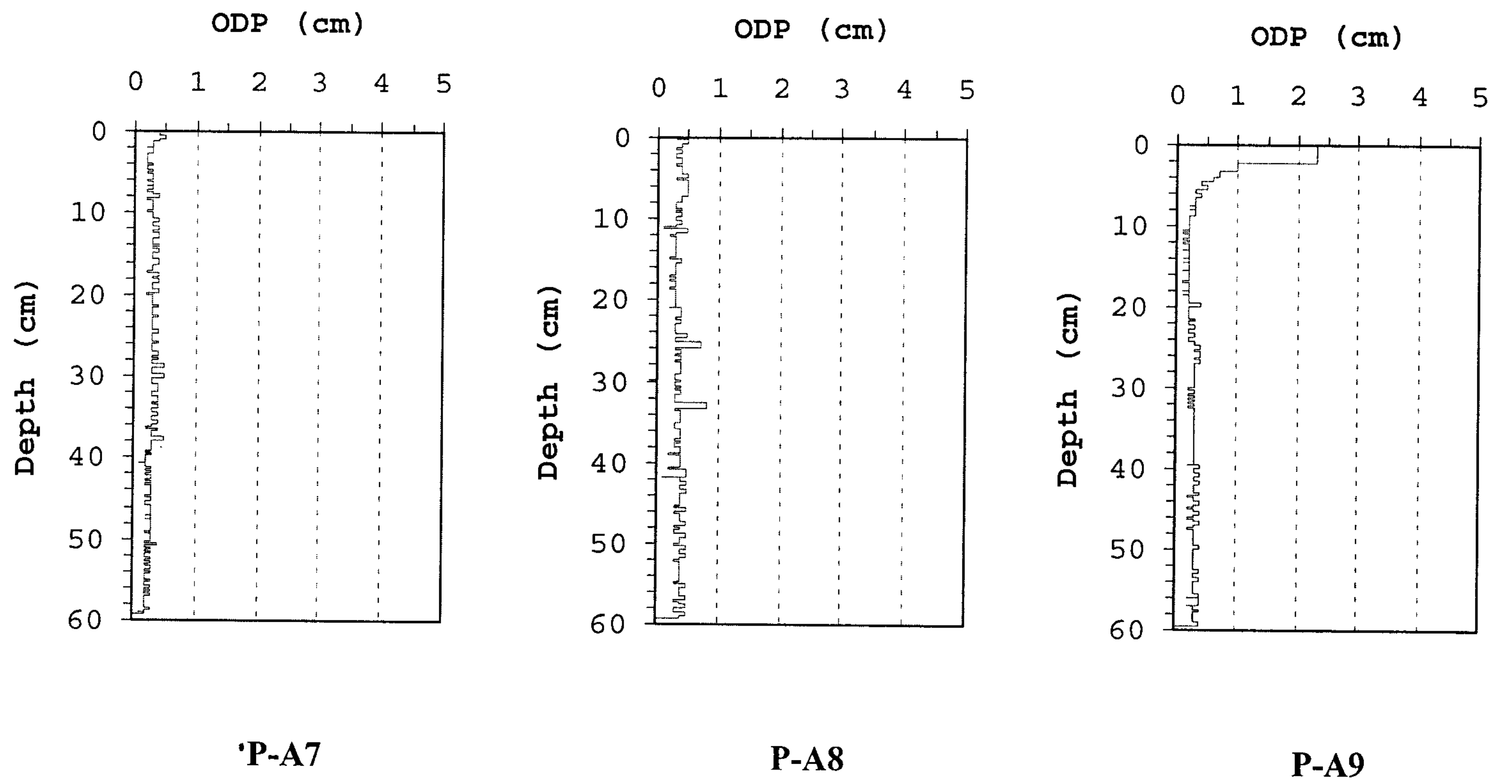


Figure 27 The typical patterns of soil hardness in soil profile of P-A7, P-A8, and P-A9 in deciduous dipterocarp forest.

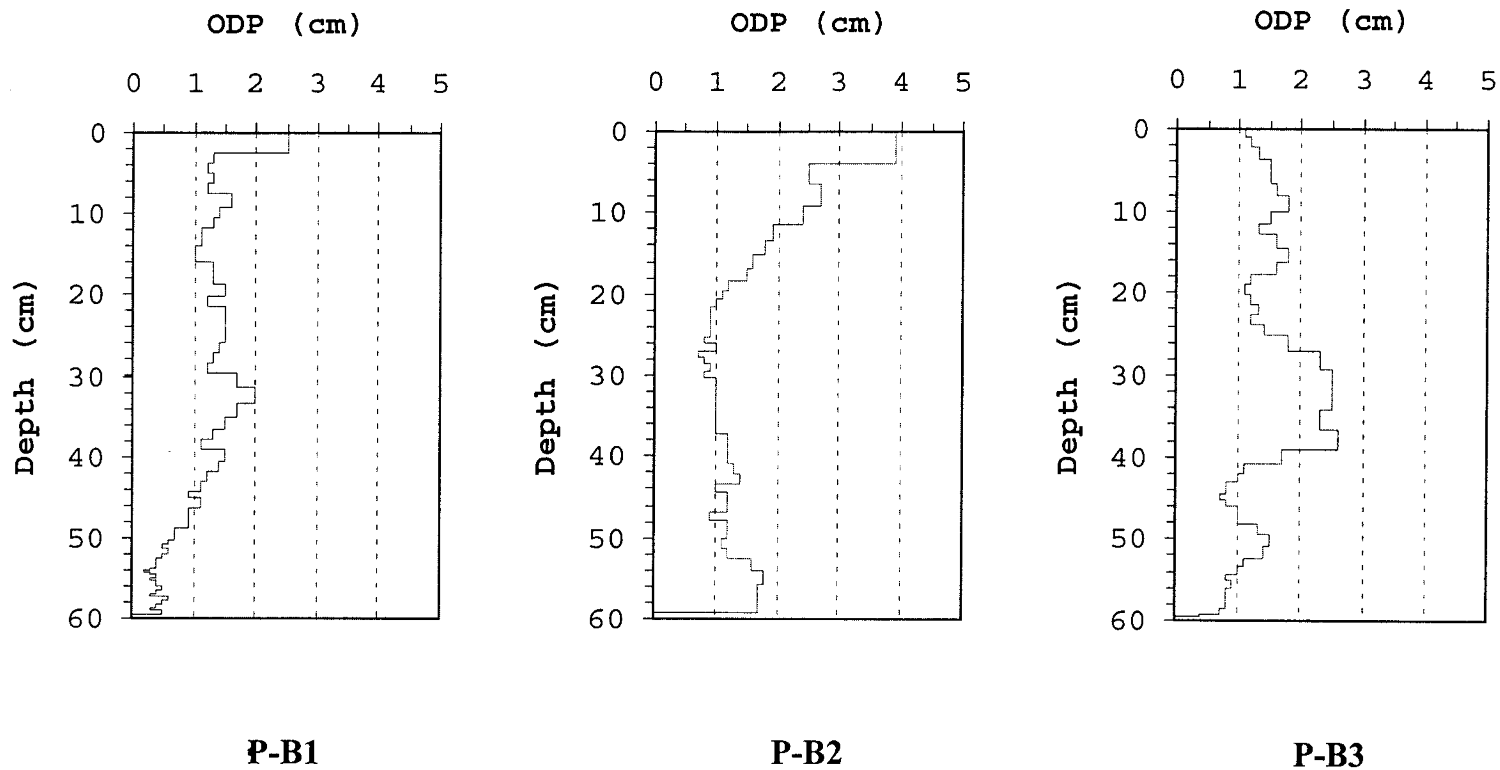
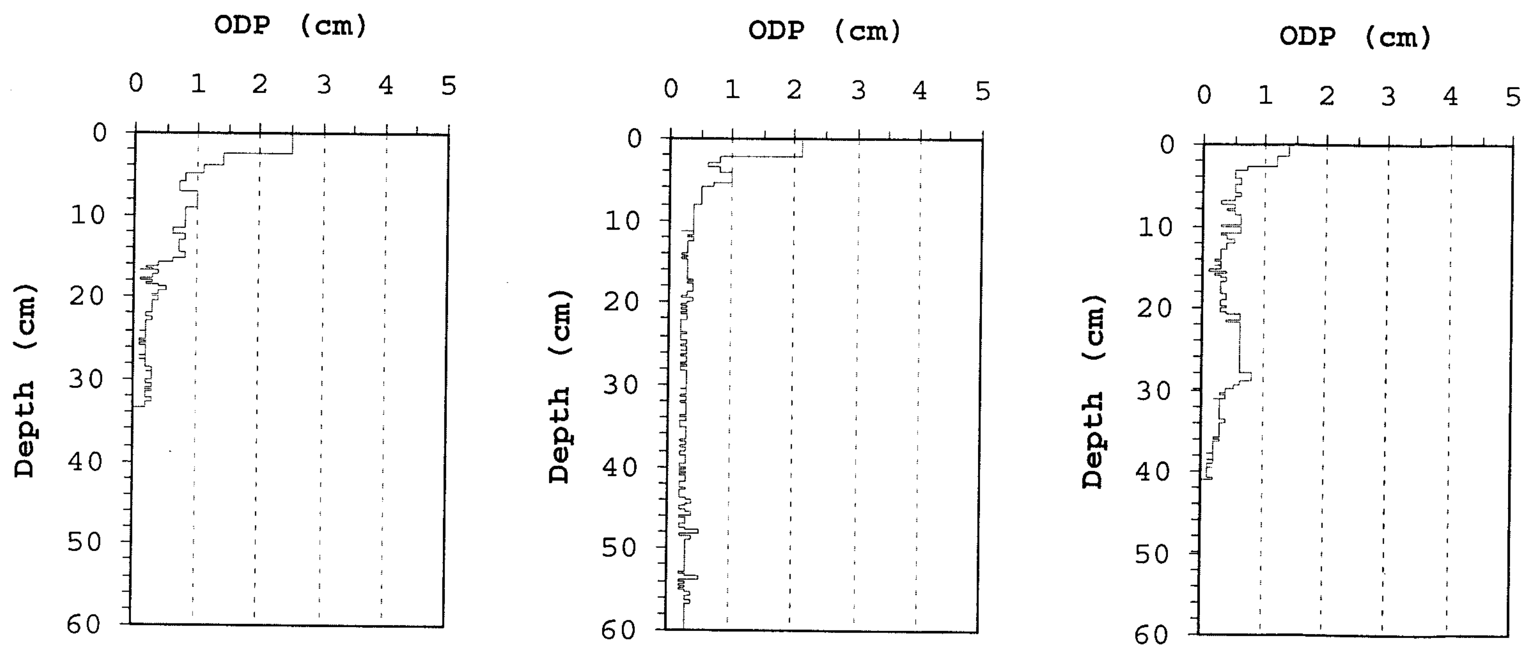


Figure 28 The typical patterns of soil hardness in soil profile of P-B1, P-B2, and P-B3 in mixed deciduous forest.



P-B4 **P-B5** **P-B6**

Figure 29 The typical patterns of soil hardness in soil profile of P-B4, P-B5, and P-B6 in mixed deciduous forest.

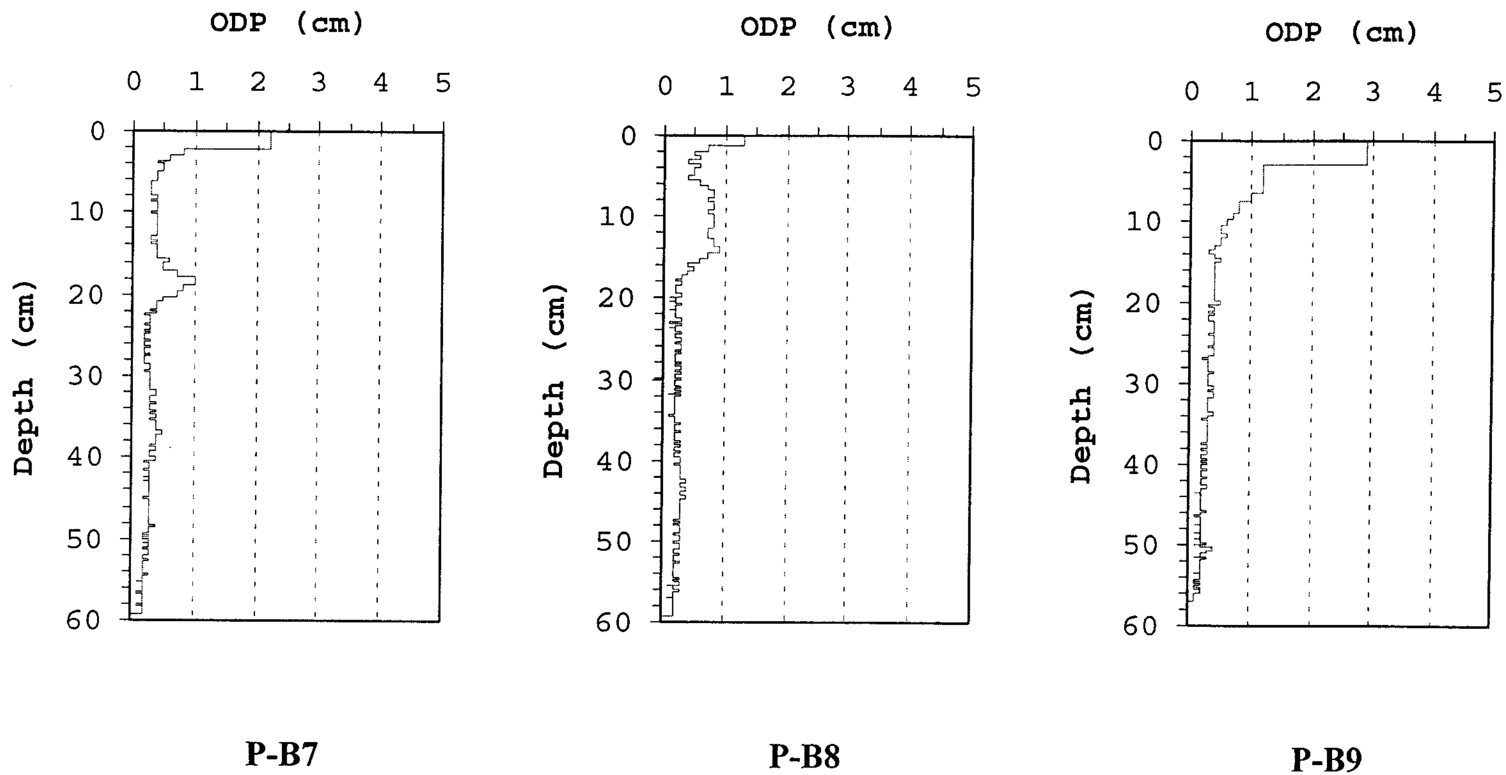


Figure 30 The typical patterns of soil hardness in soil profile of P-B7, P-B8, and P-B9 in mixed deciduous forest.

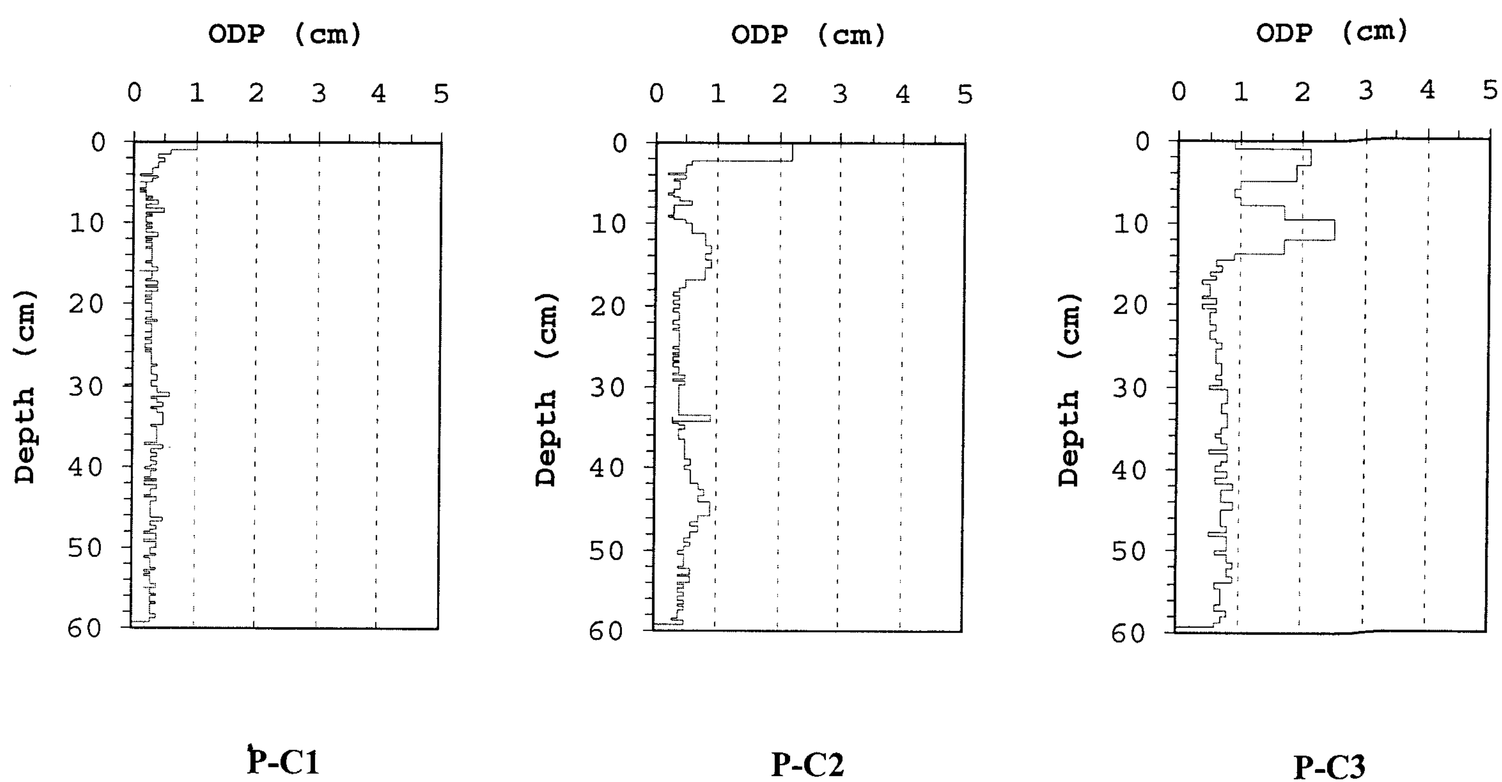


Figure 31 The typical patterns of soil hardness in soil profile of P-C1, P-C2, and P-C3 in pine-dipterocarp forest.

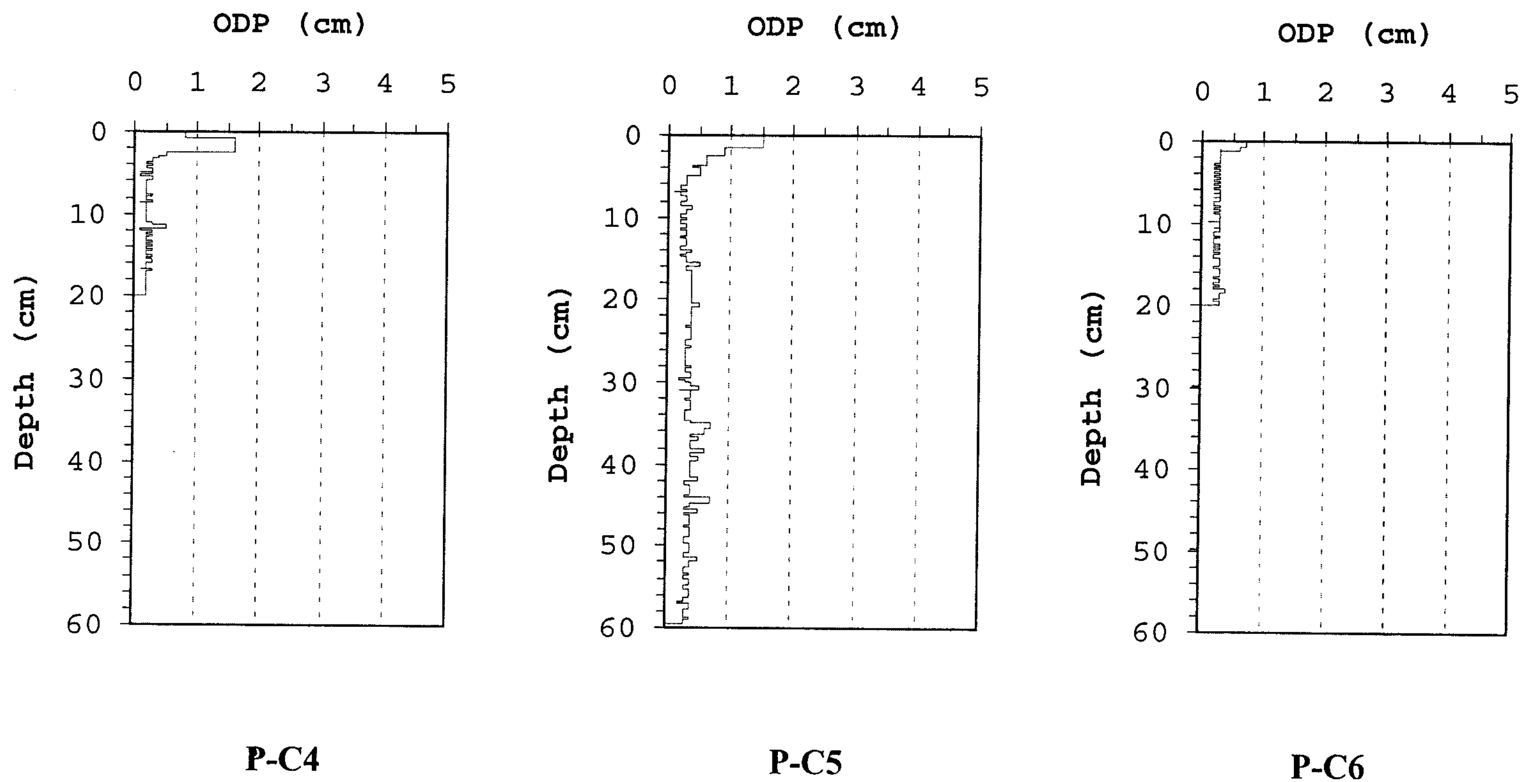


Figure 32 The typical patterns of soil hardness in soil profile of P-C4, P-C5, and P-C6 in pine-dipterocarp forest.

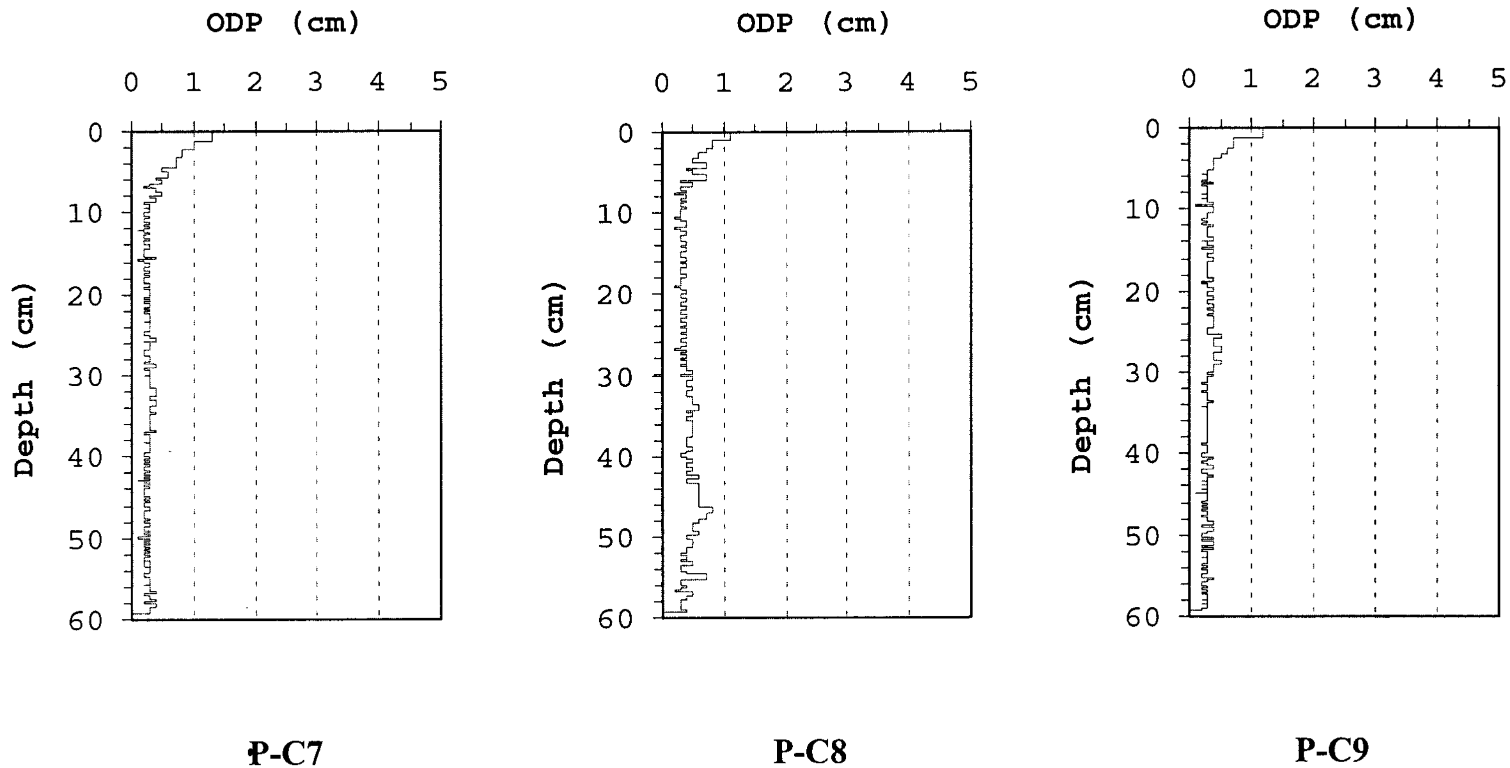


Figure 33 The typical patterns of soil hardness in soil profile of P-C7, P-C8, and P-C9 in pine-dipterocarp forest.

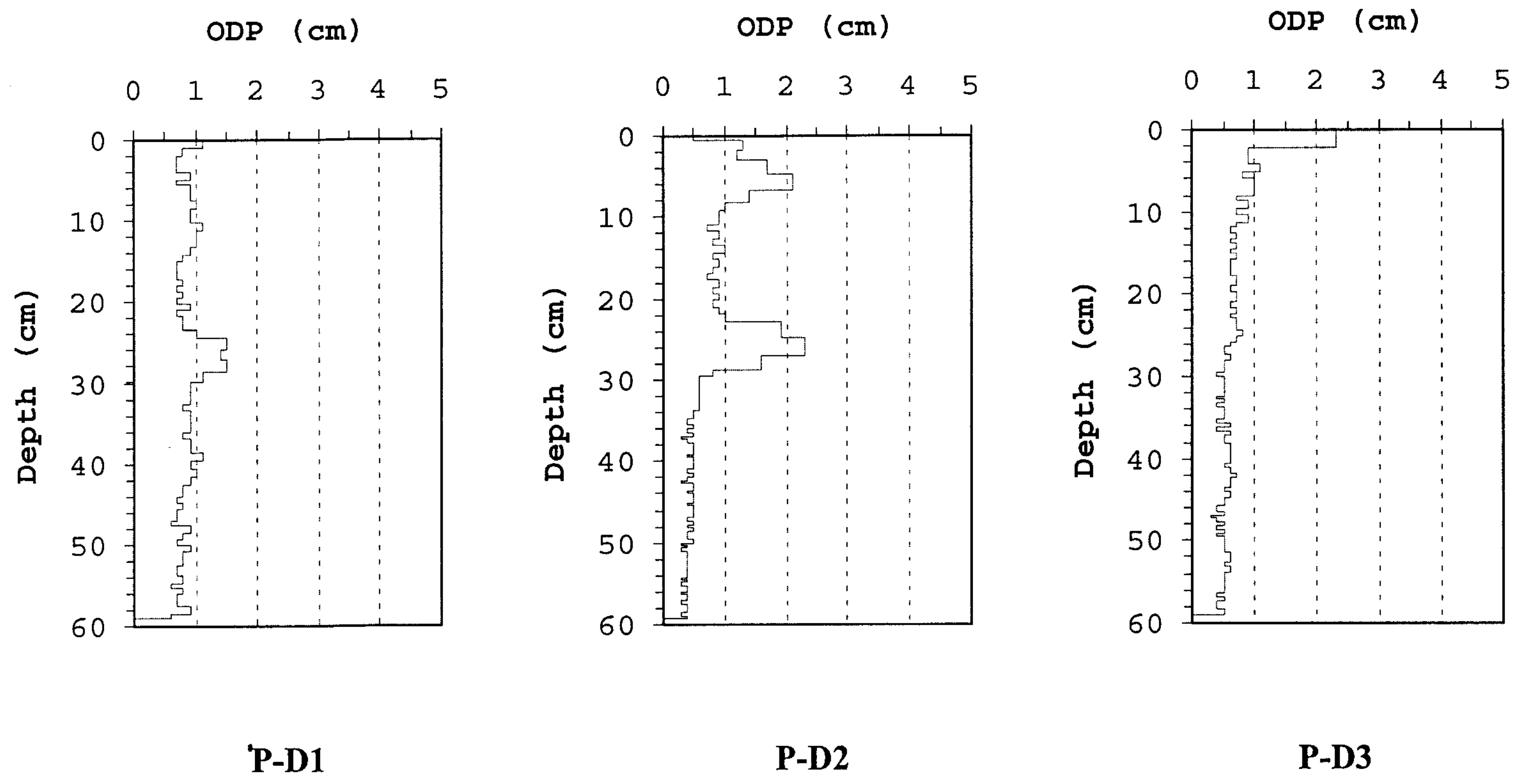
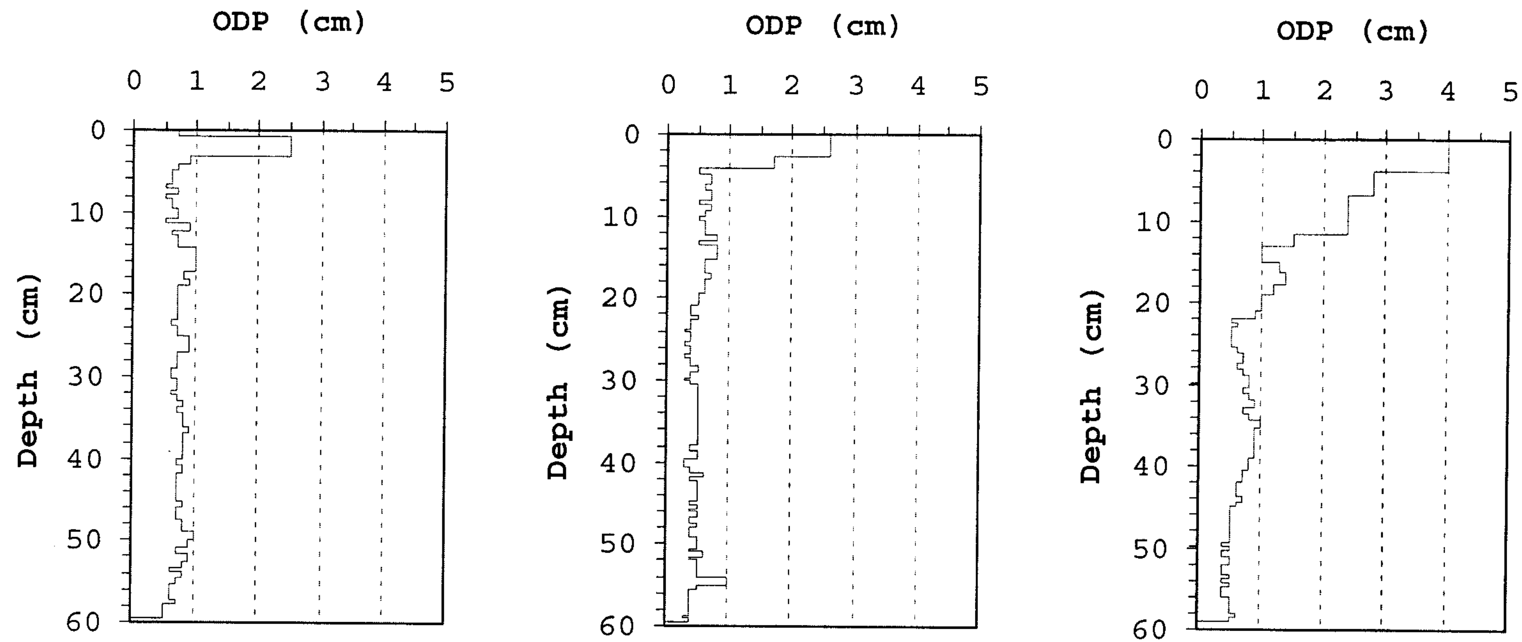
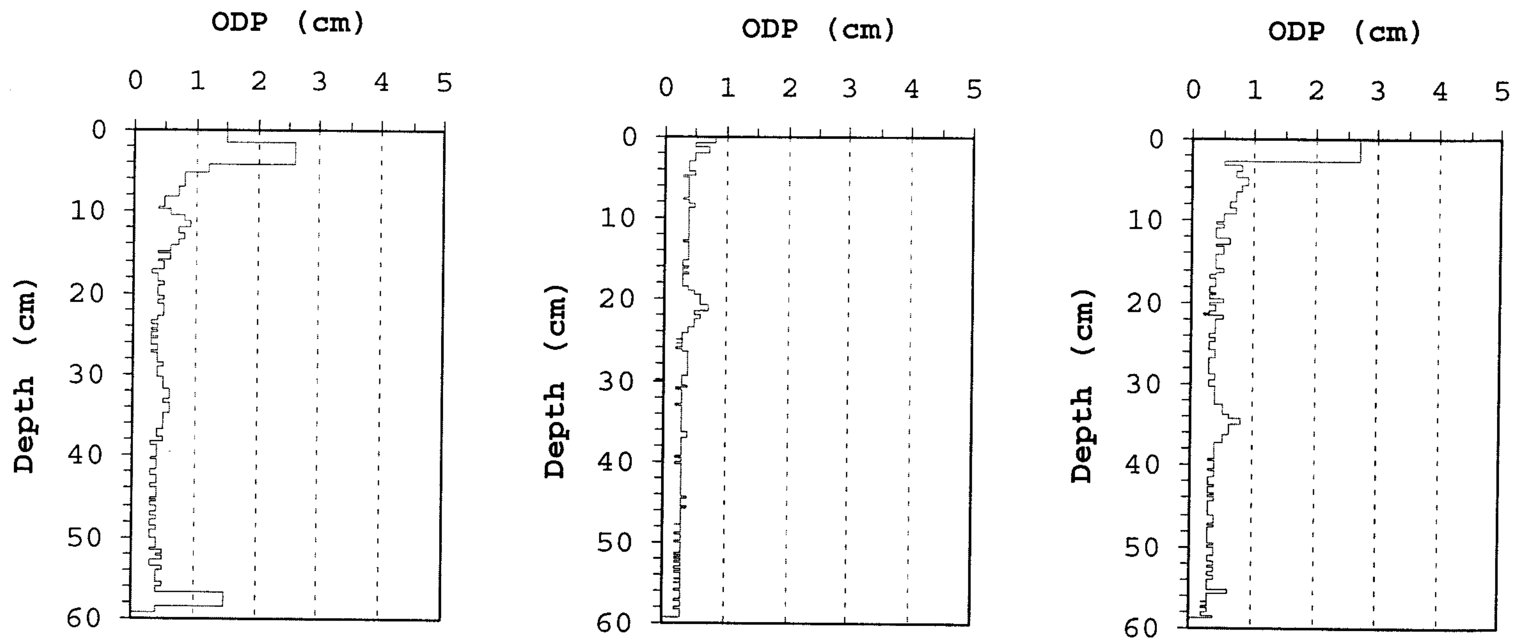


Figure 34 The typical patterns of soil hardness in soil profile of P-D1, P-D2, and P-D3 in pine-oak forest.



P-D4 **P-D5** **P-D6**

Figure 35 The typical patterns of soil hardness in soil profile of P-D4, P-D5, and P-D6 in pine-oak forest.



P-D7 P-D8 P-D9

Figure 36 The typical patterns of soil hardness in soil profile of P-D7, P-D8, and P-D9 in pine-oak forest.

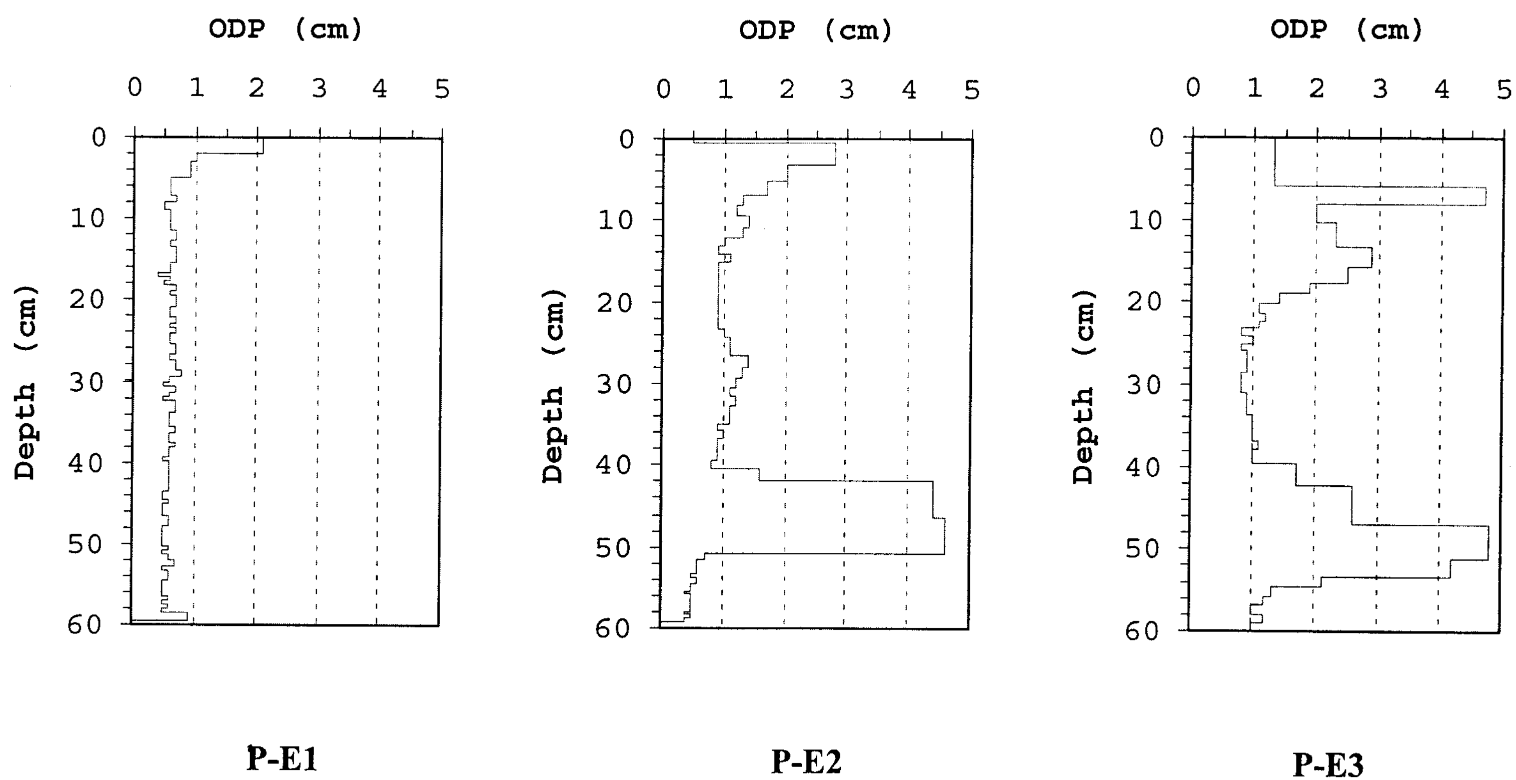


Figure 37 The typical patterns of soil hardness in soil profile of P-E1, P-E2, and P-E3 in montane forest.

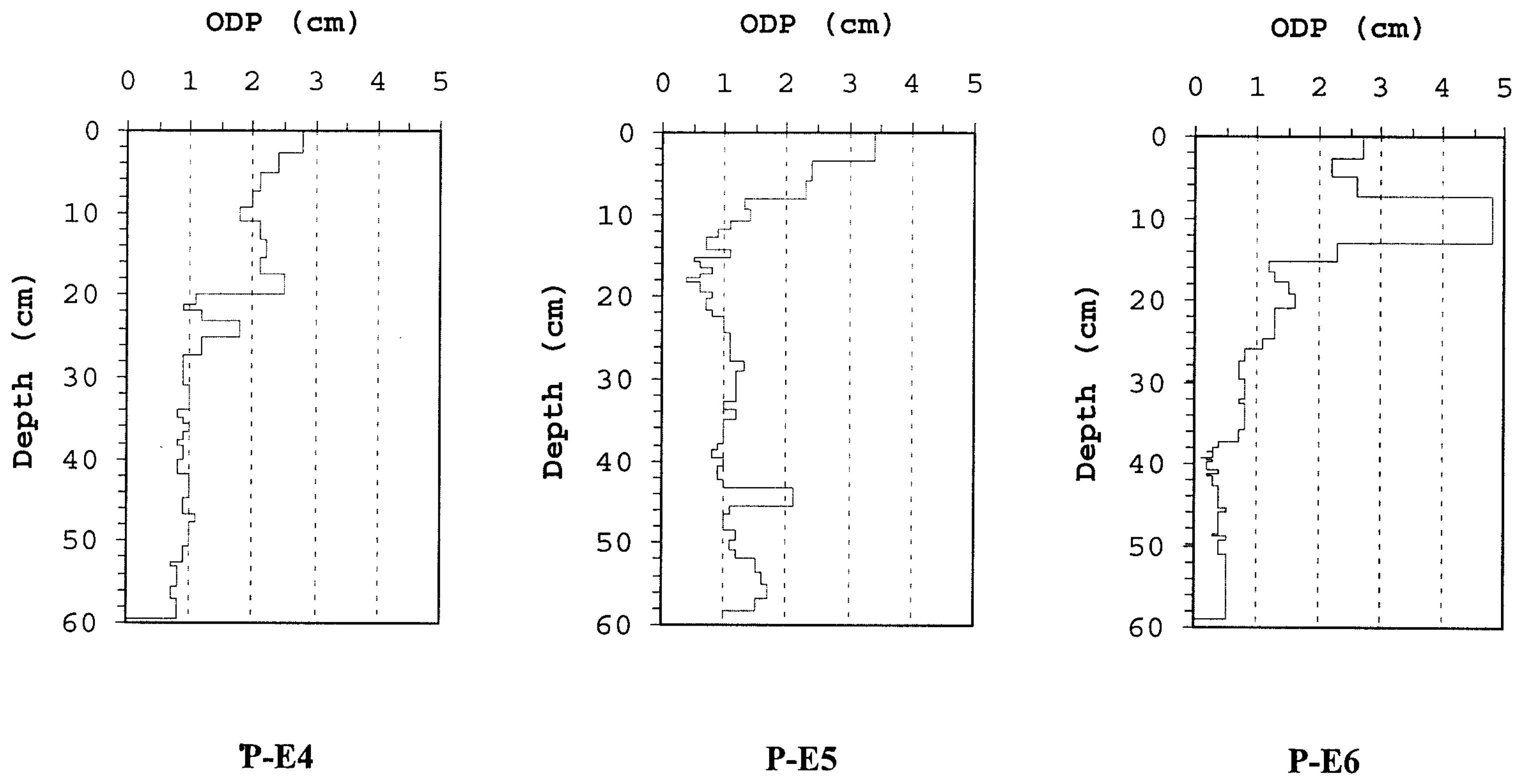


Figure 38 The typical patterns of soil hardness in soil profile of P-E4, P-E5, and P-E6 in montane forest.

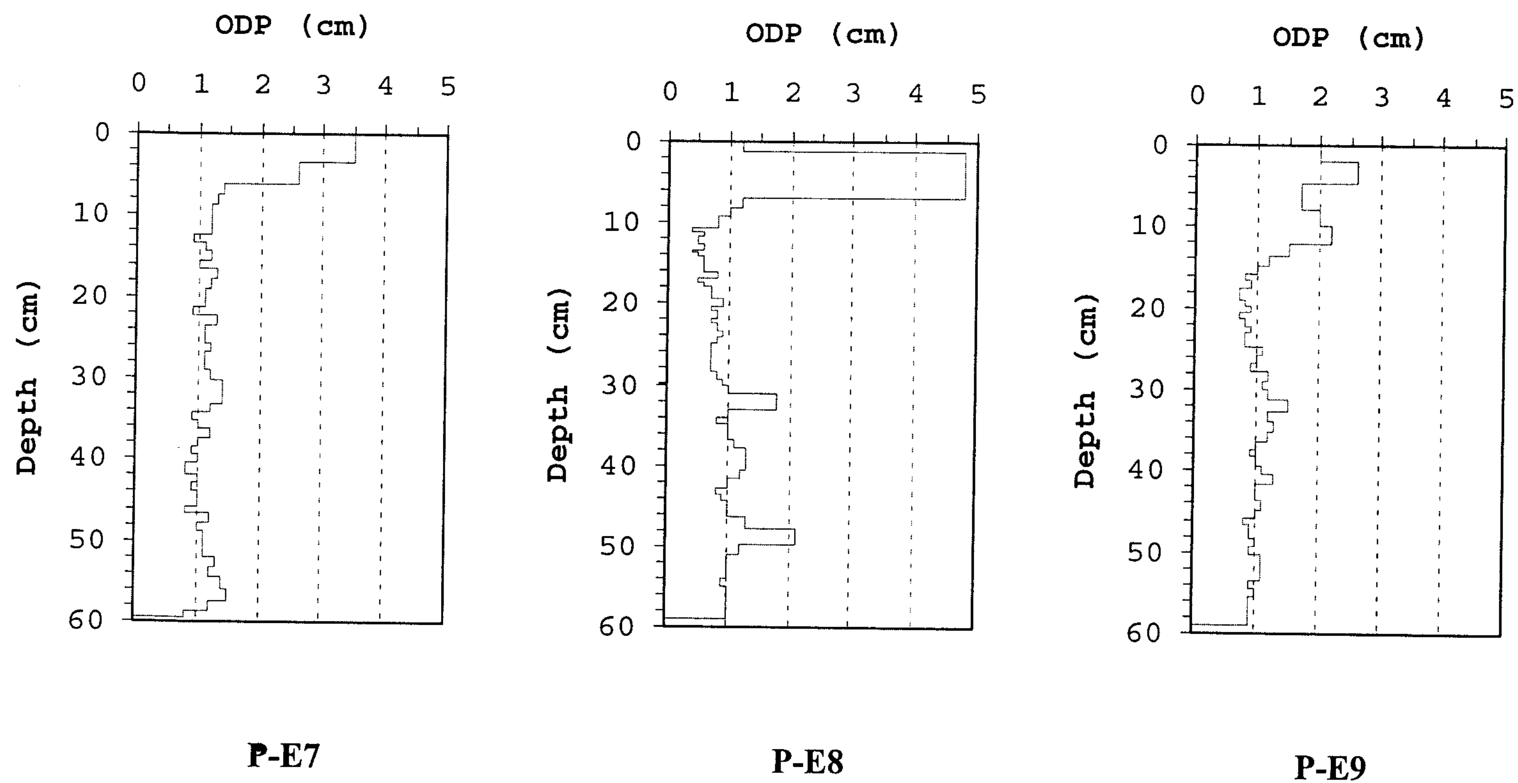


Figure 39 The typical patterns of soil hardness in soil profile of P-E7, P-E8, and P-E9 in montane forest.

Soil in P-B1, P-B2, and P-B3 in mixed deciduous forest (Figure 28), were softer throughout profile than other sample plots in this forest type. Within this transect, P-B1 was the hardest, therefore it showed moderate hard level. Soil in P-B4, P-B5, and P-B6 (Figure 29) were extremely hard except in P-B4 was soft in 0-5 cm and hard in 5 to 10 cm depth. Soil in P-B7 and P-8 (Figure 30) were also similar as other profile, but the surface soil at 0-5 cm depth was soft to moderately hard.

In pine-dipterocarp forest, the soil hardness showed moderately to extremely hard throughout profile particularly below 10 cm (Figure 31-33). However, at surface layer around 0-5 cm they were normally moderate hard. Soil in P-C1, P-C2, and P-C3 (Figure 31) were softer than other profiles in the same forest type. However, soil in P-D7, P-D8, and P-D9 (Figure 36) were very similar to soil profile in pine-dipterocarp forest. Thus, other profiles in pine-oak forest were found to be softer than previous profiles, particularly in P-D6, it might be caused by the large carbon accumulation of soil throughout profile (Figure 34-35).

The soil profile in montane forest was moderately hard throughout profile, and the irregular hardness were exhibited (Figure 37-39). However, soil in P-E1 was harder than other profile within the montane forest.

Chemical Soil Properties

Soil pH in Doi Inthanon National Park decreased with increasing altitude showing that soils of lowland forests, particularly in MDF and DDF were high and slightly decreased up to the highest area particularly in surface soil. Soil pH as measured in water was higher than that in KCl. Thus, soil in MDF clearly showed high pH value both of surface soil and subsurface soil followed in order by soils in DDF, PDF, POF and MF respectively. In addition, exchangeable Al and H varied accordingly to the pH value. Soils in MDF showed high pH value and low exchangeable Al and H while soils in MF were low in pH value but high in exchangeable Al and H especially in T3 transect (Table 7 and 8).

Electric conductivity (EC) of soils in MF distinctly showed higher than that in other forests except soils in MDF. Soils in DDF, PDF, and POF indicated low EC therefore all EC values were less than 5.5 ms cm^{-1}. This property is closely associated with exchangeable cation, therefore when soils have high EC there are high amount of exchangeable Al and H, as shown by MF soils. On the other hand, EC were high in soils of MDF, which partly were due to the dominant of exchangeable Ca and Mg in this forest.

T-C and T-N increasing were highly associated with altitudinal change. Low T-C and T-N in lowland forest, MDF and DDF were remarkable because in these areas there are always wildfire almost every year. Soils of MF clearly showed high amount of T-C and T-N, especially in T2 and T3 which indicated more than 6 % for T-C and 0.5 for T-N in surface soil followed by soils of POF and PDF respectively. In contrary, the subsurface soils of MDF, equal T-C and T-N contents were found as the same as in the horizon of MF soils.

The C/N ratios of the surface soils in PDF and POF were significantly higher than in other forests, however, there was not significantly different among those in subsurface horizon. These forest soils might have low nitrogen immobilization suggesting that there might be not enough nitrogen contents for microorganism activity. Another reasons might be because of the litter of pine leaves (coniferous tree) in which they showed high C/N ratio and very difficult to decompose (Baker and Attiwill, 1985).

Available phosphorus is one of the elements that showed no significant different among forest type. The highest amount was found in soil of MF (T3) and DDF (T3).

There were significantly different of CEC among forest types in both surface soil and subsurface soil. Therefore, CEC of soils in MDF and MF were higher than soil of PDF and POF, which had rather similar value as these forest types and soils of DDF showed the lowest value. In addition to the subsurface soil, high CEC were found in T1 of MDF and T3 of MF. Normally, CEC in tropical soils were rather low. Kaolinite is the dominant clay mineral. It is low active mineral. The CEC is mainly influenced from organic matter concerning this reason, CEC of soil showed highly association with organic matter.

Base saturation is one property that showed significantly different among forest types. Therefore, the highest values were found in soil of MDF and DDF consequently soils in other forests showed low values. Particularly, soils in T3 of MF, which is the highest plot indicated a very low base saturation, which might cause the soils on this altitude to have less amount of exchangeable cation whilst, there were high CEC values.

Table 7 The average values of surface soil chemical properties in transects at Doi Inthanon National Park.

Forest types	Transect	Altitude	Depth	EC	pH_k	pH_w	Exchangeable						CEC	BS	Available	Total		C/N ratio
							Ca	Mg	K	Na	Al	H			P	C	N	
		(m asl)	(cm)	(ms cm^{-1})			(cmol(+) kg^{-1})							(%)	(mg kg^{-1})	(g kg^{-1})		
DDF	T1	450-550	0-5	4.71	6.38	5.19	4.43	0.83	0.40	0.03	0.07	0.02	7.86	72.06	20.87	1.80	0.14	13.27
DDF	T2	580-730	0-5	4.11	6.35	5.14	4.36	1.76	0.29	0.01	0.02	0.02	8.52	75.19	28.62	1.84	0.12	15.95
DDF	T3	880-990	0-5	3.66	5.67	4.26	1.18	1.00	0.33	0.02	0.39	0.13	9.21	27.85	57.84	2.05	0.11	19.46
MDF	T1	620-690	0-5	7.53	6.95	5.76	14.29	4.01	1.17	0.01	0.02	0.01	24.10	80.78	39.09	2.74	0.20	13.51
MDF	T2	490-600	0-5	7.61	7.11	6.11	11.81	3.01	0.96	0.01	0.02	0.00	18.83	83.89	38.32	3.27	0.25	13.14
MDF	T3	650-730	0-5	7.07	6.73	5.60	10.49	2.69	0.66	0.02	0.06	0.00	17.86	76.97	39.24	3.45	0.23	15.13
PDF	T1	1000-1100	0-5	4.36	5.79	4.43	2.14	1.54	0.61	0.03	0.48	0.15	18.19	23.21	33.13	4.72	0.23	20.97
PDF	T2	980-1080	0-5	3.95	5.85	4.53	2.48	1.32	0.37	0.02	0.26	0.11	12.38	34.20	21.90	3.52	0.16	21.78
PDF	T3	1080-1100	0-5	3.52	5.46	4.23	1.29	0.73	0.27	0.02	0.91	0.17	13.08	17.12	19.25	3.51	0.15	22.42
POF	T1	1020-1070	0-5	3.71	5.29	4.19	0.57	0.42	0.22	0.02	1.60	0.24	18.28	7.02	26.40	6.09	0.27	22.58
POF	T2	1040-1120	0-5	5.21	5.44	4.30	2.60	1.24	0.26	0.04	1.19	0.19	26.51	15.99	24.14	9.42	0.39	24.64
POF	T3	1040-1120	0-5	4.09	5.44	4.26	1.02	0.61	0.25	0.03	1.15	0.18	13.91	13.06	24.91	4.63	0.18	26.47
MF	T1	1340-1440	0-5	5.24	5.49	4.29	0.60	0.70	0.42	0.03	1.26	0.17	16.65	11.01	25.99	4.70	0.27	17.00
MF	T2	1650-1710	0-5	14.71	4.59	3.98	2.07	0.64	0.20	0.04	2.55	0.59	21.53	18.46	52.06	9.37	0.68	13.48
MF	T3	2220-2320	0-5	13.67	4.51	3.46	0.50	0.41	0.31	0.05	4.97	0.83	27.61	4.61	78.36	10.74	0.75	14.28

Table 8 The average values of subsurface soil chemical properties in transects at Doi Inthanon National Park.

Forest types	Transect	Altitude	Depth	EC	pH_w	pH_k	Exchangeable						CEC	BS	Available	Total		C/N ratio
							Ca	Mg	K	Na	Al	H			P	C	N	
		(m asl)	(cm)	(ms cm^{-1})			......(cmol(+) kg^{-1})......							(%)	(mg kg^{-1})	(g kg^{-1})		
DDF	T1	450-550	20-25	1.54	5.79	4.09	1.03	0.50	0.26	0.02	0.32	0.11	4.72	38.64	2.83	0.77	0.06	12.57
DDF	T2	580-730	20-25	1.82	5.72	4.17	2.22	1.98	0.18	0.06	1.61	0.25	11.27	40.14	6.31	0.67	0.06	11.29
DDF	T3	880-990	20-25	1.78	5.27	4.11	0.47	0.51	0.29	0.01	0.79	0.13	8.59	17.17	14.98	0.67	0.06	11.98
MDF	T1	620-690	20-25	2.72	6.10	4.86	6.33	2.99	0.17	0.03	0.13	0.08	16.90	57.72	1.46	1.40	0.13	11.11
MDF	T2	490-600	20-25	2.68	6.12	4.70	5.41	2.00	0.24	0.02	0.35	0.08	13.84	54.77	5.62	1.46	0.12	11.72
MDF	T3	650-730	20-25	2.30	5.95	4.55	4.29	1.08	0.29	0.03	0.34	0.09	10.66	48.77	7.26	1.36	0.11	12.55
PDF	T1	1000-1100	20-25	1.30	5.41	4.42	0.19	0.76	0.23	0.03	0.90	0.13	12.43	9.51	3.69	0.78	0.07	11.14
PDF	T2	980-1080	20-25	1.38	5.56	4.32	0.45	1.02	0.37	0.02	0.56	0.11	11.14	16.04	2.00	0.84	0.06	13.75
PDF	T3	1080-1100	20-25	1.34	5.55	4.42	0.13	0.41	0.28	0.04	0.54	0.11	9.01	9.88	2.13	0.64	0.06	10.23
POF	T1	1020-1070	20-25	1.49	5.25	4.22	0.19	0.18	0.04	0.01	1.39	0.15	10.31	4.22	7.28	1.91	0.08	24.64
POF	T2	1040-1120	20-25	1.30	5.25	4.31	0.00	0.26	0.05	0.02	0.96	0.10	11.80	3.06	4.81	1.69	0.07	23.69
POF	T3	1040-1120	20-25	1.66	5.33	4.27	0.02	0.23	0.13	0.02	1.11	0.15	7.39	5.37	4.67	0.98	0.06	17.81
MF	T1	1340-1440	20-25	2.49	5.22	4.32	0.02	0.14	0.17	0.02	1.20	0.17	8.85	3.87	5.89	1.52	0.09	17.61
MF	T2	1650-1710	20-25	2.71	5.17	4.40	0.87	0.06	0.09	0.02	0.90	0.16	9.90	9.38	4.36	2.03	0.14	14.43
MF	T3	2220-2320	20-25	5.99	4.73	4.06	0.00	0.02	0.08	0.03	4.06	0.33	21.98	0.64	5.65	3.69	0.21	17.22

Mineralogical and Charge Properties

For the surface soils (Table 9), aluminum extracted with acid oxalate (Alo) showed very low value less than 0.2 in all of DDF and T2, T3 of MDF soils. However, the other soils showed high value more than 0.25, particularly in T1 of MDF soils were the highest value. Iron extracted with acid oxalate (Feo) were low value only in T1, T2 of DDF soils, therefore other soils were high value, especially soils in T1 of MDF and T3 of MF. Aluminum extracted with dithionite-citrate (Ald) showed very close value with extracted with acid oxalate. On the other hand, iron extracted with dithionite-citrate (Fed) showed the values higher than extracted with acid oxalate. These data indicated that the soil materials (mostly derived from granite) here still have weathering process. Thus, soils of T1 in MDF and T2, T3 in MF are more active as the Feo/Fed ratio showed more than 1.0. MDF soils showed remarkable high value, which it means that the soils of this forest still have more amount of permanent negative charge than the other soils. The clay mineral of surface soils is dominated by kaolinite similarly to other soils in tropical region. The reduction of amount of clay mineral particularly kaolinite along the altitude was remarkable. It may be due to the weathering process of soil materials are blocked with temperature.

For the subsurface soils (Table 10), aluminum extracted with acid oxalate (Alo) showed high value more than the surface soils particularly in PDF, POF, and MF soils. However, iron extracted with acid oxalate (Feo) were similar value as surface soils. Aluminum extracted with dithionite-citrate (Ald) also showed very close value with surface soils as similar as iron extracted with dithionite-citrate (Fed), but T2 and T3 of MF soils was remarkably higher values. ZPC of subsurface soils also ranged between 3.0 to 6.1. However, the highest value was obvious in POF soils. The clay minerals of subsurface soils are also dominated by kaolinite similarly to those in surface soils. The details of mineralogical and charge properties are shown in Table 8 for surface soils and Table 9 for subsurface soils.

Table 9 Some mineralogical and charge properties of surface soil in transects at Doi Inthanon National Park.

Forest types	Transect	Altitude	Depth	Alo	Sio	Feo	Ald	Sid	Fed	Alo/Ald	Feo/Fed	ZPC	Clay Mineral Composition *1					
		(m asl)	(cm)	....	....	....	(%)	....	....				HIV.	It.	Kt.	Gb.	Gt.	Qz.
DDF	T1	450-550	0-20	0.089	0.012	0.047	0.081	0.113	0.352	1.123	0.140	3.998	++	±	++	±	±	±
DDF	T2	580-730	0-20	0.062	0.009	0.061	0.068	0.154	0.428	0.912	0.140	3.504	++	±	++++	±	±	±
DDF	T3	880-990	0-20	0.190	0.022	0.142	0.171	0.134	0.634	1.209	0.275	3.702	+	±	++++	±	±	±
MDF	T1	620-690	0-20	0.683	0.167	1.339	0.623	0.301	5.267	1.098	0.256	4.888	+	±	+	±	±	±
MDF	T2	490-600	0-20	0.123	0.029	0.204	0.123	0.106	1.622	1.081	0.141	5.784	++	±	++	±	±	±
MDF	T3	650-730	0-20	0.161	0.030	0.140	0.134	0.154	0.524	1.208	0.275	4.632	++	±	++++	±	±	±
PDF	T1	1000-1100	0-20	0.878	0.154	0.230	0.667	0.147	1.774	1.315	0.133	4.209	+	±	++++	±	±	±
PDF	T2	980-1080	0-20	0.278	0.047	0.135	0.256	0.085	0.768	1.105	0.183	3.304	+	±	++++	±	±	±
PDF	T3	1080-1100	0-20	0.467	0.070	0.179	0.458	0.097	1.274	1.000	0.145	3.637	+	±	++++	±	±	±
POF	T1	1020-1070	0-20	0.818	0.099	0.219	0.744	0.130	1.318	1.095	0.171	4.239	+	±	++++	±	±	±
POF	T2	1040-1120	0-20	1.178	0.182	0.206	1.079	0.219	2.199	1.085	0.094	4.077	+	±	++++	±	±	±
POF	T3	1040-1120	0-20	0.495	0.063	0.139	0.443	0.095	0.820	1.120	0.172	3.894	+	±	++++	±	±	±
MF	T1	1340-1440	0-20	0.693	0.044	0.223	0.599	0.126	1.062	1.180	0.228	4.053	++	±	++++	±	±	±
MF	T2	1650-1710	0-20	0.691	0.017	1.391	0.777	0.123	2.886	0.874	0.478	3.799	+	+	++	±	±	±
MF	T3	2220-2320	0-20	0.335	0.011	1.031	0.401	0.188	1.931	0.843	0.533	3.076	++	++	++	±	±	±

*1) ±, 0-5 (%); +, 5-20 (%); ++, 20-40 (%); +++, 40-60 (%); ++++, >60 (%);

HIV. , Hydroxy-interlayered vermiculite; It., Illite; Kt., Kaolinite; Gb., Gibbsite; Gt., Geothite; Qz., Quartz.

Table 10 Some mineralogical and charge properties of subsurface soil in transects at Doi Inthanon National Park.

Forest types	Transect	Altitude	Depth	Alo	Sio	Feo	Ald	Sid	Fed	Alo/Ald	Feo/Fed	ZPC	Clay Mineral Composition *1					
		(m asl)	(cm)	......	......	......(%)	......	......	......				HIV.	It.	Kt.	Gb.	Gt.	Qz.
DDF	T1	450-550	20-40	0.061	0.005	0.036	0.069	0.071	0.381	0.946	0.097	3.161	++	±	++	±	±	+
DDF	T2	580-730	20-40	0.131	0.016	0.058	0.190	0.143	1.043	0.680	0.055	3.343	++	±	++++	±	±	+
DDF	T3	880-990	20-40	0.171	0.024	0.132	0.238	0.102	1.421	0.882	0.143	3.323	±	±	++++	±	±	±
MDF	T1	620-690	20-40	0.777	0.104	1.751	0.777	0.214	5.644	1.003	0.313	4.332	+	±	++	±	±	±
MDF	T2	490-600	20-40	0.157	0.018	0.207	0.172	0.058	1.676	0.907	0.136	3.829	+	±	+++	±	±	±
MDF	T3	650-730	20-40	0.135	0.021	0.172	0.132	0.106	0.584	1.016	0.289	3.441	++	±	++++	±	±	±
PDF	T1	1000-1100	20-40	0.380	0.045	0.227	0.408	0.067	2.815	0.916	0.081	4.124	+	±	++++	±	±	±
PDF	T2	980-1080	20-40	0.262	0.039	0.143	0.374	0.058	1.837	0.704	0.079	3.400	+	±	++++	±	±	±
PDF	T3	1080-1100	20-40	0.225	0.030	0.151	0.353	0.051	2.252	0.629	0.069	4.123	+	±	++++	±	±	±
POF	T1	1020-1070	20-40	0.525	0.048	0.188	0.465	0.051	1.496	1.130	0.131	6.076	+	±	++++	±	±	±
POF	T2	1040-1120	20-40	0.612	0.084	0.207	0.532	0.105	3.293	1.119	0.063	5.166	+	±	++++	±	±	±
POF	T3	1040-1120	20-40	0.238	0.024	0.107	0.281	0.055	1.260	0.843	0.086	4.290	+	±	++++	±	±	±
MF	T1	1340-1440	20-40	0.539	0.027	0.236	0.439	0.058	1.493	1.273	0.187	4.417	+	±	++++	±	±	+
MF	T2	1650-1710	20-40	0.474	0.009	0.820	0.824	0.050	4.378	0.575	0.192	4.386	+	±	+++	±	±	±
MF	T3	2220-2320	20-40	0.705	0.011	1.863	0.860	0.063	3.642	0.846	0.533	4.155	++	±	+	±	±	±

*1) ±, 0-5 (%); +, 5-20 (%); ++, 20-40 (%); +++, 40-60 (%); ++++, >60 (%);

HIV. , Hydroxy-interlayered vermiculite; It., Illite; Kt., Kaolinite; Gb., Gibbsite; Gt., Geothite; Qz., Quartz.

The Correlation among Soil Properties

The correlation between parent material, altitude, physical and chemical properties in surface and subsurface soils was studied by using Spearman's rank correlation test. In surface soils, altitude, parent material and carbon content were the important factors affecting to both physical and chemical properties. Altitude is the most important factor that was correlated with almost of all properties excepted only available phosphorus, clay content and hydraulic conductivity. Parent material was the major factor as the same as carbon content that determined the properties of both physical and chemical as shown in Table 11. Nitrogen content, available phosphorus and CEC are three chemical properties that were not correlated with parent material, therefore clay content, particle density and hydraulic conductivity are physical properties that were not correlated. Carbon content is a dominant factor that correlated with soil property particularly with the chemical properties.

Therefore, the correlation among some factors and soil properties of sub surface soil showed the similar situation as the surface soil. However, the correlation coefficients in subsurface soils were less than surface soils such as nitrogen content was correlated with altitude in surface soils but it was not in sub surface horizon. Altitude, parent material and carbon content were the dominant factors correlating with other soil properties as shown in Table 12.

Table 11 The correlation between altitude, parent materials, physical, and chemical properties of surface soils using spearman rank correlation test.

	Parent materials	altitude	Carbon content	Nitrogen content	C:N ratio	pH (H_2O)	Avai. P	Exch. Al	Exch. H	Exch. K	Exch. Ca	Exch. Mg	Exch. Na	CEC	% Base saturation
Parent materials	1.000	-0.707**	-0.390**	-0.070 ^{ns}	-0.632**	0.750**	-0.101 ^{ns}	-0.710**	-0.747**	0.653**	0.747**	0.575**	-0.436**	0.094 ^{ns}	0.714**
Altitude	-0.707**	1.000	0.749**	0.555**	0.298*	-0.829**	0.373*	0.856**	0.837**	-0.440**	-0.705**	-0.632**	0.671**	0.408**	-0.823**
Carbon content	-0.390**	0.749**	1.000	0.900**	0.235 ^{ns}	-0.641**	0.338*	0.710**	0.653**	-0.213 ^{ns}	-0.397**	-0.365*	0.703**	0.779**	-0.660**
Silt content	0.598**	-0.374*	0.040 ^{ns}	0.189 ^{ns}	-0.201 ^{ns}	0.471**	0.062 ^{ns}	-0.373*	-0.396**	0.462**	0.468**	0.451**	-0.112 ^{ns}	0.409**	0.361*
Clay content	0.015 ^{ns}	-0.162 ^{ns}	-0.047 ^{ns}	-0.157 ^{ns}	0.382*	0.133 ^{ns}	-0.499**	-0.160 ^{ns}	-0.129 ^{ns}	0.116 ^{ns}	0.015 ^{ns}	0.261 ^{ns}	-0.226 ^{ns}	0.045 ^{ns}	0.074 ^{ns}
% gravel	0.370*	-0.501**	-0.439**	-0.246 ^{ns}	-0.426**	0.446**	0.095 ^{ns}	-0.518**	-0.415**	0.202 ^{ns}	0.491**	0.404**	-0.291*	-0.293 ^{ns}	0.544**
Bulk density	0.341*	-0.731**	-0.865**	-0.811**	-0.140 ^{ns}	0.651**	-0.247 ^{ns}	-0.669**	-0.653**	0.255 ^{ns}	0.411**	0.418**	-0.593**	-0.720**	0.664**
Particle density	0.166 ^{ns}	-0.274 ^{ns}	-0.415**	-0.377*	-0.082 ^{ns}	0.152 ^{ns}	-0.110 ^{ns}	-0.199 ^{ns}	-0.182 ^{ns}	-0.050 ^{ns}	0.088 ^{ns}	0.029 ^{ns}	-0.304*	-0.309*	0.158 ^{ns}
Porosity	-0.338*	0.697**	0.807**	0.758**	0.141 ^{ns}	-0.640**	0.245 ^{ns}	0.647**	0.648**	-0.295 ^{ns}	-0.394 ^{ns}	-0.414**	0.570**	0.682**	-0.650 ^{ns}
Moisture content	-0.568**	0.844**	0.816**	0.682**	0.238 ^{ns}	-0.838**	0.209 ^{ns}	0.840**	0.845**	-0.407**	-0.637 ^{ns}	-0.638**	0.711**	0.512**	-0.810**
Ks	-0.096 ^{ns}	0.245 ^{ns}	0.328*	0.367*	-0.002 ^{ns}	-0.249 ^{ns}	0.093 ^{ns}	0.234 ^{ns}	0.332*	0.060 ^{ns}	-0.212 ^{ns}	-0.198 ^{ns}	0.324*	0.130 ^{ns}	-0.266 ^{ns}

Table 12 The correlation between altitude, parent materials, physical, and chemical properties of sub surface soils using spearman rank correlation test.

	Parent materials	altitude	Carbon content	Nitrogen content	C:N ratio	pH (H_2O)	Avai. P	Exch. Al	Exch. H	Exch. K	Exch. Ca	Exch. Mg	Exch. Na	CEC	% Base saturation
Parent materials	1.000	-0.707**	0.073^{ns}	0.368*	-0.352*	0.646**	-0.112^{ns}	-0.555**	-0.320*	0.234^{ns}	0.709**	0.579**	0.056^{ns}	0.168^{ns}	0.698**
Altitude	-0.707**	1.000	0.424**	0.213^{ns}	0.483**	-0.692**	0.093^{ns}	0.577**	0.355*	-0.419**	-0.725**	-0.776**	-0.070^{ns}	0.080^{ns}	-0.798**
Carbon content	0.073^{ns}	0.424**	1.000	0.812**	0.677**	-0.300*	0.312*	0.298*	0.156^{ns}	-0.426**	-0.245^{ns}	-0.418**	-0.197^{ns}	0.450**	-0.344*
Silt content	0.585**	-0.259^{ns}	0.317*	0.485**	-0.095^{ns}	0.099^{ns}	0.155^{ns}	-0.089^{ns}	0.192^{ns}	-0.214^{ns}	0.347*	0.105^{ns}	0.155^{ns}	0.271^{ns}	0.285^{ns}
Clay content	-0.493**	0.134^{ns}	-0.386**	-0.522**	-0.108^{ns}	-0.114^{ns}	-0.263^{ns}	0.059^{ns}	-0.224^{ns}	0.092^{ns}	-0.252^{ns}	0.067^{ns}	0.026^{ns}	0.022^{ns}	-0.227^{ns}
% gravel	0.596**	-0.553**	-0.098^{ns}	0.192^{ns}	-0.342*	0.489**	-0.047^{ns}	-0.455**	-0.214^{ns}	0.145^{ns}	0.581**	0.415**	0.056^{ns}	-0.019^{ns}	0.586**
Bulk density	-0.016^{ns}	-0.525**	-0.730**	-0.607**	-0.361*	0.316*	-0.049^{ns}	-0.302*	-0.174^{ns}	0.540**	0.316*	0.408**	-0.026^{ns}	-0.434**	0.430**
Particle density	0.192^{ns}	-0.132^{ns}	0.019^{ns}	0.013^{ns}	-0.004^{ns}	0.145^{ns}	-0.273^{ns}	-0.181^{ns}	-0.079^{ns}	0.119^{ns}	0.165^{ns}	0.154^{ns}	-0.103^{ns}	-0.022^{ns}	0.182^{ns}
Porosity	0.100^{ns}	0.478**	0.745**	0.651**	0.338*	-0.228^{ns}	-0.017^{ns}	0.221^{ns}	0.151^{ns}	-0.445**	-0.235^{ns}	-0.388**	-0.016^{ns}	0.366*	-0.349*
Moisture content	-0.740**	0.782**	0.280^{ns}	0.083^{ns}	0.295*	-0.635**	0.022^{ns}	0.481**	0.301*	-0.398**	-0.625**	-0.618**	0.056^{ns}	0.194^{ns}	-0.699**
Ks	0.324*	0.140^{ns}	0.618**	0.454**	0.400**	-0.096^{ns}	0.116^{ns}	0.139^{ns}	0.045^{ns}	-0.438**	-0.108^{ns}	-0.300*	-0.227^{ns}	0.085^{ns}	-0.192^{ns}

Soil Properties Along an Altitudinal Gradient

The results of this study revealed that many properties of soil were affected by the changing of altitude that probably due to the difference of temperature and humidity. Porosity, field moisture content, water holding capacity, T-C, T-N, exchangeable Al, H, Na, electric conductivity and CEC exhibited the increasing trends along with the rising of altitude. On the other hand, bulk density, pH, exchangeable Ca, Mg and K decreased with the rising of altitude. However, some soil properties were not correlated with altitudinal gradient for instance; gravel content, hydraulic conductivity and available phosphorus.

Results of the present study suggested that the gradient of soil properties along the altitude could be divided in accordance to forest vegetation zone into three zones as lowland, montane and transition zones. Lowland zone composing of two forest types, DDF and MDF, thus indicated soil of dry weather and associated with wildfire. MDF soil showed higher fertility than DDF due to the disturbance in DDF were more severe than in MDF and it is more erosive and easily washed by surface runoff. In contrast, the characteristics of vegetation of MDF always represent the more advantage to protect the soils. Transition zone is likely to be the optimal combination of temperature and moisture therefore, this zone showed highly weathering process and displayed the highest clay content as well as the reddish soil color. This zone was located at about 1,000 to 1,100 m asl altitude, composed of two forest types such as PDF and POF. The organic matter on the top of soil profile was remarkable on this zone particularly in POF. Montane zone is the typical soil associated with organic matter. Soil properties were closely related to amount of organic matter, such as high porosity, field moisture content, water holding capacity, T-C, T-N, exchangeable Al, H, Na, electric conductivity and CEC but low in bulk density, pH, exchangeable Ca, Mg and K.

Soil and Plant Relationships

Soil Properties in Various Forest Communities

Mean values of soil characteristics in various forest communities classified by cluster analysis are compared and shown in Table 13 and 14. The Kruskal-Wallis test indicated that there were significantly different among the forest community groups for almost all soil properties.

Regarding to surface soil (Table 13), the results showed that almost all soil properties were significantly different among forest communities except for only particle density, soil permeability and available phosphorus. Soil texture showed the major dominant difference among the forest communities. High amounts of sand content were found in soils of forest community group I, IV, V and VI while soils of forest community group II were great in silt content and group III were highest in clay content. Textural characteristics were considered to be affected by weather condition change along the altitude causing soils to be more fine-grain with the rising altitude up to around 1,200 m asl and above this altitude the amount of clay content gradually reduced. Soils in forest group I was remarkably high in gravel percentage comparing with others. Bulk density, porosity, and field moisture content showed significantly different among forest vegetation groups. Thus, bulk density gradually decreased while field moisture content and porosity increased along the altitudinal gradient (Table 13).

Soil reactions indicated high variation in both those measured by dissolving in water and in KCl. Soils of forest community group II shōwed the highest pH value and decreased with altitude. Total N and C contents gradually increased with altitude, therefore soil of forest community group V and VI showed highest contents. Exchangeable Al, H, and Na were found to be remarkably high in forest community group VI but exchangeable Ca, Mg and K were highest in forest community group II. Base saturation was also high in forest community groups II and I respectively. However, the lowest cation exchange capacity was observed in forest community group I.

Table 13 Surface soil properties (mean $\pm$ S.D.) with the different superscripts a, b, c to indicate the difference among forest vegetation groups by using a nonparametric rank test (Kruskul-Wallis' s method at $p < 0.05$). ns indicates non-significantly difference among groups of vegetation.

	Group I	Group II	Group III	Group IV	Group V	Group VI
Physical properties						
Texture	SL – SCL	SL – C	L – CL	SL – SCL	SL – SCL	SL – SCL
Sand content (%)	64.16 ± 3.71^{ab}	47.73 ± 10.50^{c}	54.60 ± 7.33^{bc}	61.68 ± 7.00^{abc}	65.68 ± 3.46^{ab}	72.01 ± 4.51^{a}
Silt content (%)	18.84 ± 3.74^{b}	26.67 ± 5.41^{a}	18.73 ± 2.39^{b}	17.00 ± 1.73^{b}	18.33 ± 1.53^{b}	17.00 ± 2.65^{b}
Clay content (%)	17.00 ± 1.19^{ab}	25.60 ± 7.47^{a}	26.67 ± 6.75^{a}	21.32 ± 6.56^{ab}	15.99 ± 4.04^{ab}	10.99 ± 2.08^{b}
Gravel (%)	29.29 ± 18.45^{a}	15.46 ± 11.87^{ab}	7.17 ± 8.69^{b}	2.88 ± 0.87^{b}	9.58 ± 2.02^{ab}	2.96 ± 1.38^{b}
Bulk density (g cm^{-3})	1.30 ± 0.13^{a}	1.13 ± 0.13^{ab}	1.01 ± 0.23^{abc}	0.89 ± 0.09^{bcd}	0.66 ± 0.13^{cd}	0.58 ± 0.17^{d}
Particle density (g cm^{-3})	2.74 ± 0.07^{a}	2.76 ± 0.17^{a}	2.70 ± 0.10^{a}	2.63 ± 0.06^{ab}	2.70 ± 0.10^{a}	2.37 ± 0.43^{b}
Porosity (%)	0.53 ± 0.06^{b}	0.59 ± 0.07^{b}	0.63 ± 0.08^{ab}	0.66 ± 0.03^{ab}	0.76 ± 0.05^{a}	0.76 ± 0.05^{a}
Field moisture content (%)	7.80 ± 3.80^{c}	7.08 ± 2.56^{c}	16.99 ± 7.90^{bc}	25.15 ± 4.79^{b}	50.39 ± 6.36^{a}	55.12 ± 6.46^{a}
Ks (cm s^{-1})	0.006 ± 0.005^{ns}	0.005 ± 0.003^{ns}	0.007 ± 0.005^{ns}	0.012 ± 0.005^{ns}	0.013 ± 0.014^{ns}	0.008 ± 0.004^{ns}
Chemical properties						
$PH_{(k)}$	5.14 ± 0.13^{b}	5.83 ± 0.46^{a}	4.36 ± 0.26^{c}	4.28 ± 0.04^{c}	3.98 ± 0.29^{cd}	3.46 ± 0.06^{d}
$PH_{(w)}$	6.36 ± 0.11^{a}	6.93 ± 0.36^{a}	5.60 ± 0.32^{b}	5.49 ± 0.07^{b}	4.59 ± 0.27^{c}	4.51 ± 0.12^{c}
EC (ms cm^{-1})	4.34 ± 1.39^{b}	7.40 ± 3.14^{b}	4.01 ± 0.87^{b}	5.24 ± 0.35^{b}	14.71 ± 3.20^{a}	13.67 ± 2.01^{a}
Carbon content (%)	1.76 ± 0.17^{b}	3.15 ± 0.59^{b}	4.73 ± 2.53^{b}	4.70 ± 1.16^{b}	9.37 ± 3.78^{a}	10.74 ± 2.01^{a}
Nitrogen content (%)	0.13 ± 0.03^{b}	0.23 ± 0.04^{b}	0.21 ± 0.10^{b}	0.27 ± 0.04^{b}	0.68 ± 0.19^{a}	0.75 ± 0.15^{a}
C/N ratio	14.23 ± 1.85^{b}	13.93 ± 1.14^{b}	22.34 ± 3.26^{a}	17.00 ± 1.44^{b}	13.48 ± 2.10^{b}	14.28 ± 0.82^{b}
Available P	25.38 ± 11.64^{b}	38.88 ± 26.12^{ab}	29.29 ± 25.93^{ab}	25.99 ± 4.70^{b}	52.06 ± 19.47^{ab}	78.36 ± 35.00^{a}
Exchangeable						
Al (cmol(+) kg^{-1})	0.049 ± 0.055^{c}	0.038 ± 0.022^{c}	0.818 ± 0.615^{c}	1.263 ± 0.427^{bc}	2.551 ± 1.782^{b}	4.968 ± 1.788^{a}
H (cmol(+) kg^{-1})	0.025 ± 0.000^{c}	0.004 ± 0.005^{c}	0.160 ± 0.083^{c}	0.167 ± 0.003^{c}	0.586 ± 0.322^{b}	0.833 ± 0.238^{a}
K (cmol(+) kg^{-1})	0.360 ± 0.083^{b}	0.930 ± 0.504^{a}	0.328 ± 0.155^{b}	0.421 ± 0.060^{ab}	0.199 ± 0.227^{b}	0.312 ± 0.072^{b}
Ca (cmol(+) kg^{-1})	4.583 ± 0.852^{b}	12.200 ± 3.427^{a}	1.695 ± 1.119^{bc}	0.599 ± 0.390^{c}	2.067 ± 2.089^{bc}	0.496 ± 0.156^{c}
Mg (cmol(+) kg^{-1})	1.041 ± 0.324^{b}	3.237 ± 0.914^{a}	1.051 ± 0.604^{b}	0.695 ± 0.250^{b}	0.637 ± 0.365^{b}	0.415 ± 0.031^{b}
Na (cmol(+) kg^{-1})	0.025 ± 0.024^{c}	0.016 ± 0.006^{c}	0.024 ± 0.010^{bc}	0.028 ± 0.008^{bc}	0.039 ± 0.010^{ab}	0.053 ± 0.013^{a}
CEC (cmol(+) kg^{-1})	8.108 ± 0.672^{c}	20.266 ± 4.415^{ab}	15.602 ± 6.101^{bc}	16.648 ± 2.577^{ab}	21.532 ± 9.854^{abc}	27.607 ± 2.379^{a}
BS (%)	73.734 ± 7.053^{a}	80.549 ± 9.215^{a}	22.201 ± 15.405^{b}	11.013 ± 5.287^{b}	18.461 ± 21.570^{b}	4.610 ± 0.377^{b}

Table 14 Subsurface soil properties (mean ± S.D.) with the different superscripts a, b, c to indicate the difference among forest vegetation groups by using a nonparametric rank test (Kruskul-Wallis' s method at $p < 0.05$). ns indicates non-significantly difference among groups of vegetation.

Soil properties	Group I	Group II	Group III	Group IV	Group V	Group VI
Physical properties						
Texture	SL – SCL	SL – C	L – CL	SL – SCL	SL – SCL	SL – SCL
Sand content (%)	51.52 ± 16.06 ^{ab}	44.40 ± 12.45 ^{ab}	31.38 ± 9.53 ^{b}	45.68 ± 6.08 ^{ab}	44.01 ± 4.04 ^{ab}	58.01 ± 1.53 ^{a}
Silt content (%)	18.88 ± 3.40 ^{abc}	24.00 ± 6.78 ^{ab}	14.32 ± 2.30 ^{c}	14.00 ± 1.00 ^{c}	17.00 ± 2.65 ^{bc}	24.67 ± 1.53 ^{a}
Clay content (%)	29.60 ± 16.98 ^{bc}	31.60 ± 10.55 ^{bc}	54.31 ± 11.18 ^{a}	40.32 ± 6.93 ^{ab}	38.99 ± 2.31 ^{abc}	10.99 ± 2.00 ^{c}
Gravel (%)	30.46 ± 16.90 ^{a}	19.18 ± 9.16 ^{ab}	5.06 ± 6.34 ^{bc}	1.62 ± 1.33 ^{c}	16.94 ± 5.45 ^{abc}	2.96 ± 2.59 ^{bc}
Bulk density (g cm^{-3})	1.36 ± 0.04	1.19 ± 0.18	1.25 ± 0.13	1.04	1.08	0.61
Particle density (g cm^{-3})	2.74 ± 0.01	2.83 ± 0.23	2.66 ± 0.15	2.79	2.73	2.72
Porosity (%)	0.50 ± 0.02	0.57 ± 0.09	0.53 ± 0.04	0.63	0.61	0.78
Field moisture content (%)	9.87 ± 8.72	11.26 ± 2.66	22.38 ± 4.01	18.29	32.93	61.17
Ks (cm s^{-1})	0.004 ± 0.005	0.004 ± 0.004	0.003 ± 0.004	0.009	0.005	0.007
Chemical properties						
$PH_{(k)}$	4.03 ± 0.25 ^{b}	4.70 ± 0.52 ^{a}	4.31 ± 0.22 ^{bc}	4.32 ± 0.02 ^{cd}	4.40 ± 0.13 ^{cd}	4.06 ± 0.09 ^{d}
$PH_{(w)}$	5.69 ± 0.44 ^{b}	6.06 ± 0.45 ^{a}	5.41 ± 0.25 ^{bc}	5.22 ± 0.11 ^{c}	5.17 ± 0.30 ^{c}	4.73 ± 0.11 ^{d}
EC (ms cm^{-1})	1.55 ± 0.42 ^{b}	2.56 ± 0.54 ^{b}	1.50 ± 0.36 ^{b}	2.49 ± 1.50 ^{b}	2.71 ± 0.02 ^{b}	5.99 ± 2.08 ^{a}
Carbon content (%)	0.73 ± 0.27 ^{b}	1.41 ± 0.27 ^{b}	1.05 ± 0.54 ^{b}	1.52 ± 0.41 ^{a}	2.03 ± 0.79 ^{a}	3.69 ± 0.54 ^{a}
Nitrogen content (%)	0.06 ± 0.01 ^{b}	0.12 ± 0.02 ^{b}	0.06 ± 0.01 ^{b}	0.09 ± 0.03 ^{b}	0.14 ± 0.03 ^{b}	0.22 ± 0.01 ^{a}
C/N ratio	12.05 ± 2.62 ^{b}	11.79 ± 1.03 ^{b}	15.96 ± 5.93 ^{a}	17.61 ± 1.32 ^{a}	14.43 ± 3.49 ^{a}	17.22 ± 2.70 ^{b}
Available P	4.16 ± 1.86 ^{ns}	4.78 ± 3.11 ^{ns}	5.70 ± 8.35 ^{ns}	5.89 ± 2.92 ^{ns}	4.36 ± 1.67 ^{ns}	5.65 ± 35.00 ^{ns}
Exchangeable						
Al (cmol(+) kg^{-1})	1.149 ± 1.938 ^{b}	0.274 ± 0.394 ^{b}	0.856 ± 0.495 ^{b}	1.199 ± 0.083 ^{b}	0.902 ± 0.682 ^{b}	4.060 ± 0.575 ^{a}
H (cmol(+) kg^{-1})	0.205 ± 0.207 ^{ab}	0.085 ± 0.082 ^{b}	0.122 ± 0.049 ^{b}	0.171 ± 0.073 ^{ab}	0.163 ± 0.048 ^{ab}	0.328 ± 0.035 ^{a}
K (cmol(+) kg^{-1})	0.195 ± 0.119 ^{ns}	0.230 ± 0.106 ^{ns}	0.205 ± 0.147 ^{ns}	0.168 ± 0.050 ^{ns}	0.086 ± 0.088 ^{ns}	0.080 ± 0.003 ^{ns}
Ca (cmol(+) kg^{-1})	1.785 ± 2.165 ^{b}	5.343 ± 2.434 ^{a}	0.236 ± 0.313 ^{b}	0.025 ± 0.034 ^{b}	0.867 ± 1.286 ^{b}	0.001 ± 0.001 ^{b}
Mg (cmol(+) kg^{-1})	0.970 ± 0.924 ^{ab}	2.024 ± 0.977 ^{a}	0.575 ± 0.577 ^{b}	0.142 ± 0.078 ^{b}	0.063 ± 0.020 ^{b}	0.025 ± 0.004 ^{b}
Na (cmol(+) kg^{-1})	0.039 ± 0.031 ^{ns}	0.029 ± 0.014 ^{ns}	0.024 ± 0.013 ^{ns}	0.016 ± 0.005 ^{ns}	0.016 ± 0.003 ^{ns}	0.033 ± 0.003 ^{ns}
CEC (cmol(+) kg^{-1})	7.858 ± 4.337 ^{b}	13.802 ± 3.728 ^{a}	10.033 ± 2.250 ^{ab}	8.845 ± 1.066 ^{ab}	9.897 ± 2.019 ^{ab}	21.977 ± 2.306 ^{a}
BS (%)	38.575 ± 20.743 ^{a}	53.754 ± 16.171 ^{a}	10.871 ± 10.391 ^{b}	3.874 ± 1.258 ^{b}	9.380 ± 11.448 ^{b}	0.642 ± 0.075 ^{b}

Subsurface soil properties also indicated the similar trends as in surface soils, thus almost all soil properties were significantly different among forest community groups except for only available phosphorus, exchangeable K and Na. Soil texture was different among the forest community groups. High sand content were found in soils of forest community group I, IV, V and VI while soils of forest community group II and VI contained greater amount of silt content and group III was highest in clay content (Table 14). Textural characteristics reflected the high effects of the altitudinal change of weather condition by which soils become to be more fine-grain with the rising of altitude up to the altitude around 1,200 m asl but above this altitude the clay content gradually reduced. Consequently, the temperature decreasing along the altitude is considered to influence to the weathering process making soils on highland still to be coarse grain (Hanawalt and Whittaker, 1977). Subsurface soils of forest vegetation group I had significantly high gravel percentage comparing to others as the same as for the surface soil. Bulk density, porosity, field moisture content and hydraulic conductivity could not be statistically compared among the forest community groups. Thus, bulk density gradually decreased whilst, field moisture content and porosity increased along the altitudinal gradient similarly to the trends in the surface soils.

The variation in soil reaction from both those dissolved by water and KCl showed the extremely wide range, but it was lower than those in the surface soils. Soils of forest community group II showed the highest pH value and gradually decreased with altitude. Total N and C contents clearly increased with altitude, therefore soils of forest community group V and VI still showed the highest contents. Exchangeable Al and H were found to be notable high in forest community group VI while exchangeable Ca and Mg were highest in forest community group II. Base saturation was also high in forest community groups II and I respectively. However, the lowest cation exchange capacity was found in the forest community group I. The trends of subsurface soil properties changing were similarly observed in surface soils, however the ranges of these soil variables were narrower than those indicated in surface soils.

Plant Community Ordination

The results of detrended correspondence analysis (DCA) are shown by diagram in Figure 40. The ordination of sample stands was clearly divided the forest community into six groups with three axes. The first axis of DCA showed highly significant group in accordance with altitude. It is therefore considered to use easily to classify the forest zones into different separating forest communities of groups V and VI, and the forest community group I and II were separated by the third axis.

Canonical correspondence analysis (CCA) is another analyzing process, which was chosen to ordinate the position of all 45 forest stands in this study. The result shown in Figure 41 indicated that the forest communities could be classified into groups by three dimensional axes. The first axis was also found to be negatively correlated with the altitude. However, the second and third axes were observed to be different from those separated by the DCA diagram. Therefore, interaction between axis 1 and 2 clearly delineated forest zone into lowland, transition, and montane forest zones. The forest community groups I and II were not clearly separated into different groups by second axis but the third axis was clearly found to be the good criteria to separate the forest in montane zone.

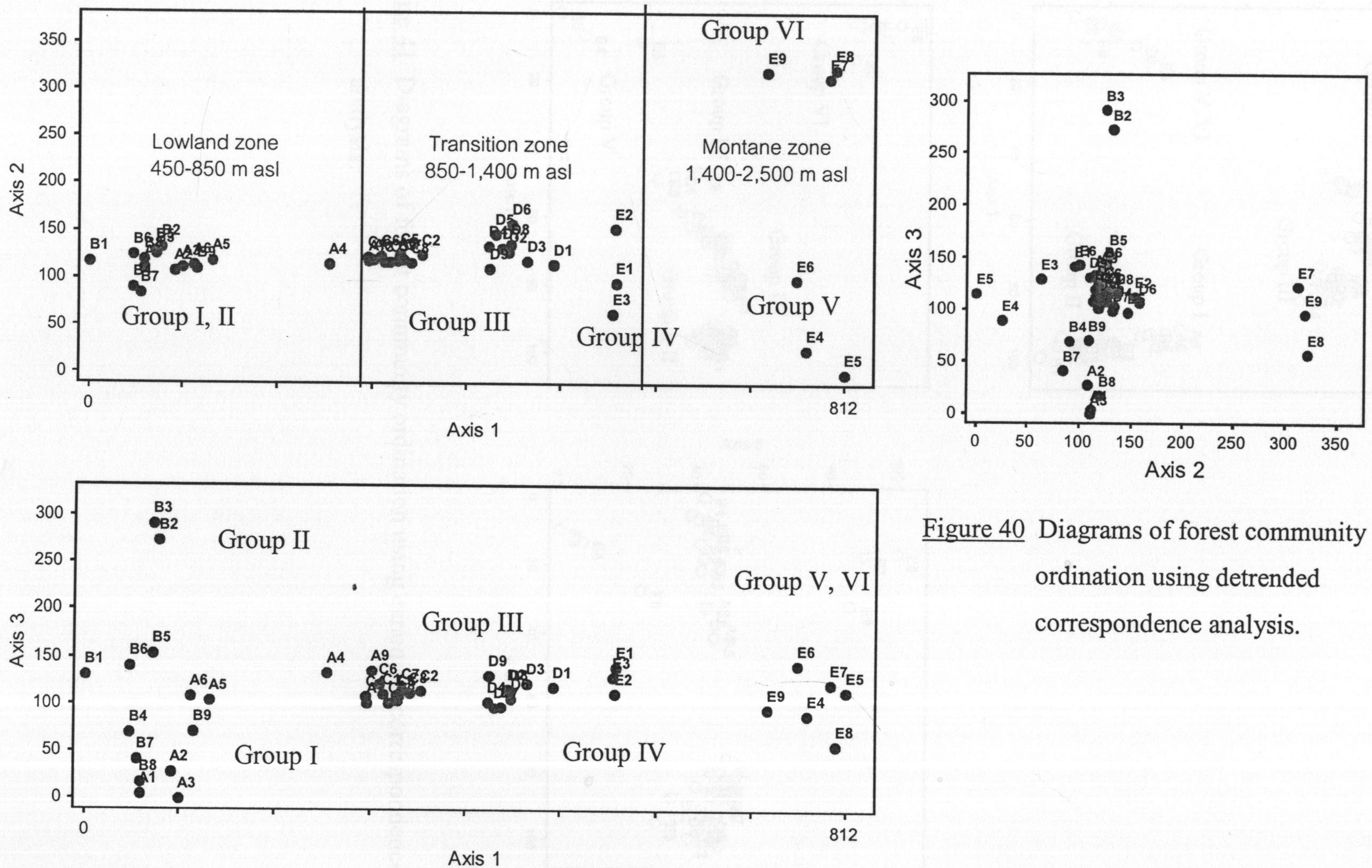


Figure 40 Diagrams of forest community ordination using detrended correspondence analysis.

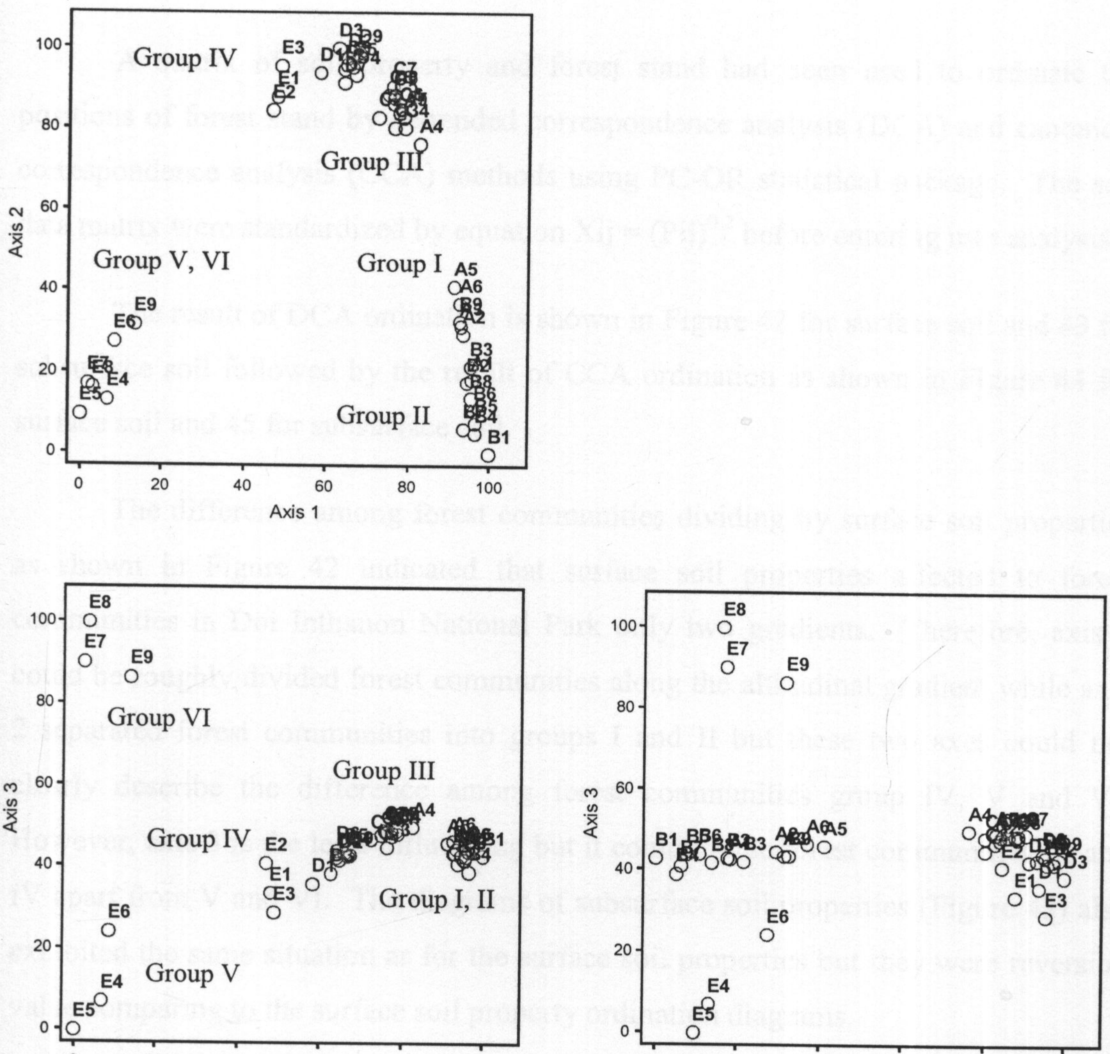


Figure 41 Diagrams of forest community ordination using canonical correspondence analysis.

Soil Property Ordination

A matrix of soil property and forest stand had been used to ordinate the positions of forest stand by detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA) methods using PC-OR statistical package. The soil data matrix were standardized by equation $Xij = (Pij)^{0.2}$ before entering into analysis.

The result of DCA ordination is shown in Figure 42 for surface soil and 43 for subsurface soil followed by the result of CCA ordination as shown in Figure 44 for surface soil and 45 for subsurface soil.

The difference among forest communities dividing by surface soil properties as shown in Figure 42 indicated that surface soil properties affected to forest communities in Doi Inthanon National Park only two gradients. Therefore, axis 1 could be roughly divided forest communities along the altitudinal gradient while axis 2 separated forest communities into groups I and II but these two axes could not clearly describe the difference among forest communities group IV, V and VI. However, axis 3 is the least influencing but it could divide forest communities III and IV apart from V and VI. The diagrams of subsurface soil properties (Figure 43) also exhibited the same situation as for the surface soil properties but they were reversion value comparing to the surface soil property ordination diagrams.

The result of CCA ordination of soil properties showed the similar result to those in DCA ordination (Figure 44 and 45). The main gradients were still being axes 1 and 2. However, the diagrams of subsurface soil property ordination did not reverse comparing with DCA diagrams.

The results of soil property ordination by the methods revealed that edaphic factor could explain the difference just only for some of forest communities. In case of forest communities in Doi Inthanon National Park, soil properties differ from those of the forest communities in lowland forest zone but do not make the difference of forest communities within transition and montane forest zones.

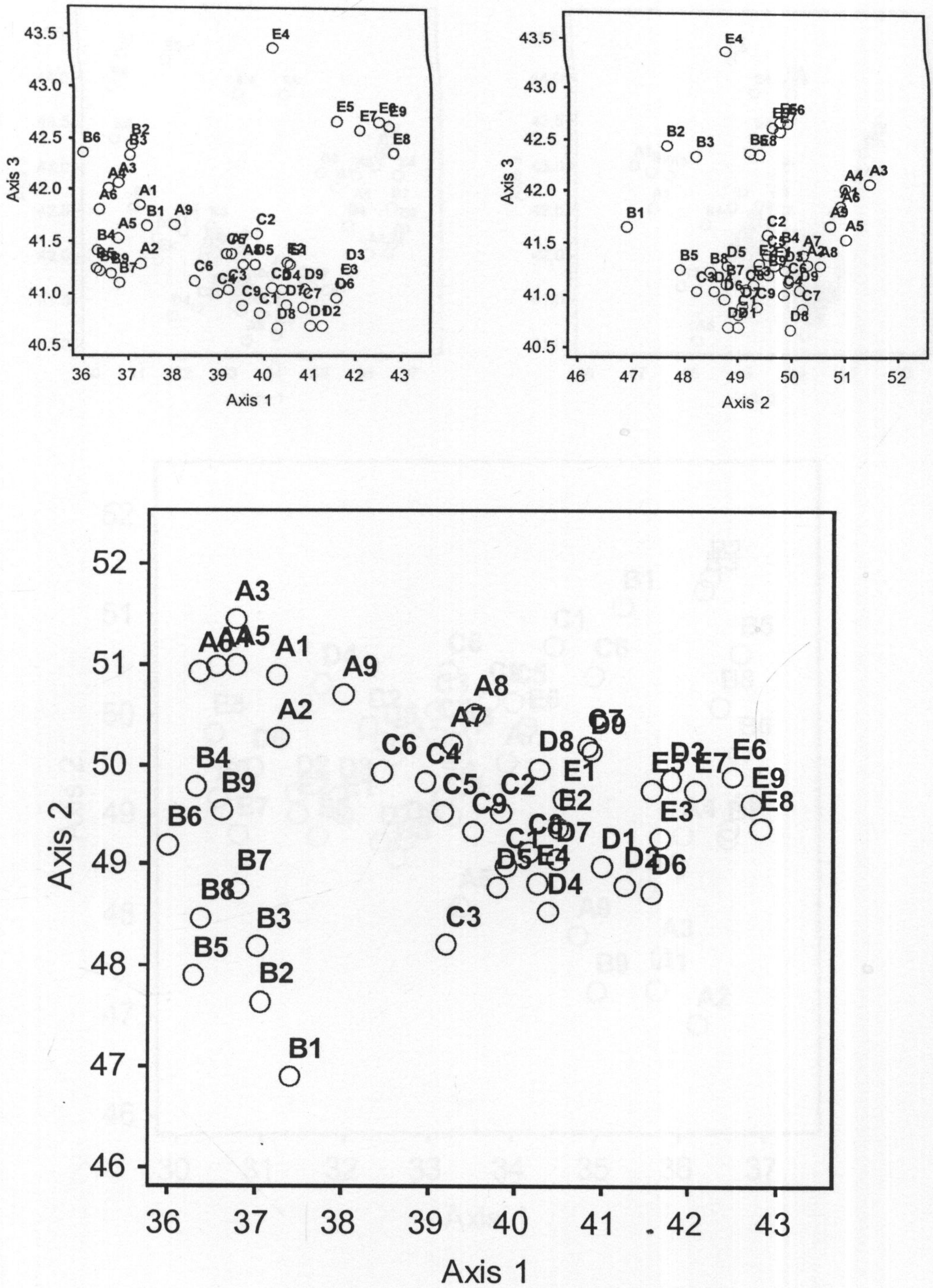


Figure 42 DCA diagrams of surface soil properties in 45 forest stands in Doi Inthanon National Park.

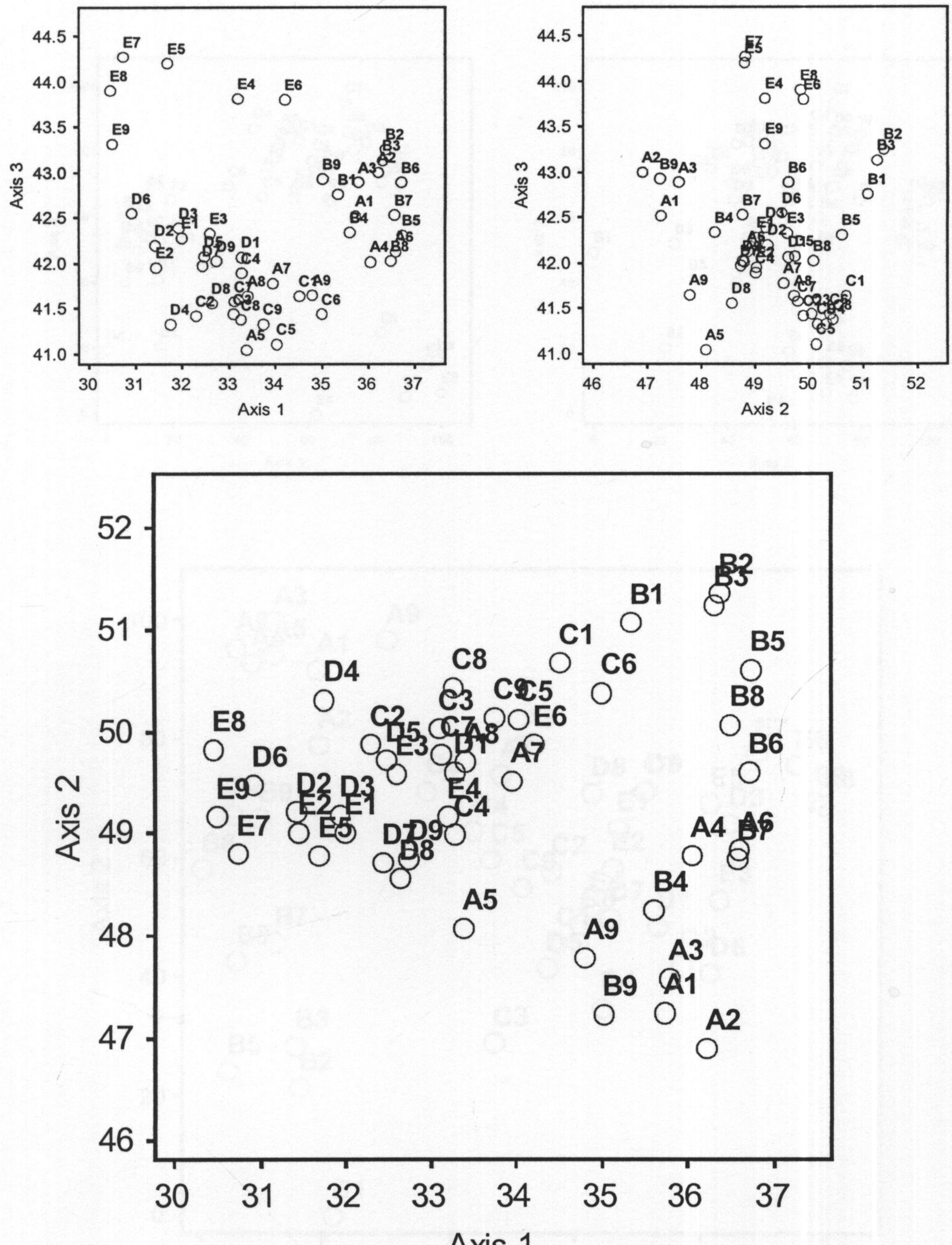


Figure 43 DCA diagrams of subsurface soil properties in 45 forest stands in Doi Inthanon National Park.

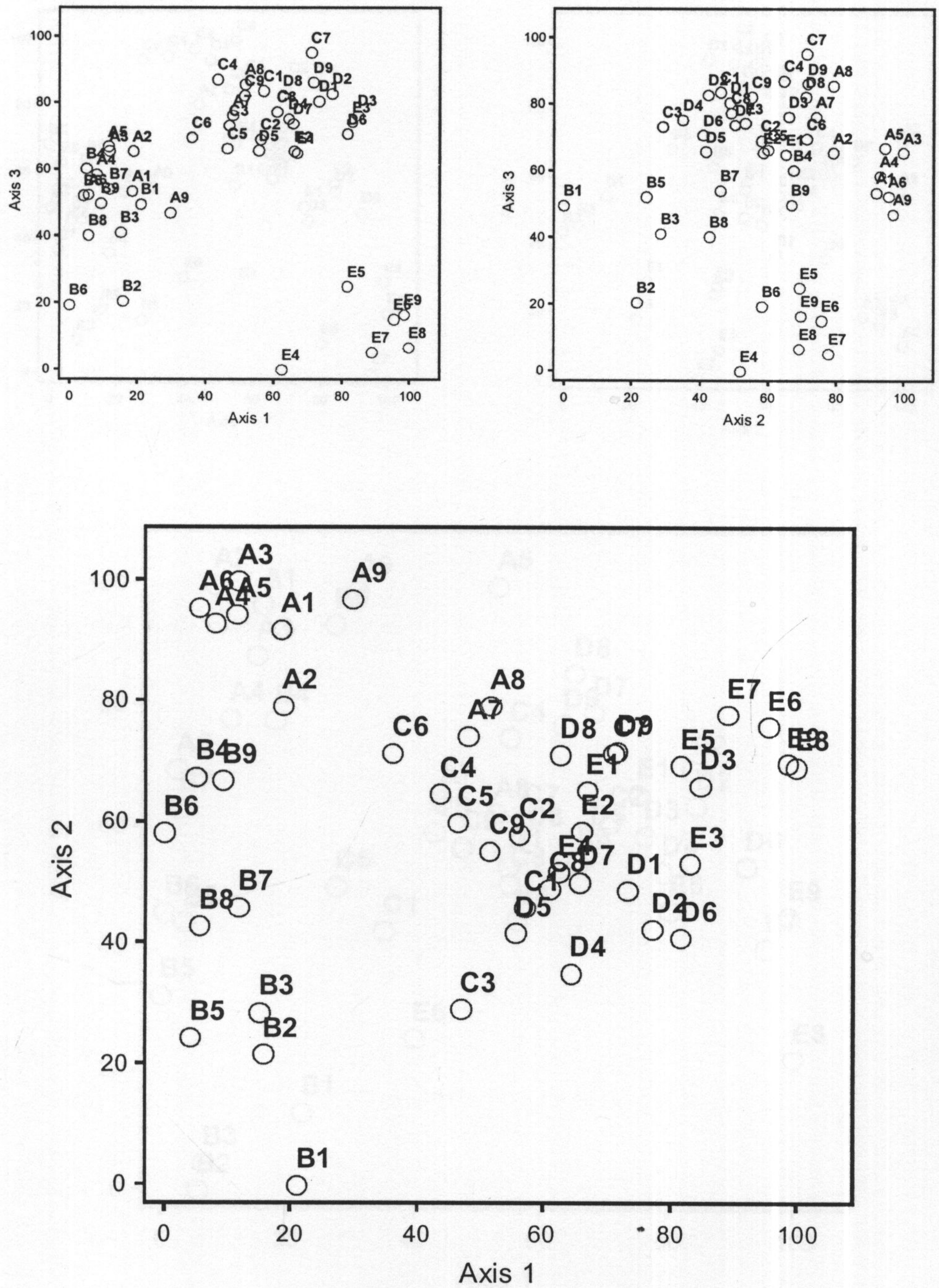


Figure 44 CCA diagrams of surface soil properties in 45 forest stands in Doi Inthanon National Park.

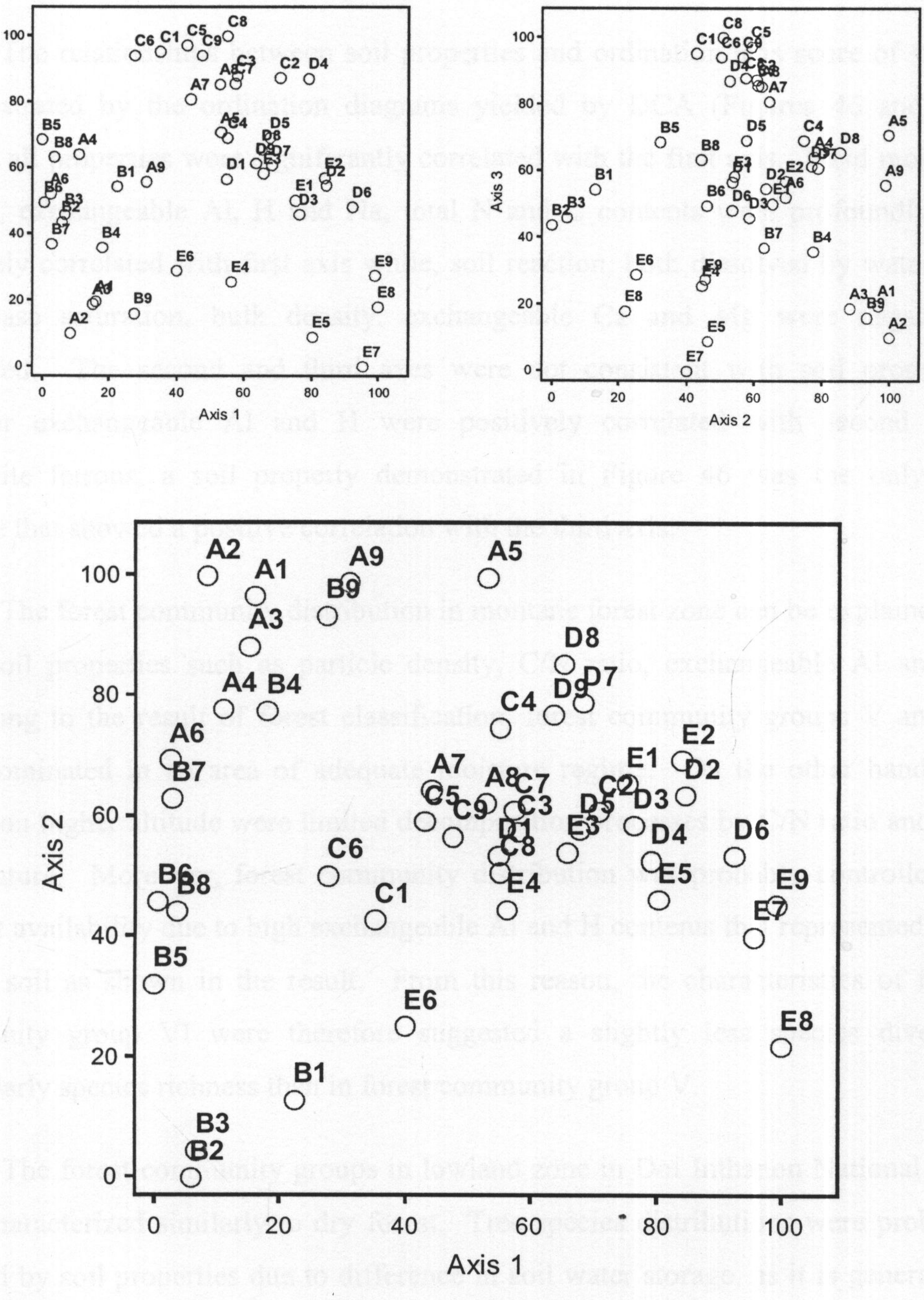


Figure 45 CCA diagrams of subsurface soil properties in 45 forest stands in Doi Inthanon National Park.

Soil and Plant Relationships Determined by Multivariate Methods

The relationships between soil properties and ordination axis score of stands are illustrated by the ordination diagrams yielded by DCA (Figures 46 and 47). Almost all properties were significantly correlated with the first axis. Field moisture content, exchangeable Al, H and Na, total N and C contents were profoundly and positively correlated with first axis while, soil reaction, both dissolved by water and KCl, base saturation, bulk density, exchangeable Ca and Mg were negatively correlated. The second and third axes were not consistent with soil properties however exchangeable Al and H were positively correlated with second axis. Dithionite ferrous, a soil property demonstrated in Figure 46 was the only soil variable that showed a positive correlation with the third axis.

The forest community distribution in montane forest zone can be explained by some soil properties such as particle density, C/N ratio, exchangeable Al and H. According to the result of forest classification, forest community groups V and VI were dominated in an area of adequate moisture regime. On the other hand, the forests on higher altitude were limited decomposition processes by C/N ratio and low temperature. Moreover, forest community distribution was probably controlled by nutrient availability due to high exchangeable Al and H contents that represented high acidity soil as shown in the result. From this reason, the characteristics of forest community group VI were therefore suggested a slightly less species diversity particularly species richness than in forest community group V.

The forest community groups in lowland zone in Doi Inthanon National Park were characterized similarly to dry forest. Tree species distributions were probably affected by soil properties due to difference in soil water storage, as it is generally a limiting factor to forest vegetation physiological processes particularly in dry season. The studies concentrated in dry forest (Oliveira-Filho *et al.,* 1989) pointed out that species distributions in dry forests have been associated with variations in ground water regime based on inference of topography, soil depth and soil texture. This is an issue to explain the difference of forest community groups I and II. Moreover, in the

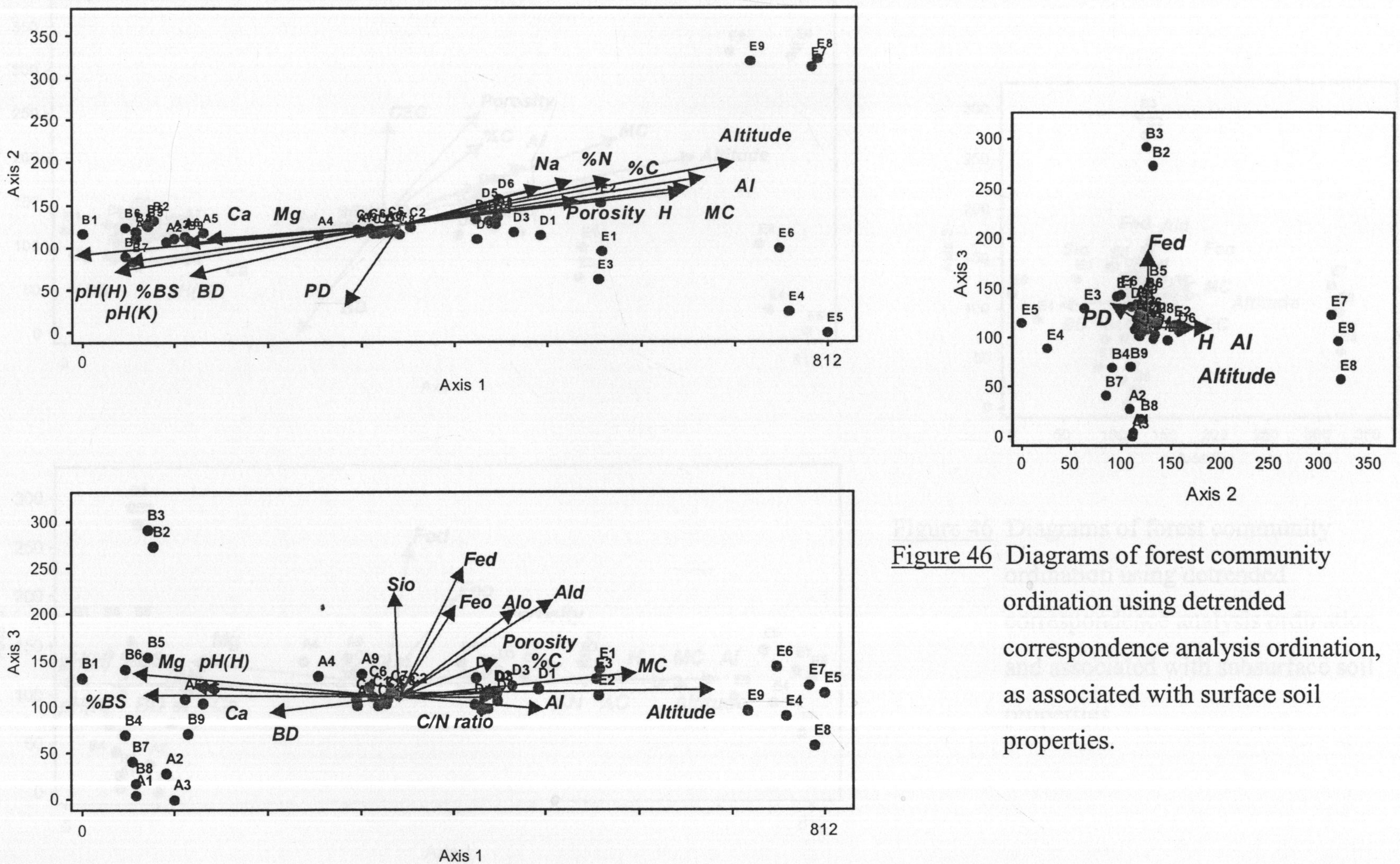


Figure 46 Diagrams of forest community ordination using detrended correspondence analysis ordination, as associated with surface soil properties.

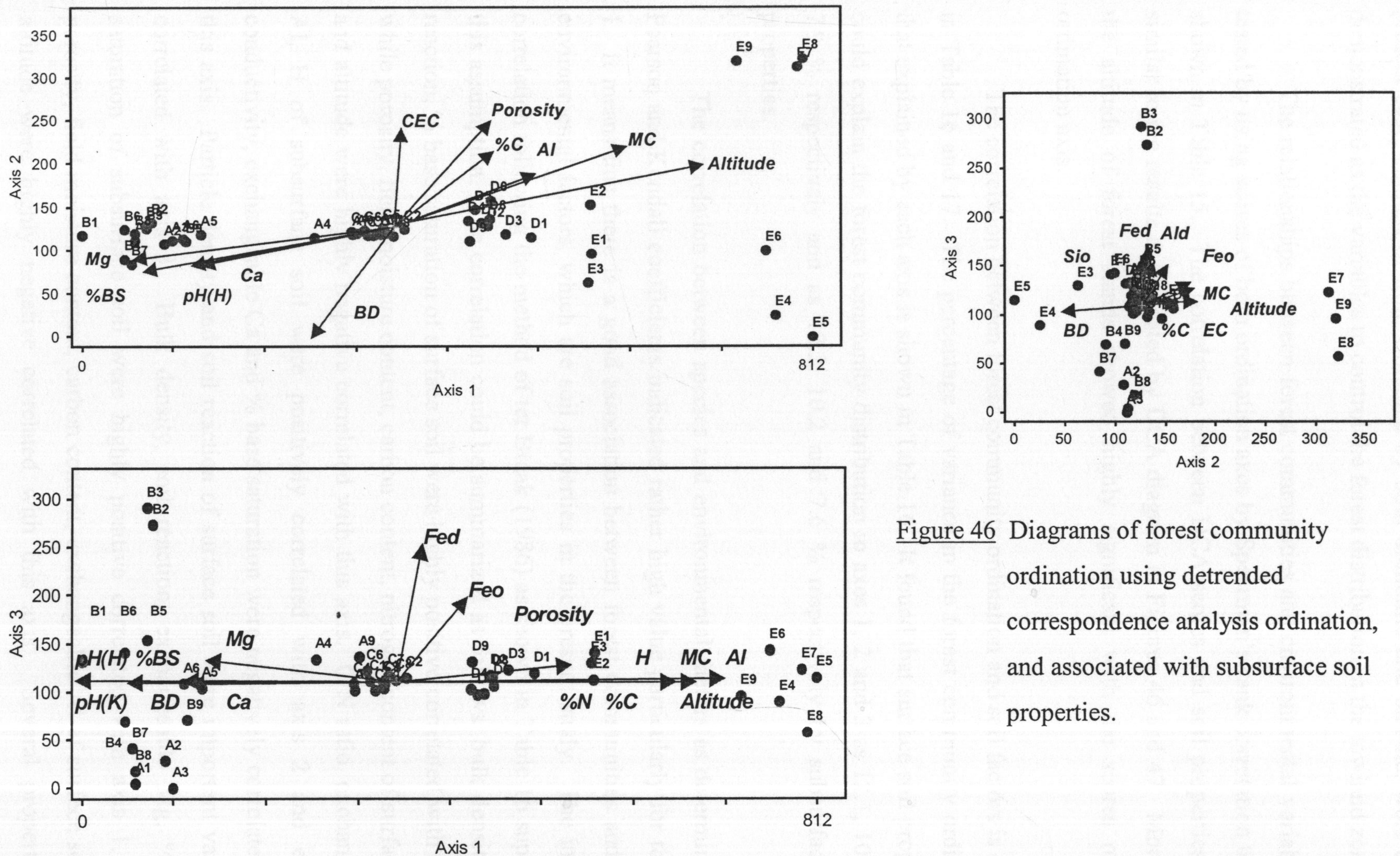


Figure 46 Diagrams of forest community ordination using detrended correspondence analysis ordination, and associated with subsurface soil properties.

present case, amount of iron, extracted by both dithionite and oxalate, were clearly demonstrated as the variables to control the forest distribution in the lowland zone.

The relationships between forest communities and environmental variables as tested by using scores of both ordination axes by Spearman's rank correlation test are shown in Table 15. The correlation between DCA scores and soil properties were similar to the results as indicated by DCA diagram in Figures 46 and 47. Moreover, the altitude of forest stands showed highly significant with the scores of first ordination axis.

The correlation between forest community ordination and soil factors is shown in Table 16 and 17. The percentage of variance in the forest community ordination that explained by each axis is shown in Table 16. It found that surface soil properties could explain the forest community distribution in axes 1, 2 and 3 as 12.1, 10.1 and 7.9 % respectively and as 12.2, 10.2 and 7.6 % respectively by subsurface soil properties.

The correlation between species and environmental factors as determined by Pearson and Kendall coefficients indicated rather high value particularly for the axis 1. It means that there is a good association between forest communities and some environmental factors, which are soil properties in the present study. The inter-set correlation following the method of ter Braak (1986) as shown in Table 16 supported this assumption. The correlation could be summarized as follows: bulk density, soil reaction, % base saturation of surface soil were highly positive correlated with axis 1, while porosity, field moisture content, carbon content, nitrogen content of surface soil and altitude were highly negative correlated with this axis. C/N ratio, exchangeable Al, H of subsurface soil were positively correlated with axis 2 and electric conductivity, exchangeable Ca and % base saturation were negatively correlated with this axis. Particle density and soil reaction of surface soil were important variables correlated with axis 3. Bulk density, soil reaction, exchangeable Mg, % base saturation of subsurface soil were highly positive correlated with axis 1, while porosity, field moisture content, carbon content, exchangeable Al of surface soil and altitude were highly negative correlated with this axis. Several properties of subsurface soil are dominating factors explaining the forest communities along the axis 2. It is also found that, clay content was positively correlated with the axis 2 in contrast to sand and silt content, % gravel, electric conductivity, nitrogen content and exchangeable Ca which were negatively correlated with this axis. For the axis 3, electric conductivity and CEC were positively correlated but bulk density was negatively correlated with this axis.

Table 15 The correlations between soil properties, altitude and scores of detrended correspondence analysis using Spearman's rank correlation test.

Soil properties	Detrended correspondence scores					
	Surface soil properties			Subsurface soil properties		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
Sand	0.390**	-0.115	-0.264	0.033	-0.229	-0.237
Silt	-0.465**	-0.004	0.084	-0.284	-0.020	-0.038
Clay	-0.238	0.081	0.214	0.084	0.189	0.151
% Gravel	-0.467**	-0.371*	-0.025	-0.541**	-0.519**	-0.111
BD	-0.723**	-0.294*	-0.111	-0.479	-0.414	-0.172
PD	-0.219	-0.176	0.176	-0.135	-0.061	0.122
Porosity	0.696**	0.280	0.126	0.416	0.317	0.229
MC	0.875**	0.294*	-0.024	0.746**	0.254	-0.050
Ks	0.312*	-0.058	-0.008	0.433	0.155	-0.108
pH (KCl)	-0.874**	-0.277	0.004	-0.144	-0.125	0.404**
pH (w)	-0.923**	-0.230	0.006	-0.758**	-0.310*	0.106
EC	0.209	0.051	0.096	0.040	-0.168	0.169
%C	0.710**	0.314*	-0.039	0.424**	0.147	0.130
%N	0.523**	0.143	-0.039	0.150	-0.078	0.137
C/N ratio	0.324*	0.428**	0.029	0.605**	0.307*	-0.002
P	0.308*	0.122	0.010	0.190	-0.102	-0.158
Al	0.913**	0.291	0.008	0.680**	0.317*	-0.122
H	0.905**	0.299*	0.010	0.466**	0.104	-0.147
K	-0.571**	-0.124	0.028	-0.499**	-0.167	0.106
Ca	-0.801**	-0.235	-0.116	-0.779**	-0.506**	0.165
Mg	-0.762**	-0.100	0.086	-0.880**	-0.206	0.169
Na	0.666**	0.178	-0.221	-0.186	0.062	-0.168
CEC	0.289	0.347*	0.150	-0.079	0.293*	0.139
%BS	-0.889**	-0.309*	-0.086	-0.865**	-0.429	0.085
Ald	0.613**	0.244	0.219	0.631**	0.245	0.310*
Sid	-0.035	0.136	0.014	-0.471**	-0.078	-0.178
Fed	0.331*	0.231	0.378*	0.350*	0.277	0.337*
Alo	0.541*	0.255	0.150	0.582**	0.372*	0.275
Sio	0.013	0.287	0.239	-0.070	0.371*	0.255
Feo	0.407**	0.237	0.365*	0.355*	0.198	0.317*
Alo/Ald	-0.216	-0.125	-0.223	-0.045	0.142	-0.079
Feo/Fed	0.215	-0.087	0.055	0.003	-0.087	0.091
Altitude	0.911**	0.285	0.093	0.911**	0.285	0.093

Table 16 The percentage of variance explained for each axis of forest community ordination.

	Canonical correspondence analysis		
	Axis 1	Axis 2	Axis 3
Surface Soils			
Eigenvalue	0.858	0.712	0.556
Variance in species data			
% of variance explained	12.1	10.1	7.9
Cumulative % explained	12.1	22.2	30.1
Pearson Correlation Spp-Env.	0.997	0.984	0.993
Kendall (Rank) Corr. Spp-Env.	0.925	0.754	0.776
Subsurface Soils			
Eigenvalue	0.860	0.722	0.540
Variance in species data			
% of variance explained	12.2	10.2	7.6
Cumulative % explained	12.2	22.4	30.0
Pearson Correlation Spp.-Env.	0.998	0.99	0.982
Kendall (Rank) Corr. Spp.-Env.	0.921	0.836	0.747

Table 17 The inter-set correlations of ter Braak (1986) between soil properties, altitude and score of canonical correspondence analysis.

Soil properties	Canonical correspondence scores					
	Surface Soils			Subsurface Soils		
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
Sand	-0.476	-0.049	0.103	-0.190	-0.530	0.082
Silt	0.412	-0.414	-0.099	0.020	-0.731	0.252
Clay	0.451	0.359	-0.183	0.121	0.668	-0.273
% Gravel	0.364	-0.445	-0.134	0.301	-0.655	-0.233
BD	0.770	-0.030	-0.060	0.708	0.247	-0.439
PD	0.359	0.078	-0.446	0.052	-0.305	-0.018
Porosity	-0.710	0.102	-0.058	-0.673	-0.294	0.294
MC	-0.876	0.153	0.013	-0.756	0.257	0.255
K	-0.322	0.065	-0.133	-0.359	-0.321	-0.095
pH(KCl)	0.779	-0.472	-0.201	0.162	-0.170	-0.186
pH(water)	0.888	-0.297	-0.059	0.677	-0.304	-0.169
EC	-0.583	-0.635	-0.017	-0.463	-0.577	0.301
% C	-0.732	0.058	0.042	-0.619	-0.361	0.170
% N	-0.767	-0.317	0.020	-0.490	-0.678	0.176
C/N	0.051	0.872	0.056	-0.407	0.319	0.030
P	-0.355	-0.271	0.186	-0.060	-0.031	-0.024
Al	-0.840	0.343	0.106	-0.553	0.255	0.247
H	-0.787	0.439	0.113	-0.414	0.142	0.144
K	0.535	-0.264	0.147	0.419	-0.033	0.117
Ca	0.621	-0.625	-0.120	0.558	-0.602	-0.190
Mg	0.632	-0.409	-0.054	0.815	-0.214	-0.042
Na	-0.608	0.070	0.108	0.163	-0.181	0.276
CEC	-0.432	-0.162	0.094	-0.243	-0.278	0.418
%BS	0.751	-0.507	-0.107	0.716	-0.454	-0.149
Ald	-0.527	0.408	-0.202	-0.698	0.117	-0.006
Sid	-0.083	-0.169	0.164	0.349	-0.155	0.038
Fed	-0.400	-0.111	-0.105	-0.492	0.030	-0.016
Alo	-0.429	0.473	-0.208	-0.606	0.161	0.048
Sio	0.170	0.486	-0.113	0.185	0.475	0.006
Feo	-0.635	-0.327	-0.017	-0.597	-0.380	0.164
Alo/Ald	0.359	0.264	-0.056	0.141	0.076	0.101
Feo/Fed	-0.529	-0.375	0.131	-0.338	-0.556	0.228
Altitude	-0.918	0.250	0.166	-0.918	0.250	0.166

Multiple linear regression models as shown below indicated the relationships between vegetation ordination patterns (DCA and CCA) and soil properties along the altitudinal gradients.

$$\text{DCA score of axis 1} = 1236.883 + 0.410\ \text{Altitude} - 219.736\ \text{pH(water)}_{(0\text{-}5)} - 6.571\ \text{MC}_{(20\text{-}25)} + 46.867\ \text{Mg}_{(0\text{-}5)} + 9.615\ \text{P}_{(20\text{-}25)}$$

$$r = 0.996,\ r^2 = 0.992$$

$$\text{DCA score of axis 2} = 695.735 - 236.559\ \text{PD}_{(0\text{-}5)} + 2.605\ \text{Silt}_{(20\text{-}25)} - 8.129\ \text{EC}_{(0\text{-}5)} + 1.259\ \text{P}_{(0\text{-}5)} + 5.104\ \text{P}_{(20\text{-}25)}$$

$$r = 0.984,\ r^2 = 0.968$$

$$\text{DCA score of axis 3} = -327.664 + 77.849\ \text{Mg}_{(20\text{-}25)} + 1.386\ \%\text{BS}_{(0\text{-}5)} + 99.743\ \text{PD}_{(0\text{-}5)} + 1.408\ \%\text{BS}_{(20\text{-}25)} + 80.675\ \text{PD}_{(20\text{-}25)} + 38.780\ \text{K}_{(0\text{-}5)} - 0.759\ \text{C/N}_{(0\text{-}5)}$$

$$r = 0.999,\ r^2 = 0.997$$

$$\text{CCA score of axis 1} = 285.973 - 0.069\ \text{Altitude} + 793.373\ \text{Na}_{(0\text{-}5)} - 1.294\ \text{MC}_{(0\text{-}5)} - 58.622\ \text{BD}_{(20\text{-}25)} - 0.537\ \text{Silt}_{(20\text{-}25)} - 23.337\ \text{PD}_{(0\text{-}5)} - 19.647\ \text{K}_{(20\text{-}25)} - 6.283\ \text{K}_{(0\text{-}5)}$$

$$r = 1.000,\ r^2 = 0.999$$

$$\text{CCA score of axis 2} = 47.059 + 2.243\ \text{C/N}_{(0\text{-}5)} + 2045.905\ \text{Ks}_{(0\text{-}5)} - 0.626\ \text{Gravel}_{(20\text{-}25)} - 2.076\ \text{EC}_{(0\text{-}5)} - 0.488\ \%\text{BS}_{(0\text{-}5)} - 34.625\ \text{H}_{(0\text{-}5)}$$

$$r = 0.995,\ r^2 = 0.990$$

$$\text{CCA score of axis 3} = 189.798 - \text{PD}_{(0\text{-}5)}$$

$$r = 0.701,\ r^2 = 0.491$$

These multiple regression models could be used for supporting the results of the simple linear relationships that have been proposed earlier in this study. The scores of DCA axis 1 of forest stand could be estimated by altitude, pH value and available Mg of surface soils as well as by moisture content and available phosphorus of subsurface soils. Particle density, electric conductivity and available phosphorus of surface soil together with silt content and available phosphorus of subsurface soils were also capable for estimating the scores of DCA axis 2. The scores of DCA axis 3 was able to be estimated by particle density, % base saturation, available potassium and C and N ratio of surface soils together with available Mg, % base saturation and particle density of subsurface soils. The scores of CCA axis 1 could also be estimated by altitude, pH value, available Na, K and particle density of surface soils together with silt content, bulk density and available K of subsurface soils. Therefore, the scores of CCA axis 2 was able to be estimated by C and N ratio, electric conductivity, % base saturation and exchangeable H of surface soils together with gravel content of subsurface soils. Particle density of surface soils is only a soil property that was able to estimate the scores of CCA axis 3. The comparison between results of DCA and CCA could be concluded that CCA axis 1 was similar to the combination of DCA axes 1 and 2 while CCA axis 2 was close to DCA axis 3. These analyses strongly support the clear quantitative relationships between soils and plants in Doi Inthanon National Park along the altitudinal gradients.

DISCUSSION

Forest Zonation along an Altitudinal Gradient in Doi Inthanon National Park

The forests of Thailand located in tropical monsoon climate zone are classified into two categories. Firstly, evergreen forest that the trees are physiognomically characterized by maintaining their green leaves throughout the year. Secondly, deciduous forest that most trees shed their leaves in the dry seasons (January to April). Santisuk (1988) suggested that the ecological distribution of the vegetation types in northern Thailand is fundamentally governed by two paramount factors, the available of moisture in the soil and elevation. The study of forest distribution along the altitude in Doi Inthanon so far suggest that the forest stands can be classified into six forest groups and three forest zones. Six forest community groups included lowland forest zone composing of group I *(Shorea siamensis - Canarium subulatum - Shorea obtusa)* and group II *(Tectona grandis - Xylia xylocarpa - Lagerstroemia calyculata - Millettia leucantha)*. Transition forest zone included group III *(Pinus kesiya - Dipterocarpus tuberculatus - Aporusa villosa - Wendlandia tinctoria - Schima wallichii - Helicia nilagirica)* and group IV *(Schima wallichii - Castanopsis ferox - Castanopsis tribuloides - Helicia nilagirica)*. Montane forest zone included group V *(Mastixia euonymoides - Castanopsis calathiformis - Drypetes indica)* and group VI *(Neolitsea pallens - Actinodaphne henryi - Rapanea yunnanensis)*. The lowland forest zone (400-850 m asl) is composed of two forest groups as described earlier by which forest group I referred to the deciduous dipterocarp forest (Faculty of Forestry, 1992; Santisuk, 1988) and forest group II, which is similarly classified as mixed deciduous forest (Faculty of Forestry, 1992) or tropical mixed deciduous forest (Santisuk, 1988) in which a few of evergreen tree species are well mixed with those of most deciduous tree species and recognized by Ogawa *et al.* (1961) as monsoon forest. These stands obviously show their distinctive structure and species diversity as compared to other forest stands at higher altitudes (Tables 2 and 3). However, there are some species of trees that occurred in this zone have in common with the transitional forest zone (Table 1). The characteristics of this zone are different from those found elsewhere in tropical wet zone e.g.; van Steenis (1984), Kitayama (1992), Pendry and Proctor (1997). Basal area and tree density in this study are lower than those reported by the studies found in other climatic regions. The distribution of vegetation in Doi Inthanon National Park is the typical of the ecological zonation in the monsoon climate zone where the distinctive dry period always prevail alternately with wet period as shown by pluviothermic graph in Figure 3. Logging and human disturbance are probably the main causes of the damage of this forest type as it contains many valuable timbers (e.g. teak; *T. grandis*) that might have been subjected to severe harvesting in an early period prior to the establishment of the National Park. Much of this land is high fertility and suitable for agriculture which is a factor that contributes to forest destruction for crop cultivation either permanently or temporarily. The transitional forest zone (850-1,400 m asl) is an intermediate zone between lowland and montane zones composing of upper dry dipterocarp forest, pine-dipterocarp forest, pine-oak forest and partly overlapping with the montane forest which may be referred to as lower montane forest as proposed by Santisuk (1988). *Pinus kesiya*, *Schima wallichii* and some species belonging to the Fagaceae family are dominant. Among canopy trees, *P. kesiya* is often found as an emergent tree in these forest stands. The characteristics of this zone are higher tree density and basal area than the lowland forest zone resulting in closed canopy and high stand density (Table 2). According to Nakashizuka *et al.* (1992), they classified a transition zone between the lowland forest zone and the montane forest zone in Malaysia by using the genera of plant to form the cluster of the forest community. The altitude of transition zone (Nakashizuka *et al.,* 1992) ranged between 700 and 1,100 m asl, which is a narrow range in comparison with that found in the Doi Inthanon mountain range in this study. In Doi Inthanon, changes in vegetation characteristics are less continuous than in the Malaysian forest studied by Nakashizuka *et al.* (1992) due to the extreme contrast between the lowland forest zone and the montane forest zone. The lowland zone is characterized by periodic drought, low soil moisture during the dry season and low humidity (Figure 3). In contrast, the montane forest zone is characterized by relatively uniform soil moisture due to high humidity and condensations from low clouds are always prevailing on this zone. Consequently, the transitional forest zone occurs over a wider altitudinal range in this region. Montane forest zone (1,400-2,500 m asl), the uppermost zone, is composed of two groups. This zone seems to be correspondent to those found by previous studies located in the more humid tropical regions (Richards, 1964; Vazquez and Givnish, 1998; Kitayama, 1992; Ohsawa *et al.*, 1985). The structure of forest stands in this zone can be separated into two groups as shown by Figure 8 and 9. The forest located between 1,500 and 1,800 m asl shows high tree density and basal area (Table 3), especially on the lower slopes. *Mastixia euonymoides* is the main dominant and canopy tree species and is found only in this area. The floristic characteristics of this high altitude plant community are not likely to be representative of the main species composition of the typical montane forest as their dominant tree families are not only Lauraceae and Fagaceae. However, forest stands located between 1,800 and 2,500 m asl are floristically dominated by those belonging to the families Lauraceae and Fagaceae.

The basal area and density of trees along the altitudinal gradient in Doi Inthanon tend to increase with altitude (Figure 17). The forests in the lowland zone have low tree basal area and density that can be attributed to some limiting factors. Low soil moisture in the dry season is considered to be the most significant factor affecting growth and development of trees in this zone. As shown in Figure 17, basal area and density of tree increase with the rising of altitude through the transitional and montane forest zones. These forest stands always obtain sufficient water via both the soil and the atmosphere making it possible for the trees in these stands to maintain their physiological activities even in dry season. This is particularly true of the montane forest zone, which is normally dominated by evergreen tree species.

Diversity of Tree Species

Diversity indices of tree species having DBH equal to or more than 4.5 cm have somewhat lower values in the lowland forest zone and increase monotonously from an altitude about 850 m asl in the transitional forest zone to an altitude around 1,800 m asl in the montane forest zone. Above this altitude they tend to decrease particularly Shannon-Wiener's, Hill's and Fisher's diversity indices as well as richness indices (Figure 18). However, evenness indices do not vary much along the altitudinal gradient. In the lowland forest zone, there are differences between the two groups of forest stands. The number of species in 0.16 ha plot are not found to vary much among the two forest groups, but the number of main species as determined by N1 and N2 (Table 3) show that group I are lower than group II. According to this result, it is attributable that the site capacity of forest group II is higher than group I therefore, several species are found luxuriantly in forest group II more than in group I. Furthermore, number of tree species of group II is greater than group I because of the habitat conditions of the forest stands of group I are more limiting. Disturbance is also an important factor in determining the success or failure of forest establishment and growth in this forest zone. Forest fire, which occurs almost every year, may cause accelerated soil erosion during the early rainy season. Therefore, forests of group I are more affected by those disturbances than forests of group II. The other reason can be explained by the nutrient availability in the soil. Higher amount of available nutrient is occurred in the forest stands of group II. So that, soil in forest group II are rather fertile than group I thus, number of tree species of group II can survive more than group I. This reason is supported by the studies of Khemnark *et al.* (1972), Kutintara (1975) and Bunyavejchewin (1983b). Adequate soil moisture content during the dry season and less disturbance are probably the main cause of the greater species diversity in transitional and montane forest zones, with diversity of tree species increasing up to the altitude of about 1,800 m asl. Diversity tends to decrease again at an altitude above 1,800 m asl, probably due to the decreasing of temperature with a rising in altitude. Temperature at an altitude of 1,800 m asl and above is always cooler, as shown in the pluviothermic diagram in Figure 3. Only some tree species can tolerate these temperatures and survive in this zone successfully. The other factors such as nutrient availability particularly nitrogen (Marr *et al.*, 1988), radiation concentration and humidity (Cavelier *et al.*, 1996) also affect to species diversity in montane forest. Moreover, a study of Vazquez and Givnish (1998) in tropical seasonal dry forest, Jalisco, Mexico suggested that the decline in plant species richness in tropical forest might cause from four reasons. The first is based on the theory of island biogeography. Local regions at high altitude are smaller in area and more isolated from similar habitats than those in low altitudes, and should thus support a lower equilibrium number of species. The second is based on the theory of equal species packing along gradients (Terborgh, 1973). A third explanation is structure and based on altitudinal differences in nutrient availability, forest stratification and plant speciation. The greater availability of nutrients at lower altitudes and moisture on rainier sites should reduce whole-plant compensation points. The final possibility may be related to altitudinal declines in the rate of plant growth and forest turnover.

Gradient Analysis and Forest Characteristics

Ordination of sample stand data by DCA (Figure 40) produced a plot of distribution pattern, which has been clearly described by the first three axes. The first gradient can be used to categorize into three forest zones, included lowland (400-850 m asl), transition (850-1,400 m asl) and montane (1,400-2,500 m asl) forest zones. The relative magnitude of the various correlations suggested that altitude plays a dominant role in determining the distribution of species and forest communities. This result supported the traditional view of the importance of altitude for the forest distribution in northern Thailand (Ogawa *et al.*, 1961 and Santisuk, 1988). Moreover, the first axis is the main gradient of soil properties, which change clearly along the altitude. The second axis display the differentiation of the forest in montane forest zone reflecting the difference of soil properties as affected from the dramatic decrease of temperature along the altitude. The third axis is the minor magnitude however it can be absolutely explained the criteria for classifying the difference among the forest in lowland zone.

There are some difference between ordination resulting from DCA and CCA. The ordination of sample stand data by CCA (Figure 41) produced a plot of distribution pattern, which has been clearly described by the first three axes as similar as the result of DCA. The first gradient can be used to categorize into three forest zones while second axis is able to determine the stand distribution between groups I, II, V and VI and groups III and VI. The third axis seems to be supported the second axis to classify the difference between groups V and VI.

Santisuk (1988) divided the forest in northern region of Thailand in upward sequence manner into two forest zones included lowland forest zone (below 1,000 m asl) and montane forest zone (above 1,000 m asl), which is further subdivided into lower and upper montane forests. The transition of two forests lies at approximately 1,800 m asl. According to Santisuk (1988), nine forest types were recognized in various altitudinal zones of the northern region. This suggestion rather differs from the tropical forest type along the altitude that proposed by Richards (1964) and Grubb *et al.*, (1963) as proposed before. The same data set used in this study also shows a clear association with DCA and CCA diagram presented here.

Soil Properties along the Altitude

The altitude is a main topographic gradient affecting to plant species distribution as well as soil properties along the differential altitude in tropical forests. According to the results in this study almost all soil properties are highly correlated with the first axis of DCA ordination as similarly as the altitude. The patterns of soil properties changing with the altitude seem to be consistent with some former study results reported elsewhere (Hanawalt and Whittaker, 1977; Hsieh *et al.,* 1998; Kitayama *et al.,* 1998 and Proctor *et al.,* 1983). For example, field moisture content, exchangeable Al and H, total N and C contents significantly increase with the altitude while soil reaction, both in KCl and water, base saturation, bulk density, exchangeable Ca and Mg decrease accordingly as shown in Table 15 by correlation efficiency. These properties are considered to be affected by the climatic changing along the altitude such as temperature decreasing with adiabatic lapse rate which is a reverse of the humidity rising as caused by the Massenerhebung effect (Grubb, 1977).

The highly weathering soils are dominantly represented around the mid of mountain at about 800 to 1,200 m asl altitudes as the high content of clay accumulation and deep profile are prevail on this altitudinal range. Clay fractions, which are important factor affecting chemical soil properties, PDF and POF soils exhibited high clay content, especially subsurface soils of PDF which were more than 50 %. Clay contents of soils generally increase with increasing precipitation and increasing temperature (Jenny, 1941). The increasing in clay fractions along the altitudinal gradient in Doi Inthanon National Park was found to be convex rather than linear. On the low altitude, air temperature is higher and soils always lack of moisture, while on the high altitude, humidity are higher and the temperature become lower. These gradients are dominantly occurred in the altitudinal zonation in drought climate zone. The results suggested that there is maximum clay formation (weathering processes) in the mid-altitudes resulting from the favorable combination of moisture and temperature at the current climatic condition. This concept would be consistent with Huntington (1954) and Hanawalt and Whittaker (1976) who found the maximum clay content on the mid-altitude. The characteristic of clay fraction change in Doi Inthanon is a typical pattern along the altitude in seasonal monsoon climate zone. Carbon content is a dominant factor which have increasing trend along the altitudinal gradient. It can be explained by reasonable hypothesis that in the lowland zone, the shortage of soil moisture during the periodic drought season of this region is the main limiting factor to determine forest community and soil development (Santisuk, 1988). Whist the low temperature condition is a main cause to obstruct any biotic and a biotic process in montane forest zone. Furthermore, organic matter and nitrogen compounds were broken down by heat of the fire (Kitur and Frye, 1983; Giovannini and Lucchesi, 1997), and some of organic matters generally lost due to erosion that often occur in low altitude areas. Several reports indicated that soil organic matter and soil acidity increase with the altitude (Grubb *et al.,* 1963; Marr *et al.,* 1988; Veneklass, 1991 and Pendry and Proctor, 1996) which is in consistent to the result of this study. However, the soil change is not smooth throughout the entire altitudinal gradient except for soil acidity, C and N contents. The high content of exchangeable Ca, Mg and K in soils on lowland zone presumably reflects the local variation in parent materials and occasional occurrence of forest disturbance. These elements are observed to be lesser content particularly on the montane zone that may cause from the different kind of parent materials. Pendleton (1962) reported that soils of montane forest in Doi Inthanon National Park are weathered from granite and gneiss as details shown in Figure 1. Available P is an important element limiting growth and plant distribution in tropical forest (Franken *et al.,* 1979; Proctor *et al.,* 1983 and Vitousek, 1984). However, this study does not show any obvious results on this aspect. It may cause from the high variation of sample site. Grubb (1977) proposed a hypothesis that the mineral supply is restricted in montane forest because a large proportion of nutrient is bound up in undecayed litter or mineralized humus.

The results of this present study also support this hypothesis that total nitrogen concentration are higher in montane forest however it may be both difficult and unavailable to be uptaken by plant. The available nitrogen is likely to be limited in both the rate of nitrogen mineralization and nitrification in soil (Marr *et al.*, 1988 and Kitayama *et al.*, 1998).

Soil and Plant Relationships

Although the altitude is an important factor contributing to plant distribution and soil development, however there are some evidences supporting that soil properties may affect the establishment of plant community. According to Tables 13 and 14, considerable different soil properties are found among each forest community group. However, a general pattern of soil may be grouped as (1) increasing porosity, field moisture content, carbon content, soil acidity and exchangeable Na, (2) decreasing bulk density and alkaline earth cations are obvious in the order of group I, II, III, IV, V and VI in consistent with the rising of the altitude.

The forest communities in lowland forest zone can be clearly separated by soil properties with particle density, % of gravel, exchangeable Ca, Mg, K, CEC, C/N ratio and % base saturation. Forest community group I (*Shorea siamensis - Canarium subulatum - Shorea obtusa*) are characterized by the poor soils, but on the other hand group II (*Tectona grandis - Xylia xylocarpa - Lagerstroemia calyculata - Millettia leucantha*) are distributed in the rather fertile soils. The results of statistical test shown in Tables 13 and 14 indicate that most of variables are highly significant different among the two forest communities. Physical properties are also distinguishable criteria to separate these communities particularly sand, silt contents and amount of gravel. Furthermore, this study also found that forest community group II as classified to be mixed deciduous forest by Santisuk (1988) especially in a community which *Tectona grandis* is a leading dominant species is very highly associated with the content of iron in the soil.

Two forest communities in transition zone show very close association with soil chemical properties as similar as the forest composition. These communities are characterized by the difference in organic matter as determined by carbon content. It is the main cause to differentiate between forest groups by physical soil properties, which included bulk density, porosity and field moisture content as shown in Table 13 and 14. In the opposite side, the difference in soil properties among the community of this forest zone is probably affected by the altitudinal gradient. The DCA diagram is also proved their differentiation.

Higher soil acidity and greater amount of organic matter are considered to be the dominant chemical characteristics of the tropical montane forest soils (Grubb *et al.,* 1963; Marr *et al.,* 1988; Veneklass, 1991 and Pendry and Procter, 1996). According to this result, exchangeable Al and H are very high in soil of the montane forest zone. This finding is coincident with other several studies (Veneklass, 1991 and Pendry and Procter, 1996). Lathwell and Grove (1986) proposed that exchangeable Al concentration was an important substantial factor affecting plant growth particularly plant root growth. Jarvis (1974) suggested that exchangeable Al, Ca and soil pH were the soil variables to determine the distribution of plant community. This suggestion was also supported by Neave *el al.* (1995) and Hseith *et al.* (1998). The details of Table 13, 14, 15, 16 and DCA diagram shown in Figures 46 and 47 clearly indicate that particle density, electric conductivity, exchangeable Al and H are the dominant soil properties to differentiate forest communities in montane forest zone. The forest community group V (*Mastixia euonymoides - Castanopsis calathiformis - Drypetes indica*) is found generally in low soil acidity, low exchangeable Al and H as compared to forest community group VI.

Although exchangeable Al and H are the important chemical soil variables controlling forest composition and structure in tropical-montane forest however, the amount of nitrogen is also recognized. Total nitrogen in soils of forest community group V where located at higher altitude show higher nitrogen concentration than in forest community group VI. Marr *et al.,* (1988) suggested on the functional activity of nitrogen in tropical montane forest that nitrogen-mineralization and nitrification rates might be reduced in this forest type, and may be a contributing factor controlling growth, species composition and stand structure.

CONCLUSION

The study on soil and plant relationships along an altitudinal gradient in Doi Inthanon National Park, Northern Thailand can be summarized as follows:

1. The forest stands in Doi Inthanon National Park could be classified into three forest zones as lowland, transitional and montane forest zones and subdivided into six forest groups along the altitudinal gradient based on cluster analysis method. Six forest community groups included lowland forest zone composing of group I *(Shorea siamensis - Canarium subulatum - Shorea obtusa)* and group II *(Tectona grandis - Xylia xylocarpa - Lagerstroemia calyculata - Millettia leucantha)*. Transition forest zone included group III *(Pinus kesiya - Dipterocarpus tuberculatus - Aporusa villosa - Wendlandia tinctoria - Schima wallichii - Helicia nilagirica)* and group IV *(Schima wallichii - Castanopsis ferox - Castanopsis tribuloides - Helicia nilagirica)*. Montane forest zone included group V *(Mastixia euonymoides - Castanopsis calathiformis - Drypetes indica)* and group *VI (Neolitsea pallens - Actinodaphne henryi - Rapanea yunnanensis)*.

2. Physical and chemical properties of soils among the forest communities in Doi Inthanon National Park are clearly different. The soil properties within forest community groups are given and discussed in detail.

3. Field moisture content, exchangeable Al, H and Na, total N and C contents, soil reaction, both dissolved by water and KCl, base saturation, bulk density, exchangeable Ca and Mg are the main variables to classify the forest community in different forest zones. Particle density, % of gravel, exchangeable Ca, Mg, K, CEC, C/N ratio and % base saturation are the significant soil properties to determine the difference between forest community group I and group II in lowland forest zone. Particle density, electric conductivity, exchangeable Al and H are the dominant soil properties to differentiate forest communities in montane forest zone.

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APPENDIX

Appendix 1 Important value index of tree species in various forest types.

Appendix Table 1 Important value index of tree species in deciduous dipterocarp forest stands.

Species	Family	A1	A2	A3	A4	A5	A6	A7	A8	A9	Sum
Albizia lebbeck	Leguminosae	0.00	0.00	0.00	0.00	0.00	3.14	0.00	0.00	0.00	3.14
Albizia odoratissima	Leguminosae	1.70	1.83	2.85	0.00	12.92	0.00	0.00	1.26	6.28	26.84
Anneslea fragrans	Theaceae	0.00	0.00	0.00	11.26	0.00	0.00	10.45	31.45	20.14	73.30
Antidesma acidum	Euphorbiaceae	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00
Antidesma ghaesembilla	Euphorbiaceae	0.00	7.74	0.00	2.80	7.28	0.00	0.00	1.21	0.00	19.02
Aporusa villosa	Euphorbiaceae	0.00	0.00	1.78	0.00	0.00	0.00	16.43	29.65	15.80	63.65
Artocarpus lakoocha	Moraceae	0.00	0.00	2.07	0.00	0.00	0.00	0.00	0.00	0.00	2.07
Bhesa robusta	Celastraceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.37	1.37
Bombax ceiba L.	Bombacaceae	5.56	10.70	0.00	0.00	5.51	3.41	0.00	0.00	0.00	25.17
Buchanania lanzan	Anacardiaceae	0.00	1.74	0.00	0.00	2.08	0.00	1.21	4.02	6.05	15.10
Callicarpa arborea	Lamiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.35	1.35
Canarium subulatum	Burseraceae	24.26	15.45	42.70	0.00	6.13	3.86	1.27	0.00	1.43	95.10
Canthium dicoccum	Rubiaceae	0.00	0.00	2.07	0.00	0.00	0.00	0.00	0.00	0.00	2.07
Canthium parvifolium	Rubiaceae	0.00	0.00	0.00	0.00	12.77	30.69	0.00	0.00	0.00	43.45
Canthium sp.	Rubiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	1.43
Cassia fistula	Leguminosae	0.00	0.00	0.00	0.00	4.21	0.00	0.00	0.00	0.00	4.21
Castanopsis argyrophylla	Fagaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.43	10.43
Castanopsis sp.1	Fagaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.56	2.56
Catunaregum tomentosa	Rubiaceae	0.00	4.72	1.77	0.00	0.00	0.00	0.00	0.00	0.00	6.49
Chionanthus sp.	Oleaceae	2.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.65	3.95
Colona flagrocarpa	Tiliaceae	0.00	0.00	0.00	0.00	2.05	0.00	0.00	0.00	0.00	2.05
Craibiodendron stellatum	Ericaceae	0.00	0.00	0.00	2.64	0.00	0.00	5.09	1.22	0.00	8.95
Cratoxylum formosum	Guttiferae	17.09	28.59	23.34	0.00	0.00	0.00	3.57	0.00	0.00	72.59
Dalbergia cultrata	Leguminosae	0.00	0.00	0.00	0.00	0.00	3.62	1.18	4.38	3.02	12.20
Dalbergia dongnaiensis	Leguminosae	0.00	2.92	0.00	0.00	23.20	28.48	0.00	0.00	0.00	54.59
Dalbergia oliveri	Leguminosae	0.00	0.00	2.94	0.00	2.54	0.00	0.00	0.00	0.00	5.48
Dalbergia rimosa	Leguminosae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.71	7.71
Dipterocarpus tuberculatus	Dipterocarpaceae	0.00	0.00	0.00	146.09	0.00	0.00	56.73	72.21	59.94	334.97
Ellipanthus tomentosus	Connaraceae	3.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.57

Appendix Table 1
(continued)

Species	Family	A1	A2	A3	A4	A5	A6	A7	A8	A9	Sum
Gardenia obtusifolia	Rubiaceae	0.00	3.42	8.29	0.00	0.00	3.21	0.00	0.00	0.00	14.92
Gardenia sootepensis	Rubiaceae	0.00	1.73	1.90	0.00	2.53	0.00	3.94	0.00	3.82	13.92
Garuga pinnata	Burseraceae	0.00	2.79	3.93	0.00	0.00	3.13	0.00	0.00	0.00	9.85
Glochidion sphaerogynum	Euphorbiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	1.41
Gluta usitata	Anacardiaceae	0.00	0.00	0.00	0.00	2.01	0.00	19.75	12.90	2.45	37.12
Grewia eriocarpa	Tiliaceae	0.00	0.00	1.86	0.00	4.77	3.18	3.65	0.00	3.03	16.50
Heterophragma sulfureum	Bignoniaceae	0.00	0.00	0.00	0.00	0.00	3.88	0.00	0.00	0.00	3.88
Hymenodictyon excelsum	Rubiaceae	0.00	1.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.71
Lagerstroemia calyculata	Lythraceae	0.00	30.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.92
Lagerstroemia macrocarpa	Lythraceae	0.00	11.01	0.00	0.00	0.00	28.87	0.00	0.00	0.00	39.88
Lagerstroemia speciosa	Lythraceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.33	7.33
Lannea coromandelica	Anacardiaceae	24.22	43.38	16.26	0.00	3.42	0.00	0.00	0.00	0.00	87.28
Lithocarpus polystachyus	Fagaceae	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.00	1.41	2.66
Litsea glutinosa	Lauraceae	1.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.70
Lophopetalum wallichii	Celastraceae	0.00	1.70	0.00	0.00	0.00	0.00	5.60	0.00	0.00	7.30
Maesa sp.	Myrsinaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.66	1.66
Mangifera caloneura	Anacardiaceae	0.00	3.67	0.00	8.45	0.00	0.00	2.53	1.22	0.00	15.87
Memecylon scutellatum	Melastomataceae	3.40	0.00	5.42	0.00	0.00	0.00	0.00	0.00	0.00	8.82
Millettia brandisiana	Leguminosae	0.00	0.00	1.94	0.00	0.00	0.00	0.00	0.00	0.00	1.94
Millettia leucantha	Leguminosae	19.39	10.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.25
Mitragyna brunonis	Rubiaceae	7.28	0.00	4.39	0.00	6.78	9.61	0.00	0.00	0.00	28.07
Morinda coreia	Rubiaceae	1.83	5.66	0.00	0.00	4.56	0.00	0.00	0.00	0.00	12.04
Morinda elliptica	Rubiaceae	0.00	1.78	0.00	0.00	2.15	3.43	0.00	0.00	0.00	7.35
Ochna integerrima	Ochnaceae	3.42	0.00	12.92	0.00	0.00	0.00	0.00	0.00	0.00	16.34
Phyllanthus emblica	Euphorbiaceae	0.00	0.00	0.00	0.00	0.00	3.12	0.00	1.19	5.67	9.99
Pinus kesiya	Pinaceae	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.00	1.38	2.63
Pterocarpus macrocarpus	Leguminosae	10.63	1.72	8.24	0.00	2.01	0.00	0.00	0.00	0.00	22.59
Quercus indica	Fagaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	1.43
Quercus kerrii	Fagaceae	0.00	0.00	0.00	16.25	0.00	0.00	5.66	1.23	31.61	54.75
Quercus kingiana	Fagaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.71	6.84	10.55

Appendix Table 1
(continued)

Species	Family	A1	A2	A3	A4	A5	A6	A7	A8	A9	Sum
Quercus ramsbottomii	Fagaceae	0.00	0.00	0.00	0.00	0.00	0.00	61.54	53.64	17.13	132.30
Rubiaceae	Rubiaceae	0.00	0.00	3.68	0.00	0.00	0.00	0.00	0.00	0.00	3.68
Schima wallichii	Theaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.53	0.00	1.53
Shorea obtusa	Dipterocarpaceae	0.00	0.00	0.00	71.91	37.81	4.62	30.19	0.00	9.74	154.27
Shorea siamensis	Dipterocarpaceae	97.23	89.26	88.25	2.70	124.71	152.84	6.42	0.00	0.00	561.42
Sindora siamensis	Leguminosae	5.04	0.00	10.83	0.00	0.00	0.00	0.00	0.00	0.00	15.86
Spondias pinnata	Anacardiaceae	2.16	1.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.99
Stereospermum neuranthum	Bignoniaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.30	6.30
Strychnos nux-vomica	Strychnaceae	0.00	0.00	0.00	2.77	4.64	3.22	0.00	0.00	1.37	12.00
Symplocos racemosa	Symplocaceae	0.00	0.00	2.13	3.18	0.00	0.00	9.07	0.00	1.41	15.78
Symplocos sp.	Symplocaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.73	20.74	23.46
Syzygium cumini	Myrtaceae	0.00	0.00	0.00	29.25	0.00	0.00	0.00	0.00	9.55	38.80
Syzygium siamensis	Myrtaceae	0.00	0.00	0.00	0.00	0.00	0.00	1.25	3.80	0.00	5.05
Tarenna collinsae	Rubiaceae	0.00	1.69	3.51	0.00	0.00	0.00	0.00	0.00	1.37	6.57
Terminalia chebula	Combretaceae	0.00	0.00	0.00	2.73	7.78	0.00	0.00	0.00	2.10	12.61
Terminalia sp.	Combretaceae	0.00	1.72	0.00	0.00	0.00	0.00	0.00	1.58	1.38	4.68
Terminalia triptera	Combretaceae	36.85	0.00	23.93	0.00	0.00	0.00	0.00	0.00	0.00	60.78
Tristania rufescens	Myrtaceae	0.00	0.00	0.00	0.00	0.00	0.00	9.21	28.84	1.39	39.43
Vaccinium sp.1	Ericaceae	0.00	0.00	0.00	0.00	0.00	0.00	3.02	0.00	1.40	4.42
Vaccinium sprengelii	Ericaceae	0.00	0.00	0.00	0.00	0.00	0.00	23.52	22.23	4.40	50.16
Vitex peduncularis	Labiatae	0.00	0.00	0.00	0.00	7.90	0.00	4.68	3.95	3.69	20.21
Vitex pinnata	Labiatae	25.84	9.78	4.82	0.00	0.00	0.00	0.00	0.00	0.00	40.43
Walsura trichostemon	Meliaceae	0.00	0.00	4.93	0.00	0.00	0.00	0.00	0.00	0.00	4.93
Wendlandia tinctoria	Rubiaceae	0.00	0.00	0.00	0.00	0.00	0.00	11.52	16.05	10.80	38.36
Xylia xylocarpa var. kerrii	Leguminosae	2.52	1.71	13.26	0.00	10.24	7.70	0.00	0.00	0.00	35.44
Grand Total		300	300	300	300	300	300	300	300	300	2700

Appendix Table 2 Important value index of tree species in mixed deciduous forest stands.

Species	Family	B1	B2	B3	B4	B5	B6	B7	B8	B9	Sum
Adenanthera pavonina	Leguminosae	0.00	0.00	0.00	0.00	0.00	0.00	3.74	8.64	0.00	12.38
Aegle marmelos	Rutaceae	0.00	0.00	0.00	0.00	0.00	9.43	0.00	0.00	0.00	9.43
Aesculus assamica	Hippocastanaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.65	2.65
Albizia lebbeck	Leguminosae	0.00	0.00	6.87	0.00	0.00	0.00	8.52	0.00	0.00	15.39
Albizia odoratissima	Leguminosae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.29	2.29
Anogeisus acuminata	Combretaceae	0.00	8.45	0.00	0.00	32.56	3.13	11.54	40.16	0.00	95.83
Antidesma acidum	Euphorbiaceae	0.00	0.00	0.00	0.00	45.13	0.00	0.00	0.00	0.00	45.13
Antidesma ghaesembilla	Euphorbiaceae	0.00	3.57	0.00	0.00	0.00	0.00	0.00	5.50	11.82	20.90
Bauhinia variegata	Leguminosae	0.00	0.00	0.00	11.09	0.00	0.00	0.00	0.00	3.32	14.40
Bombax ceiba L.	Bombacaceae	0.00	0.00	0.00	10.12	5.10	2.72	0.00	0.00	3.07	21.01
Bridelia retusa	Euphorbiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.53	7.23	10.76
Callicarpa arborea	Lamiaceae	0.00	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.50
Cananga latifolia	Annonaceae	0.00	0.00	0.00	0.00	0.00	0.00	28.33	0.00	0.00	28.33
Canarium subulatum	Burseraceae	0.00	3.53	0.00	34.76	0.00	2.60	4.95	0.00	2.25	48.09
Canthium parvifolium	Rubiaceae	0.00	0.00	0.00	0.00	0.00	2.83	0.00	0.00	8.27	11.10
Careya sphaerica	Lecythidaceae	0.00	0.00	0.00	0.00	0.00	7.98	0.00	3.87	0.00	11.85
Cassia fistula	Leguminosae	6.80	0.00	0.00	0.00	0.00	3.71	4.00	2.74	0.00	17.25
Chukrasia velutina	Meliaceae	0.00	0.00	0.00	0.00	0.00	12.24	0.00	0.00	0.00	12.24
Cordia dichotoma	Boraginaceae	0.00	3.71	0.00	0.00	8.94	0.00	0.00	0.00	0.00	12.65
Cordia sp.	Boraginaceae	0.00	0.00	0.00	0.00	26.78	0.00	0.00	0.00	0.00	26.78
Cratoxylum formosum	Guttiferae	0.00	0.00	0.00	6.38	20.92	0.00	5.58	8.92	22.14	63.93
Croton oblongifolius	Euphorbiaceae	0.00	0.00	0.00	0.00	0.00	5.41	0.00	0.00	0.00	5.41
Dalbergia cultrata	Leguminosae	0.00	0.00	0.00	0.00	8.47	5.50	0.00	0.00	5.86	19.83
Dalbergia dongnaiensis	Leguminosae	6.95	0.00	0.00	4.88	5.82	0.00	3.75	2.96	22.44	46.79
Dalbergia nigrescens	Leguminosae	0.00	0.00	0.00	8.85	0.00	10.85	0.00	0.00	0.00	19.70
Dalbergia oliveri	Leguminosae	16.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.89
Diospyros mollis	Ebenaceae	0.00	0.00	0.00	6.79	0.00	0.00	0.00	0.00	0.00	6.79
Diospyros montana	Ebenaceae	0.00	0.00	0.00	0.00	0.00	0.00	3.78	0.00	0.00	3.78
Ehretia sp.	Boraginaceae	9.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.14
Engelhardtia spicata	Juglandaceae	0.00	3.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.43
Gardenia sootepensis	Rubiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.02	5.02
Garuga pinnata	Burseraceae	0.00	0.00	0.00	0.00	0.00	0.00	27.60	0.00	2.11	29.71

Appendix Table 2
(continued)

Species	Family	B1	B2	B3	B4	B5	B6	B7	B8	B9	Sum
Gmelina arborea	Labiatae	0.00	0.00	0.00	0.00	9.86	0.00	0.00	11.74	0.00	21.60
Grewia eriocarpa	Tiliaceae	0.00	17.76	25.79	0.00	0.00	0.00	0.00	0.00	11.02	54.57
Haldina cordifolia	Rubiaceae	7.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.90
Holarrhena pubescens	Apocynaceae	0.00	0.00	0.00	0.00	0.00	0.00	19.23	14.50	0.00	33.73
Hymenodictyon excelsum	Rubiaceae	0.00	0.00	0.00	16.29	0.00	0.00	4.49	0.00	14.73	35.51
Lagerstroemia balansae	Lythraceae	0.00	0.00	0.00	0.00	0.00	0.00	15.09	0.00	0.00	15.09
Lagerstroemia calyculata	Lythraceae	11.20	0.00	0.00	15.80	0.00	14.36	87.57	70.78	29.43	229.13
Lagerstroemia villosa	Lythraceae	7.38	0.00	0.00	0.00	0.00	0.00	0.00	20.67	0.00	28.05
Lannea coromandelica	Anacardiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.73	2.53	5.26
Litsea glutinosa	Lauraceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	0.00	7.00
Millettia brandisiana	Leguminosae	0.00	0.00	0.00	10.86	7.75	0.00	0.00	0.00	0.00	18.61
Millettia leucantha	Leguminosae	66.58	0.00	14.68	39.02	19.79	24.72	7.19	0.00	2.37	174.36
Mitragyna brunonis	Rubiaceae	10.44	0.00	0.00	3.77	5.36	0.00	3.76	6.51	6.46	36.31
Morinda elliptica	Rubiaceae	0.00	0.00	0.00	0.00	0.00	7.13	0.00	0.00	0.00	7.13
Oroxylum indicum	Bignoniaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.37	5.37
Phyllanthus emblica	Euphorbiaceae	0.00	0.00	0.00	0.00	0.00	3.03	0.00	0.00	0.00	3.03
Premna sp.	Labiatae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.08	0.00	4.08
Pterocarpus macrocarpus	Leguminosae	0.00	3.55	0.00	0.00	14.89	16.09	21.30	12.41	33.26	101.49
Sarcosperma arboreum	Sapotaceae	0.00	0.00	0.00	10.80	0.00	0.00	5.29	0.00	0.00	16.08
Schima wallichii	Theaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.53	0.00	2.53
Schleichera oleosa	Sapindaceae	0.00	0.00	0.00	0.00	5.17	2.69	0.00	6.12	2.10	16.08
Shorea siamensis	Dipterocarpaceae	0.00	0.00	0.00	0.00	0.00	13.70	0.00	0.00	0.00	13.70
Spondias pinnata	Anacardiaceae	0.00	0.00	0.00	9.44	0.00	2.76	0.00	15.23	2.17	29.61
Stereospermum cylindricum	Bignoniaceae	0.00	0.00	0.00	3.50	0.00	0.00	0.00	0.00	0.00	3.50
Stereospermum neuranthum	Bignoniaceae	0.00	0.00	0.00	0.00	17.14	0.00	0.00	0.00	0.00	17.14
Strychnos nux-vomica	Strychnaceae	0.00	22.89	34.50	0.00	0.00	0.00	0.00	0.00	2.15	59.54
Styrax benzoides	Stryraceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.70	11.70
Tectona grandis	Labiatae	89.96	154.41	128.55	4.06	30.74	52.98	0.00	0.00	0.00	460.70
Terminalia chebula	Combretaceae	0.00	3.49	5.64	0.00	0.00	0.00	0.00	0.00	0.00	9.13
Terminalia dafeuillana	Combretaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.54	7.25	9.79
Terminalia sp.	Combretaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.87	32.75	35.62

Appendix Table 2
(continued)

Species	Family	B1	B2	B3	B4	B5	B6	B7	B8	B9	Sum
Terminalia triptera	Combretaceae	0.00	0.00	0.00	17.78	0.00	0.00	6.38	5.95	0.00	30.10
Vitex canescens	Labiatae	0.00	0.00	0.00	0.00	7.03	3.03	17.24	0.00	0.00	27.30
Vitex peduncularis	Labiatae	0.00	0.00	4.96	0.00	0.00	2.63	0.00	0.00	5.29	12.88
Vitex pinnata	Labiatae	0.00	0.00	5.09	21.61	0.00	11.08	0.00	2.56	0.00	40.34
Vitex vestita	Labiatae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.56	5.68	8.24
Wrightia arborea	Apocynaceae	6.55	0.00	0.00	0.00	5.09	0.00	0.00	2.58	0.00	14.21
Xylia xylocarpa var. kerrii	Leguminosae	45.83	71.71	69.14	9.73	17.65	79.41	0.00	30.30	27.28	351.05
Zizyphus oenoplia	Rhamnaceae	0.00	0.00	4.77	32.83	5.79	0.00	0.00	0.00	0.00	43.39
Zollingeria acuminata	Sapindaceae	14.38	0.00	0.00	21.64	0.00	0.00	10.68	0.00	0.00	46.70
Grand Total		300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	2700.00

Appendix Table 3 Important value index of tree species in pine-dipterocarp forest stands.

Species	Family	C1	C2	C3	C4	C5	C6	C7	C8	C9	Sum
Actinodaphne sp.1	Lauraceae	0.00	0.00	1.74	0.00	0.00	0.00	0.00	0.00	0.00	1.74
Adinandra sp.	Theaceae	0.00	0.00	0.00	0.00	0.00	1.45	0.00	0.00	0.00	1.45
Albizia chinensis	Leguminosae	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	1.47
Albizia lebbeck	Leguminosae	0.00	0.00	4.20	0.00	0.00	1.69	0.00	0.00	12.08	17.97
Albizia odoratissima	Leguminosae	8.25	8.14	11.18	1.25	0.00	0.00	0.00	0.00	0.00	28.83
Anneslea fragrans	Theaceae	2.25	4.43	0.00	15.22	2.80	5.81	4.98	14.00	8.58	58.07
Antidesma ghaesembilla	Euphorbiaceae	1.92	1.45	1.53	0.00	0.00	6.81	0.00	0.00	0.00	11.71
Aporusa villosa	Euphorbiaceae	3.91	29.83	4.74	26.44	36.20	44.30	13.27	28.64	27.53	214.87
Artocarpus lakoocha	Moraceae	0.00	0.00	9.56	0.00	0.00	0.00	0.00	0.00	0.00	9.56
Artocarpus sp.	Moraceae	0.00	0.00	0.00	0.00	2.27	0.00	0.00	0.00	0.00	2.27
Beilschmiedia gammieana	Lauraceae	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.95
Bhesa robusta	Celastraceae	0.00	0.00	0.00	1.32	6.00	0.00	3.26	29.19	11.21	50.98
Bridelia retusa	Euphorbiaceae	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	1.50
Buchanania lanzan	Anacardiaceae	0.00	3.67	2.29	1.27	0.00	0.00	0.00	5.58	0.00	12.80
Callicarpa arborea	Lamiaceae	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00	1.40
Canarium subulatum	Burseraceae	0.00	0.00	1.51	1.55	0.00	3.66	0.00	0.00	0.00	6.71
Canthium sp.	Rubiaceae	0.00	0.00	1.40	0.00	0.00	0.00	0.00	3.18	0.00	4.59
Careya sphaerica	Lecythidaceae	0.00	0.00	0.00	0.00	2.66	0.00	0.00	0.00	0.00	2.66
Castanopsis argyrophylla	Fagaceae	12.80	8.64	0.00	0.00	0.00	6.32	0.00	3.82	2.34	33.93
Castanopsis armata	Fagaceae	1.89	1.55	1.88	0.00	0.00	0.00	0.00	0.00	0.00	5.33
Castanopsis sp.1	Fagaceae	0.00	1.44	2.21	0.00	0.00	0.00	0.00	0.00	0.00	3.65
Castanopsis sp.2	Fagaceae	2.34	0.00	4.87	0.00	0.00	0.00	0.00	0.00	0.00	7.21
Colona flagrocarpa	Tiliaceae	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00	1.40
Craibiodendron stellatum	Ericaceae	12.93	1.69	3.08	11.67	2.48	1.57	2.91	7.12	4.60	48.05
Cratoxylum cochinchinensis	Guttiferae	3.11	0.00	6.41	0.00	0.00	4.45	0.00	0.00	0.00	13.97
Cratoxylum formosum	Guttiferae	1.90	0.00	2.70	0.00	0.00	0.00	0.00	0.00	2.20	6.80
Dalbergia cultrata	Leguminosae	2.58	1.44	2.04	8.28	12.51	8.36	6.72	4.99	0.00	46.92
Dalbergia dongnaiensis	Leguminosae	2.65	13.05	6.16	0.00	0.00	0.00	0.00	11.38	0.00	33.24
Dalbergia nigrescens	Leguminosae	0.00	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49
Dalbergia rimosa	Leguminosae	0.00	0.00	0.00	0.00	0.00	1.48	0.00	0.00	0.00	1.48
Dillenia obovata	Dilleniaceae	0.00	1.50	0.00	0.00	0.00	0.00	0.00	3.24	0.00	4.74
Dillenia ovata	Dilleniaceae	0.00	0.00	3.66	0.00	0.00	0.00	0.00	0.00	0.00	3.66

Appendix Table 3
(continued)

Species	Family	C1	C2	C3	C4	C5	C6	C7	C8	C9	Sum
Diospyros ehretioides	Ebenaceae	0.00	0.00	0.00	0.00	2.31	0.00	0.00	0.00	0.00	2.31
Dipterocarpus tuberculatus	Dipterocarpaceae	34.47	15.89	14.29	52.13	65.64	37.10	43.58	38.41	16.29	317.79
Ellipanthus tomentosus	Connaraceae	0.00	0.00	0.00	0.00	0.00	1.45	0.00	0.00	0.00	1.45
Engelhardtia spicata	Juglandaceae	0.00	1.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.68
Gardenia sootepensis	Rubiaceae	0.00	0.00	1.40	5.41	0.00	4.45	6.43	1.55	0.00	19.24
Glochidion sphaerogynum	Euphorbiaceae	0.00	0.00	3.52	0.00	0.00	0.00	0.00	0.00	0.00	3.52
Gluta usitata	Anacardiaceae	17.67	12.67	12.14	10.81	18.19	6.69	22.91	2.81	5.77	109.65
Grewia eriocarpa	Tiliaceae	2.67	1.96	7.48	1.32	0.00	0.00	1.42	0.00	0.00	14.84
Helicia nilagirica	Proteaceae	3.01	9.47	8.27	0.00	0.00	0.00	0.00	0.00	0.00	20.75
Heliciopsis terminalis	Proteaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.58	0.00	1.58
Ilex umbellulata	Aquifoliaceae	0.00	0.00	3.47	0.00	0.00	1.56	0.00	0.00	0.00	5.03
Lagerstroemia macrocarpa	Lythraceae	0.00	0.00	1.74	0.00	0.00	0.00	0.00	0.00	0.00	1.74
Lithocarpus aggregatus	Fagaceae	0.00	8.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.04
Lithocarpus polystachyus	Fagaceae	21.90	10.15	35.48	0.00	0.00	1.46	0.00	8.79	0.00	77.78
Lithocarpus sp.	Fagaceae	0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.45
Lophopetalum wallichii	Celastraceae	0.00	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.00	1.42
Maesa sp.	Myrsinaceae	0.00	0.00	0.00	1.43	0.00	0.00	0.00	0.00	0.00	1.43
Mangifera caloneura	Anacardiaceae	4.59	0.00	1.76	1.59	0.00	3.02	0.00	0.00	0.00	10.96
Maytenus curtisii	Celastraceae	0.00	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.44
Phyllanthus emblica	Euphorbiaceae	0.00	1.45	0.00	3.03	0.00	2.54	0.00	0.00	0.00	7.02
Pinus kesiya	Pinaceae	80.76	34.71	35.14	28.30	66.38	70.51	60.06	29.87	80.67	486.41
Premna villosa	Labiatae	0.00	0.00	1.62	0.00	0.00	0.00	0.00	0.00	0.00	1.62
Pterocarpus macrocarpus	Leguminosae	1.95	0.00	0.00	0.00	2.28	0.00	0.00	0.00	0.00	4.23
Quercus kerrii	Fagaceae	11.75	2.04	0.00	2.66	0.00	16.13	15.11	16.21	8.54	72.45
Quercus kingiana	Fagaceae	0.00	0.00	0.00	0.00	0.00	2.46	0.00	0.00	0.00	2.46
Quercus ramsbottomii	Fagaceae	9.13	34.59	6.19	64.28	37.56	9.33	14.82	2.93	22.37	201.21
Quercus sp.	Fagaceae	0.00	0.00	13.79	0.00	0.00	1.83	0.00	0.00	0.00	15.62
Schima wallichii	Theaceae	0.00	15.71	8.78	0.00	2.29	0.00	1.44	13.63	8.59	50.45
Shorea obtusa	Dipterocarpaceae	2.12	0.00	0.00	8.25	5.41	3.40	0.00	0.00	0.00	19.17
Shorea siamensis	Dipterocarpaceae	0.00	26.72	28.42	4.62	0.00	3.44	0.00	10.34	24.16	97.70

Appendix Table 3
(continued)

Species	Family	C1	C2	C3	C4	C5	C6	C7	C8	C9	Sum
Stereospermum neuranthum	Bignoniaceae	0.00	0.00	0.00	1.32	0.00	0.00	0.00	0.00	0.00	1.32
Styrax benzoides	Stryraceae	0.00	0.00	2.92	0.00	0.00	0.00	0.00	0.00	0.00	2.92
Symplocos racemosa	Symplocaceae	0.00	0.00	0.00	0.00	0.00	0.00	6.96	0.00	2.20	9.16
Symplocos sp.	Symplocaceae	0.00	0.00	0.00	0.00	0.00	1.52	1.42	0.00	0.00	2.94
Syzygium cumini	Myrtaceae	0.00	0.00	0.00	0.00	0.00	1.67	0.00	0.00	0.00	1.67
Syzygium siamensis	Myrtaceae	0.00	2.79	1.46	0.00	0.00	0.00	0.00	0.00	0.00	4.25
Terminalia chebula	Combretaceae	0.00	0.00	0.00	5.48	0.00	1.48	1.62	0.00	0.00	8.58
Ternstroemia gymnanthera	Theaceae	0.00	1.46	0.00	0.00	0.00	0.00	0.00	2.22	0.00	3.67
Tristania rufescens	Myrtaceae	3.34	0.00	1.43	0.00	0.00	0.00	25.82	8.11	23.69	62.39
Tristaniopsis burmanica	Myrtaceae	0.00	1.46	0.00	10.47	4.89	23.12	0.00	0.00	0.00	39.94
Unidentified	Unidentified	0.00	0.00	1.74	0.00	0.00	0.00	0.00	1.57	0.00	3.31
Vaccinium sp.1	Ericaceae	0.00	0.00	0.00	0.00	0.00	1.62	0.00	0.00	0.00	1.62
Vaccinium sp.2	Ericaceae	0.00	0.00	0.00	0.00	0.00	1.57	0.00	0.00	0.00	1.57
Vaccinium sprengelii	Ericaceae	8.23	13.07	0.00	12.14	8.63	2.96	25.69	10.70	11.45	92.88
Vaccinium whitmove	Ericaceae	0.00	0.00	0.00	0.00	0.00	1.47	0.00	1.59	0.00	3.07
Viburnum inopinatum	Caprifoliaceae	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.00	1.47
Vitex peduncularis	Labiatae	5.82	5.22	0.00	1.30	2.50	1.60	0.00	9.63	2.24	28.31
Vitex pinnata	Labiatae	2.74	0.00	0.00	1.32	0.00	0.00	0.00	0.00	0.00	4.06
Wendlandia tinctoria	Rubiaceae	31.37	19.71	33.51	15.66	19.00	10.25	40.16	28.92	25.49	224.06
Grand Total		300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	2700.00

Appendix Table 4 Important value index of tree species in pine-oak forest stands.

Species	Family	D1	D2	D3	D4	D5	D6	D7	D8	D9	Sum
Actinodaphne henryi	Lauraceae	1.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.71
Adenanthera pavonina	Leguminosae	0.00	0.00	0.00	2.19	8.54	0.00	0.00	0.00	0.00	10.73
Albizia chinensis	Leguminosae	2.19	4.59	0.00	0.00	0.00	4.59	0.00	0.00	0.00	11.37
Albizia odoratissima	Leguminosae	0.00	0.00	0.00	0.00	0.00	0.00	1.33	0.00	0.00	1.33
Anneslea fragrans	Theaceae	0.00	3.07	0.00	10.68	1.72	0.00	4.70	1.96	11.99	34.12
Aporusa villosa	Euphorbiaceae	32.25	2.94	33.95	20.92	27.94	63.40	57.22	12.64	32.62	283.88
Archidendron clypearia	Leguminosae	0.00	2.96	0.00	1.82	2.75	0.00	2.60	2.85	1.40	14.37
Artocarpus chaplasha	Moraceae	0.00	0.00	0.00	1.79	1.12	0.00	0.00	0.00	0.00	2.92
Artocarpus lakoocha	Moraceae	0.00	0.00	0.00	0.00	0.00	2.11	0.00	0.00	0.00	2.11
Artocarpus lanceolata	Moraceae	6.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.35
Beilschmiedia sp.	Lauraceae	1.62	0.00	0.00	0.00	0.00	0.00	2.89	1.41	0.00	5.92
Buchanania lanzan	Anacardiaceae	0.00	6.62	8.02	9.60	1.27	11.12	0.00	0.00	21.51	58.14
Callicarpa arborea	Verbenaceae	0.00	0.00	0.00	0.00	0.00	0.00	1.82	0.00	0.00	1.82
Canarium subulatum	Burseraceae	0.00	1.48	0.00	0.00	0.00	0.00	2.21	0.00	0.00	3.69
Castanopsis acuminatissima	Fagaceae	0.00	3.60	0.00	0.00	1.21	2.12	2.66	4.25	0.00	13.85
Castanopsis armata	Fagaceae	1.90	8.18	21.19	0.00	2.59	2.80	9.94	6.86	0.00	53.46
Castanopsis calathiformis	Fagaceae	5.47	0.00	0.00	0.00	0.00	0.00	2.43	1.40	0.00	9.30
Castanopsis cerebrina	Fagaceae	0.00	0.00	0.00	1.79	0.65	0.00	0.00	4.83	7.42	14.69
Castanopsis indica	Fagaceae	5.50	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	6.09
Castanopsis tribuloides	Fagaceae	2.12	3.85	4.60	5.20	0.00	0.00	4.10	11.94	11.90	43.71
Chionanthus ramiflorus	Oleaceae	0.00	0.00	0.00	3.83	2.49	5.65	0.00	0.00	0.00	11.97
Cleidon javanicum	Euphorbiaceae	4.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.29
Colona floribunda	Tiliaceae	1.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.84
Craibiodendron stellatum	Ericaceae	0.00	1.52	0.00	0.00	5.25	0.00	0.00	0.00	0.00	6.77
Cratoxylum cochinchinensis	Guttiferae	0.00	0.00	0.00	0.00	9.10	0.00	9.05	0.00	0.00	18.15
Dalbergia cochinchinensis	Leguminosae	0.00	0.00	0.00	1.81	0.00	0.00	0.00	0.00	0.00	1.81
Dalbergia cultrata	Leguminosae	0.00	0.00	4.06	12.21	9.67	8.77	11.86	26.03	7.88	80.48
Dalbergia dongnaiensis	Leguminosae	0.00	0.00	0.00	0.00	0.00	0.00	1.21	0.00	0.00	1.21
Dalbergia floribunda	Leguminosae	6.68	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.00	7.25
Dalbergia velutina	Leguminosae	1.66	0.00	0.00	0.00	0.00	0.00	14.98	0.00	0.00	16.64
Dillenia parviflora	Dilleniaceae	6.18	0.00	3.95	0.00	0.00	2.93	1.30	3.32	0.00	17.68
Elaeocarpus sp.1	Elaeocarpaceae	1.85	2.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.06

Appendix Table 4
(continued)

Species	Family	D1	D2	D3	D4	D5	D6	D7	D8	D9	Sum
Elaeocarpus sp.2	Elaeocarpaceae	0.00	0.00	2.21	0.00	0.00	0.00	0.00	0.00	0.00	2.21
Engelhardtia serrata	Juglandaceae	0.00	0.00	0.00	3.12	0.00	2.11	2.73	2.80	0.00	10.77
Engelhardtia sp.	Juglandaceae	0.00	1.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64
Eriobotrya bengalensis	Rosaceae	1.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.73
Euonymus cochinchinensis	Celastraceae	2.35	0.00	0.00	7.20	0.00	5.38	0.00	0.00	0.00	14.93
Euonymus similis	Celastraceae	1.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.62
Eurya acuminata	Theaceae	15.67	1.47	0.00	1.79	0.57	0.00	2.23	0.00	1.29	23.02
Flacourtia jangomas	Flacourtiaceae	2.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.42
Glochidion rubrum	Euphorbiaceae	6.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.74
Glochidion sp.	Euphorbiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.40	0.00	1.40
Glochidion sphaerogynum	Euphorbiaceae	1.63	1.55	0.00	1.81	0.58	2.42	10.43	1.41	0.00	19.82
Gluta usitata	Anacardiaceae	0.00	1.52	0.00	0.00	0.00	0.00	1.13	0.00	1.69	4.33
Gordonia dalglieshiana	Theaceae	4.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.40
Helicia nilagirica	Proteaceae	0.00	31.39	9.07	6.75	4.51	0.00	0.00	2.98	0.00	54.69
Helicia sp.	Proteaceae	1.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.99
Ilex umbellulata	Aquifoliaceae	1.73	0.00	0.00	0.00	0.00	2.63	0.00	2.31	1.82	8.49
Lannea coromandelica	Anacardiaceae	0.00	0.00	0.00	1.84	0.00	0.00	1.11	3.44	0.00	6.39
Lindera sp.	Lauraçeae	0.00	0.00	0.00	0.00	0.00	0.00	1.42	0.00	0.00	1.42
Lithocarpus aggregatus	Fagaceae	0.00	0.00	0.00	0.00	0.00	0.00	1.37	0.00	0.00	1.37
Lithocarpus annamensis	Fagaceae	9.62	0.00	2.34	0.00	0.00	0.00	0.00	0.00	0.00	11.96
Lithocarpus elegans	Fagaceae	8.15	28.31	18.44	5.32	30.69	18.98	8.15	33.65	24.84	176.53
Lithocarpus nestratus	Fagaceae	0.00	0.00	0.00	0.00	0.00	2.12	0.00	0.00	0.00	2.12
Lithocarpus polystachyus	Fagaceae	0.00	0.00	0.00	0.00	0.00	2.71	3.80	1.40	1.40	9.32
Litsea glutinosa	Lauraceae	3.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.54
Maesa ramentacea	Myrsinaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.74	1.74
Meliosma simplicifolia	Meiosmaceae	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.61
Paramichelia bailonii	Magnoliaceae	0.00	0.00	0.00	1.80	0.00	2.12	0.00	0.00	0.00	3.92
Pavetta tomentosa	Rubiaceae	0.00	0.00	3.91	0.00	0.00	0.00	0.00	0.00	0.00	3.91
Payena paralleloneura	Sapotaceae	0.00	0.00	0.00	0.00	0.00	2.60	0.00	0.00	0.00	2.60
Phoebe lanceolata	Lauraceae	1.64	1.50	7.67	1.85	0.00	0.00	3.14	1.74	0.00	17.53

Appendix Table 4
(continued)

Species	Family	D1	D2	D3	D4	D5	D6	D7	D8	D9	Sum
Phoebe sp.	Lauraceae	0.00	0.00	2.05	0.00	0.00	0.00	0.00	0.00	0.00	2.05
Phyllanthus emblica	Euphorbiaceae	0.00	0.00	0.00	1.87	0.00	2.16	0.00	0.00	0.00	4.02
Pinus kesiya	Pinaceae	78.46	98.54	115.70	104.05	85.64	96.86	74.16	72.04	77.42	802.88
Quercus kerrii	Fagaceae	0.00	0.00	0.00	5.53	0.63	0.00	0.00	5.78	10.04	21.97
Rhus chinensis	Anacardiaceae	0.00	0.00	0.00	0.00	9.75	8.73	0.00	0.00	0.00	18.48
Rhynchotechum obovatum	Gesneriaceae	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00
Sarcosperma arboreum	Sarcospermataceae	3.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.42
Savravia napaulensis	Actinidiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80	0.00	2.80
Schima wallichii	Theaceae	33.61	15.33	17.86	1.79	34.02	14.61	26.81	33.21	0.00	177.23
Sterculia rubiginosa	Sterculiaceae	0.00	0.00	0.00	0.00	0.00	2.90	0.00	1.44	0.00	4.33
Stereospermum cylindricum	Bignoniaceae	1.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.81
Stereospermum neuranthum	Bignoniaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.55	0.00	1.55
Styrax benzoides	Stryraceae	3.68	16.43	2.45	5.58	0.57	2.11	9.59	10.07	4.76	55.25
Symplocos cochinchinensis	Symplocaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.28	1.28
Syzygium albiforum	Myrtaceae	0.00	0.00	14.46	0.00	1.40	0.00	0.00	0.00	0.00	15.86
Syzygium angkae	Myrtaceae	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.63
Syzygium siamensis	Myrtaceae	1.68	4.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.66
Ternstroemia gymnanthera	Theaceae	4.11	18.20	7.08	0.00	0.00	0.00	0.00	4.61	5.31	39.31
Tristania rufescens	Myrtaceae	0.00	2.26	0.00	8.16	0.00	0.00	1.13	6.75	35.64	53.94
Tristaniopsis burmanica	Myrtaceae	1.63	0.00	0.00	4.05	25.94	4.91	0.00	0.00	0.00	36.53
Unidentified	Unidentified	3.90	0.00	4.61	2.46	0.00	0.00	0.00	1.41	0.00	12.38
Unidentified 17	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	2.62	0.00	0.00	2.62
Unidentified 18	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.61	0.00	6.61
Unidentified 27	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	1.51	0.00	0.00	1.51
Unidentified 37	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	1.61	0.00	0.00	1.61
Vaccinium sprengelii	Ericaceae	0.00	1.48	0.00	18.92	4.54	2.17	1.09	1.56	0.00	29.76
Viburnum inopinatum	Caprifoliaceae	8.18	5.06	0.00	7.66	3.02	2.13	3.97	5.96	8.15	44.12
Vitex peduncularis	Labiatae	1.65	1.47	0.00	2.17	0.00	0.00	0.00	0.00	0.00	5.29
Wendlandia tinctoria	Rubiaceae	6.80	27.86	14.44	34.42	22.69	18.87	11.70	17.60	29.92	184.29
Wrightia arborea	Apocynaceae	0.00	0.00	1.94	0.00	0.00	0.00	0.00	0.00	0.00	1.94
Grand Total		300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	2700.00

Appendix Table 5 Important value index of tree species in montane forest stands.

Species	Family	E1	E2	E3	E4	E5	E6	E7	E8	E9	Sum
Acer laurinum	Aceraceae	0.00	0.00	0.00	21.33	3.37	3.32	0.00	43.48	2.19	73.68
Actinodaphne henryi	Lauraceae	0.00	0.00	0.00	0.00	0.00	2.30	68.76	0.00	0.00	71.06
Adenandra integerrima	Leguminosae	0.00	0.00	3.36	0.00	0.00	0.00	0.00	0.00	0.00	3.36
Adinandra sp.	Theaceae	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	1.50
Aidia yunnanensis	Rubiaceae	1.47	1.26	0.00	7.11	20.79	13.25	0.00	0.00	0.00	43.88
Anneslea fragrans	Theaceae	0.00	0.00	4.13	0.00	0.00	0.00	0.00	0.00	0.00	4.13
Aporusa nenvosa	Euphorbiaceae	0.00	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.21
Aporusa octandra	Euphorbiaceae	2.74	0.00	5.85	0.00	0.00	0.00	0.00	0.00	0.00	8.59
Archidendron clypearia	Leguminosae	0.00	5.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.97
Ardisia rubro-glandulosa	Myrsinaceae	0.00	0.00	0.00	0.00	0.00	0.00	22.61	0.00	0.00	22.61
Ardisia sp.	Myrsinaceae	0.00	0.00	0.00	0.00	0.00	3.38	0.00	0.00	0.00	3.38
Artocarpus chaplasha	Moraceae	0.00	9.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.44
Atalantia monophylla	Rutaceae	0.00	0.00	0.00	0.00	0.00	1.14	0.00	0.00	0.00	1.14
Beilschmiedia assamica	Lauraceae	0.00	2.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.64
Beilschmiedia gammieana	Lauraceae	2.04	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	3.43
Beilschmiedia globularia	Lauraceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.94	0.91	42.85
Beilschmiedia roxberghiana	Lauraceae	0.00	0.00	0.00	0.00	0.00	0.00	33.18	0.00	0.00	33.18
Betula alnoides	Betulaceae	0.00	3.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.34
Bombax ancep	Bombacaceae	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.04
Brassiopsis speciosa	Araliacea	0.00	0.00	0.00	0.00	1.41	0.00	0.00	0.00	0.00	1.41
Calophyllum polyanthum	Guttiferae	0.00	0.00	0.00	6.79	19.68	5.22	0.00	0.00	0.00	31.69
Camellia oleifera	Theaceae	0.00	0.00	0.00	1.34	2.70	5.53	0.00	0.00	0.00	9.56
Camellia siamensis	Theaceae	0.00	0.00	0.00	0.00	0.00	0.00	1.90	33.62	2.09	37.62
Canarium denticulatum	Burseraceae	0.00	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.21
Canarium strictum	Burseraceae	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22
Canthium coffeoides	Rubiaceae	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36
Capparis sabiifolia	Capparidaceae	0.00	0.00	0.00	0.00	1.38	0.00	0.00	0.00	0.00	1.38
Carellia braciata	Rhizophoraceae	0.00	0.00	0.00	0.00	0.00	2.53	0.00	0.00	0.00	2.53
Castanopsis acuminatissima	Fagaceae	0.00	0.00	4.09	0.00	0.00	2.84	0.00	0.00	1.65	8.58
Castanopsis calathiformis	Fagaceae	9.43	6.12	13.26	0.00	0.00	52.27	0.00	0.00	0.00	81.08
Castanopsis ferox	Fagaceae	0.00	51.88	0.00	0.00	0.00	0.00	0.00	33.05	55.13	140.06
Castanopsis purpurea	Fagaceae	0.00	0.00	0.00	2.50	0.00	0.00	0.00	0.00	0.00	2.50

Appendix Table 5
(continued)

Species	Family	E1	E2	E3	E4	E5	E6	E7	E8	E9	Sum
Castanopsis roxkii	Fagaceae	1.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.52
Castanopsis tribuloides	Fagaceae	25.05	0.00	25.29	0.00	0.00	0.00	0.00	0.00	0.00	50.34
Chionanthus ramiflorus	Oleaceae	0.00	0.00	0.00	4.28	0.00	0.00	0.00	29.66	8.83	42.78
Cinnamomum bejolghota	Lauraceae	0.00	0.00	0.00	2.60	2.88	0.00	0.00	0.00	0.00	5.49
Cinnamomum caudatum	Lauraceae	0.00	0.00	5.75	0.00	0.00	0.00	0.00	0.00	0.00	5.75
Cinnamomum glaucescens	Lauraceae	0.00	5.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.36
Cinnamomum javanicum	Lauraceae	0.00	0.00	0.00	6.38	0.00	0.00	0.00	0.00	0.00	6.38
Claoxylou longiflolia	Euphorbiaceae	3.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.43
Cryptocarya dencifolia	Lauraceae	0.00	0.00	0.00	4.46	19.55	7.29	0.00	0.00	0.00	31.30
Cryptocarya sp.	Lauraceae	0.00	0.00	0.00	7.33	8.62	0.00	0.00	0.00	0.00	15.95
Dalbergia velutina	Leguminosae	13.75	1.35	4.26	0.00	0.00	0.00	0.00	0.00	0.00	19.36
Daphniphyllum sp.	Daphniphyllaceae	0.00	0.00	0.00	0.00	0.00	2.35	0.00	0.00	0.00	2.35
Dillenia parviflora	Dilleniaceae	3.95	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.56
Diospyros glandulosa	Ebenaceae	9.60	2.56	10.48	0.00	0.00	0.00	0.00	0.00	0.00	22.64
Drypetes hoaensis	Euphorbiaceae	0.00	1.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.24
Drypetes indica	Euphorbiaceae	0.00	0.00	0.00	27.53	27.00	0.00	0.00	0.00	0.00	54.53
Elaeocarpus floribundus	Elaeocarpaceae	0.00	0.00	10.17	0.00	0.00	0.00	0.00	0.00	0.00	10.17
Elaeocarpus lanceaefolius	Elaeocarpaceae	0.00	0.00	0.00	4.47	0.00	1.24	0.00	0.00	0.00	5.71
Elaeocarpus sp.1	Elaeocarpaceae	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.35
Eleaocarpus branciana	Elaeocarpaceae	0.00	0.00	0.00	0.00	0.00	2.04	0.00	0.00	0.00	2.04
Eleaocarpus lanceaefolius	Elaeocarpaceae	0.00	0.00	0.00	0.00	0.00	1.17	0.00	0.00	0.00	1.17
Engelhardtia sp.	Juglandaceae	0.00	0.00	0.00	1.24	0.00	1.68	0.00	0.00	0.00	2.93
Engelhardtia spicata	Juglandaceae	2.89	1.47	4.22	0.00	0.00	0.00	0.00	0.00	0.00	8.58
Eriobotrya bengalensis	Rosaceae	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22
Eriolaena candollei	Sterculiaceae	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.61
Erythrina subumbrans	Leguminosae	0.00	5.61	2.94	0.00	0.00	0.00	0.00	0.00	0.00	8.55
Eurya acuminata	Theaceae	15.36	3.13	11.21	0.00	0.00	0.00	0.00	0.00	0.00	29.70
Eurya nitida	Theaceae	0.00	2.57	0.00	0.00	0.00	4.64	0.00	28.17	0.00	35.39
Garcinia sp.	Guttiferae	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	1.61	3.08
Glochidion acuminatum	Euphorbiaceae	0.00	0.00	0.00	0.00	0.00	0.00	22.29	17.76	0.00	40.04
Glochidion sp.	Euphorbiaceae	5.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.09

Appendix Table 5
(continued)

Species	Family	E1	E2	E3	E4	E5	E6	E7	E8	E9	Sum
Glochidion sphaerogynum	Euphorbiaceae	0.00	2.50	4.37	0.00	0.00	0.00	0.00	0.00	0.00	6.87
Glyptopetalum sp.	Celastraceae	0.00	0.00	0.00	1.43	0.00	0.00	0.00	0.00	0.00	1.43
Gomphandra quadrifolia	Icacinaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.39	2.13	19.53
Helicia atteneuta	Proteaceae	0.00	9.83	0.00	0.00	0.00	0.00	0.00	13.01	0.00	22.84
Helicia formosana var.oblane	Proteaceae	0.00	0.00	0.00	0.00	0.00	0.00	25.19	8.48	3.40	37.07
Helicia nilagirica	Proteaceae	32.44	46.23	10.16	0.00	0.00	0.00	0.00	0.00	0.00	88.83
Homalium ceylanicum	Flacourtiaceae	0.00	0.00	6.77	0.00	0.00	0.00	0.00	0.00	0.00	6.77
Ilex sp.	Aquifoliaceae	0.00	0.00	0.00	0.00	2.78	0.00	0.00	0.00	0.00	2.78
Ilex triflora	Aquifoliaceae	0.00	0.00	0.00	0.00	0.00	14.97	6.06	0.00	6.01	27.03
Ilex umbellulata	Aquifoliaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.41	2.41
Lasianthus kurzii	Rubiaceae	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	1.25
Lindera metacafaena	Lauraceae	0.00	0.00	0.00	0.00	0.00	15.30	0.00	0.00	0.00	15.30
Lindera missneri	Lauraceae	5.75	1.27	8.61	0.00	0.00	0.00	0.00	0.00	0.00	15.63
Lindera sp.	Lauraceae	1.37	0.00	0.00	0.00	0.00	13.16	0.00	0.00	0.81	15.34
Lithocarpus aggregatus	Fagaceae	0.00	0.00	0.00	10.39	14.89	7.44	4.09	7.23	7.57	51.61
Lithocarpus ceriferus	Fagaceae	3.53	0.00	11.32	0.00	0.00	0.00	0.00	0.00	0.00	14.85
Lithocarpus dealbatus	Fagaceae	4.03	0.00	17.45	0.00	0.00	0.00	0.00	0.00	0.00	21.48
Lithocarpus elegans	Fagaceae	7.47	14.92	11.43	0.00	0.00	0.00	0.00	0.00	0.00	33.82
Lithocarpus tomsonii	Fagaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.17	0.00	5.17
Lithocarpus triboides	Fagaceae	0.00	0.00	21.55	0.00	0.00	0.00	0.00	0.00	0.00	21.55
Lithocarpus truncatus	Fagaceae	1.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.35
Litsea beusekomii	Lauraceae	0.00	0.00	0.00	7.58	6.07	0.00	0.00	0.00	0.00	13.65
Litsea chatacea	Lauraceae	0.00	0.00	0.00	2.69	8.20	0.00	0.00	0.00	0.00	10.88
Litsea dubele	Lauraceae	0.00	0.00	0.00	6.98	1.38	0.00	44.74	4.62	4.48	62.19
Litsea firma	Lauraceae	0.00	0.00	0.00	1.26	0.00	0.00	0.00	0.00	0.00	1.26
Litsea glutinosa	Lauraceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.00	0.86
Litsea lancifolia	Lauraceae	0.00	0.00	0.00	12.01	4.53	0.00	0.00	0.00	0.00	16.54
Litsea lentifolia	Lauraceae	0.00	0.00	0.00	0.00	1.39	0.00	0.00	0.00	0.00	1.39
Litsea sp1.	Lauraceae	0.00	0.00	0.00	5.20	5.97	1.13	0.00	0.00	0.00	12.30
Litsea sp2.	Lauraceae	0.00	0.00	0.00	2.88	0.00	0.00	0.00	0.00	0.00	2.88
Litsea umbellata	Lauraceae	0.00	0.00	4.37	0.00	0.00	0.00	0.00	0.00	0.00	4.37

Appendix Table 5
(continued)

Species	Family	E1	E2	E3	E4	E5	E6	E7	E8	E9	Sum
Litsia cubeba	Lauraceae	2.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.47
Mallotus khasianus	Euphorbiaceae	0.00	0.00	0.00	20.43	21.12	1.18	0.00	0.00	0.00	42.73
Mangleitia garrettii	Magnoliaceae	0.00	0.00	0.00	28.42	15.40	3.23	0.00	0.00	0.00	47.05
Mastixia euonymoides	Cornaceae	0.00	0.00	0.00	41.30	18.17	8.23	2.70	0.00	0.00	70.40
Myrica esculenta	Myricaceaae	1.88	1.37	0.00	0.00	0.00	0.00	1.94	0.00	7.47	12.67
Myrsine semiserrata	Myrsinaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.58	0.72	5.30
Neolitsea pallens	Lauraceae	0.00	0.00	0.00	0.00	0.00	0.00	17.82	4.02	81.38	103.22
Nyssa javanica	Nyssaceae	0.00	0.00	0.00	1.41	11.92	12.92	0.00	0.00	0.00	26.26
Ostodes paniculata	Euphorbiaceae	0.00	0.00	0.00	21.77	20.20	0.00	0.00	0.00	0.00	41.97
Parenaria camelliflora	Magnoliaceae	0.00	0.00	0.00	0.00	0.00	0.00	6.87	2.05	0.00	8.93
Pavetta aspera	Rubiaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	2.45	3.95
Phoebe lanceolata	Lauraceae	1.48	1.23	0.00	0.00	0.00	11.28	4.55	0.00	0.00	18.54
Phyllanthus emblica	Euphorbiaceae	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.37
Podocarpus nerriifolius	Podocarpaceae	0.00	0.00	0.00	0.00	0.00	2.32	0.00	0.00	0.00	2.32
Polyalthia sp.	Annonaceaae	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	0.00	1.47
Polyosma integrifolia	Saxifragaceae	0.00	0.00	0.00	0.00	2.87	3.99	0.00	0.00	0.00	6.86
Premna latifolia	Labiatae	1.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42
Premna villosa	Labiatae	0.00	1.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.76
Protium serratum	Burseraceae	1.33	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.33
Prunus placostictus	Rosaceae	0.00	0.00	0.00	0.00	0.00	1.17	0.00	0.00	0.00	1.17
Pyrenaria camalliflora	Theaceae	0.00	0.00	0.00	0.00	1.70	0.00	0.00	0.00	0.00	1.70
Quercus glabricupula	Fagaceae	1.41	0.00	7.26	4.41	5.62	1.13	0.00	0.00	0.00	19.84
Quercus lenticellata	Fagaceae	0.00	0.00	0.00	0.00	2.23	28.73	1.92	1.28	16.40	50.56
Quercus purpurea	Fagaceae	0.00	0.00	0.00	0.00	1.46	0.00	0.00	0.00	0.00	1.46
Rapanea yunnanensis	Myrsinaceae	0.00	0.00	0.00	0.00	0.00	14.66	0.00	1.18	59.74	75.58
Rhus chinensis	Anacardiaceae	0.00	1.32	0.00	2.67	1.37	0.00	0.00	0.00	0.00	5.37
Sarcosperma arboreum	Sacrospermataceae	0.00	0.00	0.00	9.13	0.00	0.00	0.00	0.00	0.00	9.13
Savravia napaulensis	Actinidiaceae	1.33	13.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.44
Schefflera hypoleucoides	araliaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.64	10.64
Schima wallichii	Theaceae	47.78	37.83	43.56	0.00	0.00	0.00	0.00	0.00	0.76	129.93
Schoepfia fragrans	Olacaceae	0.00	0.00	0.00	0.00	0.00	1.13	0.00	0.00	0.00	1.13

Appendix Table 5
(continued)

Species	Family	E1	E2	E3	E4	E5	E6	E7	E8	E9	Sum
Sterculia sp.	Sterculiaceae	0.00	0.00	0.00	3.48	1.45	0.00	0.00	0.00	0.00	4.93
Sterculia villosa	Sterculiaceae	0.00	1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36
Stereospermum neuranthum	Bignoniaceae	5.91	6.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.39
Styrax benzoides	Stryraceae	7.53	21.08	8.69	0.00	0.00	0.00	0.00	0.00	0.00	37.31
Symplocos cochinchinensis	Symplocaceae	2.79	1.55	14.07	0.00	1.38	2.49	0.00	0.00	0.00	22.28
Symplocos hookerii	Symplocaceae	0.00	0.00	0.00	4.72	8.28	1.55	0.00	0.00	0.00	14.55
Symplocos longifolia	Symplocaceae	0.00	0.00	0.00	0.00	0.00	0.00	8.44	0.95	14.20	23.58
Symplocos macrophylla	Symplocaceae	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.47
Symplocos sp.	Symplocaceae	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	1.40
Syzygium angkae	Myrtaceae	27.64	2.49	12.53	2.64	10.09	5.68	26.95	0.00	0.00	88.02
Syzygium balsamea	Myrtaceae	0.00	1.38	0.00	4.47	11.12	14.70	0.00	0.00	0.00	31.67
Tarenna disperma	Rubiaceae	0.00	0.00	0.00	0.00	0.00	16.10	0.00	0.00	0.00	16.10
Tarennoidea wallichii	Rubiaceae	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34
Ternstroemia gymnanthera	Theaceae	10.58	12.62	12.85	0.00	0.00	0.00	0.00	0.00	0.00	36.05
Unidentified	Unidentified	0.00	0.00	0.00	3.24	0.00	1.13	0.00	0.00	0.00	4.37
Vaccinium sprengelii	Ericaceae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	7.00
Walsura trijuga	Meliaceae	0.00	0.00	0.00	1.47	8.67	2.71	0.00	0.00	0.00	12.85
Wendlandia tinctoria	Rubiaceae	15.15	1.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.37
Xantolis burmanica	Sapotaceae	0.00	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.34
Xantolis sp.	Sapotaceae	9.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.96
Zyzyphus incuwa	Rhamnaceae	0.00	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.21
Grand Total		300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	2700.00

Appendix 2 Soil profile description in middle topographic stand of sampling each locations.

Profile No. A2
Location: Doi Inthanon
Vegetation: DDF
Elevation: 500 m
Physiography: Hill
Topography: Mid slope
Slope: 15 degree, N
Parent material: Anatexitic
Stoniness; Many surface stone (chart)
Date: 99/03/25

0-8	A	(10YR3/2, wet); sandy loam; moderate, very fine subangular blocky; non sticky, non plastic (wet), friable (moist); few gravels (10 mm); common fine root (5 mm); dry; 25 mm; clear smooth boundary to,
8-25	B	(7.5YR5/6, wet); sandy loam; moderate very fine subangular blocky; non sticky, non plastic (wet), friable (moist); many gravel (10 mm); many fine root (5 mm); dry; 27 mm; clear smooth boundary to,
25-41	BC	(7.5YR5/6, wet); sandy clay loam; strong very fine subangular blocky; non sticky, non plastic (wet), friable (moist); many gravel (10 mm); common root; 30 mm; dry; clear smooth boundary to,
41-65+	C	(7.5YR5/6, wet); sandy clay loam moderate; non structure; many gravel (10 mm); very few root; dry to moist; 30 mm

Profile No.	A5
Location:	Doi Inthanon
Vegetation:	DDF
Elevation:	640 m
Physiography:	Hill
Topography:	Ridge
Slope:	15 degree, S
Parent material:	Gneiss
Stoniness;	Abundant surface stone (chart)
Date:	99/01/14

0-3/5	A	(10YR3/2, wet)(10YR5/2, dry); loam; strong, coarse, subangular blocky; non sticky, slightly plastic (wet), hard (dry); few gravel (10 mm); few root; 20 mm; abrupt wavy boundary to,
3/5-20/25	B	(10YR6/3)(10YR5/6)(wet), (10YR6/3)(10YR5/6)(dry); clay; strong coarse subangular blocky; sticky, plastic (wet), extremely hard (dry); few gravel (10 mm); very few root; 28 mm; clear broken boundary to,
20/25-40	BC	(10YR6/6, wet); clay; strong coarse subangular blocky; sticky, plastic (wet), extremely hard (dry); common gravel (20 mm); very few root; 28 mm; abrupt broken boundary to,
40-75+	C	(10YR6/4, wet)(10YR7/3, dry); sandy clay loam; no structure; slightly sticky, slightly plastic (wet); no gravel; very few root; 31 mm

Profile No.	A8
Location:	Doi Inthanon
Vegetation:	DDF
Elevation:	930 m
Physiography:	Hill
Topography:	Flat ridge
Slope:	10 degree, S
Parent material:	Granite
Stoniness;	Few surface stone (sand stone)
Date:	99/03/26

0-5	A	(7.5YR4/3, wet)(7.5YR6/6, dry); loam; strong, very fine subangular blocky; slightly sticky, non plastic (wet), friable (moist), slightly hard (dry); few gravel (3 mm); common tree root; dry; 20 mm; abrupt smooth boundary to,
5-13	AB	(5YR4/6, wet), (5YR6/8, dry);clay loam to clay; strong very fine to fine subangular blocky; sticky, plastic (wet), friable (moist), slightly hard (dry); few gravel (3 mm); common root; dry; 16 mm; abrupt smooth boundary to,
13-25	BA	(2.5YR5/8, wet); clay; strong very fine to fine subangular blocky; very sticky, plastic (wet), friable to firm (moist), few gravel (3 mm); few root; 30 mm; dry to moist; clear smooth boundary to,
25-45	B1	(2.5YR5/8, wet); clay; strong fine subangular blocky; very sticky, plastic (wet), firm (moist); few gravel (3 mm); very few root; dry to moist; 30 mm; gradual smooth boundary to,
45-60+	B2	(2.5YR5/8, wet); clay; strong fine subangular blocky; very sticky, very plastic (wet), firm (moist); very few gravel (3 mm); very few root; dry to moist; 30 mm

Profile No.	B2
Location:	Doi Inthanon
Vegetation:	MDF
Elevation:	550 m
Physiography:	Hill
Topography:	Mid slope
Slope:	30 degree, S
Parent material:	Tuff, Phyllite
Stoniness;	Some surface stone (chart)
Date:	99/03/31

0-14	A	(7.5YR3/2, wet)(7.5YR4/4, dry); clay loam; weak, very fine subangular blocky; slightly sticky, slightly plastic (wet), friable (moist), soft to slightly hard (dry); common gravel (10 mm); many fine root; dry; 25 mm; clear smooth boundary to,
14-28	B	(7.5YR3/3, wet), (7.5YR4/4, dry); clay; weak very fine subangular blocky; sticky, plastic (wet), friable (moist), slightly hard (dry); common gravel (10 mm); common root; dry; 20 mm; gradual irregular boundary to,
28-40	BC	(7.5YR3/4, wet), (7.5YR4/6, dry); clay; weak very fine subangular blocky; sticky, plastic (wet), friable (moist), slightly hard (dry); common gravel (10 mm); few root; 30 mm; dry; clear irregular boundary to,
40-75+	CB	(7.5YR4/6, wet)(7.5YR5/6, dry); clay; non structure; sticky, plastic (wet); many weathering rock (10 mm); very few root; dry to moist; 15 mm

Profile No. B5
Location: Doi Inthanon
Vegetation: MDF
Elevation: 550 m
Physiography: Hill
Topography: Mid slope
Slope: 20 degree, SW
Parent material: Tuff, Phyllite
Stoniness; Some surface stone (chart)
Date: 99/01/15

0-10	A	(10YR2/3, wet)(10YR4/3, dry); clay; strong, very fine subangular blocky; slightly sticky, plastic (wet), friable (moist), very hard (dry); few gravels (10 mm); many bamboo root; dry; 25 mm; clear smooth boundary to,
10-25	AB	(7.5YR3/4, wet), (7.5YR4/4, dry); clay; strong very fine subangular blocky; very sticky, plastic (wet), friable (moist), extremely hard (dry); common gravel (10 mm); few root; dry; 27 mm; gradual broken boundary to,
25-40	BA	(7.5YR3/4, wet), (7.5YR4/6, dry); clay; strong very fine subangular blocky; very sticky, very plastic (wet), firm (moist), extremely hard (dry); common gravel (10 mm); few root; 30 mm; dry; abrupt smooth boundary to,
40-85+	B	(5YR4/8, wet)(5YR3/6, dry); clay; strong fine subangular blocky; very sticky, very plastic (wet), firm (moist), extremely hard (dry); few gravel (10 mm); very few root; dry to moist; 30 mm

Profile No.	B8
Location:	Doi Inthanon
Vegetation:	MDF
Elevation:	550 m
Physiography:	Hill
Topography:	Mid slope
Slope:	25 degree, S
Parent material:	Anatexitic
Stoniness;	Some surface stone (chart)
Date:	99/04/01

0-20	A	(10YR2/1, wet)(10YR3/3, dry); clay; strong, very fine subangular blocky; sticky, plastic (wet), firm (moist), hard to very hard (dry); few gravel (10 mm); common fine root; dry; 10 mm; abrupt smooth boundary to,
14-27	AB	(10YR4/3, wet), (10YR5/4, dry); clay; strong fine subangular blocky; sticky, plastic (wet), firm (moist), hard to very hard (dry); few gravel (10 mm); few root; dry; 7 mm; clear smooth boundary to,
27-40	BA	(10YR5/4, wet), (10YR6/4, dry); clay; strong fine subangular blocky; very sticky, very plastic (wet), firm to very firm (moist), hard (dry); common gravel (5 mm); few root; 25 mm; dry; clear smooth boundary to,
40-70+	B	(5YR4/3, wet)(10YR4/8, dry); clay; strong fine subangular blocky; very sticky, very plastic (wet); many gravel (8 mm); very few root; dry to moist; 10 mm

Profile No.	C2
Location:	Doi Inthanon
Vegetation:	Pine-DDF
Elevation:	1,050 m
Physiography:	Hill
Topography:	Slope
Slope:	13 degree, SE
Parent material:	Granite
Stoniness;	Few surface stone (sand stone)
Date:	99/03/30

0-4	A	(5YR3/6, wet)(7.5YR4/6, dry); clay loam; strong, very fine subangular blocky; slightly sticky, plastic (wet), very friable to friable (moist), slightly hard (dry); few gravel (3 mm); common tree root; dry; 2 mm; abrupt wavy boundary to,
4-10	AB	(5YR3/6, wet), (5YR5/8, dry); light loam; strong very fine to fine subangular blocky; sticky, plastic (wet), friable to firm (moist), slightly hard to hard (dry); very few gravel (3 mm); few root; dry; 5-10 mm; clear wavy boundary to,
10-20	BA	(2.5YR4/6, wet), (2.5YR4/8, dry); clay; strong very fine to fine subangular blocky; very sticky, plastic (wet), friable to firm (moist), few gravel (3 mm); few root; 5 mm; dry to moist; gradual smooth boundary to,
20-50+	B	(2.5YR3/6, wet)(2.5YR4/8, dry); clay; strong fine subangular blocky; very sticky, very plastic (wet), firm (moist); few gravel (3 mm); very few root; dry to moist; 15 mm,

Remarks; Cutan was observed in B horizons, but its development was weak.

Profile No.	C5
Location:	Doi Inthanon
Vegetation:	Pine-DDF
Elevation:	1,020 m
Physiography:	Hill
Topography:	Flat ridge
Slope:	5 degree, S
Parent material:	Granite
Stoniness;	Few surface stone (sand stone)
Date:	99/01/16

0-3	A	(10YR2/3, wet)(10YR3/3, dry); loam; strong, very fine subangular blocky; slightly sticky, plastic (wet), very friable to friable (moist), slightly hard (dry); few gravel (3 mm); common tree root; dry; 20 mm; abrupt smooth boundary to,
3-10	AB	(7.5YR3/4, wet), (7.5YR4/4, dry);clay loam; strong very fine to fine subangular blocky; sticky, plastic (wet), very friable to friable (moist), slightly hard to hard (dry); few gravel (3 mm); few root; dry; 26 mm; abrupt wavy boundary to,
10-23	BA	(5YR4/6, wet), (5YR5/8, dry); clay; strong very fine to fine subangular blocky; very sticky, plastic (wet), friable to firm (moist), few gravel (3 mm); few root; 30 mm; dry to moist; clear smooth boundary to,
23-43	Bt1	(5YR4/6, wet)(5YR5/8, dry); clay; strong fine subangular blocky; very sticky, plastic (wet), firm (moist); few gravel (3 mm); very few root; dry to moist; 30 mm; gradual smooth boundary to,
43-90+	Bt2	(5YR4/6, wet)(5YR5/8, dry); clay; strong fine subangular blocky; very sticky, plastic (wet), firm (moist); very few gravel (3 mm); very few root; dry to moist; 30 mm

Remarks; Cutan was observed in Bt1 and Bt2 horizons, but its development was weak.

Profile No.	C8
Location:	Doi Inthanon
Vegetation:	Pine-DDF
Elevation:	1,060 m
Physiography:	Hill
Topography:	Slope
Slope:	13 degree, S
Parent material:	Granite
Stoniness;	Very few surface stone (sand stone)
Date:	99/03/29

0-4	A	(7.5YR3/4, wet)(7.5YR4/4, dry); clay loam; moderate, fine subangular blocky; sticky, plastic (wet), friable (moist), hard to very hard (dry); few gravel (3 mm); common tree root; dry; 2 mm; abrupt smooth boundary to,
4-12	AB	(5YR3/4, wet), (5YR4/6, dry); heavy loam; strong fine subangular blocky; very sticky, very plastic (wet), friable to firm (moist), hard to very hard (dry); very few gravel (3 mm); few root; dry; 5-10 mm; clear irregular boundary to,
12-22	BA	(2.5YR4/8, wet), (2.5YR4/8, dry); clay; strong fine subangular blocky; very sticky, very plastic (wet), firm (moist), few gravel (3 mm); few root; 5 mm; dry to moist; gradual smooth boundary to,
22-55+	B	(2.5YR5/8, wet)(2.5YR5/8, dry); clay; strong fine subangular blocky; very sticky, very plastic (wet), firm (moist); few gravel (3 mm); very few root; dry to moist; 15 mm,

Remarks; Cutan was observed in B horizons, but its development was weak.

Profile No.	D2
Location:	Doi Inthanon
Vegetation:	Pine-Oak
Elevation:	1,050 m
Physiography:	Mountain
Topography:	slope
Slope:	20 degree, NW
Parent material:	Granite
Stoniness;	No surface stone
Date:	99/03/28

0-4	A	(10YR2/3, wet)(10YR3/4, dry); loam; moderate very fine subangular blocky; slightly sticky, slightly plastic (wet), very friable to friable (moist); no gravel; many tree root; moist; 14 mm; abrupt smooth boundary to,
4-13	AB	(7.5YR2/3, wet), (7.5YR4/6, dry); clay; moderate very fine to fine subangular blocky; sticky, plastic (wet), friable to firm (moist); no gravel; common tree root; moist; 17 mm; abrupt smooth boundary to,
13-31	BA	(2.5YR4/6, wet), (5YR5/6, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), friable to firm (moist); very few gravel (5 mm); common to few root; 23 mm; moist; clear broken boundary to,
31-51	Bt1	(2.5YR4/6, wet)(2.5YR5/8, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), firm (moist); very few gravel (5 mm); few root; moist; 27 mm; clear smooth boundary to,
51-71+	Bt2	(2.5YR4/6, wet)(2.5YR5/8, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), firm to very firm (moist); very few gravel (5 mm); very few root; moist; 28 mm,

Profile No.	D5
Location:	Doi Inthanon
Vegetation:	Pine-Oak
Elevation:	1,080 m
Physiography:	Mountain
Topography:	Flat ridge
Slope:	15 degree, SE
Parent material:	Granite
Stoniness;	No surface stone
Date:	99/01/18

0-4	A	(7.5YR2/3, wet)(7.5YR3/4, dry); loam; moderate very fine subangular blocky; slightly sticky, plastic (wet), friable (moist); no gravel; many tree root; moist; 14 mm; abrupt smooth boundary to,
4-13	AB	(5YR3/4, wet), (7.5YR4/8, dry); clay; moderate very fine to fine subangular blocky; sticky, plastic (wet), friable to firm (moist); no gravel; common tree root; moist; 17 mm; abrupt wavy boundary to,
13-31	BA	(2.5YR4/6, wet), (2.5YR4/8, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), friable to firm (moist); very few gravel (5 mm); common to few root; 23 mm; moist; clear broken boundary to,
31-51	Bt1	(2.5YR4/6, wet)(2.5YR4/8, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), firm (moist); very few gravel (5 mm); few root; moist; 27 mm; clear smooth boundary to,
51-71	Bt2	(2.5YR4/8, wet)(2.5YR5/8, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), firm to very firm (moist); very few gravel (5 mm); very few root; moist; 28 mm; clear smooth boundary to,
71-95+	Bt3	(2.5YR4/8, wet)(2.5YR5/8, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), very firm (moist); few gravel (5-10 mm); very few root; moist; 28 mm

Remarks; Cutan was observed in Bt1, Bt2, and Bt3 horizons, but its development was weak.

Profile No.	D8
Location:	Doi Inthanon
Vegetation:	Pine-Oak
Elevation:	1,060 m
Physiography:	Mountain
Topography:	Flat ridge
Slope:	10 degree, SW
Parent material:	Granite
Stoniness;	No surface stone
Date:	99/03/27

0-5	A	(105YR2/3, wet)(10YR4/4, dry); sandy loam, loam; moderate very fine subangular blocky; slightly sticky, slightly plastic (wet), friable (moist); no gravel; many tree root; moist; 14 mm; abrupt smooth boundary to,
5-15	AB	(7.5YR4/6, wet), (7.5YR6/6, dry);clay; moderate very fine to fine subangular blocky; sticky, plastic (wet), friable to firm (moist); no gravel; common tree root; moist; 17 mm; abrupt smoot boundary to,
15-25/30	BA	(5YR5/8, wet), (5YR6/8, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), friable to firm (moist); very few gravel (5 mm); common to few root; 23 mm; moist; clear broken boundary to,
25/30-55+	B1t	(5YR5/8, wet)(5YR6/8, dry); clay; moderate fine subangular blocky; very sticky, very plastic (wet), firm (moist); very few gravel (5 mm); few root; moist; 27 mm

Profile No.	E2
Location:	Doi Inthanon
Vegetation:	Hill Evergreen Forest
Elevation:	1,200 m
Physiography:	Mountain
Topography:	Mid slope
Slope:	15 degree, E
Parent material:	Granite
Stoniness;	No surface stone
Date:	99/04/02

0-5	A	(10YR4/3, moist)(10YR4/8, dry); loam; moderate fine subangular blocky; slightly sticky, slightly plastic (wet), friable (moist); few gravel (5 mm); many tree root; moist; 13 mm; abrupt smooth boundary to,
5-11/18	AB	(10YR4/6, moist)(10YR3/4, dry); clay loam; moderate fine subangular blocky; sticky, plastic (wet), very friable to friable (moist), slightly hard (dry); very few gravel (5 mm); few tree root; moist; 14 mm; clear broken boundary to,
11/18-28	BA	(7.5YR5/6, moist); clay; moderate very fine to fine subangular blocky; sticky, plastic (wet), friable (moist); few gravel (10 mm); few root; 21 mm; moist; gradual smooth boundary to,
28-60+	B	(7.5YR6/8, moist); clay; moderate fine subangular blocky; very sticky, very plastic (wet), friable (moist); few gravel (10 mm); few root; moist; 20 mm,

Profile No.	E5
Location:	Doi Inthanon
Vegetation:	Hill Evergreen Forest
Elevation:	1,680 m
Physiography:	Mountain
Topography:	Flat slope
Slope:	15 degree, E
Parent material:	Gneiss
Stoniness;	No surface stone
Date:	99/01/19

0-11 A	(7.5YR3/3, moist); clay loam; weak very fine subangular blocky break into weak very fine granular; slightly sticky, very plastic (wet), very friable (moist); few gravel (5 mm); many tree root; moist; 13 mm; abrupt broken boundary to,
11-20 AB	(7.5YR4/6, moist); clay; moderate very fine to fine subangular blocky; sticky, plastic (wet), very friable to friable (moist); few gravel (5 mm); common tree root; moist; 14 mm; clear smooth boundary to,
20-33/38 BA	(7.5YR5/8, moist); clay; moderate very fine to fine subangular blocky; sticky to very sticky, very plastic (wet), friable (moist); common gravel (10 mm); few root; 21 mm; moist; clear wavy boundary to,
33/38-53 B	(5YR4/8, moist); clay; moderate fine subangular blocky; very sticky, very plastic (wet), friable to firm (moist); many gravel (10 mm); few root; moist; 24 mm; clear smooth boundary to,
53-83 CB	(5YR5/8, moist); clay; no structure; very sticky, very plastic (wet); many gravel (10 mm); few root; moist; 25 mm; clear smooth boundary to,
83-100+ C	(7.5YR6/8, moist); clay; no structure; very sticky, very plastic (wet); common gravel (10 mm); very few root; moist; 15 mm

Remarks;	1) Some big holes were observed in CD and C horizon, which was made by termite or decayed root and filled with surface soil. 2) Charcoal was seen on the A, AB, BA, and B horizons.

Profile No.	E8
Location:	Doi Inthanon
Vegetation:	Hill Evergreen Forest
Elevation:	2,280 m
Physiography:	Mountain
Topography:	Mid slope
Slope:	25 degree, E
Parent material:	Gneiss
Stoniness;	No surface stone
Date:	99/04/02

0-6	A	(10YR3/1, moist); clay loam to clay; weak very fine subangular blocky break into weak very fine granular; slightly sticky, plastic (wet), very friable to firm (moist); very few gravel (5 mm); many tree root; moist; 13 mm; abrupt broken boundary to,
6-10/15	BA	(10YR5/6, moist); clay; weak very fine to subangular blocky; sticky, plastic (wet), friable (moist); few gravel (5 mm); common tree root; moist; 14 mm; abrupt broken boundary to,
10/15-70+	B	(10YR6/8, moist); clay; weak very fine subangular blocky; very sticky, very plastic (wet), very friable to friable (moist); few gravel (5 mm); few root; 15 mm; moist,