รายงานวนศาสตร์วิจัย

FOREST RESEARCH BULLETIN

เล่มที่ ๕๒ NUMBER 52

เมษายน ๒๕๒๑ APRIL 1978

ผลผลิตและองค์ประกอบทางเคมีของทรากพืชในป่าของประเทศไทย

PRODUCTION AND CHEMICAL COMPOSITION OF FOREST LITTER IN THAILAND

บุญวงศ์ ไทยอุตส่าห์ BUNVONG THAIUTSA

วิสุทธิ์ สุวรรณาภินันท์ WISUT SUWANNAPINUNT

วสันต์ เกตุปราณีต WASAN KAITPRANEET

คณะวนศาสตร์ FACULTY OF FORESTRY

มหาวิทยาลัยเกษตรศาสตร์ KASETSART UNIVERSITY

กรุงเทพฯ BANGKOK 9. THAILAND

รายงานวนศาสตร์วิจัย

FOREST RESEARCH BULLETIN

เล่มที่ ๕๒

เมษายน ๒๕๒๑

NUMBER 52

APRIL 1978

ผลผลิตและองค์ประกอบทางเคมีของหรากพืชในป่าของประเทศไทย

PRELIMINARY STUDY OF PRODUCTION AND CHEMICAL COMPOSITION OF FOREST LITTER IN THAILAND

บุญวงศ์ ไทยอุตสาห์

วิสุทธิ์ สุวรรณาภินันท์

วสันต์ เกตุปราณีต

BUNVONG THAIUTSA

WISUT SUWANNAPINUNT

WASAN KAITPRANEET

คณะวนศาสตร์

มหาวิทยาลัยเกษตรศาสตร์

กรุงเทพฯ ๙

FACULTY OF FORESTRY

KASETSART UNIVERSITY

BANGKOK 9

ABSTRACT

The investigation was carried out in Central and Northern Thailand, having mean monthly temperature and total annual rainfall of about 24°C and 1,500 mm, respectively. The results showed that dry period in terms of temperature-precipitation relationship is the principal factor affecting litter production in a specific stand. The highest amount of litter-fall occured during the dry months of the year, ranging from mid-November to mid-April. For teak as well as in dry dipterocarps forest this amount was about 80 % of the total production. Prescribed burning prior to dry period was recommended for forest floor management. The relationship between hydrofactor and the total annual litter production had been found, with the maximum litter yield having the moderate hydrofactor value. The total annual litter-fall in dry dipterocarps, bamboo, hill evergreen, teak, and pine stands was 4.7, 4.8, 6.9, 7.9, and 11.3 t/ha, respectively.

Plant nutrients in litter varied with species and location. N content was highest in dry dipterocarps forest, and lowest in hill evergreen forest, whereas bamboo, teak, and pine forests were intermediate. Order of abundance of nutrients was Ca > N > K > Mg > P for teak forest; N > Ca > K > Mg > P for dry dipterocarps forest; Ca > Mg > N > P > K for hill evergreen forest; N > K > Ca > Mg > P for pine plantation; and Si > N > K > Ca > Mg > P for bamboo forest. N and K contents in litter of the higher-elevation stands were less than those of the lower-elevation stands. The tremendous amount of essential plant nutrients gained annually from litter-fall is challenging for future studies.

ACKNOWLEDGEMENT

This study is a portion of the Silviculture and Wood Properties Research Project led by Dr. Lert Chantanaparb. It was supported financially by Kasetsart University. Chemical composition of litter was analysed under the impressive cooperation of the Agricultural Chemistry Division, Department of Agriculture.

The authors are also grateful to Prof. Harvey Doner of the UC Berkeley Department of Soils and Plant Nutrition for kindly going through the manuscript and offering valuable suggestions.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Thailand, situated in the heart of Southeast Asia, has an area of 515,160 km^2. Forest covers about 35 % of the total area of the country. The principal forest types are evergreen, dry dipterocarps, and mixed deciduous forests which occupy about 39 %, 37 %, and 21 % of the forest area, respectively. The less than 3 % remainder is covered by mangrove, scrub, pine, and swamp forests. Productivity of such wildlands tends to decrease rapidly due to the problems of shifting cultivation, forest fire, soil erosion, and improper silvicultural practices. Forest fertilization widely used to improve site quality in temperate zones may be uneconomic for this region. Management through the silvicultural implication of nutrient cycling concept, i.e., inputs, turnovers or storages, and outputs, seems to be more reasonable since green plant is the primary producer of the food chain. In stable or undisturbed ecosystem, the simplifying assumption is made that input equals output.

Litter-fall which includes such things as small branches, bits of barks, flower parts, fruits, and leaves in all stages of decomposition is a portion of nutrient cycling. Only a part of organic matter produced by woodland plants is retained within the ecosystem. The rest is lost in such various ways as leaching and removal by man through harvesting. If litter is to be utilized commercially, harvesting methods will need to be developed. In the future, forest litter may assume additional significance. Thailand's present birth rate of 2.8 %, with its consequent pressure on food supply and accelerated depletion of non-renewable resources, such as tin, will eventually necessitate much fuller use of organic production.

The objective of this investigation is to estimate the litter accumulation and chemical composition in some forest types in Thailand.

REVIEW OF LITERATURE

Factors Affecting Litter-fall

The amount of litter production varies from biome to biome. Several factors affecting litter-fall are plant species, environment, silvicultural practices, and time factor. Bray and Gorham (1964) cited a hundred references in their discussion of those factors. Because of their evergreen nature, Gymnosperms yields about one-sixth more total litter annually than the deciduous Angiosperm trees. Jenny *et al.* (1949) reported the annual production of organic matter that in the form of leaves and twigs was much greater in tropical forests (8.4 - 11.8 t/ha) than in temperate forests (0.9 - 3.1 t/ha). Moreover, litter-fall in Amazonian zone was as high as 21.9 t/ha/yr (Stark, 1971). Little variation in litter production is evident from 15 to 32 years of age of unthinned loblolly pine plantation (Van Lear and Goebel, 1976).

Climate, especially precipitation and temperature seems to be the most predominant influence among the several environmental factors. A study in a tropical rain forest in Trinidad showed higher rate of litter-fall during the dry season when evapotranspiration exceeded rainfall (Cornforth, 1970). Annual litter production decreases linearly as latitude increases, with a maximum level of over 11 tons per hectare at the Equator declining to a little less than 1 ton per hectare at latitude 65°N in Europe where forest grades into tundra (Bray and Gorham, 1964). The second category of environment is altitude and exposure. A peak litter production occurs at the intermediate elevations on the NE slope, generally considered to be least exposed to the heating and drying effects of insolation, while the lowest average litter production is at the SW slope of both lower and higher elevations. Since soil fertility affects site class, it indicates higher litter-fall on more fertile soils. Litter production on the poorest site (V) is only one-third that on the best site (I), whereas the intermediate site class produces two-thirds as much litter as the best class. If the total annual litter-fall is plotted versus soil moisture, the inverse relationship may be found out.

Silvicultural operations from this point of view include such external treatments as plantations and native stands, tree density and thinning effect, and effect of litter removal. Generally, plantation yields more litter-fall than the natural stand. This may be caused by the even-aged condition of plantation rather than stand density.

Several investigators failed to show any consistent relationship between litter production and tree density. However, if a closed canopy forest is thinned, there is a decrease in litter production which is roughly proportional to the degree of thinning (Bray and Gorham, 1964). The control stand has the highest litter-fall and the most heavily thinned stand the lowest.

Seasonal variation of litter-fall is closely related to climatic conditions, i.e., dry period of the year. In the equatorial forests of Africa (Egunjobi, 1974; John, 1973; Nye, 1961), South America (Cornforth, 1970; Jenny et al., 1949), and Southeast Asia (Boonyawat and Ngampongsai, 1974; Paevongsar, 1976; Tsai, 1974), litter-fall is continuous throughout the year with the maximum level during the first quarter of the year. The seasonal pattern of the northern hemisphere forests is highest during second half of the year (Bray and Gorham, 1964; Lang, 1974; Loomis, 1975; Rochow, 1974; Van Lear and Goebel, 1976), while a peak of leaf litter in New Zealand occurs in summer and of other litter in winter (Daniel, 1975). Furthermore, total litter-fall may vary greatly in different years. The annual variation is due to climatic fluctuation.

Decomposition and Nutrient Cycling

The patterns of litter-fall, accumulation, and decomposition are very important in the overall recycling of nutrients. The major processes of nutrient cycling in a forest community include nutrient uptake by root system; nutrient accumulation in various stand components; return of organic matter and nutrients to the forest floor and soil by litter-fall, foliar leaching, stemflow, root sloughing and mortality; and release of nutrients from organic matter by decomposition. There are many factors influencing decomposition rates of litter. Moisture and temperature are among the most important ones (Brinson, 1977; Singh, 1969b), because of their effects on development of plant cover and on the activities of microorganisms, which are highly critical factors in soil formation. Kononova (1975) cited several publications and concluded that the highest intensity of organic matter decomposition was observed under conditions of moderate temperature (about 30°C) and soil moisture of about 60 to 80 % of its maximum water-holding capacity. Simultaneous increase or decrease of temperature and moisture beyond the optimal levels brought about a decline in the rate of organic matter decomposition. Moreover, for each decrease of 10°C in annual temperature, the rate of decomposition decreases two to three times.

Decomposition rates also vary with season. Gosz et al. (1973) and Loomis (1975) found that decomposition of litter was rapid in summer. However, Lang (1974) estimated the leaf litter decomposition rates of 3.75 gm/m^2/day during the autumn months, and 0.8 gm/m^2/day during the remainder of the year. Boonyawat and Ngampongsai (1974) supported Lang's result when they found that the highest decomposition of hill evergreen forest residues occurred in late rainy season and early winter (0.36 t/ha/month) and the lowest rate in summer (0.14 t/ha/month).

As mentioned previously, soil microorganisms play a great role in controlling humus formation, higher decomposition rates were observed in stands where large-bodied earthworms were found feeding on litter than where those species were replaced by other members of soil fauna (Lsépy, 1974).

Plant species and plant parts are the another important factor in this point of interest, may be because of variation in chemical composition. Goss et al. (1973) found that decomposition rates for leaf litter varied with yellow birch > sugar maple > beech. Decomposition rate for hardwood branches was greater than that for coniferous branches, but differences between hardwoods were not significant. For the tropical tree species studied in India (Pradhan, 1973), litter decomposition was greatest for Tectona grandis (47.1 %) and least for Acacia arabica (43.5 %) during the first rainy season. Generally, rate of decomposition is highest in species having maximum ash and nitrogen contents and lowest C/N ratio and lignin content. Lowest decomposition rate occurs in species which are relatively poor in ash and nitrogen contents and show highest lignin content as well as C/N ratio. Species showing medium ash, nitrogen, and lignin contents and C/N ratio indicate intermediate rate (Singh, 1969b). Most investigators reported that 3 to 15 months were required for almost complete decomposition of litter. To support this concept, Hoohow (1974) obtained the k value, the turnover rates, of 0.347 and 0.234 for leaf and woody litter, respectively. Phillipson et al. (1975) approximated that the annual mean litter input above ground was 235 gm/m^2, while the annual litter loss by decomposition was 234.8 gm/m^2, indicating a steady state in the overmature *Fagus sylvatica* woodland.

Chemical change in litter is associated with its breakdown. During the decomposition process the C/N ratio of litter undergoes a progressive change. As the decomposition proceeds, carbon dioxide is given off but the nitrogenous material tends to accumulate in the organisms, carrying out the decomposition, so that the C/N ratio is progressively reduced (Howard and Howard, 1974). Freshly fallen plant material may have a C/N ratio as high as 50 : 1 in nitrogen-poor species. In the H layer of the forest floor, C/N ratio is usually near 10 : 1 or 12 : 1. Sodium is very rapidly removed from the freshly fallen litter and much of the potassium is wash out within a few weeks. The phosphate content also falls rapidly, as does the magnesium content. Part of the calcium seems to be fairly rapidly mobilised, but something like half of it remains quite firmly held in the plant material.

Tree species differ greatly in the relative amounts of nutrients absorbed from soil. Consequently, the composition of leaves of various species is different even when the trees are growing in the same habitat. In highly productive woodland the build up of organic matter results in a large annual accumulation of plant nutrient, about 60 kg N/ha, 6 kg P/ha, 23 kg K/ha, 53 kg Ca/ha, and 8 kg Mg/ha (Ovington, 1962). Approximately, a quarter of these amounts is retained in the tree trunk and the rest is contained in the leaves. Tree leaves are periodically or continuously dropped on the ground as litter which decomposes in time to release the nutrients contained therein into the soil, from where they are recirculated. The transport of nutrients through plant-soil-atmosphere continuum constitutes a nutrient cycle. Nutrient cycle is a special case of the elemental cycles, where the element in question functions in part of the life processes. Elemental cycle is a historicaldescription of an element pathway as related to sources and sinks.

Three specific indices used to describe the nutrient cycles are abiotic storage index, biotic storage index, and recycling index. The descriptive technique of cycling is a deterministic linear model, which the assumption that chemical input to the biotic part of the system equals chemical output from the biota. A typical flow model of nutrient cycling shown in Figure 1 was developed by Golley et al. (1975). Waide and Swank (1976) modified a flow model of nitrogen cycle for an undisturbed oak-hickory forest. Most of nitrogen in this ecosystem was contained in a large storage pools which turn over slowly. That is, over 80 % of the total nitrogen was bound within soil organic matter with about 11 % in total vegetation, 3 % in litter pools, 4 % in microbial biomass, and 2 % in free soil pools. Of the total estimated uptake of 142 kg N/ha/yr, only about 10 % is retained in plant increments. A large amount of nitrogen, about 51 kg/ha/yr, recycles annually within plants. This nitrogen is withdrawn from leaves prior to abscission and stored in woody tissues until being remobilized for new growth of the following spring (Waide and Swank, 1976).

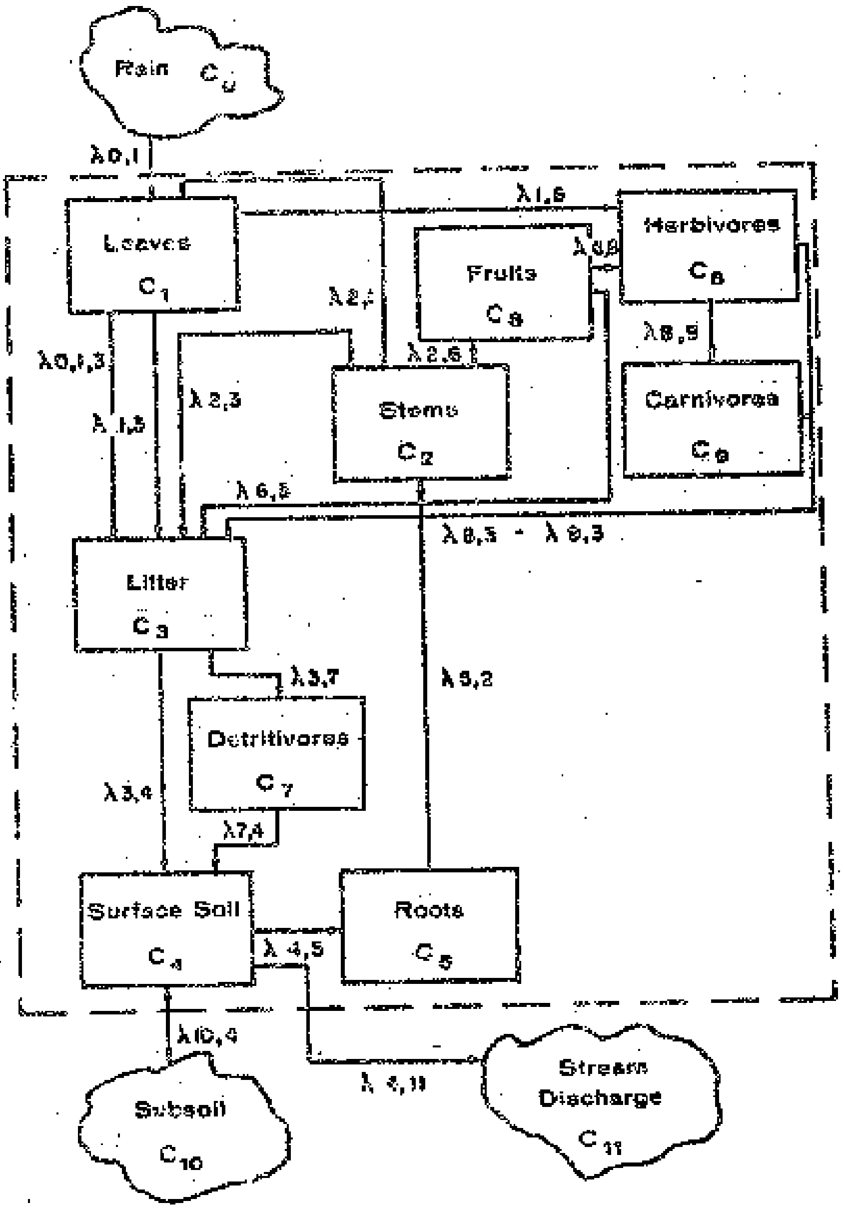

Figure 1. A diagrammatic model of nutrient cycling. The diagram depicts the nine organic compartments and illustrates the flow of minerals through the system. The compartments are labeled as C_1, C_2, ... C_{11}. C_o is the atmosphere compartment and C_{11} the river. Transfers between compartments are identified by λ, with subscripts indicating the compartment the flow was from and the compartment the flow goes to. Forest compartments are represented by a rectangle, compartments external to the system are represented by the amorphous figure. (From Golley *et al.*, 1975).

Obviously, decomposition of organic matter must occur before nutrients in forest residues can be recycled in soil-plant system. A rapid rate of decomposition of litter is a desirable objective of forest soil management. Conversely, natural or man-created stimulations where forest litter steadily accumulates on the surface of the mineral soil are undesirable, because both nutrients and organic matter cycles develop progressively slower rates of turnover. This is the main point to maximize site quality through the silvicultural implication of nutrient cycling.

METHODS

Study Area

Field measurement were carried out in different forest types, both natural stands and plantation. All sites are in Central and Northern Thailand (Figure 2). Table 1 shows the detail of each experimental area.

Methods of Study

Six litter collection boxes, constructed of wood and wire screening, were randomly placed in a 1-ha plot of each experimental site. The box is approximately a meter square and is held 20 cm above the forest floor by wooden legs to prevent decay. Litter was collected

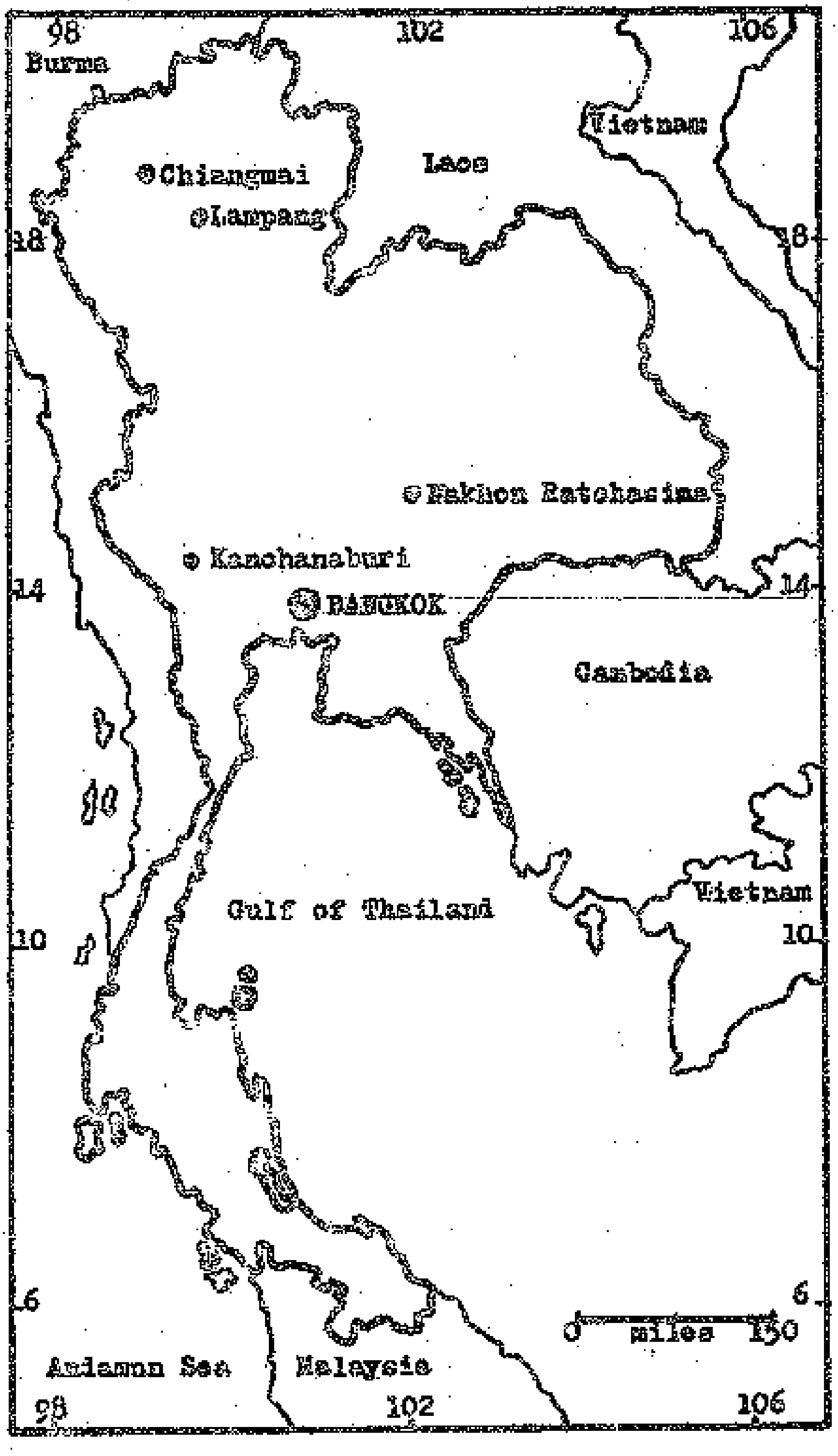

Figure 2. Location of litter-fall studies in some forest types : Chiangmai (hill evergreen forest and pine plantation, Lampang (teak forest), Kanchanaburi (bamboo forest), and Nakhon Ratchasima (dry dipterocarps forest).

Table 1. Information of the litter-fall study sites

Forest type	Characteristics	Location	Elevation (m)	Soil type	Stand density (trees/ha)	Temperature range (°C)	Annual rainfall (mm)	Note
Teak	natural	Lampang	340	red-yellow podzolic on old alluvium	223	7 - 40	1,393	mixed stand
Pine	plantation	Chiangmai	950	red-yellow podzolic on old residuum and colluvium from acid rock	2,300	4 - 33	1,246	12-year-old unthinned plantation
Bamboo	natural	Kanchanaburi	210	non-calcic brown soil	4,800	12 - 36	1,365	pure stand
Dry dipterocarps[1]	natural	Nakhon Ratchasima	480	red-yellow latosols	440	9 - 35	1,428	mixed stand
Hill evergreen[2]	natural	Chiangmai	1,400	reddish brown lateritics	400	5 - 27	2,102	mixed stand

1 Paovongsar (1976)

2 Boonyawat and Ngampongsai (1974)

from the trays once a month, from April 1975 to March 1976, and dried at 75 °C for 24 hours. Temperature and rainfall were recorded throughout the study period. In April 1976, the composite samples of each site were analyzed some essential elements, i.e., nitrogen, phosphorus, potassium, calcium, and magnesium, at the Agricultural Division of the Department of Agriculture, Bangkok.

Nitrogen was determined by macro-Kjeldahl method. For the determination of cations and phosphorus, a wet digestion was performed with a mixture of 1 : 9 perchloric-nitric acid mixture, evaporated to dryness and the residue dissloved in 0.1 N HCl. Calcium and magnesium were determined by atomic absorption spectrophotometer after addition of lanthanum chloride to suppress phosphate interference. Patassium was determined by flame photometer, and phosphorus by the nitric-vanadomolybdate method (Watson, 1956).

RESULTS AND DISCUSSION

Litter Production

Figures 3 - 7 show the monthly litter-fall in teak forest, pine plantation, bamboo forest, dry dipterocarps forest, and hill evergreen forest, respectively. Monthly temperature and rainfall data were plotted on the basis of pluviothermic graph (Van Goor and Barney, 1968), i.e., 2T = P, where T = temperature (°C) and P = rainfall (mm), in order to estimate the dry period of each location, and then relate these climatic relationships to the amounts of litter-fall.

It is evident that dry period in Northern and Central Thailand covers 3 - 5 months, ranging from mid-November to mid-April. In all forest types, the highest litter production is found during the dry season. Figure 8 indicates that the approximate amounts of litter-fall in teak forest, dry dipterocarps forest, hill evergreen forest, bamboo forest, and pine plantation during the dry months are 81.86 %, 78.03 %, 40.82 %, 65.54 %, and 67.85 % of the total production, respectively. Therefore, dry period in terms of temperature-rainfall relationship is the main factor affecting litter production in Thailand. Similar results were reported by Cornforth (1970), Egunjobi (1974), John (1973), and Woods and Gallegos (1970). Forest fire seems to be a critical problem in litter management under such conditions. Prescribed burning is a reasonable way to reduce fire detriment (Biswell and Schultz, 1957). It should be carried out prior to or early dry months, e.g., around mid-November for teak forest in Northern Thailand.

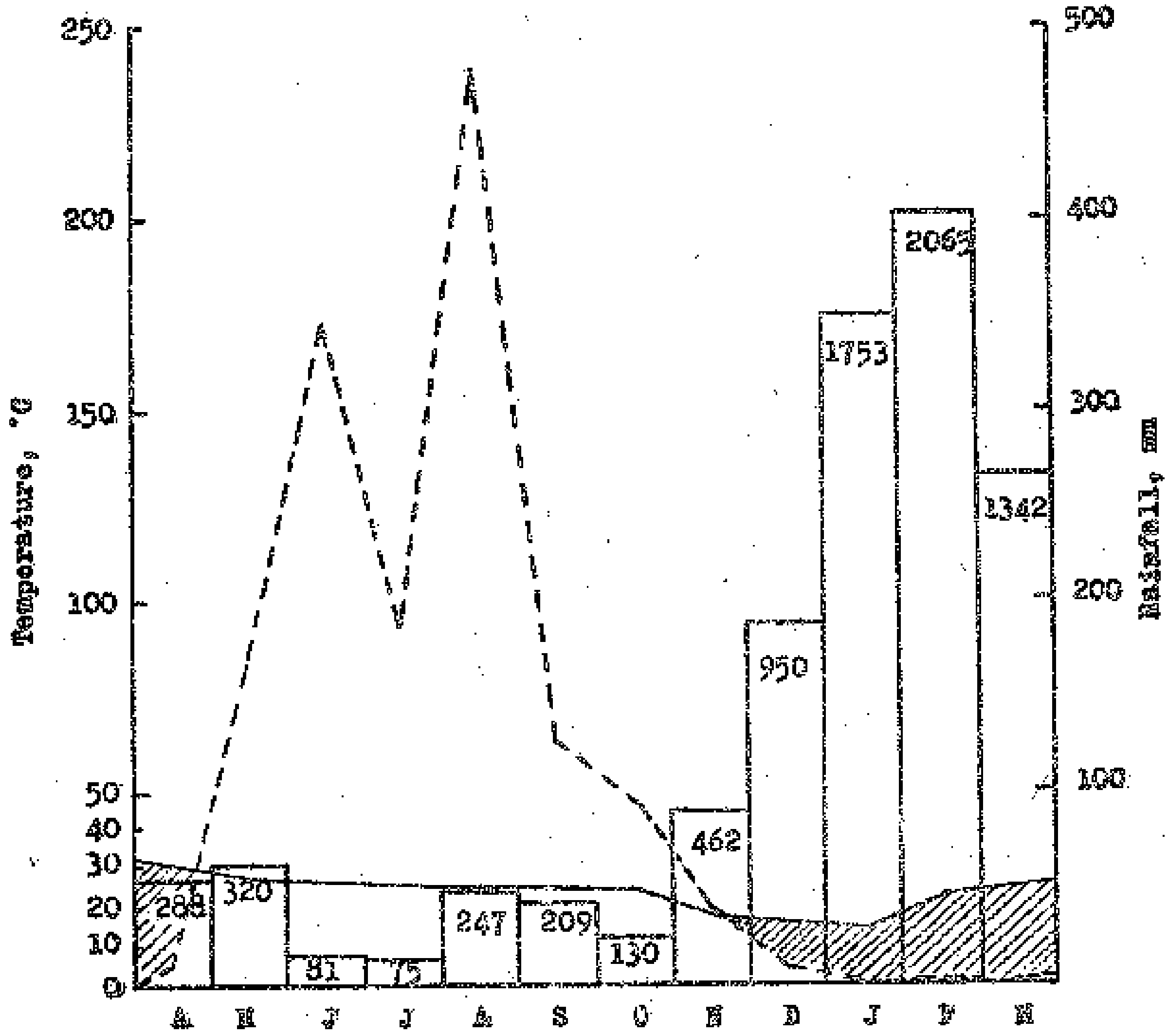

Figure 3. Litter production in teak forest (kg/ha) in relation to monthly rainfall (- - - -) and temperature (———) expressed by pluviothermic graph. Dry period from mid-November to late April.

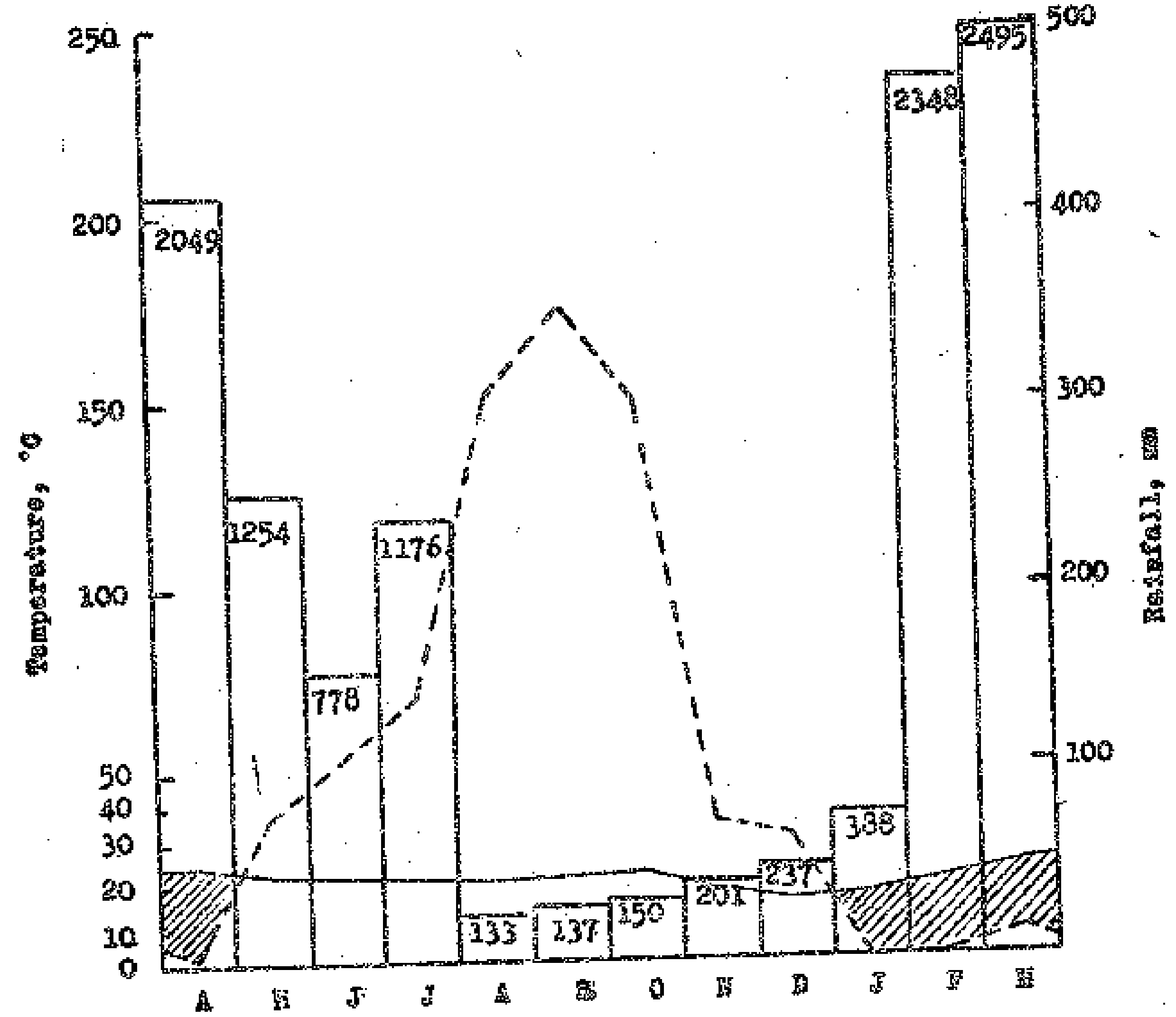

Figure 4. Litter production in pine plantation (kg/ha) in relation to monthly rainfall (------) and temperature (———) expressed by pluviothermic graph. Dry period from early January to early March.

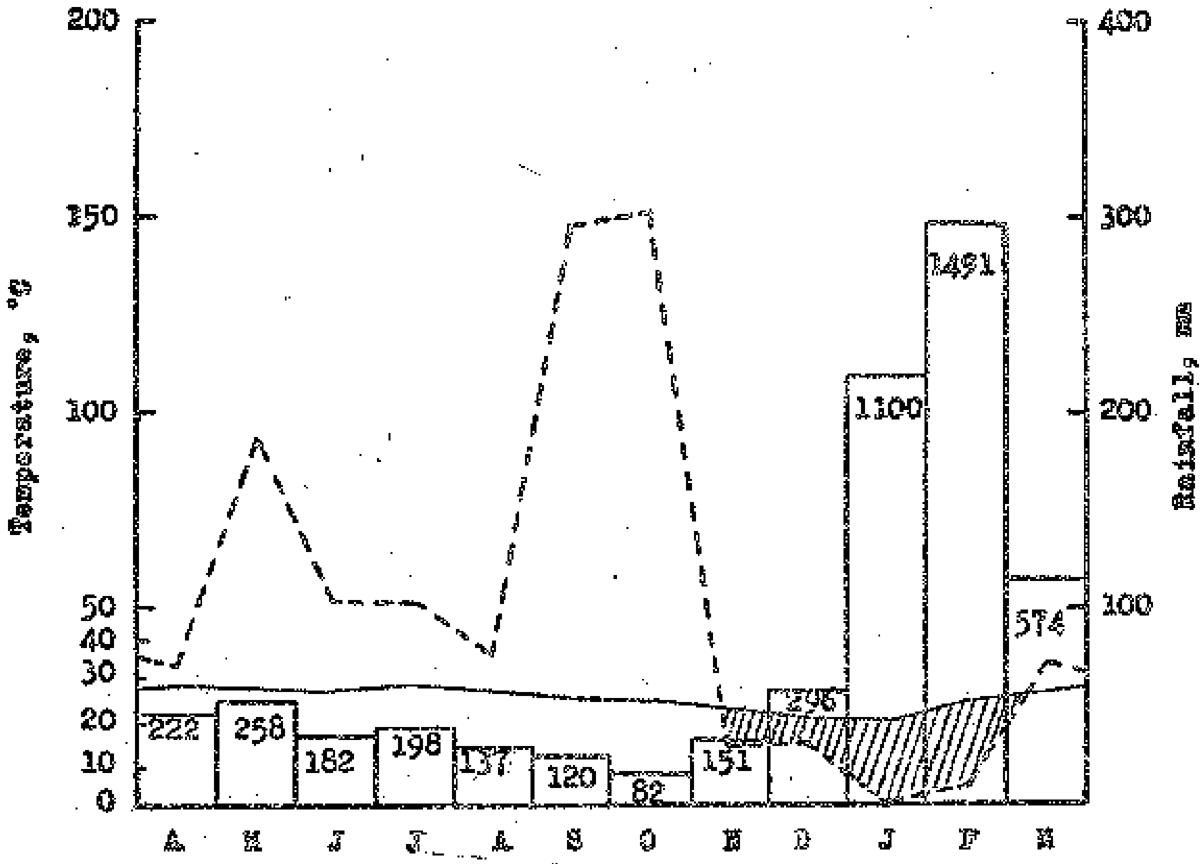

Figure 5. Litter production of bamboo forest (kg/ha) in relation to monthly rainfall (- - - -) and temperature (———) expressed by pluviothermic graph. Dry period from mid-November to early March.

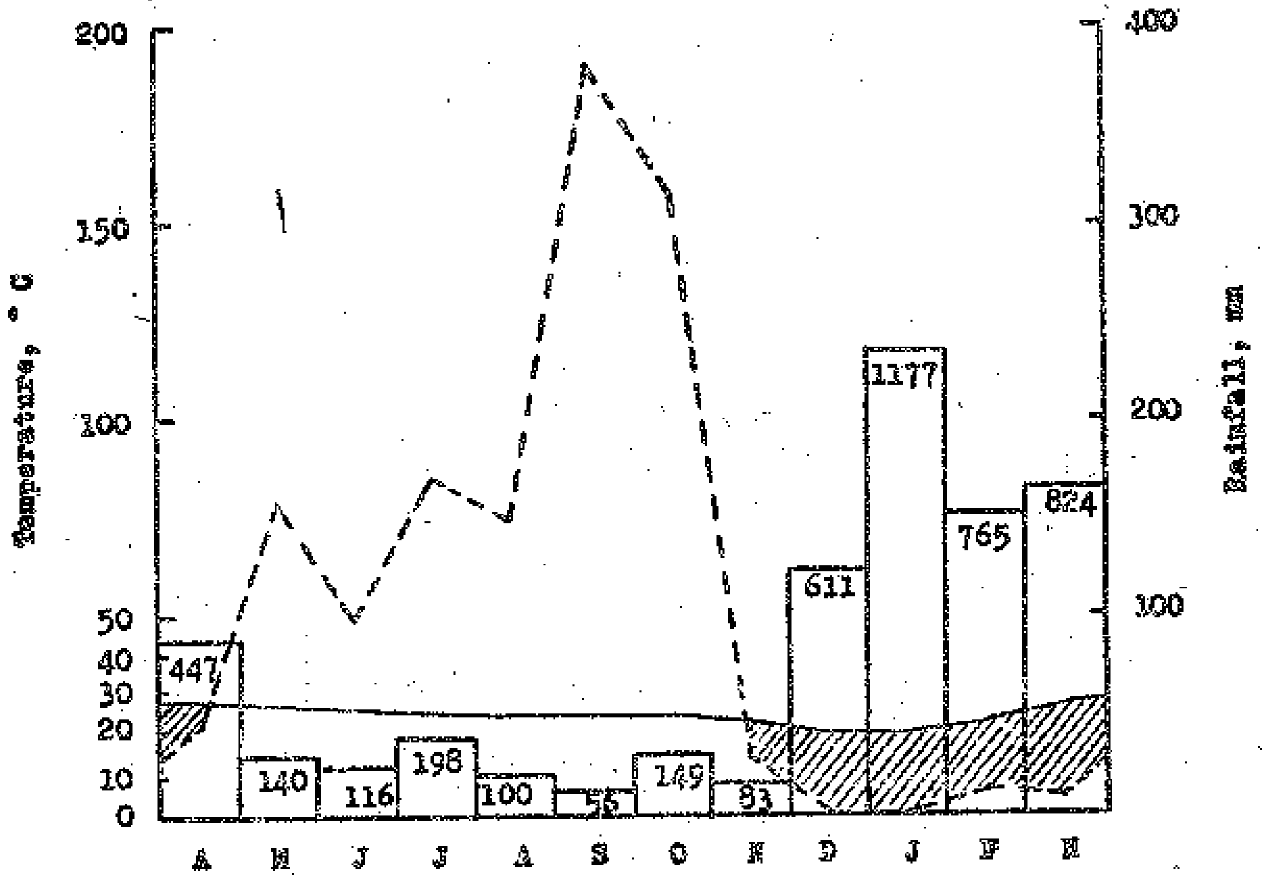

Figure 6. Litter production in dry dipterocarps forest (kg/ha) in relation to monthly rainfall (- - - - -) and temperature (———) expressed by pluviothermic graph. Dry period from mid-November to mid-April. (Data from Peovongsar, 1976).

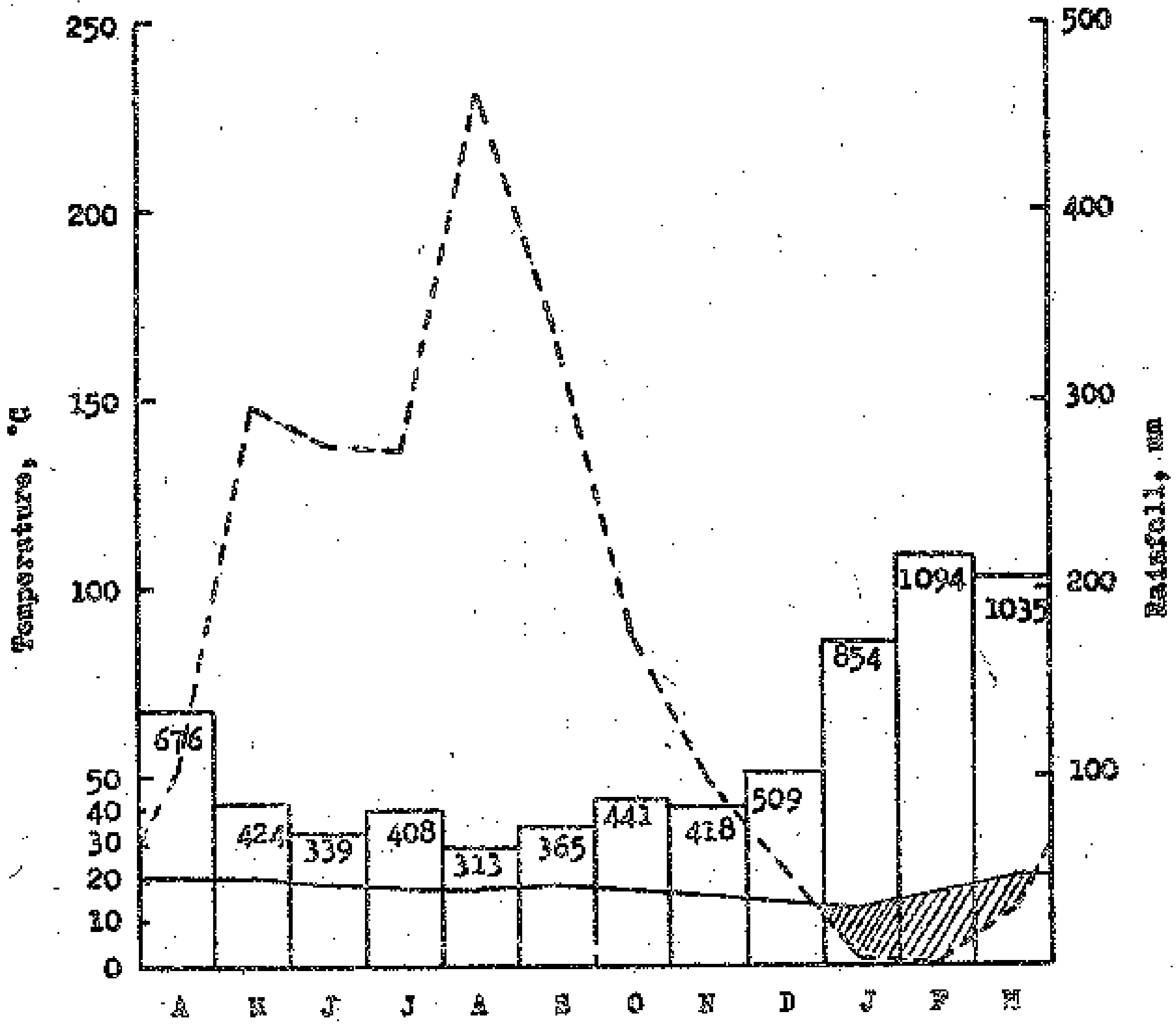

Figure 7. Litter production in hill evergreen forest (kg/ha) in relation to monthly rainfall (- - - - - -) and temperature (————) expressed by pluviothermic graph. Dry period from late December to late March. (Data from Boonyawat and Ngampongsai, 1974).

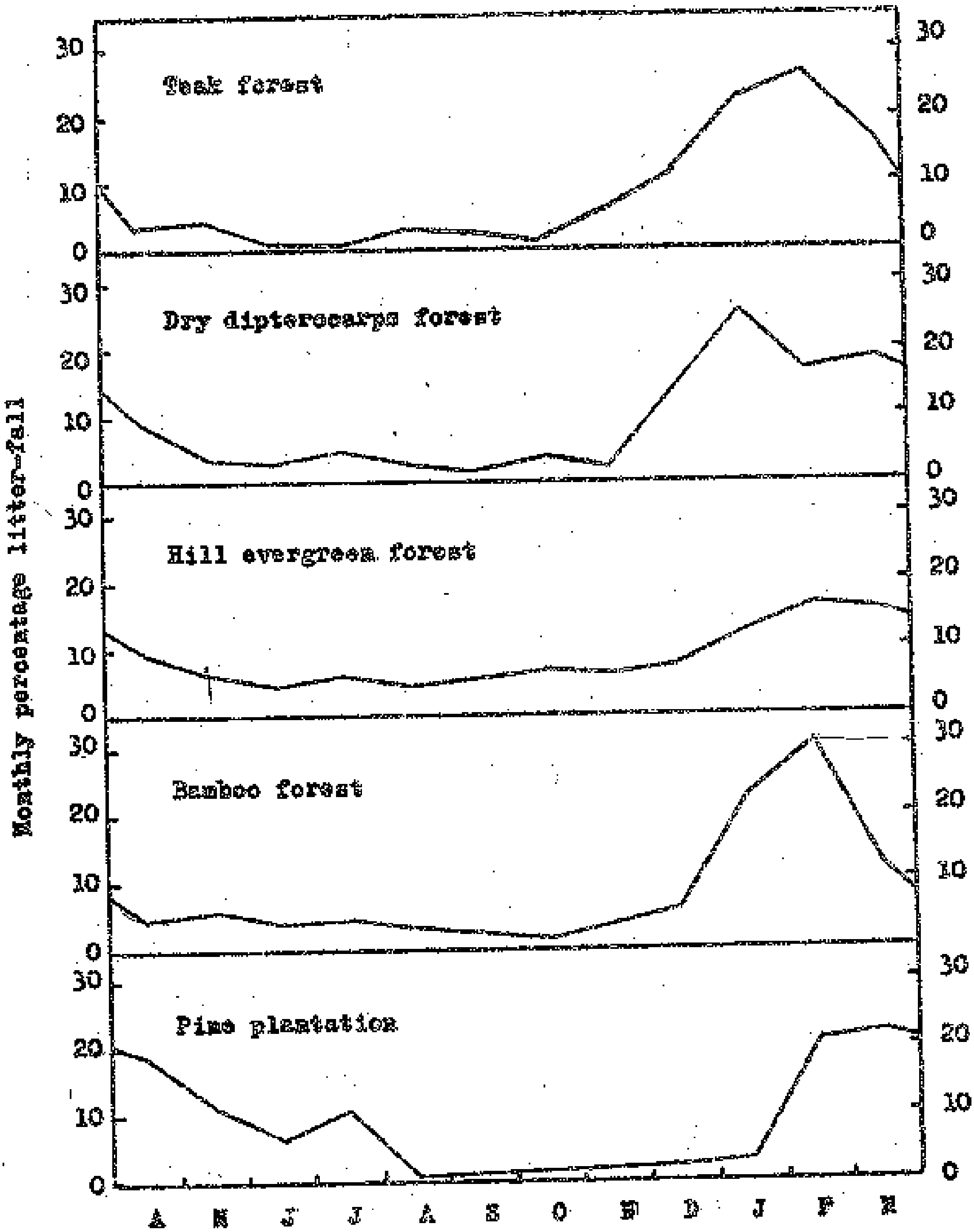

Figure 8. Seasonal litter-fall in different forest types

Using the empirical equation cited by Kononova (1975), the value of hydrofactor is estimated and related to the amount of litter-fall.

$$Hf = 43.2 \log P - T$$

where
Hf = hydrofactor
P = mean annual total precipitation, mm
T = mean annual temperature, °C

Kononova (1975) mentioned that soils with high humus contents have moderate values of the hydrofactor. For hydrofactor values smaller than 110 or exceeding 112, the humus content decreases sharply. This study obtained a similar trend for the total annual litter-fall, even though the samples seem to be limited. Hydrofactor values of this investigation are 107.41, 110.49, 113.16, 114.97, and 123.48 for bamboo forest, dry dipterocarps forest, teak forest, pine plantation, and hill evergreen forest, respectively (Figure 9).

Plant species itself as well as silvicultural operations have been found to be among the important factors controlling litter production. Evergreen Gymnosperm, unthinned pine plantation, produces about 50% more total annual litter than natural Angiosperm stands. The total annual production of dicots species is much greater than that of monocots. However, it is not clearly significant in total amount between evergreen forests and deciduous forests and between the stands having different densities. Even though the quantity of each litter component was not estimated, more than 70 % of which was observed to be leaf litter.

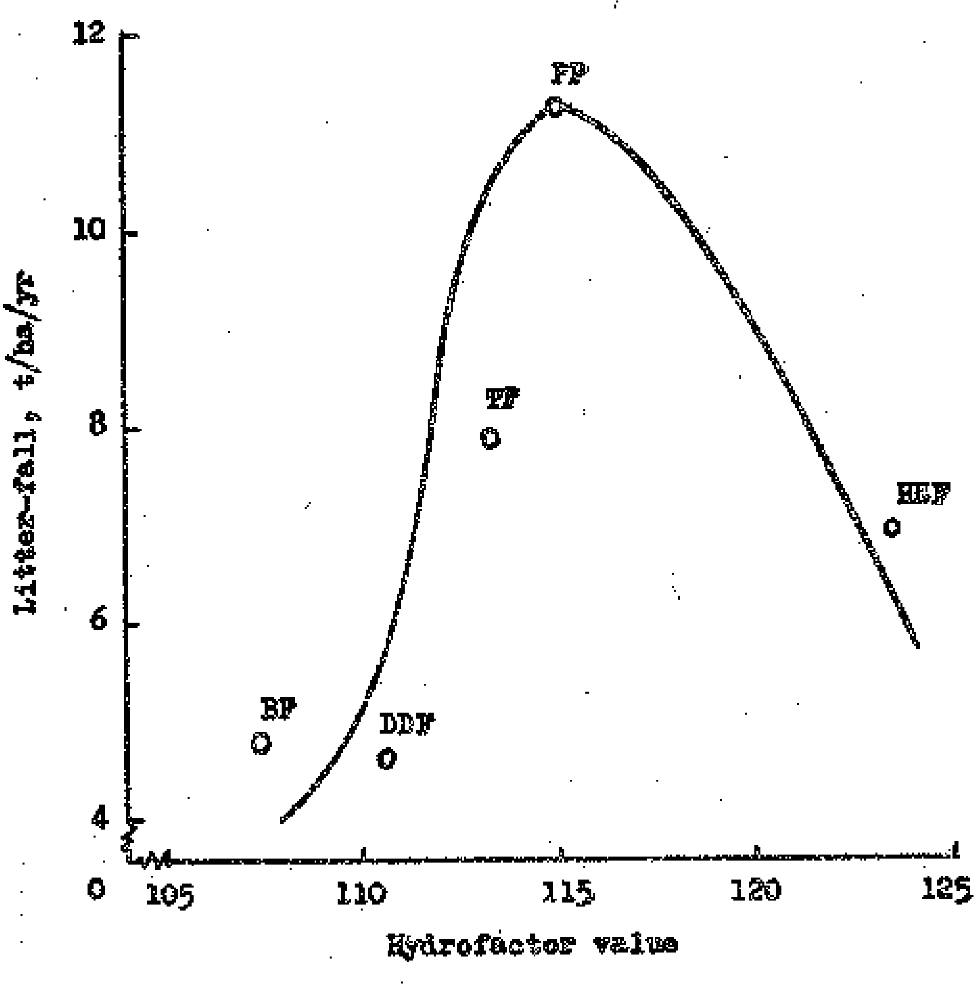

Figure 9. Total annual litter-fall in relation to hydrofactor value of different forest types : BF, bamboo forest; DDF, dry dipterocarps forest; TF, teak forest; FP, pine plantation; and HEF, hill evergreen forest.

Table 2 shows the amounts of total annual litter-fall obtained from this study in comparison to the results found elsewhere, especially in the tropical zones. Two samples from America and Europe are used to be the representatives of temperate forests. It is doubtful that litter production of the tropical forests is more than that of temperate forests, i.e., the amounts of litter-fall decrease with increasing latitude either up or down from the Equator.

Chemical Composition of Litter

Obviously, litter-fall is variable in elemental contents because of the varying proportions of leaf, wood, bark, fruit, and flower parts which compose litter. The heavier elements such as Cu, Mn, and Ca tend to accumulate in older litter (Stark, 1971). Chemical composition of litter also varies with soil type. Lamb and Florence (1975) found that concentration of N and P were smaller and rates of nutrient turnover were slower in litter on sand podzol than on terra rossa, meadow podzol, and humus podzol soil types. Howard and Howard (1974) showed the marked fluctuations in N content of oak, hazel, elm, and lime with time. Oppositely, K and Mg contents decrease with time (Gosz et al., 1973).

Table 2 compared the chemical composition of litter from this study to the results of other investigators. All nutrients obtained are among the ranges found elsewhere. N and K contents of samples from hill evergreen forest and pine plantation are lower than those

Table 2. Comparison of total litter production (kg/ha/yr) and chemical composition of litter (% dry weight) in some forests

Location	Forest type	Litter-fall (kg/ha/yr)	Chemical composition (%)					Remarks	Reference
			N	P	K	Ca	Mg		
Thailand	Teak forest	7,922	0.71	0.09	0.62	1.95	0.21	mature stand	Current study
Thailand	Pine (*P. kesiya*)	11,346	0.55	0.05	0.42	0.25	0.11	12-yr-old plantation	Current study
Thailand	Bamboo	4,811	0.79	0.09	0.67	0.16	0.10	pure stand	Current study
Thailand	Dry dipterocarps	4,666	2.57	0.16	1.48	1.95	0.51	mature stand	Paovongsar, 1976
Thailand	Hill evergreen	6,878	0.12	0.11	0.03	1.11	0.38	mature stand	Boonyawat and Ngampongsai, 1974
Thailand	Teak plantation	11,650	-	-	-	-	-	10-yr-old	Aksornkoae *et al.*, 1972
India	Teak plantation	5,300	2.08	0.44	0.76	5.24	0.20	leaf litter	Seth *et al.*, 1963
India	*Shorea robusta* plantation	5,000	1.84	0.36	0.76	3.08	0.40	leaf litter	Seth *et al.*, 1963
Ghana	Moist tropical	10,500	1.54	0.06	0.45	1.98	0.24	mixed stand	Nye, 1961
Nigeria	Teak plantation	9,045	3.64	0.40	2.84	7.52	0.86	7-yr old	Egunjobi, 1974
Panama	Premontane Wet	10,480	-	0.16	0.26	0.18	0.31	mixed stand	Golley *et al.*, 1975
Trinidad	Tropical rain	7,000	2.45	0.13	0.46	2.72	0.60	mixed stand	Cornforth, 1970
England	Scots pine	2,900	1.12	0.08	0.12	0.44	0.04	plantation	Ovington and Madgwick, 1959
U.S.A.	Pine (*P. taeda*)	4,100	6.84	0.85	0.63	2.55	0.48	12-yr-old plantation	Van Lear and Goebel, 1976

from the other three stands. Generally speaking, N and K contents of lower elevation stands are greater than N and K contents of the higher elevation samples. Golley et al. (1975) also reported the similar results from studying in Panama that litter K content of Premontane Wet forest appearing on the highlands was doubled the K content received from Riverine forest occuring along the river. The order of abundance was expressed in Table 3 together with some previous investigations.

Table 3. Order of abundance of nutrients in forest litter

Location	Forest type	Order of abundance	Reference
Thailand	Teak forest	Ca > N > K > Mg > P	Current study
Thailand	Pine plantation	N > K > Ca > Mg > P	Current study
Thailand	Bamboo forest	Si > N > K > Ca > Mg > P	Current study
Thailand	Dry dipterocarps	N > Ca > K > Mg > P	Paovongsar, 1976
Thailand	Hill evergreen	Ca > Mg > N > P > K	Boonyawat and Ngampongsai, 1974
India	Teak forest	Ca > N > K > Mg > P > Na	Vyas et al., 1976
India	Tropical deciduous	Ca > Mg ≷ K ≷ P > Na	Singh, 1969a
Ghana	Moist tropical	Ca > N > K > Mg > P	Nye, 1961
Brazil	Tropical rain	N > Ca > Mg > K > P	Stark, 1971
Peru	Tropical rain	Ca > N > K > Mg > P	Stark, 1971
England	Scots pine	N > K > Ca > P > Mg > Na	Ovington, 1962
U.S.A.	Maple, beech, fir	N>Ca<Fe>S>P>Mn>K>Mg>Na>Zn>Cu	Gosz et al., 1976

The comparison of annual nutrient contents in litter collected from different stands are illustrated by Figure 10. Some macronutrients gained from forest litter-fall throughout the country are approximated on the basis of area percentage of each major forest type. The results are shown in Table 4. Additionally, Si content in bamboo litter is estimated of about 34.75 kg/ha/yr or 1.39 % dry weight.

Table 4. Nutrients gained from forest litter-fall in Thailand

Forest type	Area, km^2	Annual nutrients gained, t/yr				
		N	P	K	Ca	Mg
Mixed deciduous (teak forest)	38,428	68,210	8,646	59,102	187,337	20,559
Dry dipterocarps	67,988	436,483	27,059	251,420	331,781	86,617
Evergreen (hill evergreen)	71,059	21,318	19,541	5,329	197,189	67,506
Scrub (bamboo)	2,843	5,615	611	4,728	1,137	711
Pine	895	1,226	103	929	559	251
Total	181,213	532,852	55,960	321,508	718,003	175,644

There is no doubt that litter-fall produces a tremendous amount of plant nutrients. Therefore, typical management of forest litter is extremely important to approach both favorably direct and indirect effects on soil productivity. Loss of forest residues in improper time through the improper ways may be highly detrimental problems.

CONCLUSIONS

Dry period in terms of temperature-rainfall relationship is the principal factor affecting the amount of litter-fall in a specific stand. The highest litter production occurs during the dry months, ranging from mid-November to mid-April, which some forest types may produce as high as 80 % of the total litter yield. Unthinned pine plantation produces about 50 % more total annual litter than natural Angiosperm stands. The total annual production of dicot species is greater than that of monocots. The chemical composition of litter varies with species and location. N and K contents in litter tend to decrease with increasing stand elevation. The tremendous amounts gained annually may affect the economic development if the treatment of forest litter is not carried out properly. The fate of essential plant nutrients from litter-fall offers an important question to be answered.

FUTURE STUDIES

Since a sound system of forest floor management is required, investigation in this field of interest should be paid more attention in future. Such factors affecting litter production and decomposition rates as C/N ratio and hydrothermal factors as well as those influencing nutrient losses and nutrient cycling are challenging in this country.

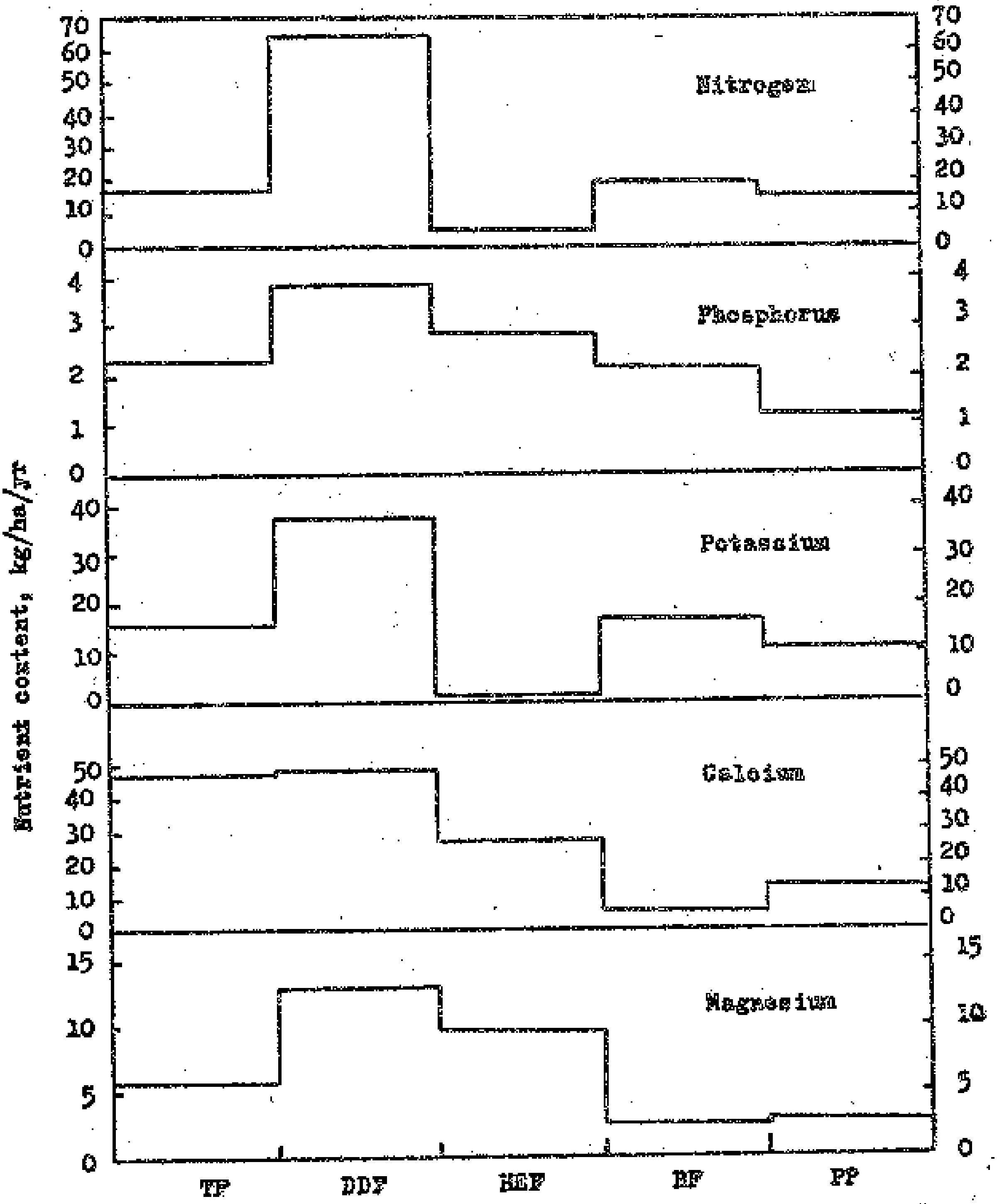

Figure 10. The annual nutrient return through litter-fall of different forest types : TF, teak forest; DDF, dry dipterocarps forest; HEF, hill evergreen forest; BF, bamboo forest; and PP, pine plantation.

REFERENCES

Aksornkoae, S., C. Khemnark, and T. Kaewla-iad. 1972. Study on organic matter in teak plantation. Kasetsart Univ. For. Res. Bull. No. 23. 36 p. (In Thai with English summary).

Biswell, H.H. and A.M. Schultz. 1957. Surface runoff and erosion as related to prescribed burning. J. For. 55 :372 - 374.

Boonyawat, S. and C. Ngampongsai. 1974. An analysis of accumulation and decomposition of litter fall in hill evergreen forest, Doi Pui, Chiangmai. Kasetsart Univ. Kog-ma Watershed Res. Bull. No. 17. 21 p. (In Thai with English summary).

Bray, J.R. and E. Gorham. 1964. Litter production in forest of the world. Adv. Ecol. Res. 2 : 101 - 157.

Brinson, M.M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecol. 58 : 601 - 609.

Cornforth, I.S. 1970. Leaf-fall in a tropical rain forest. J. Appl. Ecol. 7 : 603 - 608.

Daniel, M.J. 1975. Preliminary account of litter production in a New Zealand lowland Podocarp-Rata-broadleaved forest. N.Z. J. Bot. 3 : 173 - 187.

Egunjobi, J.K. 1974. Litter fall and mineralization in a teak (Tectona grandis) stand. Oikos 25 : 222 - 226.

Golley, F.B., J.T. McGinnis, R.G. Clements, G.I. Child, and M.J. Duever. 1975. Mineral cycling in a tropical moist forest ecosystem. Univ. of Georgia Press, Athens. 248 p.

Gosz, J.R., G.E. Likens, and F.H. Bormann. 1973. Nutrient release from decomposing leaf and branch litter in the Hubbard Brook forest, New Hampshire. Ecol. Monogr. 43 : 173 - 191.

Gosz, J.R., G.E. Likens, and F.H. Bormann. 1976. Organic matter and nutrient dynamics of the forest and forest floor in the Hubbard Brook forest. Oecologia 22 : 305 - 320.

Howard, P.J.A. and D.M. Howard. 1974. Microbial decomposition of tree and shrub leaf litter. I. Weight loss and chemical composition of decomposing litter. Oikos 25 : 341 - 352.

Isépy, I. 1974. Leaf-litter production and the measurement of litter decomposition rate in mesophyll broadleaved stands. Hungarian Agric. Rev. 25 : 74.

Jenny, H., S.P. Gessel, and F.T. Bingham. 1949. Comparative study of decomposition rates of organic matter in temperate and tropical regions. Soil Sci. 68 : 419 - 432.

John, D.M. 1973. Accumulation and decay of litter and net production of forest in tropical West Africa. Oikos 24 : 430 - 435.

Kononova, M.M. 1975. Humus of virgin and cultivated soils. In : Soil component Vol. I (J.E. Gieseking, Ed.) pp. 475 - 526. Springer-Verlag, New York.

Lamb, D. and R.G. Florence. 1975. Influence of soil type on the nitrogen and phosphorus content of radiata pine litter. N.Z. J. For. Sci. 5 : 143 - 151.

Lang, G.E. 1974. Litter dynamics in a mixed oak forest on the New Jersey Piedmont. Bull. Torrey Bot. Club 101 : 277 - 286.

Loomis, R.M. 1975. Annual changes in forest floor weights under a Southeast Missouri oak stand. USDA For. Serv. Res. Note NC-184. 3 p.

Metson, A.J. 1956. Methods of chemical analysis for soil survey samples. Soil Bur. Bull. No. 2. 12.

Nye, P.H. 1961. Organic matter and nutrient cycles under moist tropical forest. Plant & Soil 13 : 333 - 346.

Ovington, J.D. 1962. Quantitative ecology and the woodland ecosystem concept. Adv. Ecol. Res. 1 : 103 - 192.

Ovington, J.D. and H.A.I. Madgwick. 1959. Distribution of organic matter and plant nutrients in a plantation of Scots pine. For. Sci. 5 : 344 - 355.

Paovongsar, S. 1976. Litter fall and mineral nutrient content of litter in dry dipterocarps forest. M.S. Thesis, Kasetsart Univ. 75 p. (In Thai with English summary).

Phillipson, J., R.J. Putman, J. Steel, and S.R.J. Woodell. 1975. Input, litter decomposition and the evaluation of carbon dioxide in a beech woodland - Wytham woods, Oxford. Oecologia 20 : 203 - 217.

Pradhan, I.P. 1973. Preliminary study of interception through leaf litter. Indian For. 99 : 440 - 445.

Rochow, J.J. 1974. Litter fall relations in a Missouri forest. Oikos 25 : 80 - 85.

Seth, S.K., O.N. Kaul, and A.C. Gupta. 1963. Some observations on nutrient cycle and return of nutrients in plantations at New Forest. Indian For. 89 : 90 - 98.

Singh, K.P. 1969a. Nutrient concentration in leaf litter of ten important tree species of deciduous forest at Varanasi. Trop. Ecol. 10 : 83 - 95.

Singh, K.P. 1969b. Studies in decomposition of leaf litter of important trees of tropical deciduous forests at Varanasi. Trop. Ecol. 10 : 292 - 311.

Stark, N. 1971. Nutrient cycling II. Nutrient distribution in Amazonian vegetation. Trop. Ecol. 12 : 177 - 201.

Tsai, L.M. 1974. Litterfall and mineral nutrient content of litter in Pasoh Forest Reserve. IBP-Synthesis Meeting, Kuala Lumpur. (mimeographed).

Van Goor, A.Y. C.W. Barney. 1968. Forest tree planting in arid zones. Ronald Press Co., New York. 409 p.

Van Lear, D.H. and N.B. Goebel. 1976. Leaf fall and forest floor characteristics in loblooly pine plantations in the South Carolina Piedmont. Soil Sci. Soc. Amer. J. 40 : 116 - 119.

Viro, P.J. 1955. Investigations on forest litter. Comm. Ins. For. Fenn. 45 (6). 65 p.

Vyas, L.N., R.K. Garg, and N.L. Vyas. 1976. Litter production and nutrient release in deciduous forest of Bansi, Udaipur, India. Flora German Dem. Rep. 165 : 103 - 111.

Waide, J.B. and W.T. Swank. 1976. Nutrient recycling and the stability of ecosystems : Implications for forest management in the Southeastern U.S. Soc. Amer. For. Proc. 1975 : 404 - 424.

Woods, F.W. and C.M. Gallegos. 1970. Litter accumulation in selected forests of the Republic of Panama. Biotropica 2 (1) : 46 - 50.

No 26 Suvit Sangtongproaw : Morphological study of pines in Thailand.*

No 27 Pricha Dhanmanonda: Site Quality of mixed deciduous forest with teak at Mae Huad, Lampang, as determined by soil aggregate.

No 28 Choompol Ngampongsai: The distribution and development of teak-root in different ages plantation.*

1974 No 29 Wiraj Chunwarin & Damrong Sri-Aran: Macroscopic and microscopic structure of important woods in Series Calyciflorae, Inferae, Heteromerae, Bicarpellatae, Micembryae, Dayhnales, and Unisexuales.*

No 30 Wasan Kaitpraneet & Somsak Sukwong: Height growth of teak (Tectona grandis, Linn. F.) as related to environmental factors.*

No 31 Somkid Siripatanadilok: Development of teak flower (Tectona grandis, Linn).*

1975 No 32 Prakong Intrachandra: Efficiency comparison between machanize and hand weeding at Ban Dan Lan Hoy Teak Plantation, Sukhothai Province.*

No 33 Wuthipol Hoamuangkaew: Economics of lac production: a case study of the extension and research station of lac at Klangdong, Amphor Packchong, Changwat Nakhonratchasima.*

No 34 Tawee Kaewla-iad, Somsak Sukwong: Point sampling trial in dry dipterocarps forest.*

No 35 Somneug Pongampai: Morphology of some forest trees in Dipterocarpaceae.*

No 36 Charn Boonyasirikool and Wuthipol Hoamuangkaew: Testing accuracy of some log rules.*

No 37 Bunvong Thaiutsa, Choob Khemnark, Wisut Suwannapinunt, and Somporn Chaicharus: Soil properties of plantation after thinning.*

1976 No 38 Sanit Aksornkoae: Strucutre of mangrove forest at Amphoe Khlung Changwat Chantaburi, Thailand.

No 39 Bunvong Thaiutsa, Wisut Suwannapinunt, Wasan Kaitpraneet, Somsak Sukwong: Changes of soil properties in Teak forest under the Different Silvicultural Systems.*

No 40 Pongsak Sahunalu: Foliage Area Estimation of Local Pines.

No 41 Pitaya Petmak, Bunvong Thaiutsa, Pongsak Sahunalu : Dry weight increment of PINUS KESIYA seedlings after fertilizer application.*

No 42 Chow Chutpong, Bunvong Thaiutsa, Choob Khemnark, Wisut Suwannapinunt, Wasan Kaitpraneet : Nutrient composition of needles from fertilized and unfertlized PINUS KESIYA royle ex gordon.*

No 43 Wasan Kaitpraneet, Bunvong Thaiutsa, Wisut Suwannapinunt, Manop Kamchornchird: Effects of Thinning and Fertilization on Soil Properties of Pine Plantation.*

No 44 Sathit Wacharakitti : Tropical Forest Land-Use Evolution/Northern Thailand.

No 45 Pongsak Sahunalu, Boonyong Sureepong, Suree Bhumibhamon : Effect of Light on The Germination of Pinus Kesiya Royle ex Gordon Seeds.*

No 46 Pongsak Sahunalu, Pramook Likitthamanit, Prin Sri-Aran: Diameter and age Distributions of pinus merkusii jungh and devries and pinus kesiya royle ex gordon stands.

No 47 Wiraj Chunwarin: Culm structure and Composition of three Thai bamboos.

No 48 Wiraj Chunwarin: Physical Properties of Three Thai Bamboos.

No 49 Praphant Kocsomboon: Attitude of High School Student in Bangkok Toward Forest Resources Conservation.

No 50 Wasan Kaitpraneet, Bunvong Thaiutsa, Paitoon Kanchanapinpong, Somsak Sukwong : Soil Improvement of Teak Plantation by Agricultural Intercropping.

No 51 Chalerm mahittikul, Prin sri-aran, Kasem sooksathan, Seri Drabyasara: Utilization of Waste from Agriculture for Fiber-Overlaid Plywood and Properties of Panels.

* In Thai with English summary