STUDIES ON STRUCTURAL AND FUNCTIONAL ASPECTS OF TWO SUB-TROPICAL HUMID FOREST TYPES OF MEGHALAYA

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I certify that the thesis entitled "STUDIES ON STRUCTURAL AND FUNCTIONAL ASPECTS OF TWO SUB-TROPICAL HUMID FOREST TYPES OF MEGHALAYA" submitted by Jasbir Singh for the Degree of Doctor of Philosophy of the North-Eastern Hill University, Shillong, embodies the record of original investigation carried out by him under my supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. Degree. This work has not been submitted for any Degree of any other University.

Supervisor.

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PREFACE

The present study has two sections. One pertains to the 50 year old secondary forest at Lailad which forms one in the series developing subsequent to slash and burn agriculture (jhum) at lower elevations of the Khasi Hills of Meghalaya. As such an attempt has been made to relate the present studies on the Lailad forest with the ecology of shifting agriculture in this region under "General considerations related to shifting agriculture (jhum) around Lailad" given at the end of this section. The study has 6 chapters dealing with study area, vegetation analysis, biomass production, litter dynamics, nutrient input into and output from the system and nutrient cycling.

Section II of the thesis is based on plantation studies on *Shorea robusta* Gaertn., growing at Umtesor which is in the same general geographical areas as that at Lailad. *Shorea robusta* which is a late successional tree and which is also an important component in a 50 year stand at Lailad has been studied in detail using 9 to 19 year old plantations. This section is divided into 2 chapters one dealing with growth analysis and productivity of S. robusta and the other dealing with intrasystem nutrient flow through soil, plant litter and biomass.

The thesis has a General Introduction dealing with a review of literature on forest ecosystem analysis. Each chapter has a brief 'Introduction' and 'Methods of Study.' Results and Discussion on the findings is given for each chapter, followed by 'Summary.'

CHAPTER 1

GENERAL INTRODUCTION

GENERAL INTRODUCTION

Vegetation Analysis :

Vegetation may be defined as an assemblage of plants growing together in a particular location and may be characterised either by its component species or by a combination of structural and functional characters that characterise the appearance or physiognomy of the vegetation. Structural or physiognomic methods do not demand species identification and are often considered more meaningful for detailed ecological studies. The changing nature of vegetation is its dynamic nature, that is changes in the distribution and structure of components occur in due course of time. The long term changes of the vegetation result in succession, and several communities may succeed one another to establish a climax community which is controlled by the climate of the region (Clements, 1916) or the stable community may be the result of cyclic changes (Tansley, 1935). However, the dynamics of vegetation or community are a complex subject and have been reviewed by Margalef (1968) and Odum (1963).

Vegetation has been described or classified in accordance with the major philosophies, the discontinuous and continuous concepts. The discontinuous concept, the more traditional approach, provides a description that enable one to discuss a gross vegetational unit. Gleason's (1926) individualistic concept provides a framework for examining plant community in greater detail as a dynamic unit.

In nature plants rarely grow isolated from one another. Individuals of a species are usually grouped into a population and populations of different species may be intermingled. Some of the plants grow more successfully than the others as indicated by their behaviour, size and number. The characteristics of the species which differ according to the genetic pattern and physiology determine not only the kind of habitats it can occupy, but also the kind of interrelations it forms with other species.

A common approach for vegetation analysis is the gathering of species abundance data from numerous study areas. A large number of such phytosociological studies have yielded considerable information on community-environment relationships and the nature of the community itself in temperate regions. However, many analyses of tropical forests are based on structural, physiognomical and floristic compositions (Knight, 1975). The early works in this respect are mostly descriptive with a focus on the kind and number of species in the forest. As species identification become more feasible and as better quantitative methods developed, studies occurred more frequently on the identification and causes of floristic patterns in relation to succession and site. With regard to site relationships, the studies of Ashton (1964a,b), Greig-Smith *et al* (1967), Bruning (1968), Tracey (1969), Webb (1969), Webb *et al* (1967 a,b, 1970, 1972), Hatheway (1971) and Austin *et al* (1972) are notable for their use of complex quantitative methods in the analysis of floristic data. Their results suggested that composition and classification methods are useful for analysing the vegetation and that certain species-rich communities also yield diagnostic and comprehensive ecological informations. Webb (1969), William and Webb (1969), Webb *et al* (1970), Budowski (1970) and Orloci and Mukkattu (1973) used physiognomical, structural and floristic features for vegetational analysis and classification. Many other workers considered the physical and chemical properties of the soil for composition and species distribution. A number of other workers based phenological studies for community analysis and classification. (Rees, 1964; Gibbs and Leston, 1970; Doubenmire,1972; Frankie *et al*,. 1974).

Biomass production :

Improved demands for forest products, the search for renewable source of raw materials and increased interest in the structure and function of forest ecosystems, in recent years, has stimulated research in biomass and production of different forest types throughout the world. The accumulation of large quantities of dry matter is a fundamental and distinguishing characteristic of forest ecosystems.

Total biomass itself is not a measure of productivity so far as forests are concerned. The biomass of forests is rather a function of age because stem biomass, which is accumulated year after year occupies extremely high percentage of the total biomass. In north temperate regions, productivity studies have been done for a number of species growing in even aged plantations or uneven aged natural or semi-natural woodlands (Westlake, 1963; Ovington, 1965; Whittaker, 1966; Whittaker and Woodwell, 1968). The geographical patterns of biomass distribution per unit area for the major types of terrestrial vegetation have been summarized by Rodin and Bazilevich (1967). Besides the information collected by these two authors additional data on biomass of different regions of the world was obtained during the International Biological Programme (Molchanov, 1964; Bazilevich, 1967; Kira and Shidei, 1967; Golley et al, 1969; Jenik, 1971; Whittaker, 1971).

In the past few years, biomass estimates of individual species have been published by a number of workers. Such studies included the information on the productive structure of the stand only. Although the weights of sample trees are frequently estimated by sub-sampling, very little information in the accuracy and precission of existing methods are available (Ellenberg, 1971; Hughes, 1971; Kestemont, 1972 , 1973; Neuwirth, 1972; Yamakura et al, 1972; Egunjobi, 1975). Overton et al (1973) have discussed the physical problem of estimating weights of very large trees. Art and Marks (1971) presented a working table of major species, the age and the location of the stand, the oven-dry weight of biomass and net annual productivity for about 280 forest stands. Madgwick (1976) briefly reviewed the literature concerning the methodology of estimating sample trees and stand weights with emphasis on statistical methods.

Since 1955, many studies on primary productivity of forest ecosystems, have been published by Japanese workers in temperate and tropical forests. These studies were mostly based on harvest methods (Kira and Schidei, 1967 and Newbould, 1967). The data obtained from more than three hundred stands were reviewed by Kira and Schidei (1967); Tadaki and Hatiya (1968) and Satoo (1968, 1970, 1971) while Ogawa et al (1965) have made some critical account of plant biomass for two luxuriant forests of tropical Africa.

Burger (1951) estimated leaf and branch weights in a large number of Swiss woodlands which vary in age from 13 to 92 years. Moller (1947) evaluated the dry weights for leaves of oak, ash, birch, spruce, scots pine and larch. Satoo et al (1955, 1956, 1959), Satoo and Senda (1958) in Japan and Whittaker (1965) in USA estimated the leaf and branch biomass and reported that leaf biomass cannot increase infinitely with forest growth and that there must be a limit specific to species or groups of ecologically similar species.

The estimation of biomass of individual tree or a stand by harvest method is the basic procedure for production relations. But this is very laborious and is neither practical nor permitted under many circumstances. Therefore, allometric relations based on some easily measurable variables such as diameter at breast height, plant height, diameter at the crown base and various measures of crowns have been used with success in developing prediction equations for individual tree components and stand of trees (Ovington and Madgwick, 1959; Attiwill, 1962; Baskerville, 1965; Ovington et al, 1967; Peterson et al, 1970; Zavitkovski and Stevensen, 1971). However, for estimation of crown, branch and foliage dry weight correlations with the diameter at the crown base or branch diameter usually give the best results (Attiwill, 1962; Peterson et al, 1970).

The woodland community with its various strata forms a complex association in which the reactions of different members are closely interrelated. Trees are the dominants of the community and by virtue of their size, stratification and longivity, they are able to determine to some extent the site conditions under which the associated plants live (Ovington, 1959). The contribution of ground vegetation is of great importance for a number of ecosystem processes (Ovington, 1962). In contrast to the tree cover, ground vegetation production has a high proportion of leafy material and a low proportion of biomass (Hughes, 1971). The production relationship between species in the ground vegetation which determine the process of natural regeneration of the woodland has been evaluated by Toumey and Kienholz (1931). That the tree cover which intercepts radiation, precipitation and other environmental factors influence the growth and relative performance of species on different woodlands have been shown by Blackmann and Rutter (1947), Begley (1955)and Ford and Newbould (1970).

Litter dynamics :

The amount and composition of the annual litter fall has long been considered to be of major importance for exchange of organic and inorganic materials between living organisms and soil. The role of litter in the forest ecosystem has been recognised for a long period of time and consequently many investigations have been made in its relation to productivity, nutrient cycling, energy flow and decomposition of forest organic matter. Bray and Gorham (1964) in their review of literature on litter production by the major world's forests state that in "the study of the quantitative aspects of litter fall remains an important part of forest ecology, dealing with a major pathway for both energy and nutrient transfer". The litter is the fuel for nutrient cycling in the upper soil horizons and is of importance in the nutrition of woodlands particularly on soils of low nutrient status, where the trees rely to a great extent upon the recycling of litter nutrients. In order to understand the biological process of the upper soil horizons, the quantity and composition of the litter and its pattern of fall throughout the year must be known.

The dynamics of litter accumulation process are of particular interest in the humid tropical forests where rates of litter production and decomposition are high. Litter in these forests accumulate on the soil until litter fall equals litter decomposition, after which a mean steady state ratio will be maintained.

Considerable amount of data exists for litter production and nutrient release in forest ecosystems, but still the literature on litter dynamics in tropical forests is much less and this is evident from the comprehensive review of work of Bray and Gorham (1964) which contain approximately 205 references of which a very minor fraction pertain to tropical forests. Seasonal litter fall in deciduous forests has been studied by Carlisle et al, (1966a), Sykes and Bunce (1970), Hughes (1971) and Gosz et al (1972) [illegible] but comparisons among species and years have been limited largely to total annual litter fall.

The litter consists of dead or decaying leaves, twigs, branches, flowers, fruits, bark and other debris. Out of these, leaf happens to be the major source of litter which may fall seasonally as is the case of deciduous trees or it may continuously accumulate throughout the year as we find in evergreen forests. The litter is attacked by a variety of micro-organisms and is decomposed to such a degree that eventually it becomes an inseparable ingredient of the soil system.

Information on litter production in aspen stand is available for the U.S.S.R. (Rodin and Bazilevich, 1967) and also for Alaska (Van Cleve and Noonan, 1971). In northern Wisconsin, U.S.A., Crow (1974) studied litter fall in predominantly aspen and aspen-paper birch stands. In tropical forests of Africa nutrient content of litter has been studied by Laudelaout and Meyer (1954), Ney (1961), Hopkins (1966), Bernehard (1970) and Egunjobi (1974). Similar studies on litter fall and nutrient content of the forest litter are available for European forests (Tarrant et al, 1951; Metz, 1952; Owen, 1954; Scott, 1955; Wright, 1957;

Kendrick, 1959; Monk et al, 1970 and Zavilkovoski and Newton, 1971). In New Zealand's evergreen beech forests litter fall has been measured by Miller and Hurst (1957) and Miller (1963).

Many studies on the seasonal dynamics of litter fall in forest ecosystems are available though only a few detailed studies on the dynamics of wood litter have been published. The wood litter fall in forest ecosystem is generally characterised by a great annual variation but lack of a clear seasonal pattern. This is mainly due to the non-periodic occurrence of high wind force during which dead wood material is dislodged. However, other factors may act in a complex way creating a seasonal pattern in the dynamics of wood litter fall.

Bray and Gorham (1964) suggested that woody litter amounts to about 30% of the total annual litter fall. This means that a considerable proportion of litter fall in forest ecosystems accumulates as dead wood in the wood fraction of soil litter, constituting a significant nutrient and energy reservoir (Healey and Swift, 1971). The production of dead leaves and dead wood, which trophically form the basis for many consumer chains play an important role in ecosystem functioning (Duvingneaud, 1971; Kestemont, 1971).

In temperate deciduous forests 19-39% of total annual litter fall is formed by the wood fraction (Christensen, 1975, 1978) resulting in a significant amount of dead wood in the forest floor. Although dead wood is poor in nutrients, a remarkable amount of minerals and especially energy may be released through the dead wood fraction which play an important role in mature forest ecosystem Healey and Swift, 1971). Generally a relationship between peak wood fall and maximum wind speed always exists. In a temperate forest, Gosz et al (1972) found a bimodal pattern of wood fall and they pointed out that branch fall is apparently a good indicator of storm intensity. In a moist semi-deciduous forest in tropical West Africa, the peak wood fall corresponds to the dry season when the trees are expected to be under greatest water stress, and a complex combination of intrinsic and extrinsic factors influences the timing and triggering off of litter fall (Jones, 1955). Addicott (1970) noted that almost all discretic parts of several high plant species are abscissed. However, abscission of organs other than leaves and to a lesser extent flowers and fruits has received only sporadic attention. Quantitative aspects of the accumulation and turnover of wood litter on the forest floor have been very poorly understood so far, except in a very limited number of forest types (Satchell, 1971) as compared with chemical and microbiological sides of the process (Kaarik, 1974).

Most of the studies on litter decomposition pertain to leaf litter only. However, wood litter also form a large proportion of the substrata decomposited on forest floor. The non-Leaf litter accounts for about 1/3 of the total litter fall in most forests, sometimes as much as 1/2 in climax forests (Kira and Schidei, 1967). Woody organs decomposed more slowly than leaves, while their original shape and volume are maintained for quite a long time under the protection of bark which is very resistant to decay. Yoneda (1975 I, II) made an attempt to estimate the rate of decomposition of wood litter in a warm temperate evergreen oak forest of Japan, adopting loss of weight and carbon dioxide evolution as measures of decomposition rate.

Litter decomposition is a dessimilation process mediated by a succession of organisms and associated enzyme systems (Alexender, 1961). The oxidation and hydrylic process converts the raw litter to carbon-dioxide and stabilised organic matter or humus. The mineralisation of organic to CO_2 which represents a major carbon loss or output route whereas humus formation may be regarded as a key carbon reservoir or conservation pathway. In most of the terrestrial systems, the decomposition of litter forms the major source of energy and nutrients for the soil and litter organisms of the deciduous woodlands. A great proportion of carbon fixed by the autotrophs return to the soil in the form of litter. The most important groups of organisms which play a role in decomposition are bacteria, actinomycetes, fungi, protozoa, nematodes, worms etc. Much attention has recently been paid to techniques used for studying decomposition of litter and the rate of decomposition of different types of plant litter in different climatic zones (Bocock and Gilbert, 1957; Edwards and Heath, 1963; Howard, 1965; Van-Cleave, 1971; Anderson, 1973b, Gosz et al, 1973; Howard and Howard, 1974; Jensen, 1974; Suffling and Smith, 1974; Wood, 1974). The process and organisms concerned in decomposition had mainly been studied by Bell (1974), Dickinson (1974), Edwards (1975), Frankland (1974), Harding and Stuttard (1974), Jensen (1974), Mason (1974), Millar (1974), Pugh (1974), William and Gray (1974), and Wood (1974).

The soil respiration is another biological phenomenon of decomposition which has long been considered as an index of soil metabolism (Wollny, 1831; Boussingault and Levy, 1853, Mina, 1962 and Reiners, 1968). Measurements of soil respiration are widely accepted as being the most important approach for studying the biological activities and the carbon and energy flows with respect to detritus ecology. The soil respiration is generally governed by the three biological process (a) microbial respiration (b) root respiration and (c) faunal respiration and one non-biological process i.e. chemical oxidation (Bunt and Rovira, 1954).

Although the study of litter production is of great significance in forest ecology, not much work has been done on this aspect under Indian conditions. In India estimation of annual litterpproduction in deciduous and in some evergreen forests have been made by Champion (1936), Puri (1953), Seth et al (1963), Singh (1968), Faruqi (1972) Billore and Amrithphali (1975) have also determined the nutrient content of litter fall. Most of the Indian workers mentioned above have worked with reference to forest plantations while practically no work is available on natural humid mixed forest types of India.

Rainfall interception, throughfall, stemflow and nutrient losses through run off and percolation :

The amount of incoming precipitation transmitted to or into the soil is of great importance to understand the water regime of plant communities. The diverse physiognomical structure of various plant associations plays an important role in precipitation interception and the amount of precipitation which is arriving on the soil surface. The precipitation generally falling on vegetation is usually leached in different ways. Some of the water reaches the ground through the canopy, some through the tree trunk and some part is intercepted by the vegetal cover which never reaches the ground. The amount of water which drips down through the forest canopy is referred to as throughfall; stemflow refers to the precipitation which reaches the ground by running down the boles of trees. The amount of water which is retained by the vegetal cover subsequently evaporates back to the atmosphere and is called the intercepted water. The interception of precipitation by vegetal cover is an important aspect of hydrological cycle influencing the water budget and nutrient movement, and plays an important role in the net rainfall reaching the ground surface. The quantities and modes of flow of precipitation to the forest floor have been studied for a long time. Interception studies have been reviewed by Kittredge (1948) and Zinke (1967). A number of studies have been done on this aspect by different workers (Hamilton and Rowe, 1949; Hoover, 1953; Ovington, 1954; Voigt, 1960; Rutter, 1963; Helvey, 1967; Smith, 1974).

Interception by the canopy usually affect the chemistry of the throughfall in a number of ways (Eaten et al, 1973). (1) Some of the chemicals which the precipitation contain are retained in the canopy and will not appear in the throughfall at that time (2) some of the nutrients may be leached into the water at the time of interception by the leaves and deposited as salts on the leaf surface as the water evaporates (3) although the concentration of nutrients in throughfall increases than in the original precipitation, it is apparent that nutrients can be absorbed into the leaves from the water (Boynton, 1954; Carlisle et al, 1965 and Wittwer and Teubner, 1969) or be taken up by the microflora on the surface of the leaves and branches (Carlisle et al, 1967). Moreover, the extent of precipitation interception by the forest canopy is affected by tree species, size and form of the tree as well as storm size and intensity (Ovington, 1954b; Gieger, 1965; Carlisle et al, 1965).

In forest ecosystems, a significant portion of the nutrient is recycled into the soil by means of leaf litter and its decomposition and also through precipitation. Duvigneaud et al (1971) reported that in temperate forests 3/4 of the total amount of circulating minerals are returned to the soil with leaf litter, throughfall and stem flow. Almost half of the total amount of potassium arrives into the soil with canopy throughfall and stem flow annually (Carlisle et al, 1967; Nebe, 1973). A large portion of magnesium finds its way back to the soil in the same way, and in case of calcium and sodium the return through litter and decomposition is probably of greater significance. The importance of water dripping from the tree crowns and the role of minor tree litter fraction (bud scales, male flowers, capules, bark, etc.) in the nutrient cycling of a sessile oak (Quercus petreae) woodland on a low fertility siliceous site in a high rainfall area has been demonstrated by Carlisle (1965) and Carlisle et al (1966a, b).

A significant amount of nutrients is also transferred from the various plant parts to the soil as precipitation which passes through the forest canopy, the elements being added directly to the available nutrient pool without the intervention of any process of decomposition on the forest floor. The total ecosystem approach for quantifying nutrient budget and cycling phenomena of the northern hardwood forest has been successfully done by Bormann and Likens (1967). Several studies (LeClerc and Breazeale, 1908; Mes, 1954; Tukey and Amling, 1958; Tukey et al, 1958) have demonstrated that rainfall may remove substantial quantities of nutrients from the foliage of horticultural plants. Others have shown that rainwater which passes through the tree crown contain significantly higher quantities of many nutrient elements than rainfall collected in adjacent openings (Tamm, 1951; Madgwick and Ovington, 1959; Will, 1959; Voigt, 1960; Rahman, 1964; Cole et al 1968; Tarrant et al 1968). It is only recently that the study of input and deposition of nutrients from the atmosphere by way of precipitation into the ecosystem has attracted attention. Nye (1961); Carlisle et al (1967) and Reiners (1972) have measured the quantity of nutrient in precipitation received by different ecosystems and emphasized the role of vegetation in enriching the mineral content of rainwater. The quantity of minerals present in rainwater can be of special significance in the nutrient cycle of ecosystems especially in nutrient poor areas (Allen et al, 1968).

The leaching of elements from the forest canopy by precipitation is mainly dependent on the fact that an element must be present, indicating either a biological requirement or a non-selective uptake of the element by the plants. Elements which are present in large amounts in the leaves are leached in larger absolute quantities, but in some cases leaching may be independent of the amounts present in the leaves.

The atmosphere is a source of chemical to terrestrial ecosystems, as well as a source of water vapour for precipitation. Chemicals may become bonded with water vapour and delivered in a dissolved form with precipitation. Some of the chemicals like chlorine and sodium are commonly dissolved in precipitation which falls along ocean coasts (Gambell and Fisher, 1966) or chemicals may adhere to dust particles which become temporarily suspended in the atmosphere and returned to the surface as dry fall out between storms. The large surface area of the foliage which is exposed to wind and interception of rainwater by forest vegetation, plays an important role as a trapping device for dust particles, and rainfall which drips from the foliage (throughfall) may be substantially enriched in some chemical elements.

Precipitation water carries certain quantities of nutrients from air borne dust, gases, etc; the composition of which undergoes significant changes once they gain access to the ecosystem (Tamm, 1958; Stenlid, 1958; Tukey, 1970). This rainwater when falling on foliage surface, branches and stems of trees in forested ecosystems washes off the dust and thereby leaches a portion of the nutrient elements from them.

The chemistry of precipitation varies from area to area depending on the origin of air masses. Gore (1968) reported that 32.14 kg/ha of sodium is deposited annually by the precipitation from maritime air masses at Moor House, U.K. but Likens et al (1971) reported that the annual deposition of sodium is only 1.5 kg/ha at Hubbard Brook where air masses are primarily continental. The Ca/Mg ratio in precipitation has been used as an indicator of the source of air borne chemicals by some workers (Eriksson, 1952). Again, the intensity of rainfall affects the nutrient input through precipitation. Mecklenburg et al, (1966) and Attiwill (1966) showed that the amount of nutrients leached per unit quantity is greater during a low intensity of rain than it is during a heavy rain. Attiwill (1966) found that the decrease in nutrient content of leaves is greatest during the first hours of wetting.

The stimulation of nutrient mobilisation in the forest soil after clear cutting has been known for a long time but no attempt has been made so far to measure the losses of nutrient from the system through run-off of water or that percolating through the soil. The clear cutting of forest cover tends to increase stream water flow (Lull, 1959; Hornbeck _et al_, 1970; Pierce _et al_, 1970; Pierce _et al_, 1972) and stream temperature (Tamm, 1958). The amount of nitrogen discharged from a forested ecosystem after clear cutting is equivalent to the amount of nitrogen that is annually returned to the system under undisturbed conditions and losses of cations were 2 to 3 times greater than from an undisturbed system (Bormann _et al_, 1968, 1969).

Nutrient Cycling :

Ecosystem represents complex organization of living organisms, interacting with each other and with their physical environment. In attempts to understand such complex systems, ecologists group their components into a number of more or less easily definable categories. One of the most important functions of the forest ecosystem is nutrient cycling and a knowledge of thisis needed to obtain high productivity required to meet the increasing demands for forest products.

The detailed information on nutrient cycling is especially important because it defines the relationship between soil and plants. Numerous studies have been conducted in different geographical regions of the world assessing the means and distribution of nutrients in various forest ecosystems. Much of this work has been summarized by Rodin and Bazilevich (1967) and Ovington (1968). Cole et al (1968) Marks and Bormann et al (1972) emphasized the effect of fertilizer and clear cutting in nutrient cycling.

During the past decade, ecologists have become increasingly interested in the flow of nutrients through ecological systems and in the role that these particular ecosystems play in the larger biogeochemical cycles of the earth. A vital characteristic of any ecosystem is the continuous flow of nutrient and energy through it. Within the intra-system cycle of an ecosystem, several workers (Duvigneaud and Denaeyer-De Smet, 1964; Ovington, 1965; Cole et al, 1968; Bormann and Likens, 1970 and Jorgensen et al 1975) have carefully evaluated the size and rates of exchange between various nutrients pools. However, measurements of systems present major difficulties and only a few quantitative studies have so far been done (Likens et al, 1967), particularly in tropics.

Quantitative approach of nutrient budgets for a terrestrial ecosystem may be determined by measuring the metereological, geological and biological inputs and outputs (Bormann and Likens, 1967). The terrestrial ecosystem participates in the various larger biogeochemical cycles of the earth by input and output through the system. Geological input and output through balance of mineral elements in an ecosystem may be positive or negative, that is elements can be accumulating in the systems or the system can be in the process of depletion. Accumulation of elements in the biotic portion of the ecosystem often occurs as a result of successional process (Odum, 1969) as the amount of biomass in an system increases. The elements through geological inputs are generally carried into the system by moving water or colluvial action, or both, and outputs generally refer to the elements which are leaving the system in the form of dissolved or particulate matter in moving water, through the diffusion or transport of gases or particulate matter by wind (meteoreological output) or as a result of the activity of animals including man (biological output). Metereological input enters the ecosystem through the atmosphere in the form of gaseous materials and of dissolved or particulate matter in precipitation, dust and other wind borne materials.

The rate and magnitude of movement along individual pathways differ for different chemical elements and the general pattern of flow within the system depends upon many factors, particularly the nutrient status of the soil and the type and age of the woodland. Pioneering work by Ovington (1965), Rodin and Bazilevich (1967) and Duvigneaud and Denaeyer-De Smet (1970) along with comprehensive reviews and synthesis of data by Bray and Gorham (1964), Bakuzis (1964), Overton *et al* (1973), Larcher (1975), Jorgensen *et al* (1975) and Lieth and Whittaker (1975) have brought considerable attention to the process of nutrient cycling and production in forest ecosystems.

The most striking features of a woodland community from the nutrient circulation point of view is the annual return of nutrients to the soil through the litter from the vegetation cover. Smirnova and Gorodentseva (1958) reported that in birch woodlands of about 70 years age, annual defoliation returns 80 to 90 percent of the nutrients to the soil. Litter which include the leaves, bark, branches, dead stems, inflorescences and seeds are usually the largest components for the nutrient cycling in the forest ecosystem. However, in open woodlands the well developed shrubs and herb layers may contribute more litter than that from trees (Scott, 1955). The litter falling to the ground in woodlands is very heterogenous being composed of organic material differing greatly in structure and chemical composition and the mechanism and efficiency of litter breakdown varies greatly even in the same wood. (Alway and Zon, 1930, Wittich, 1939; Mork, 1944; Tarrent et al, 1951; Owen 1954; Gosz et al, 1972). The importance of soil organic matter in mature forest ecosystem was emphasized by Rodin and Bazilevich (1967), Likens et al (1970), Pierce et al (1972), Whittaker et al (1974), Gosz et al (1976). Nutrient cycling through decomposition of leaf and wood litter in tropical and temperate forests has been studied by many workers (Laudelout and Meyer, 1954; Nye, 1961; Witkamp and Olson, 1963; Olson, 1963; Bray and Gorham, 1964; Ovington, 1965; Bernhard, 1970; Anderson, 1973a; Gosz et al, 1973; Lousier and Parkison, 1976).

In order to evaluate the quantitative and qualitative aspects of productivity or to explore the nutrient cycling in the ecosystem, the knewledge of water circulation pattern in time and space is very important. Water circulation itself is a very complex process and it mainly deals with the pathway of water reaching the ecosystem in the form of precipitation to the soil, water in the soil, output of nutrient through water etc. And it is only in the last two decades that the study of the nutrients input and deposition from the atmosphere by way of precipitation is becoming of increasing interest. (Tamm, 1951, Viro, 1953, Madgwick and Ovington, 1959; Tukey and Tukey, 1959; Voigt, 1960; Nye, 1961; Carlisle et al, 1965, Likens, et al, 1967; Bormann and Likens 1967; Tarrant et al, 1968; Cole et al, 1968; Allen et al, 1968; Ulrich et al 1971; Reiners 1972; Szabo and Csortos, 1975).

Available nutrient not only enter the ecosystem from outside but are added by the action of physical chemical and biological weathering of rock and soil minerals. Physical and chemical weathering of the mineral soil and sub-soil increases the availability of nutrients in forest ecosystems but little is known of the release of nutrients by this process under natural conditions. The release of nutrients by weathering will depend greatly upon the soil type and underlying rocks but is also influenced by climate and the nature of the woodland.

CHAPTER 2

STUDY AREA

STUDY AREA

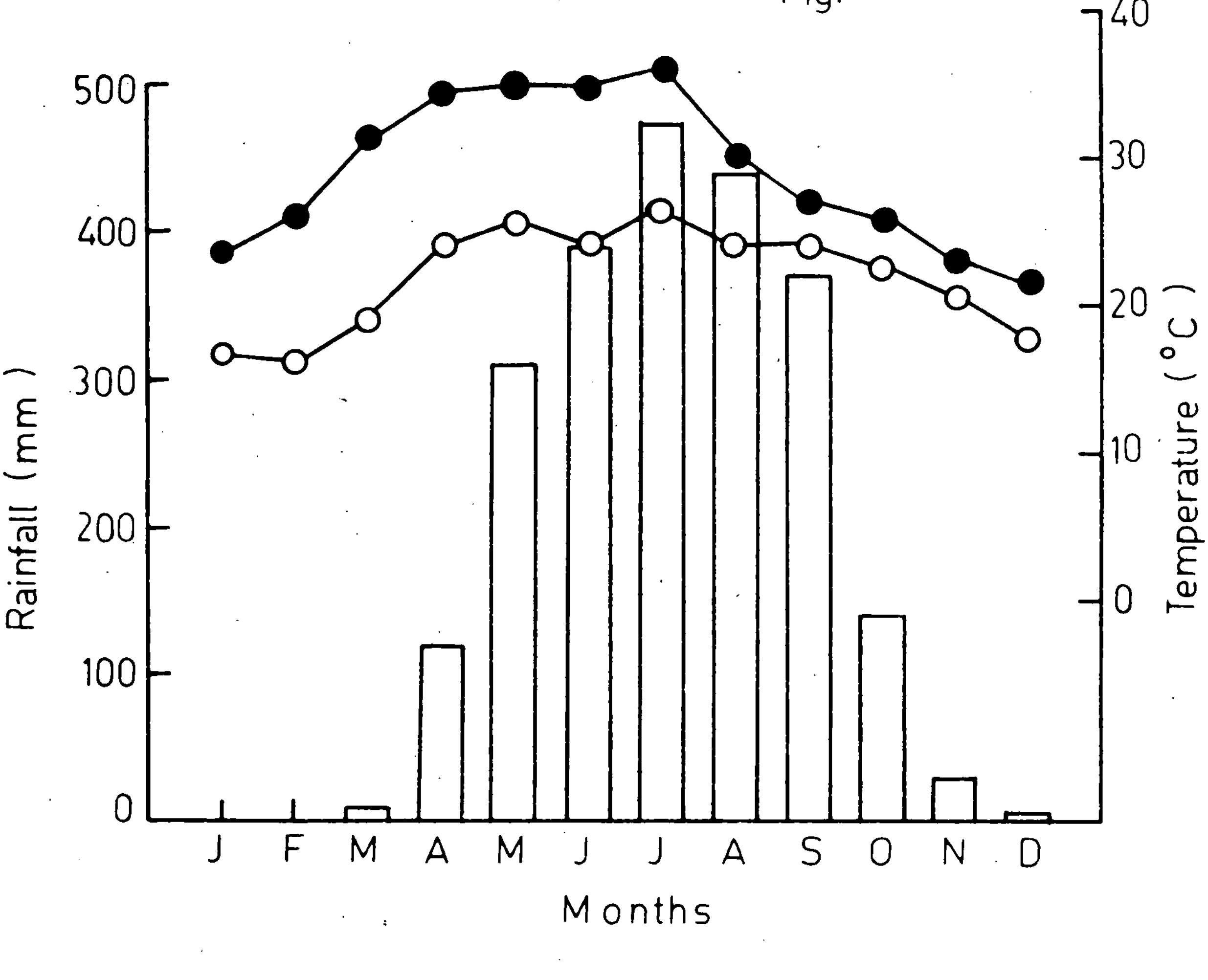
Lailad Reserve Forest :

One of the study areas (discussed under Section I) as shown in Fig. 2-1 is located at Lailad which is about 70 km. towards the northern side of Shillong city the capital of Meghalaya in the north-eastern region of India. It lies between 25°45" - 26°0" N latitude and 91°45" - 92°0" E longitude at an elevation of about 296 m. The pre-cambrian rocks are represented by gneiss, schists and granites. The soil is red, sandy loam and is of laterite origin. The pH ranges from 5.8 to 6.3. Angles of the slopes generally range from 20° to 60°. The climate is typically monsoonic with most of the rainfall (84%) of the total annual fall occuring during May to September. April and October are also quite wet. The rest of the period is practically dry. The monsoon season is followed by a mild winter during mid November to mid February. March and early April represent a brief dry summer period (Fig. 2-2).

The total area of the study site which is tropzoidal shaped (Inset Fig. 2-1) is about 5 hectares and is a part

Fig. 2-1. Climate of Lailad and Umtesor based on the average of two years - 1977 and 1978 (data obtained from Department of Silviculture, Government of Meghalaya). Maximum temperature, ● ; minimum temperature, ○ ; rainfall, □ .

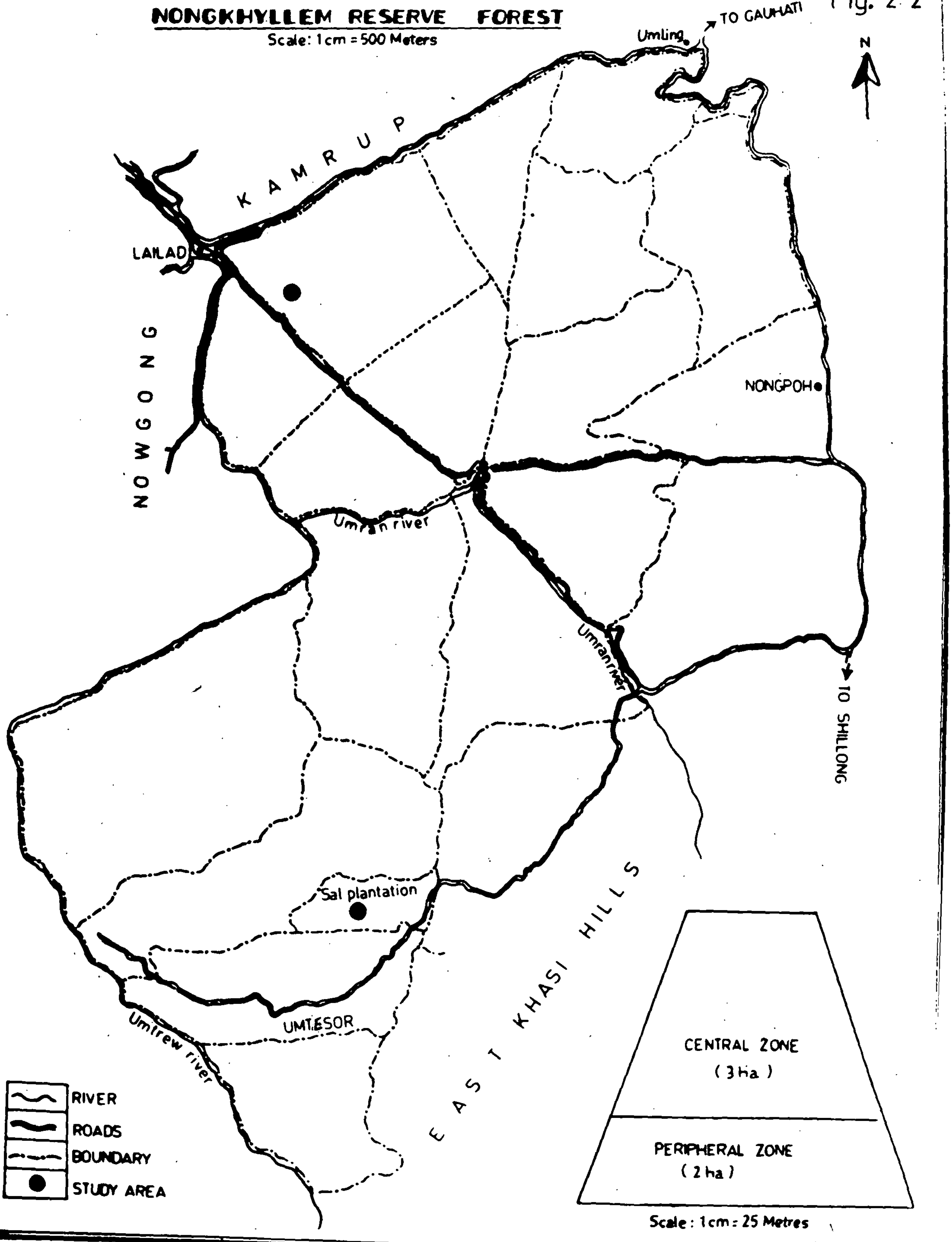
Fig. 2-1



500
400
300
200
100
0
Rainfall (mm)
40
30
20
10
0
Temperature (°C)
J
F
M
A
M
J
J
A
S
O
N
D
Months

Fig. 2-2. Map of Nongkhyllum reserve forest showing the study areas.

Fig. 2-2


NONGKHYLLEM RESERVE FOREST
Scale: 1 cm = 500 Meters
Umling
TO GAUHATI
N
KAMRUP
LAILAD
NOWGONG
NONGPOH
Umran river
Umran river
TO SHILLONG
Sal plantation
UMTESOR
Umtrew river
EAST KHASI HILLS
RIVER
ROADS
BOUNDARY
STUDY AREA
CENTRAL ZONE
(3 ha)
PERIPHERAL ZONE
(2 ha)
Scale : 1 cm : 25 Metres

of a reserve forest known as Nongkhyllum reserve forest which is under Meghalaya Forest Department since 1910. The forest is bounded on the north and northwest by Kamrup district and on the northwest by Nowgong district of Assam. The southern side of the forest is covered by the Shillong sub-division. The age of the forest which is approximately estimated to be 50 years is represented by a small hillock with average of 80% slope. Although the study area is located in a reserve forest, the peripheral zone is subjected to biotic disturbances, such as cutting of trees for firewood and removal of bamboo for fencing and house building purposes by the local tribal population. Therefore, only the central zone of the forest is representative of a 50 year old stand whereas the peripheral zone represents an arrested stage of succession with 20-25 year old vegetation.

The present study was done on a 5 hectare area indicated in Inset Fig. 2-2 considering the disturbed peripheral zone of 2 ha and the 50 year old stand of 3 ha in the hillock mentioned earlier. This study was undertaken as part of a larger programme on the ecology of shifting agriculture (jhum) which is extensively practised in this area by the local tribal population, namely the Garos (Ramakrishnan and Toky, 1978; Ramakrishnan, 1978; Ramakrishnan *et al*, 1980). The 50 year stand at Lailad represents the oldest fallow of the jhum practised at lower elevations of the Khasi Hills of Meghalaya.

Umtasor Shorea robusta (Sal) plantations :

The other study area (discussed under Section II) with *Shorea robusta* plantations at Umtasor is situated at about 50 km. north of Shillong at an elevation of 760 m. This forest also lies between 25°45" - 26°0" N latitude and 91°45" - 92°0" E longitude. Topography, climatic and soil conditions are, in general, same as at Lailad forest. This forest is also a part of Nongkhyllum reserve forest. The total area and age of different plantations of *Shorea robusta* are in Table 2-1.

Table 2-1. Age and area of different plantations of *Shorea robusta* at Umtesor

Stand age (year)	Area (hectare)
9	16
11	27
13	4
15	6
17	10
19	4

SECTION - I

ECOLOGICAL ANALYSIS OF A 50 - YEAR FOREST AT LAILAD

CHAPTER 3

VEGETATION ANALYSIS AND PHENOLOGY OF THE FOREST AT LAILAD

VEGETATION ANALYSIS AND PHENOLOGY OF THE FOREST AT LAILAD

INTRODUCTION

The structure of a vegetational unit depends *upon the species represented, on the relative number of* individuals and on the total number of individuals (Gleason, 1926). A common approach for vegetation analysis is the gathering of species abundance data from numerous study areas. Such phytosociological data are important to collect basic information on community-environment relationship, succession and the autecology of many species. Early work in this respect was mostly descriptive with a focus on the kind and number of species in the forest. As better quantitative methods developed, many studies were done on structural and physiognomic features and causes of floristic patterns in relation to succession and site. With regard to site relationships, the study of Ashton (1964a,b) Greig-Smith et al (1967), Webb et al (1967,1970, 1972), Tracey (1969), Webb (1969), Hatheway (1971) and Austin et al (1972) are important.

METHODS OF STUDY

Phytosociological studies were conducted in the outer peripheral zone with about two hectare area as well as in the central zone with about three hectare area of the forest. The peripheral zone which was influenced by many biological disturbances was selected to compare the species composition along with other aspects with the central zone of the forest. Phytosociological studies for tree, shrub and herb species were done in July 1976, at the peak of growing season. In order to study the density, frequency, basal area and important value index for tree 20 quadrats of 10 X 10m were laid down along a transect. For shrubs, the quadrat size was 5 X 5m whereas for herbaceous species 1 X 1m quadrats were used. The important value index is an integrated measure of relative frequency, relative density and relative basal area and was calculated following Misra (1968). The diversity and dominance indices were determined according to Margalef (1968) and Simpson (1949) respectively. Phenological studies with respect to leaf development, leaf fall, flowering and fruiting were done for all the major tree species for one year period during 1976.

RESULTS AND DISCUSSION

Vegetation Structure :

In the forest community as a whole, tree species like Dendrocalamus hamiltonii, Schima wallichii, Castanopsis indica, Shorea robusta and Miliusa roxburghiana dominate. Though M. roxburghiana had high density and frequency values in the community it is not one of the dominant species in the community as indicated from the low value for I.V.I. Thus Artocarpus chaplasa and Vitex peduncularis had high I.V.I. values inspite of low density and frequency and this was due to greater basal area of these species (Table 3-1).

Since the peripheral zone of the forest is more disturbed than the central zone, it became necessary to separate these two distinct zones for purpose of comparison. Dendrocalamus hamiltonii, Mesua ferrea, Miliusa roxburghiana and Vitex peduncularis were more dominant along the periphery of the forest compared to the centre. It may be noted that these species are all early successional species and it has been shown that D. hamiltonii reaches its peak in a community of about 20 years old after which it declines (Ramakrishnan and Toky, 1978). On the other hand the species like S. wallichii, C. indica and S. robusta were more dominant towards

Table 3-1 Density, frequency, basal area and importance value index of tree species in the peripheral and central zones of the sub-tropical forest at Lailad.

Species	Density/ha		Frequency		Basal area (m^2/ha)		I.V.I.	
	Peripheral zone	Central zone	Peripheral zone	Central zone	Peripheral zone	Central zone	Peripheral zone	Central zone
Amoora wallichii	6	8	11	7	0.332	0.442	2.21	2.46
Artocarpus chaplasa	24	16	4	14	13.774	9.182	14.88	15.37
Castanopsis indica	92	122	34	64	13.234	17.550	35.09	43.42
Castanopsis tribuloides	24	26	28	32	2.234	2.420	5.19	6.56
Dillenia indica	18	14	21	17	1.984	1.554	6.39	4.96
Dillenia pentagyna	16	12	11	7	0.452	0.340	3.95	3.66
Dendrocalamus hamiltonii	770	350	54	21	5.368	2.440	83.40	41.56
Dysoxylum birectarferum	4	2	7	4	0.064	0.032	1.53	0.78
Dysoxylum procerum	12	16	11	4	0.190	0.254	3.11	3.77
Eugenia tetragonia	-	2	-	4	-	0.230	-	4.29
Eugenia kurzii	4	10	4	11	0.388	0.970	1.15	3.15
Garcinia cowa	18	28	21	29	0.700	1.088	4.52	8.43
Garcinia peniculata	-	2	-	4	-	0.076	-	3.00
Gmelina arborea	12	16	11	43	2.326	3.102	4.51	6.59
Glochidion multiloculata	8	6	11	7	0.754	0.558	3.32	4.97
Hybiscus macrophylla	4	10	7	11	0.100	0.250	2.50	4.33
Ilex excelsa	-	2	-	4	-	1.088	-	2.97
Milusa roxburghiana	90	32	75	36	0.716	0.254	18.60	7.59
Mesua ferea	8	-	11	-	0.626	-	3.87	-
Machilus khasiana	8	14	14	18	0.254	0.630	2.43	4.69
Phoebe lanceolata	16	16	21	18	0.334	0.334	6.25	7.13
Pterospermum acerifolium	6	2	7	4	0.060	0.020	1.47	0.64
Sterculia villosa	20	8	29	11	0.520	0.208	5.29	3.72
Schima wallichii	144	204	68	89	1.454	20.600	39.51	60.60
Shorea robusta	62	90	60	50	9.198	13.352	27.87	30.87
Terminalia citrina	2	6	4	7	0.132	0.398	0.72	2.03
Terminalia chebula	20	22	14	21	1.320	1.452	5.70	7.88
Vitex peduncularis	44	32	21	49	1.944	1.250	16.59	14.52
	1442	1078						

2858

the central zone of the forest with higher I.V.I. values.

The comparison of the dominance values, calculated on the basis of Simpson's index of dominance (1949) with early successional fallows indicate that dominance is high in early successional fallows reaching a maximum in a 5 year old fallow after the burn for slash and burn agriculture (Jhum) and is very low in a 50 year old fallow as in the present study. Conversely diversity (calculated on the basis of Margalef's, 1968-'Shanon Index of General Diversity') reaches a maximum value in a 50 year old forest (2.58) (Table 3-2).

The disturbed zone along the periphery showed a dominance index value of 2.53 compared to the central zone. This is due to the high density of D. hamiltonii in this zone which is a species indicative of early successional communities or disturbed sites. It may be noted that 28% of the total I.V.I. along the periphery was contributed by D. hamiltonii whereas it contributed only 13.8% of the total I.V.I. in the central zone. These results are in agreement with that of Risser and Rice (1971) and Mellinger and McNaughton (1975) who showed that

Table 3-2 Species diversity and dominance in successional stands from younger to older fallows (partly based on Toky and Ramakrishnan, unpublished).

Successional ages of fallows (year)	Diversity	Dominance
0	0.12	0.215
5	0.21	0.705
10	1.01	0.519
15	1.48	0.556
20	1.50	0.501
50	2.58	0.511

species diversity increased and dominance decreased with progression of succession. These results also seem to be in general agreement with the basic hypothesis of Margalef (1963, 1968) that succession is accompanied by increased biological diversity and reduced dominance.

Croton oblongifolium, *Litsaea khasyana*, *Leea sambucina*, *Anona wallichii*, *Randia densiflora* and *Micromelum pubescence* were the important components of the shrub layer of the forest as a whole. The dominance and diversity indices were more or less the same along the periphery and the centre of the forest with values 0.074 and 2.711 respectively, along the periphery and 0.065 and 2.785 respectively in the centre. It may be noted that species like *C. oblongifolium* had very high I.V.I. value along the peripheral zone of the forest whilst quite a few species like *Anona wallichii*, *Combretum decandrum*, *Litsaea khasyana*, *Leea sambucina*, *Morinda umbellata*, *Phylogacanthus tubiflorus* and *Sterculia coccinia* along the peripheral zone showed slightly higher I.V.I. values compared to their values in the central zone. In general, however, the I.V.I. values in the centre and periphery of the forest are not quite different because of the fact that low density of some of the species in the centre of the forest was partly compensated by the larger basal area (Table 3-3). This would also explain similar diversity and dominance values in these two zones.

Panicum khasianum, *Cyeprus elegans*, *Hedychium gracile*, *Fimbristylis dichotoma*, *Abacopteris multilineata* and *Passiflora nepalensis* are predominant amongst herbaceous species with high importance value indices (I.V.I.). A large number of herbaceous species possess more I.V.I. in the peripheral zone of the forest in comparison to the central zone (Table 3-4). This may be due to the lesser number of tree species with reduced canopy cover which permitted greater light penetration and less competition in the peripheral zone.

The dominance index of herbaceous species was found to be slightly more in the disturbed peripheral zone (0.40) in comparison to the undisturbed central zone (0.35). Conversely diversity was higher in the central zone (3.73) in comparison to the peripheral zone (3.61).

The forest at Lailad also comprises of lianas like *Bauhinia vahlii*, *Spotholobos roxburghii*, *Entada purseetha*, *Hudgsonia macrocarpa* and *Gnetum ula*. Another interesting feature of the forest is the predominance of epiphytic plants.

Table 3-3. Density, frequency, basal area and importance value index of shrub species in the peripheral and central zones of the forest at Lailad.

	Density/ha		Frequency		Basal area (cm^2/ha)		I.V.I.	
	Peripheral zone	Central zone	Peripheral zone	Central zone	Peripheral zone	Central zone	Peripheral zone	Central zone
Anona wallichii	72	48	50	40	160.02	100.24	25.74	17.96
Allophylus serratus	80	80	67	43	4.43	4.62	8.91	8.45
Actinodaphne angustifolia	96	104	70	73	40.82	40.04	16.66	19.03
Croton oblongifolium	240	120	60	53	200.62	100.42	42.41	28.41
Combretum decandrum	160	80	40	30	17.22	8.38	12.69	13.96
Litsaea khasyana	160	120	73	40	261.60	201.02	26.63	21.00
Leea sambuchina	104	138	27	30	121.34	140.62	29.44	26.71
Morrinda umbellata	120	120	37	30	61.06	60.82	16.67	17.79
Maesa indica	160	120	43	37	8.70	6.60	12.52	13.49
Maesa chisia	64	16	30	13	10.36	3.62	8.37	12.06
Micromelum pubescence	144	96	47	37	12.32	8.70	16.37	24.05
Murraya koenighi	56	104	30	50	4.10	6.82	6.92	13.84
Phlagocanthus thyrsiflorus	160	80	47	30	12.10	7.02	9.50	14.96
Phlagocanthus tubiflorus	240	80	60	43	14.82	4.02	19.42	14.57
Randia densiflora	160	200	60	87	40.62	40.42	16.80	24.64
Sterculia cocinia	80	112	35	46	72.40	101.30	17.59	15.34

16/8

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Table 3-4 Density, frequency, basal area and importantevalue index of herbaceous species in the peripheral and central zones of the forest at Lailad.

Species	Density/m^2		Frequency		Basal area (cm^2/m^2)		I. V. I.	
	Peripheral zone	Central zone	Peripheral zone	Central zone	Peripheral zone	Central zone	Peripheral zone	Central zone
Abacopteris multilineata	0.74	0.40	67	45	1.86	0.20	7.08	6.08
Begonia thomsoni	0.34	0.20	40	17	0.18	0.10	3.88	2.59
Cyperus elegans	2.02	2.06	55	67	1.02	0.80	19.90	18.33
Carex baecaus	0.80	0.40	60	27	0.34	0.20	8.74	4.33
Curcuma lenga	0.54	0.40	30	40	0.30	0.12	4.17	2.93
Curceligo orchieides	0.20	-	30	-	0.16	-	2.50	-
Colocasia affinis	0.20	-	45	-	0112	-	2.30	-
Costus speciosus	0.86	0.60	53	43	0.60	0.20	7.18	5.75
Caryota urerus	0.20	0.20	7	27	0.64	0.40	3.37	5.36
Desmodium lasurnifolium	0.66	0.20	20	30	0.46	0.40	5.88	5.63
Dracaena spicata	0.02	0.38	7	40	0.02	0.42	2.54	5.19
Dioscorea bulbifera	0.20	0.26	7	30	0.16	0.18	2.05	3.99
Elatostoma sessile	0.26	0.20	30	7	0.08	0.06	2.96	1.06
Embelia mutans	0.10	0.10	23	18	0.76	0.96	1.21	1.37
Eragrosteso pilosa	1.74	1.00	70	55	0.62	0.40	9.71	3.12
Floscopa scandens	0.16	0.04	20	7	0.06	0.08	5.50	1.19
Fimbristylis dichotoma	1.74	1.60	73	63	0.90	1.00	14.10	14.12
Globba clarkei	0.34	0.40	40	30	0.14	0.14	5.41	3.31
Gomphostemma parviflorum	0.20	.34	33	40	0.12	0.18	2.88	4.38
Hedycium gracile	1.40	0.80	67	50	0.48	0.40	16.26	9.35
Hedycium cornonarium	0.80	0.86	50	63	0.26	0.08	9.01	7.36
Ipomea digitata	0.32	0.20	30	33	0.08	0.06	2.52	1.89
Juslicia procumbens	0.20	0.14	30	17	0.14	0.04	3.99	2.65
Lygodium japonicum	0.20	0.50	7	40	0.12	0.12	2.01	5.70
Mimosa pudica	0.40	-	30	-	0.34	-	4.25	-
Merrewa vitifolia	1.60	1.00	73	63	0.06	0.04	7.03	4.89
Oplismenus compositus	1.00	1.60	73	47	0.60	0.40	11.65	7.87
Ophiorrhiza ochroleuca	0.26	0.20	27	7	0.06	0.40	4.81	2.71
Oldenlandia diffusa	0.46	0.20	20	7	0.16	0.36	3.34	3.80
Oryza meyeriana	0.38	0.26	30	7	0.30	0.10	5.56	2.35
Parynium pubinervium	0.20	0.06	27	7	0.08	0.04	2.04	1.80
Pavata indica	0.40	0.34	17	40	0.16	0.16	3.85	3.19
Pogostemon villosus	0.40	0.34	27	20	0.42	0.20	5.00	4.33
Phyllanthus glauca	0.20	0.20	7	15	0.06	0.12	1.92	2.38
Panicum khasianum	17.54	4.00	83	67	1.80	2.00	40.23	15.53
Piper longum	0.60	0.54	47	33	0.14	0.16	5.45	4.35
Passiflora nepalensis	0.20	0.46	20	30	1.32	0.80	10.21	11.14
Rungia repens	0.80	0.40	50	50	0.34	0.14	6.02	3.05
Strobilanthus anisophyllus	0.26	0.20	23	20	0.10	0.10	3.30	3.08
Sida rhomboidea	0.40	-	40	-	0.12	-	3.56	-
Smilax ferox	0.66	0.40	43	30	0030	0.38	6.43	5.03
Thysanolaena maxima	0.20	0.34	27	37	0.6	0.30	2.06	4.02
Thunbergia grandiflora	*0.26*	*0.20*	*27*	*30*	*0.10*	*0.06*	*2.90*	*2.55*
Uncaria sessilifroctus	0.16	0.10	17	10	0.04	0.04	1.92	1.50
Vernonia cinerea	0.34	0.40	17	30	0.20	0.06	2.29	3.67
Vites assanica	0.40	0.80	40	50	0.10	0.20	2.13	4.39

Mention may be made of species of Orchids like Dendrobium moschatum, Vanda sp. Rhyncostylis sp., Cymbidium sp. etc. A quantitative assessment of these components in the forest however, could not be made during the present study.

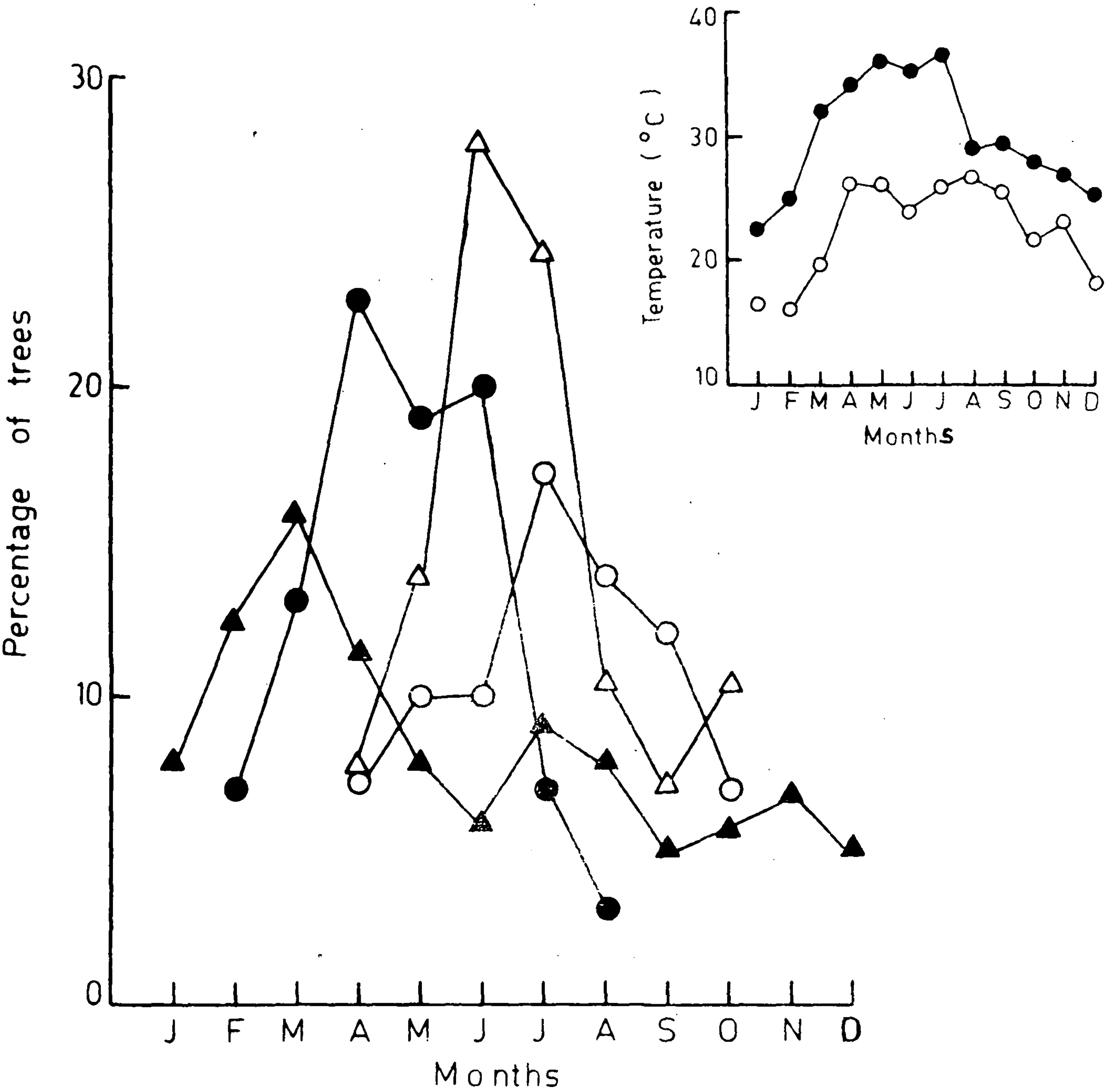
Phenological observations of tree species :

Fig. 3-1 illustrates the phenological pattern of tree species and the time of different phenophases in a year at Lailad forest. All the species considered here flowered once in a year. Most of the species were in full bloom with peak flowering for about 50% of the tree species in April-June and this declined sharply during subsequent months. Flowering seems to be associated with high moisture and temperature conditions and long day conditions of the summer. None of the species under observations flowered during September-January. Although moisture related factors may play some role in controlling flowering in tropical trees, African studies by Njoku (1958, 1963) and Lawton and Akpan (1968) suggest that a change in photoperiod may be an important stimulus in triggering flowering.

Fruit production pattern is closely related to flowering and peaked during June for the majority of the

Fig. 3-1. Monthly pattern of phenological phases of tree species at Lailad forest. Flowering, ● ; fruiting, ○ ; leaf fall, △ ; leaf flushing, △ ; (Inset figure shows the pattern of atmospheric temperature, maximum, ● ; minimum, ○).

Fig. 3-1



40
30
20
10
Temperature (°C)
J F M A M J J A S O N D
Months
30
20
10
0
Percentage of trees
J F M A M J J A S O N D
Months

species; fruits matured and fall occured during July-September. No fruiting occured during December-February. This again may be related at least in part to moisture status of the environment. Shortage of soil moisture has been shown to reduce the rate of enlargement and final size of fruits (Zahner, 1968). Again the wet season may be advantageous as greater moisture in the soil was shown to favour better germination of seeds and seedling establishment in tropical wet and dry forests of Costa Rica (Frankie *et al*, 1974). Some amount of staggered flowering and fruiting by different species at different times of the year may also help to avoid competition for pollination by pollen vectors. Species like *Ammora wallichii*, *Artocarpus chaplasa*, *Dillenia indica*, *Eugenia* sp. *Garcinia cowa* and *Gmelina arborea* shed their fruits during June-September (Heinrich and Raven, 1972; Frankie *et al*, 1974). These species shed their fruits in July during the period of maximum rainfall which may help in fair germination and establishment of these species. Species like *Schima wallichii* which produce dry fruits with winged seeds, shed their seeds in drier months (March-April) to ensure wide dissemination by wind.

Leaf fall was maximum during the dry months of

February-April with 30% of the tree species shedding their leaves. During this period about 56.5% of the total annual litter fall was contributed by the different tree species in the forest. The number of species shedding their leaves remained at a steady low level in subsequent months. Correlation of phenological activity with seasonally occuring events was best examplified for the pattern of leaf fall of different species. The period of greatest leaf fall correspond with relatively xeric condition of the dry season (Beard, 1946; Madge, 1965; Hopkins, 1966; Frankie _et al_,1974)

It is often assumed that flushing is partly a function of rainfall which is evident from the Fig. 3-1. With the onset of monsoon in the month of May-July most of the species produced new leaves. It decreased during the subsequent months. Flushing was fairly high during June which is the early part of the monsoon season and some trees did not flush before the month of August after more than three months of favourable conditions. Age is one of the most important factors in determining the time of bud break and flushing. Coppice shoots and young tree of _Dillenia indica_ (Juvenille phase) preceded in flushing to the old trees of the same species. It is evident that rainfall data cannot always be correlated with growth initiation (Njoku, 1964).

SUMMARY

Density, frequency, basal area and importance value index of different species of trees, shrubs and herbs in a 50 year old secondary forest at Lailad was analysed. Since the peripheral zone of the forest is more disturbed, for phytosociological studies this region was considered separately from the undisturbed central zone. In the forest as a whole *Dendrocalamus hamiltonii*, *Schima wallichii*, *Castanopsis indica*, *Shorea robusta*, *Miliusa roxburghiana*, *Artocarpus chaplasa* and *Vitex peduncularis* were dominant. The early successional species like *Dendrocalamus hamiltonii*, *Messua ferea*, *Miliusa roxburghiana* and *Vitex peduncularis* were found to be more dominant along the peripheral zone of the forest while species like *Schima wallichii*, *Castanopsis indica*, and *Shorea robusta* were dominant in the central zone of the forest. *Croton oblongifolium*, *Litsea khasyana*, *Leea sambucina*, *Anona wallichii*, *Randia densiflora* and *Micromelum pubesence* were some of the important components of shrub layers of the forest. The most important herbaceious species were *Panicum khasianum*, *Cyperus elegans*, *Fimbristylis dichotoma*, *Hedychium gracile* and *Passiflora nepalensis*.

Phenological observations of tree species showed that about 50% of the total tree species flowered during the months of April-June. The most favourable period of fruiting for majority of the tree species was found to be July-September while the period for peak litter fall was during February-April when 56.5% of the fall was recorded. The monsoon period (May-July) was found to be most favourable for production of new leaves by most of the tree species in the present study.

The phytosociological studies at Lailad has been related to the secondary successional communities that develop subsequent to jhum in this region. This indicates that the peripheral zone of Lailad forest has elements representing 15-20 year old fallow that would develop after jhum and this is due to frequent human disturbance in the forest like cutting down of the vegetation for fuel. The central zone of the forest along represent the true 50 year old fallow.

CHAPTER 4

BIOMASS PRODUCTION OF THE FOREST AT LAILAD

BIOMASS PRODUCTION OF THE FOREST AT LAILAD

INTRODUCTION

Increased demands for forest products, the search for renewable source of raw materials and an increased concern for the well being of forest ecosystems have combined to stimulate study of the total forest biomass (Madgwick, 1976). Biomass measurements have long been of principal interest to ecologists, whereas complete tree utilisation concepts involving biomass measurements are relatively new to forestry. Biomass data are essential for the quantitative evaluation of renewable resource potential (Duvigneaud, 1971) and as a source of large scale energy supply (Szago and Kemp, 1973; Grantham and Ellis, 1974). Biomass data have often been used for comparing plant communities, studying the biological and physical processes that affect the productivity and utilisation relationships in nature (Stanek and State, 1978).

The work on productivity in natural and semi-natural woodlands and in different plantations has been done by many workers in temperate regions (Westlake, 1963; Ovington, 1965; Whittaker, 1966 and Whittaker and Woodwell, 1968). Rodin and Bazilevich (1967) have summarised the pattern of biomass distribution per unit area for the major type of terrestrial vegetation and data on biomass of different regions of the world was obtained during the International Biological Programme (Molchanov, 1964; Bazilevich, 1967; Pyavchenko, 1968; Golley et al, 1969; Jenik, 1971; Whittaker, 1971).

Although the weights of sample trees are frequently estimated by subsampling, very little information on the accuracy of different methods is available (Whittaker and Woodwell, 1971; Ellenberg, 1971; Hughes, 1971; Yamakura et al, 1972; Egunjobi, 1975). Overton et al (1973) have discussed the physical problems of estimating the weights of very large trees. However, a variety of methods have been used for the correlation of production and biomass. The estimation of biomass of individual tree or a stand by harvest method as has been suggested by Newbould (1967) is not possible in many circumstances. Therefore most of the workers have used allometric relations to produce organic matter production from simple external measurements as age, diameter at breast height, height and various measures of crowns (Ovington and Madgwick, 1959; Attiwill, 1962; Baskerville, 1965; Ovington et al, 1967; Peterson et al, 1970). The present study is an attempt to evaluate biomass production of the various strata of the forest community at Lailad which is a 50 year old stand in the secondary succession subsequent to Jhum. An understanding of the biomass distribution of the trees and shrubs and herbs in the forest is important for an understanding of the structural and functional aspects of this ecosystem.

METHODS OF STUDY

Biomass estimation of tree species was done in a specified area during August, at the time when the leaves were fully matured. Three different girth classes of ten major tree species namely, *Shorea robusta*, *Schima wallichii*, *Castanopsis indica*, *Artocarpus chaplasa*, *Gmelina arborea*, *Garcinia cowa*, *Miliusa roxburghiana*, *Sterculia villosa*, *Dillenia indica*, *Vitex peduncularis* and *Dendrocalamus hamiltonii* were harvested. Three replicates for each girth class of each species were taken into consideration. After harvest various parameters like diameter of bole at base, middle and top, total height of the tree, diameter and length of the branches and total number of leaves were recorded. The fresh weight of all branches and leaves were determined in the fields and subsamples of large branches, small twigs and leaves were brought to the laboratory in polythene bags. Small discs (2-3cm thick) from the base and top of the bole were taken for computation of dry weight. All the sub-samples were oven dried at 80°-85°C to constant weight. The biomass estimates for the standing crop of a given tree species were computed using density values alongwith different girth classes (Newbould, 1967).

For shrubs and herbaceous species 20 quadrats of 5 X 5m and 1 X 1m respectively were laid along a transect extending from the peripheral zone to the central zone of the forest and all the species were harvested. These were sorted out into different species. Sub-samples of stems and leaves in the case of shrubs and different species of herbs were brought to the laboratory. These were oven dried at 80°-85°C to constant weight.

All the sub-samples of trees, shrubs and herbs were ground and stored for chemical analyses.

RESULTS AND DISCUSSION

Maximum biomass was produced by A. chaplasa and S. robusta (577.50 and 530.00 kg/tree) for 40.1-50.0cm girth class : Tree species like C. indica, D. indica, S.wallichii and *G.* *arborea* approximate the above mentioned two tree species with 445-490 kg/tree. Much lower biomass was recorded in the case of other species (Table 4-1). The high biomass for *A.* *chaplasa* and *S.* *robusta* may partly be related to the fact that in these two species the leaf area per tree as well as leaf biomass was higher in other species. *Castanopsis* *indica*, *Dillenia* *indica* and *Schima* *wallichii* also showed more leaf area, for the same dbh class which again may be related to comparatively high biomass of these three species (Table 4-2).

In *Gmelina* *arborea* although the leaf area is comparatively low, probably better photosynthetic efficiency of the leaves contributed to greater non-photosynthetic organic matter build up in this species. This is clear from the non-photosynthetic and photosynthetic ratio, given in Table 4-3 which was found to be more in this species compared to others. Moreover, the high organic production by species like *A.* *chaplasa*, *S.* *robusta*, *C.* *indica*, *D.* *indica*, *S.* *wallichii* and *G.* *arborea* may be also due to their height which enable them to exploit the light resources to the maximum. These species generally form the overstorey of the forest whilst others like *G.* *cowa*, *M.* *roxburghiana*, *S.* *villosa* and *V.* *peduncularis* are

Table 4-1. Total Biomass of plant components in different diameter classes by major tree species and *D. hamiltonii* at Lailad forest with standard errors.

Species	Diameter Classes (cm)	Height (m)	Biomass (kg/tree)			Total
			Bole	Branches	Leaves	
Artocarpus chaplasa	10.1-20.0	16.50	80.60±16.95	28.50±7.50	4.80±1.24	113.90
	20.1-30.0	21.70	155.93±20.35	59.50±10.65	10.17±4.84	225.60
	30.1-40.0	27.25	307.60±21.60	135.50±15.60	17.00±3.50	454.50
	40.1-50.0	31.50	390.00±31.60	166.00±24.30	21.50±7.10	577.50
Castanopsis indica	10.1-20.0	-	-	-	-	-
	20.1-30.0	19.75	150.90±15.65	51.50±11.81	8.36±1.65	210.78
	30.1-40.0	27.87	263.06±22.00	63.34±11.00	10.46±3.84	336.84
	40.1-50.0	32.33	376.45±36.84	98.48±21.50	15.73±3.40	490.66
Dendrocalamus hamiltonii	1.1-5.0	14.28	2.65±0.06	-	-	2.65
	5.1-6.0	16.00	8.62±1.60	2.00±0.03	1.41±0.03	12.03
	6.1-7.0	17.06	9.09±1.70	2.32±0.05	1.86±0.03	13.27
	7.1-8.0	18.45	12.08±1.78	2.58±0.07	2.70±0.04	17.36
Dillenia indica	10.1-20.0	-	-	-	-	-
	20.1-30.0	13.85	149.69±21.00	43.65±11.80	8.45±2.80	201.79
	30.1-40.0	22.15	257.66±32.50	99.55±18.60	16.50±4.00	373.71
	40.1-50.0	30.37	328.63±40.65	123.00±21.00	20.87±7.00	472.50
Gmelina arborea	10.1-20.0	-	-	-	-	-
	20.1-30.0	13.03	44.03±9.00	12.18±4.50	1.53±0.65	57.74
	30.1-40.0	20.88	147.22±17.50	46.35±4.46	5.70±0.90	199.27
	40.1-50.0	28.97	326.81±28.50	108.43±19.00	9.90±2.00	445.14
Garcinia cowa	10.1-20.0	9.93	52.08±6.80	11.87±4.20	2.93±0.56	66.88
	20.1-30.0	15.08	128.65±11.30	39.25±7.80	5.03±0.90	172.93
	30.1-40.0	21.50	216.00±27.00	72.50±9.00	7.70±1.50	296.20
	40.1-50.0	-	-	-	-	-
Milusa roxburghiana	10.1-20.0	16.07	59.09±9.00	16.55±4.80	3.76±0.60	79.40
	20.1-30.0	24.03	121.45±13.00	43.13±7.80	10.17±2.80	174.75
	30.1-40.0	-	-	-	-	-
	40.1-50.0	-	-	-	-	-
Schima wallichii	10.1-20.0	-	-	-	-	-
	20.1-30.0	19.66	120.50±12.50	37.50±8.00	5.37±1.60	163.17
	30.1-40.0	22.63	286.67±21.50	91.37±11.00	8.47±1.50	386.51
	40.1-50.0	34.67	340.33±33.50	117.67±21.00	12.50±2.10	470.50
Shorea robusta	10.1-20.0	13.33	64.45±9.80	13.28±3.50	2.85±0.85	81.58
	20.1-30.0	16.93	132.73±18.00	39.98±4.00	9.65±1.20	182.23
	30.1-40.0	23.33	261.67±30.10	97.00±13.80	16.83±3.00	375.50
	40.1-50.0	33.40	350.00±39.80	158.50±20.80	21.50±3.50	530.00
Sterculia villosa	10.1-20.0	-	-	-	-	-
	20.1-30.0	14.80	65.48±7.50	90.30±3.80	2.50±0.80	87.28
	30.1-40.0	16.00	75.00±12.40	21.00±3.10	5.10±0.95	111.10
	40.1-50.0	21.00	194.00±18.00	30.00±7.80	8.10±1.80	232.10
Vitex peduncularis	10.1-20.0	11.68	35.71±3.80	12.60±2.00	2.35±0.20	50.61
	20.1-30.0	18.05	93.72±9.21	29.91±7.00	5.48±1.20	129.11
	30.1-40.0	23.10	179.00±11.50	58.00±5.80	8.10±1.20	245.10
	40.1-50.0	-	-	-	-	-

Table 4-2. Leaf biomass, number and area of major tree species and *D. hamiltonii* at Lailad forest.

Species	Dbh (cm)	No. of leaves/ tree	Leaf area (m^2/tree)	Leaf bio- mass (kg/ tree)	Indivi- dual leaf area (cm^2)
Artocarpus chaplasa	45.0	8400	252.00	21.50	300
Castanopsis indica	45.0	19255	208.53	16.65	108
Dillenia indica	45.0	5775	144.37	20.87	250
Gmelina arborea	45.0	8067	83.19	9.90	110
Garcinia cowa	35.0	13167	98.75	7.90	75
Mil~~l~~usa roxburghiana	25.0	20333	46.76	12.20	23
Schima wallichii	45.0	18000	127.26	12.50	71
Shorea robusta	45.0	12000	165.60	21.50	138
Sterculia villosa	45.0	3815	76.68	8.10	201
Vitex peduncularis	35.0	16200	32.40	7.63	20
Dendrocalamus hamiltonii	7.5	1941	42.24	2.70	218

Table 4-3. Biomass relationships of different plant fragments on a percentage weight basis.

Species	Dbh Classes (cm)	Bole (%)	Branches (%)	Leaves (%)	Non-photosynthetic/photosynthetic ratio
Artocarpus chaplasa	10.1-20.0	70.26	25.05	4.21	22.75
	20.1-30.0	69.12	26.37	4.57	21.70
	30.1-40.0	66.81	24.49	3.70	26.03
	40.1-50.0	67.65	28.79	3.59	27.09
Castanopsis indica	10.1-20.0	-	-	-	-
	20.1-30.0	71.60	24.43	3.97	24.19
	30.1-40.0	78.10	18.80	3.10	31.26
	40.1-50.0	76.72	20.07	3.21	30.15
Dillenia indica	10.1-20.0	-	-	-	-
	20.1-30.0	74.18	21.63	4.19	22.87
	30.1-40.0	68.95	26.64	4.42	21.63
	40.1-50.0	69.55	26.03	4.42	21.62
Gmelina arborea	10.1-20.0	-	-	-	-
	20.1-30.0	76.26	21.09	2.65	36.74
	30.1-40.0	73.88	23.26	2.76	33.97
	40.1-50.0	73.42	24.26	2.24	43.65
Garcinia cowa	10.1-20.0	77.87	17.74	4.30	21.65
	20.1-30.0	74.39	22.70	2.91	33.36
	30.1-40.0	72.92	24.48	2.60	37.46
	40.1-50.0	-	-	-	-

Species	Dbh Classes (cm)	Bole (%)	Branches (%)	Leaves (%)	Non-photosynthetic/ photosynthetic ratio
Milusa roxburghiana	10.1-20.0	74.42	20.84	4.74	20.10
	20.1-30.0	69.50	24.60	5.82	17.97
	30.1-40.0	-	-	-	-
	40.1-50.0	-	-	-	-
Schima wallichii	10.1-20.0	-	-	-	-
	20.1-30.0	73.84	22.98	3.29	29.43
	30.1-40.0	74.17	23.69	2.19	44.66
	40.1-50.0	72.33	25.01	2.66	36.59
Shorea robusta	10.1-20.0	79.00	16.27	4.72	20.18
	20.1-30.0	72.84	21.94	5.29	17.92
	30.1-40.0	69.68	25.83	4.48	21.32
	40.1-50.0	66.04	29.90	4.06	23.63
Vitex peduncularis	10.1-20.0	70.56	24.90	4.54	21.03
	20.1-30.0	72.59	23.17	4.24	22.58
	30.1-40.0	73.03	23.66	3.30	29.30
	40.1-50.0	-	-	-	-
Sterculia villosa	10.1-20.0	-	-	-	-
	20.1-30.0	75.02	22.11	2.86	33.96
	30.1-40.0	74.18	20.77	5.04	18.84
	40.1-50.0	71.76	22.71	6.13	15.31
Dendrocalamus hamiltonii	11.1-5.0	-	-	-	-
	5.1-6.0	71.65	16.63	11.72	7.53
	6.1-7.0	68.50	17.48	14.02	6.13
	7.1-8.0	69.59	14.86	15.55	5.43

shaded and are components of the next layer down below. Dry weight of trunk, branches and leaves of each tree was found to increase with increasing dbh or age as estimated in the present case.

The standing crop biomass (Table 4-4) which was calculated with the help of density (Table4-4) of each species in one hectare shows that the maximum biomass was contributed by *S. wallichii*, *C. indica* and *S. robusta*. The high standing crop biomass in these species was due to their higher density in the forest. Whereas species like *A. chaplasa* and *S. robusta* gave high standing crop mainly due to very high values for individual tree species, fairly high values for *D. hamiltonii* and *M. roxburghiana* was due to a high density of these species particularly along the periphery of the forest as also discussed below.

The pattern of biomass distribution in the forest for the important species can be related to the age of the forest as well as to biotic disturbances along the periphery. Of the total biomass, only 35.33% was along the periphery and the remaining 64.67% was along the centre due to greater species diversity here. *Schima wallichii*, *Castanopsis indica* and *Shorea robusta* contributed largest share of the biomass

Table 4-4. Standing crop biomass contribution by major tree species and D. <u>hamiltonii</u> in the forest at Lailad.

Species	Biomass (t/ha)
Artocarpus chaplasa ✓	6.47
Castanopsis indica ✓	33.84
Dendrocalamus hamiltonii	5.28
Dillenia indica	4.77
Gmelina arborea	3.31
Garcinia cowa	3.54
Milusa roxburghiana	5.47
Schima wallichii ✓	55.03
Shorea robusta ✓	14.90
Sterculia villosa	3.65
Vitex peduncularis ✓	1.37

in the peripheral zone and in the central zone. However, these three species contributed more than two folds in the central zone of the forest compared to the peripheral zone. Besides, the biomass/ha was also significantly higher in the central zone in the case of *A. chaplasa*, *V. peduncularis*, *D. indica*, *G. arborea* and *G. cowa* also. This increased biomass contribution by these species in the central zone is due to both increased density and individual biomass in the case of all these species. The greater biomass contribution by *D. hamiltonii* and *M. roxburghiana* along the periphery of the forest was to their high density and frequency here (Table 4-5).

Leea sambucina, *Annona wallichii*, *Sterculia coccinia*, *Litseae khasyana* and *Croton oblongifolium* account for the largest biomass contribution by the shrubs in the forest. Of the total biomass, 54.28% was due to shrub along the peripheral zone of the forest and the remaining 45.72% was due to those in the interior zone. This may be related to high biotic disturbances in the periphery. Large proportion of biomass in the peripheral zone was due to *L. sambucina*, *S. coccinia*, *A. wallichii*, *C. oblongifolium* and *L. khasyana* and in the interior zone, *L. sambucina* and *L. khasyana* contributed most. *Annona wallichii*, *Croton oblongifolium*,

Table 4-5. Density, frequency and biomass contribution by major tree species and D. hamiltonii in the peripheral and central zones of the forest at Lailad (values in parenthesis represents the percentage of the total amount).

Species	Density/ha		Frequency		Biomass (kg/ha)	
	Peripheral zone	Central zone	Peripheral zone	Central zone	Peripheral zone	Central zone
Artocarpus chaplasa	24	16	4	14	3796.20 (1.38)	9124.20 (3.32)
Castanopsis indica	24	26	28	32	22484.12 (8.17)	45199.92 (16.42)
Dendrocalamus hamiltonii	770	350	54	21	6914.80 (2.51)	3638.20 (1.32)
Dillenia indica	16	12	11	7	4594.58 (1.67)	2939.42 (1.71)
Gmelina arborea	12	16	11	43	2033.80 (0.74)	4589.16 (1.67)
Garcinia cowa	18	28	21	29	1967.34 (0.71)	5118.68 (1.86)
Milusa roxburghiana	90	32	75	36	6185.68 (2.25)	4744.52 (1.72)
Schima wallichii	144	204	68	89	35113.96 (12.76)	74900.38 (27.22)
Shorea robusta	62	90	60	50	8416.30 (3.06)	21395.94 (7.77)
Sterculia villosa	20	8	29	11	4674.76 (1.70)	2614.40 (0.95)
Vitex peduncularis	44	32	21	49	1052.10 (0.38)	1698.70 (0.62)

Sterculia coccinia, *Actinodephine angustifolia* and *Micromelium pubescense* had higher biomass/ha along the peripheral zone compared to the interior zone whereas the reverse was the case for species like *L. khasyana*, *L. sambucina* and *R. densiflora*. It is also significant that density and frequency of shrubs in general was much higher along the peripheral zone than in the central zone (Table 4-6). Of the total plant biomass in the forest as a whole 64.51% was in the central zone and only 35.49% was along the peripheral zone. Of the plant biomass along the periphery, shrubs and herbs contributed larger share whereas trees contributed most in the centre (Table 4-7).

The total biomass of the study area which was recorded by the present worker was 137 X 10^3kg/ha. This was lower than the values reported by some other workers in tropical forest (Greenland and Kowal, 1960; Ogawa *et al*, 1965; Klinge *et al*, 1975; Papp, 1974; Johnson and Risser, 1974). Art and Marks (1971) and Rodin and Bazilevich (1966) reported 45-75 X 10^4 kg/ha^{-1} in natural tropical forests, while Whittaker and Likens (1973a,b) in their review reported a mean value of 35-45 X 10^4 kg/ha biomass for some tropical and seasonal forests. However, the present values lie between 60-350 m t/ha reported by Whittaker (1975) for some temperate

Table 4-6. Density, frequency and Biomass contribution by shrub layer in the pheripheral and central zones of the forest at Lailad (values parenthesis represents the percentage of the total amount).

Species	Density/ha		Frequency		Biomass (kg/ha)	
	Peripheral zone	Central zone	Peripheral zone	Central zone	Peripheral zone	Central zone
Anona Wallichii	72	48	50	40	196.20 (6.17)	65.40 (2.06)
Actinodaphne angustifolia	96	104	70	73	141.60 (4.46)	94.40 (2.97)
Croten oblongifolium	240	120	60	53	184.00 (5.79)	147.20 (4.63)
Combretum decandrum	160	80	40	30	127.40 (4.00)	72.80 (2.29)
Litsea khasyana	160	120	73	40	186.00 (5.85)	248.00 (7.80)
Leea sambucina	104	136	27	30	265.00 (8.33)	371.00(11.67)
Morinda umbellata	120	120	37	30	151.20 (4.75)	108.00 (3.40)
Phlogacanthus thyrsiflorus	160	80	47	30	208.00 (6.54)	124.80 (3.92)
Randia densiflora	160	200	60	87	73.60 (2.31)	92.00 (2.89)
Others					193.00 (6.07)	131.24 (4.13)

Table 4-7. Biomass Contribution by major tree species, shrub and herbaceous layers in the peripheral and central zones of the forest at Lailad (values in parenthesis represents the percentage of the total amount).

Different layers	Biomass (t/ha)	
	Peripheral zone	Central zone
Tree	97.234 (35.29)	177.984 (64.59)
Shrub	0.172 (0.06)	0.146 (0.05)
Herbaceous	0.008 (0.03)	0.004 (0.01)

evergreen and tropical seasonal forests and much higher than that for temperate coniferous forests (Akai et al, 1968; Smith et al, 1971; Hegyi, 1972; Switzer and Nelson, 1972; Nemeth, 1972; Ralston et al, 1972).

Relationships between morphological growth parameters viz; diameter (dbh) height and diameter square X height (d^2h) on the one hand and biomass of individual tree species as well as fractional plant parts on the other hand was found to be highly significant. Linear regression equations have been derived with the best fitted parameters for total biomass of individual trees as well as for fractional plant parts of all the major tree species except D. hamiltonii where significant correlations were found with dbh only but not with height (Fig. 4 - 1,2,3,4,5,6,7,8,9,10, 11,12). This may be explained by the fact that this species attained its maximum height within a short time of establishment while the biomass increment was not so rapid but increased gradually with age.

SUMMARY

The dry matter production by different strata in the forest namely trees, shrubs and herbs was estimated. The total amount of biomass contributed by the forest as a whole was found to be 137×10^3kg/ha. Out of this total, 99.84, 0.12% and 0.04% was due to trees, shrubs and herbs respectively. Maximum biomass/tree was recorded for *Artocarpus chaplasa* and *Shorea robusta* (577.50 and 530.00 kg/tree respectively) for 40.1-50.0 cm girth class. The maximum standing biomass was recorded for *Schima wallichii*, *Castanopsis indica* and *Shorea robusta* with 55.03, 33.84 and 13.80 t/ha, respectively. Various parameters like leaf area, weight/leaf and non-photosynthetic/photosynthetic ratios were worked out for various tree species.

Biomass distribution in the central and peripheral zones were 64.67% and 35.33% of the total. In the forest as a whole maximum biomass contribution was due to *Schima wallichii*, *Castanopsis indica* and *Shorea robusta*. *Dendrocalamus hamiltonii* and *Miliusa roxburghiana* contributed more biomass along the peripheral zone of the forest in comparison to the central zone. 54.09% and 66.67% respectively of the total shrub and herb biomass was along the peripheral zone of the forest. Linear relationships were worked out for different tree species by taking three independent variables, namely dbh, height and d^2h with different dependent variables like bole, branches, leaves and total biomass.

Fig. 4-1. Relationship between dbh and above ground biomass of different tree species.

Fig. 4-1

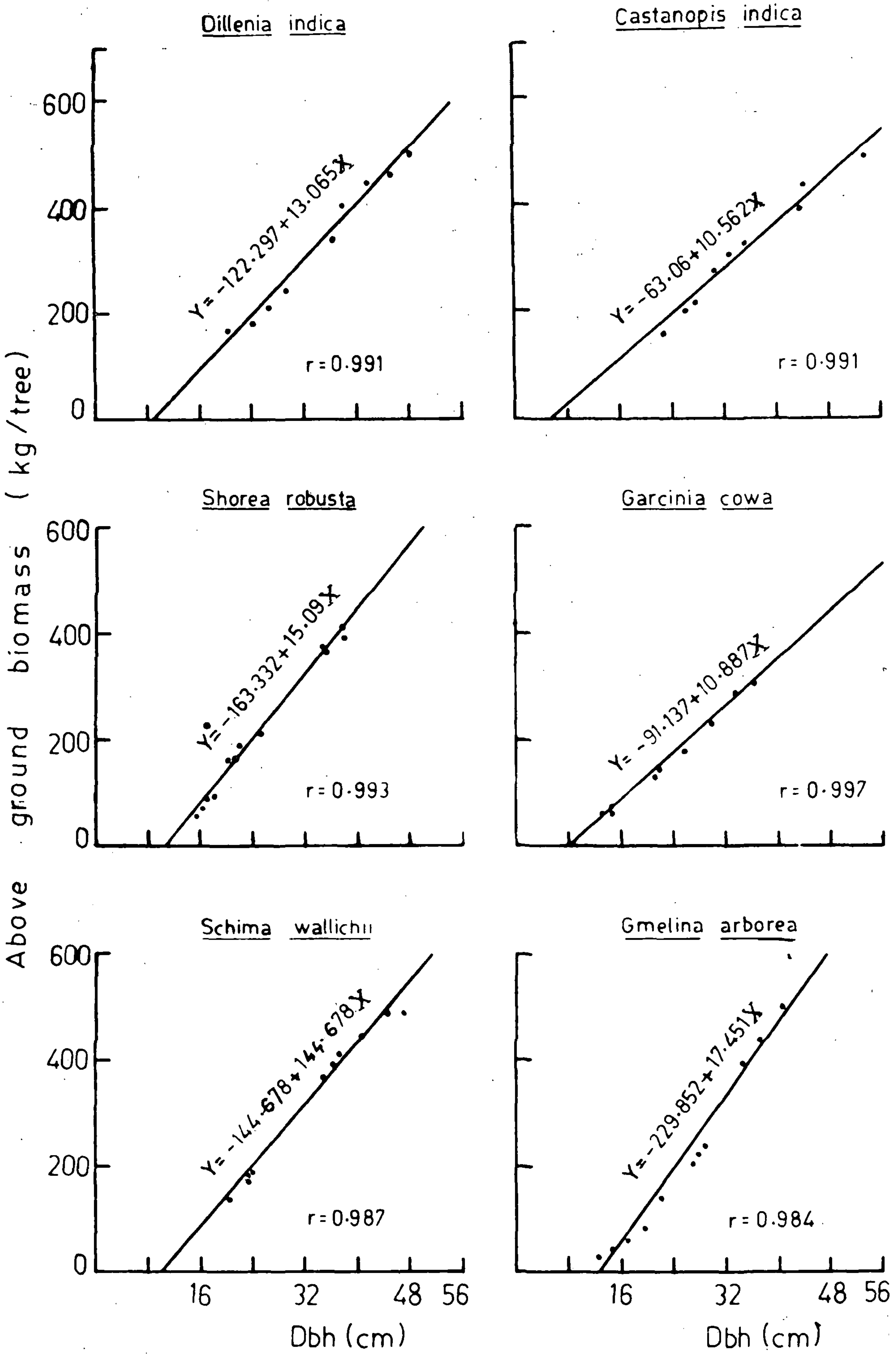

Dillenia indica
Y= -122.297+13.065X
r = 0.991
Castanopis indica
Y= -63.06+10.562X
r = 0.991
Shorea robusta
Y= -163.332+15.09X
r = 0.993
Garcinia cowa
Y= -91.137+10.887X
r = 0.997
Schima wallichii
Y= -144.678+144.678X
r = 0.987
Gmelina arborea
Y= -229.852+17.451X
r = 0.984
Above ground biomass (kg/tree)
0
200
400
600
16
32
48
56
Dbh (cm)

Fig. 4-1

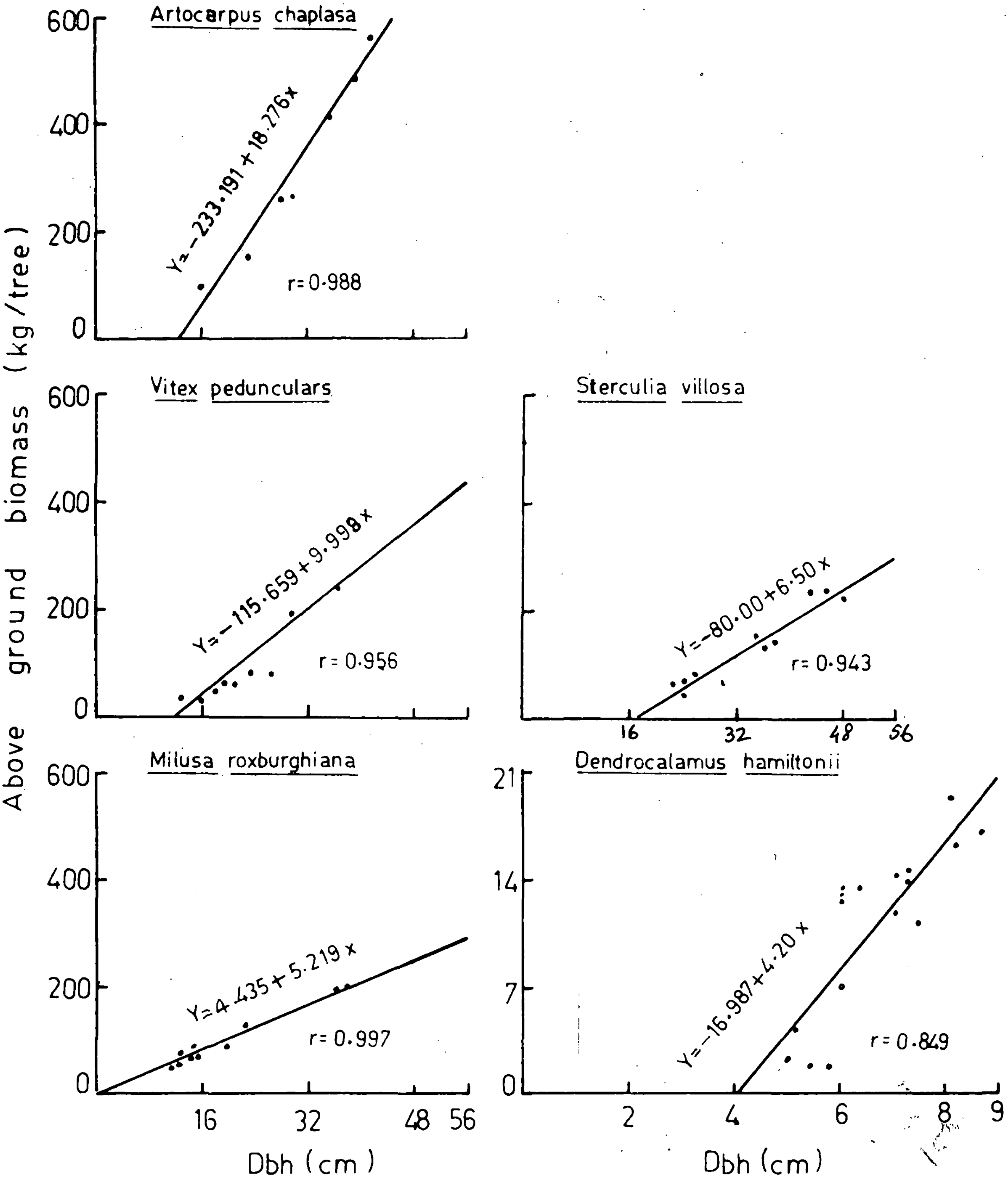

Above ground biomass (kg/tree)
Artocarpus chaplasa
Y=-233.191+18.276x
r=0·988
600
400
200
0
Vitex pedunculars
Y=-115.659+9.998x
r=0.956
600
400
200
0
Sterculia villosa
Y=-80.00+6.50x
r=0·943
16
32
48
56
Milusa roxburghiana
Y=4.435+5.219x
r=0.997
600
400
200
0
16
32
48
56
Dbh (cm)
Dendrocalamus hamiltonii
Y=-16.987+4.20x
r=0.849
21
14
7
0
2
4
6
8
9
Dbh (cm)

Fig. 4-2. Relationship between dbh and bole biomass of different tree species.

Fig. 4-2

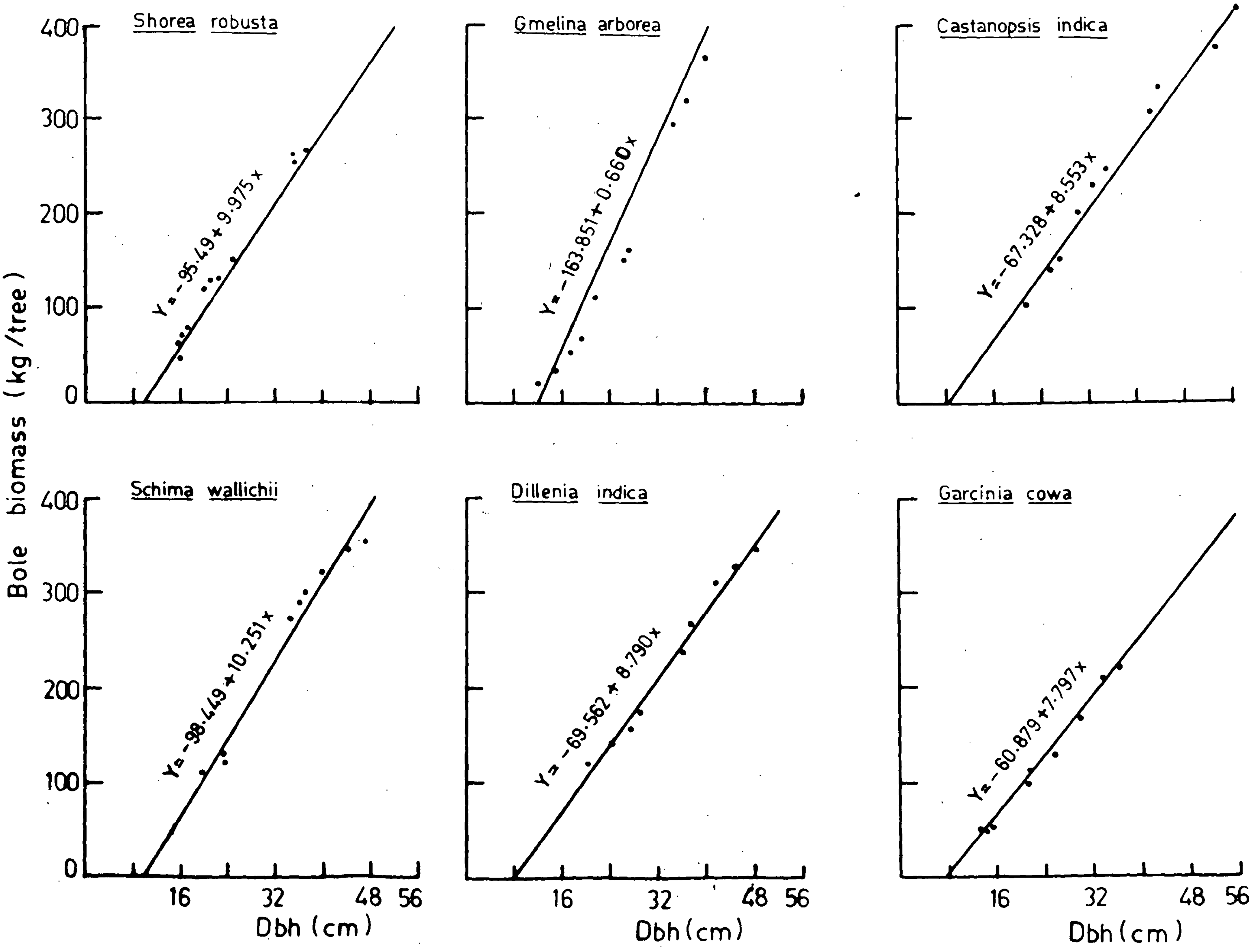

Shorea robusta
Y= -95.49+9.975x
Gmelina arborea
Y= -163.851+0.660x
Castanopsis indica
Y= -67.328+8.553x
Schima wallichii
Y= -98.449+10.251x
Dillenia indica
Y= -69.562+8.790x
Garcinia cowa
Y= -60.879+7.797x
Bole biomass (kg/tree)
0
100
200
300
400
16
32
48
56
Dbh (cm)

Fig. 4-2

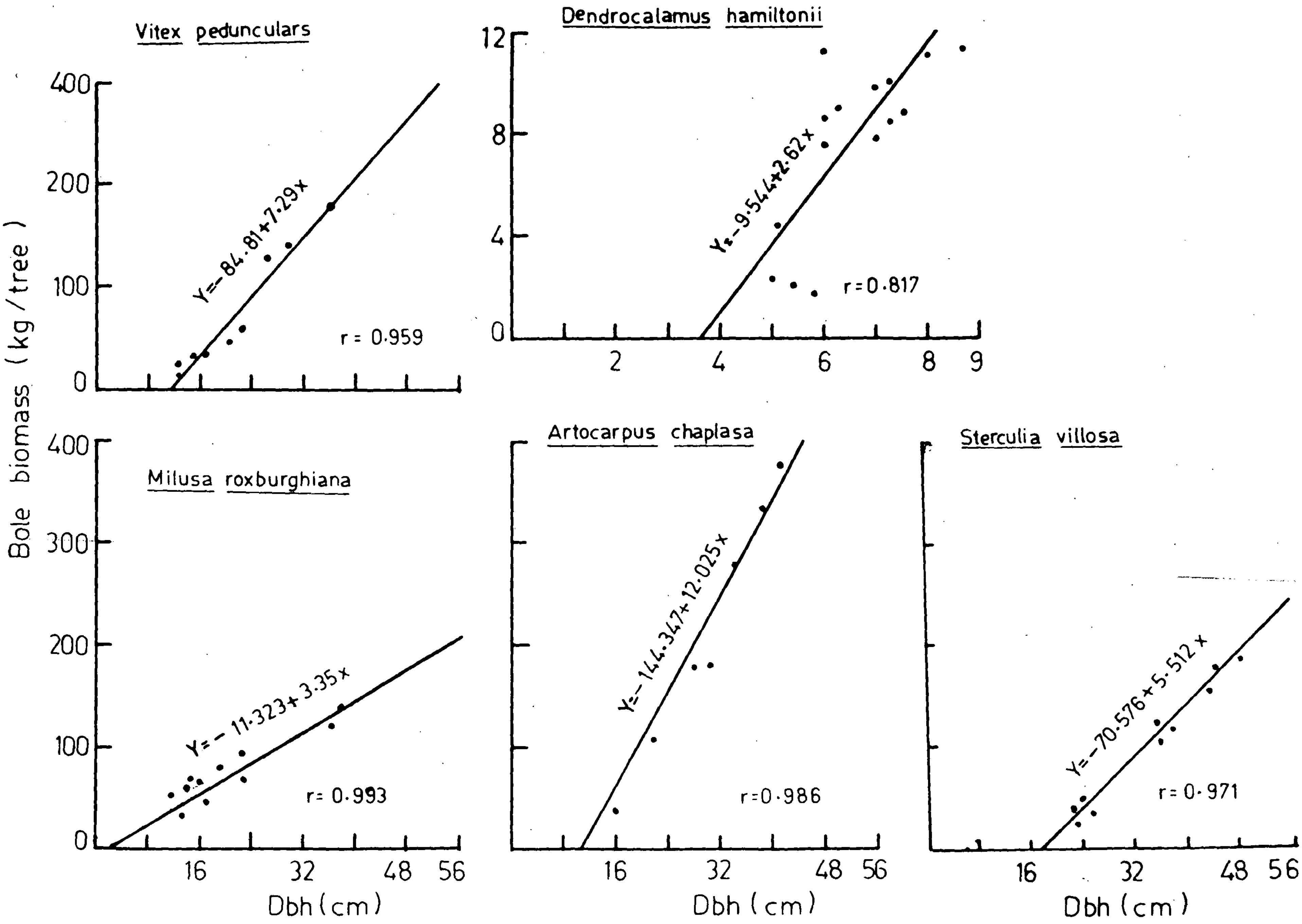

Vitex peduncularis
Y=-84.81+7.29x
r = 0.959
Dendrocalamus hamiltonii
Y=-9.544+2.62x
r=0.817
Milusa roxburghiana
Y=-11.323+3.35x
r= 0.993
Artocarpus chaplasa
Y=-144.347+12.025x
r=0.986
Sterculia villosa
Y=-70.576+5.512x
r=0.971
Bole biomass (kg/tree)
400
300
200
100
0
12
8
4
0
2
4
6
8
9
16
32
48
56
Dbh (cm)

Fig. 4-3. Relationship between dbh and branch biomass of different tree species.

Fig. 4-3

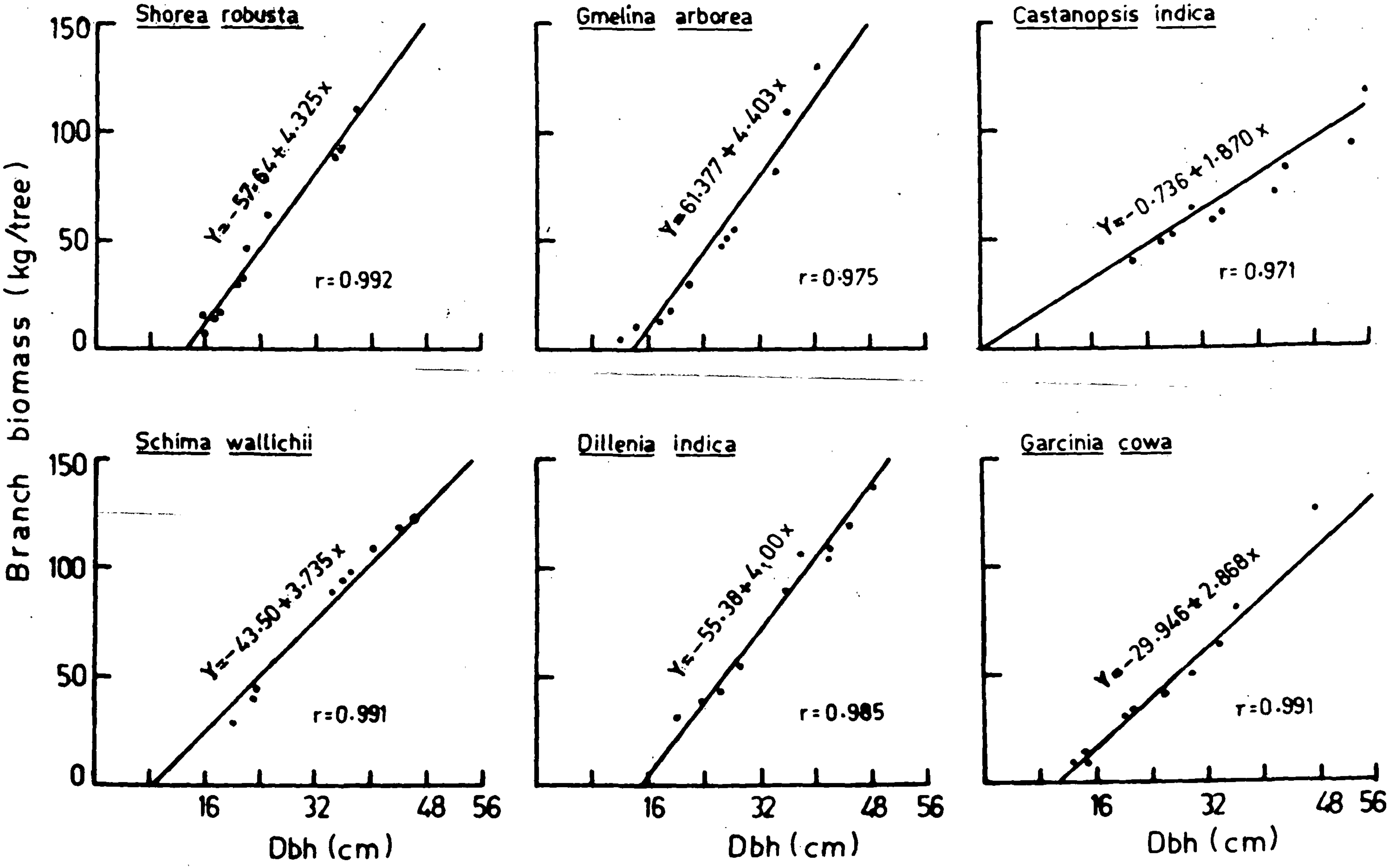

Branch biomass (kg/tree)
Shorea robusta
Y=-57.64+4.325x
r=0.992
Gmelina arborea
Y=61.377+4.403x
r=0.975
Castanopsis indica
Y=-0.736+1.870x
r=0.971
Schima wallichii
Y=-43.50+3.735x
r=0.991
Dillenia indica
Y=-55.38+4.00x
r=0.985
Garcinia cowa
Y=-29.946+2.868x
r=0.991
150
100
50
0
16
32
48
56
Dbh (cm)

Fig. 4-3

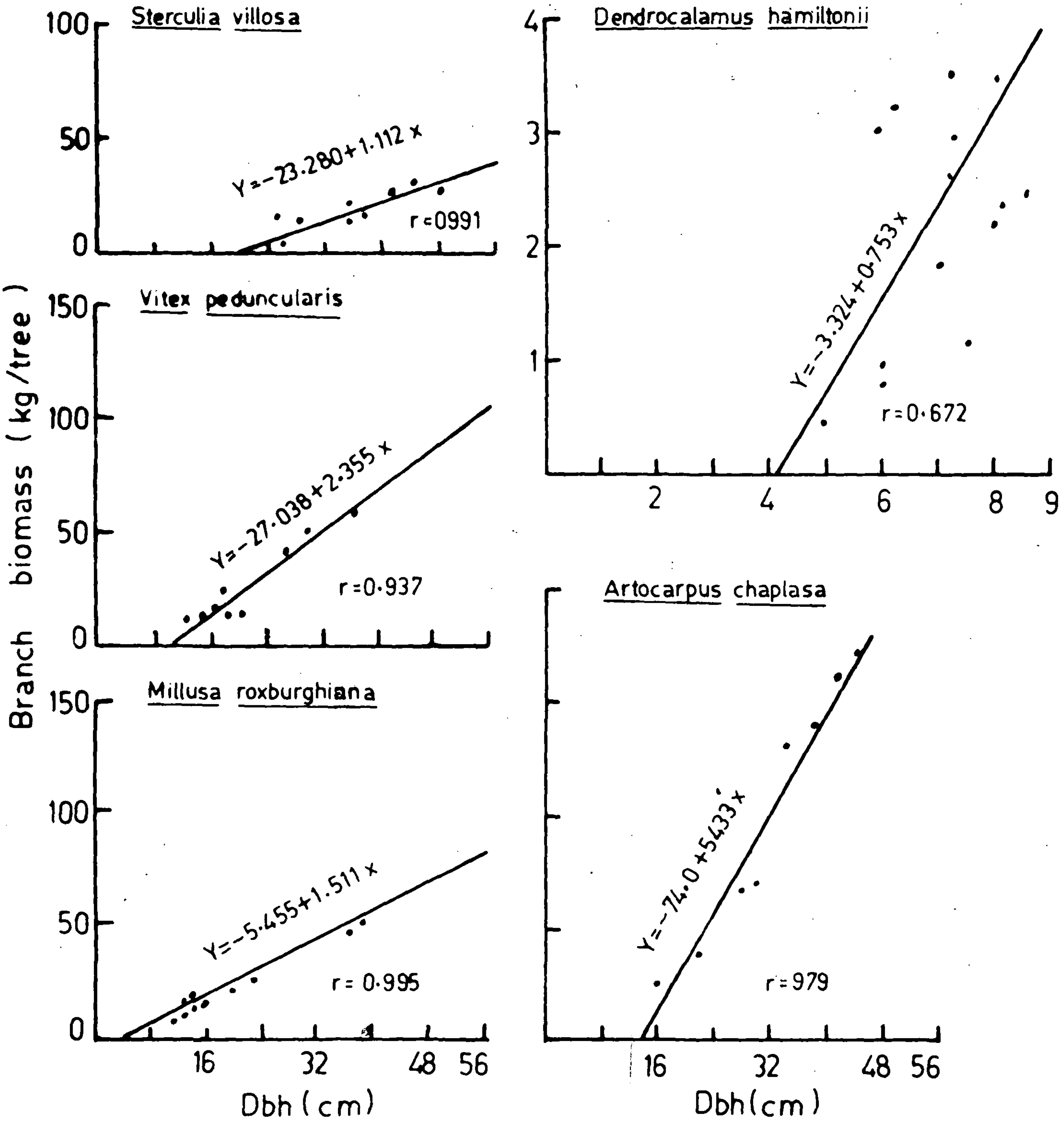

Sterculia villosa
100
50
0
Y=-23.280+1.112 x
r=0991
Vitex peduncularis
150
100
50
0
Y=-27.038+2.355 x
r=0.937
Millusa roxburghiana
150
100
50
0
Y=-5.455+1.511 x
r= 0.995
16
32
48
56
Dbh (cm)
Branch biomass (kg/tree)
Dendrocalamus hamiltonii
4
3
2
1
Y=-3.324+0.753 x
r=0.672
2
4
6
8
9
Artocarpus chaplasa
Y=-74.0+5.433 x
r=979
16
32
48
56
Dbh (cm)

Fig. 4-4. Relationship between dbh and leaf biomass of different tree species.

Fig. 4-4

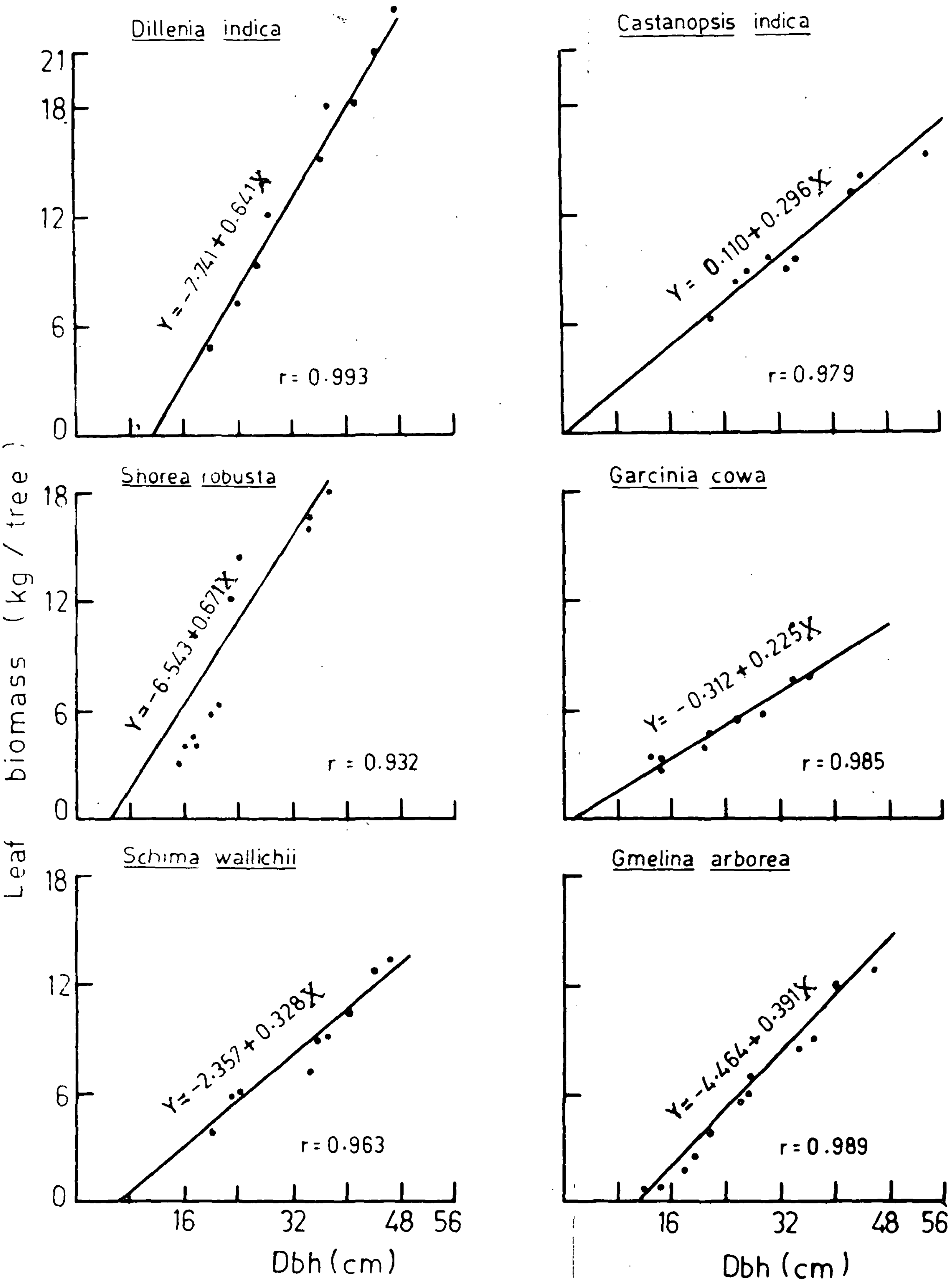

Dillenia indica
Y = -7.741 + 0.641X
r = 0.993
Castanopsis indica
Y = 0.110 + 0.296X
r = 0.979
Shorea robusta
Y = -6.543 + 0.671X
r = 0.932
Garcinia cowa
Y = -0.312 + 0.225X
r = 0.985
Schima wallichii
Y = -2.357 + 0.328X
r = 0.963
Gmelina arborea
Y = -4.464 + 0.391X
r = 0.989
Leaf biomass (kg / tree)
0
6
12
18
21
16
32
48
56
Dbh (cm)

Fig. 4-4

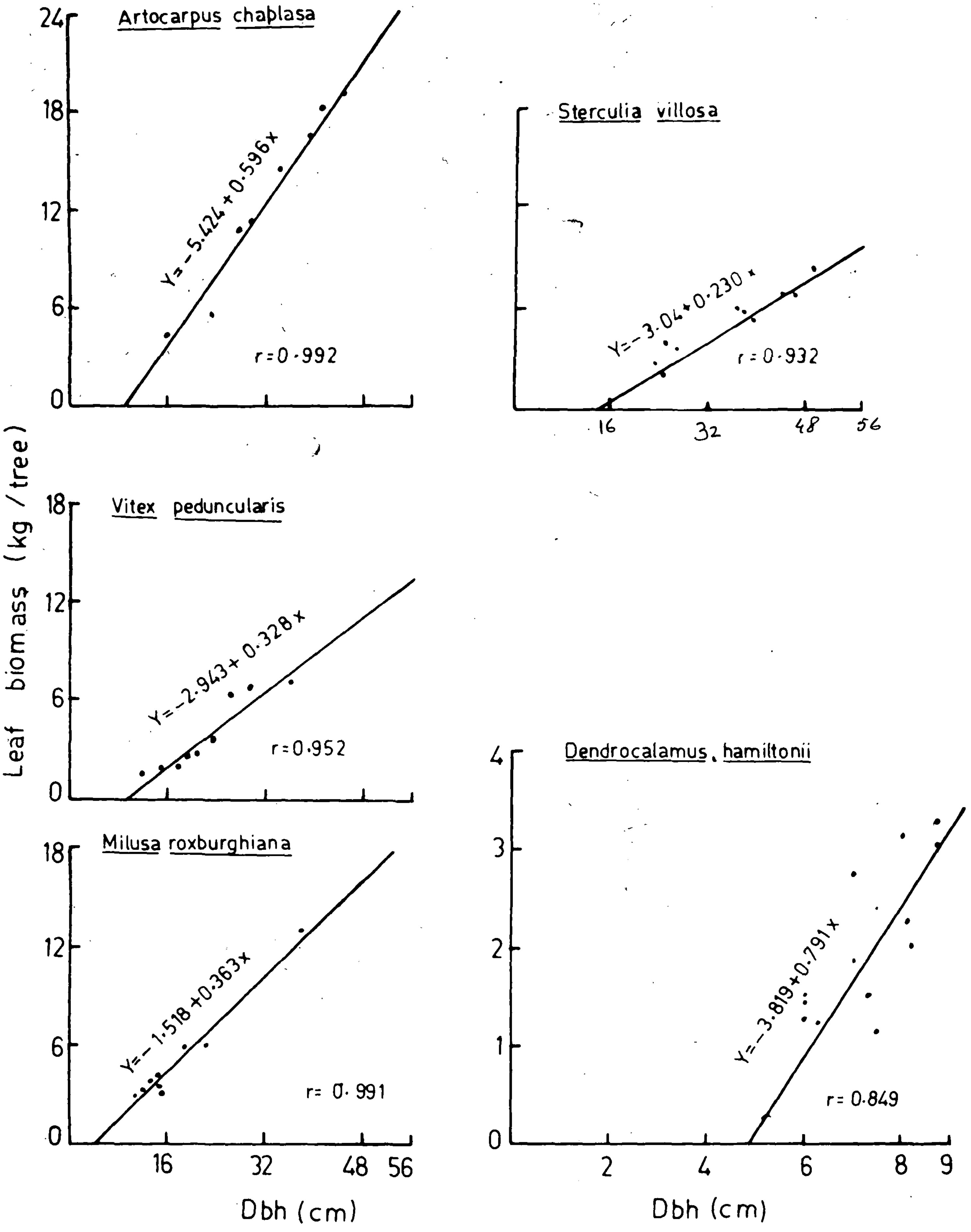

Leaf biomass (kg / tree)
Artocarpus chaplasa
Y= -5.424+0.596x
r=0·992
24
18
12
6
0
Sterculia villosa
Y=-3·04+0·230x
r=0·932
16
32
48
56
Vitex peduncularis
Y=-2·943+0·328x
r=0·952
18
12
6
0
Milusa roxburghiana
Y=-1·518+0·363x
r= 0·991
18
12
6
0
16
32
48
56
Dbh (cm)
Dendrocalamus hamiltonii
Y=-3·819+0·791x
r= 0·849
4
3
2
1
0
2
4
6
8
9
Dbh (cm)

Fig. 4-5. Relationship between height and above ground biomass of different tree species.

Fig. 4-5

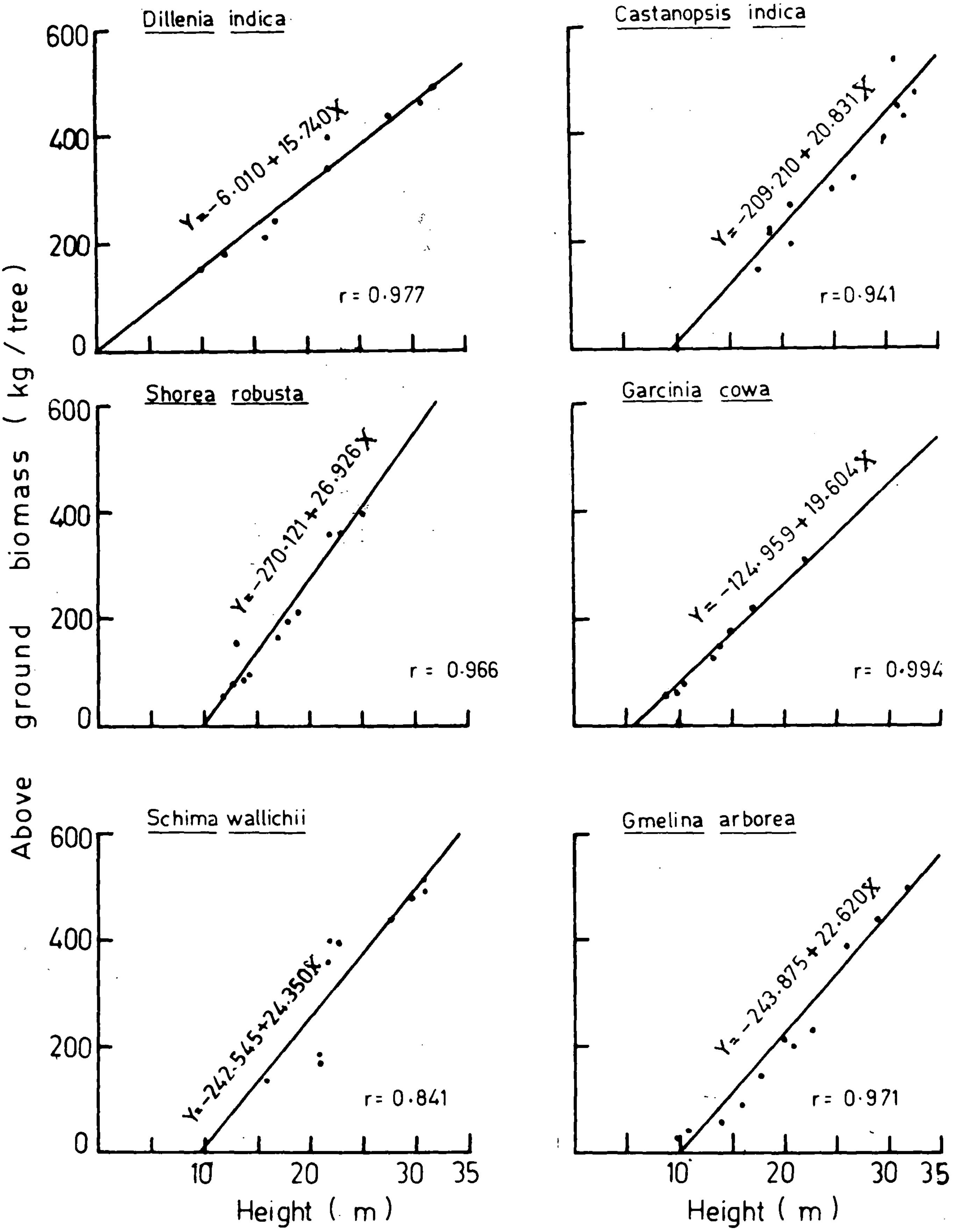

Dillenia indica
Y = -6.010 + 15.740X
r = 0.977
Castanopsis indica
Y = -209.210 + 20.831X
r = 0.941
Shorea robusta
Y = -270.121 + 26.926X
r = 0.966
Garcinia cowa
Y = -124.959 + 19.604X
r = 0.994
Schima wallichii
Y = -242.545 + 24.350X
r = 0.841
Gmelina arborea
Y = -243.875 + 22.620X
r = 0.971
600
400
200
0
10
20
30
35
Height (m)
Above ground biomass (kg / tree)

Fig. 4-5

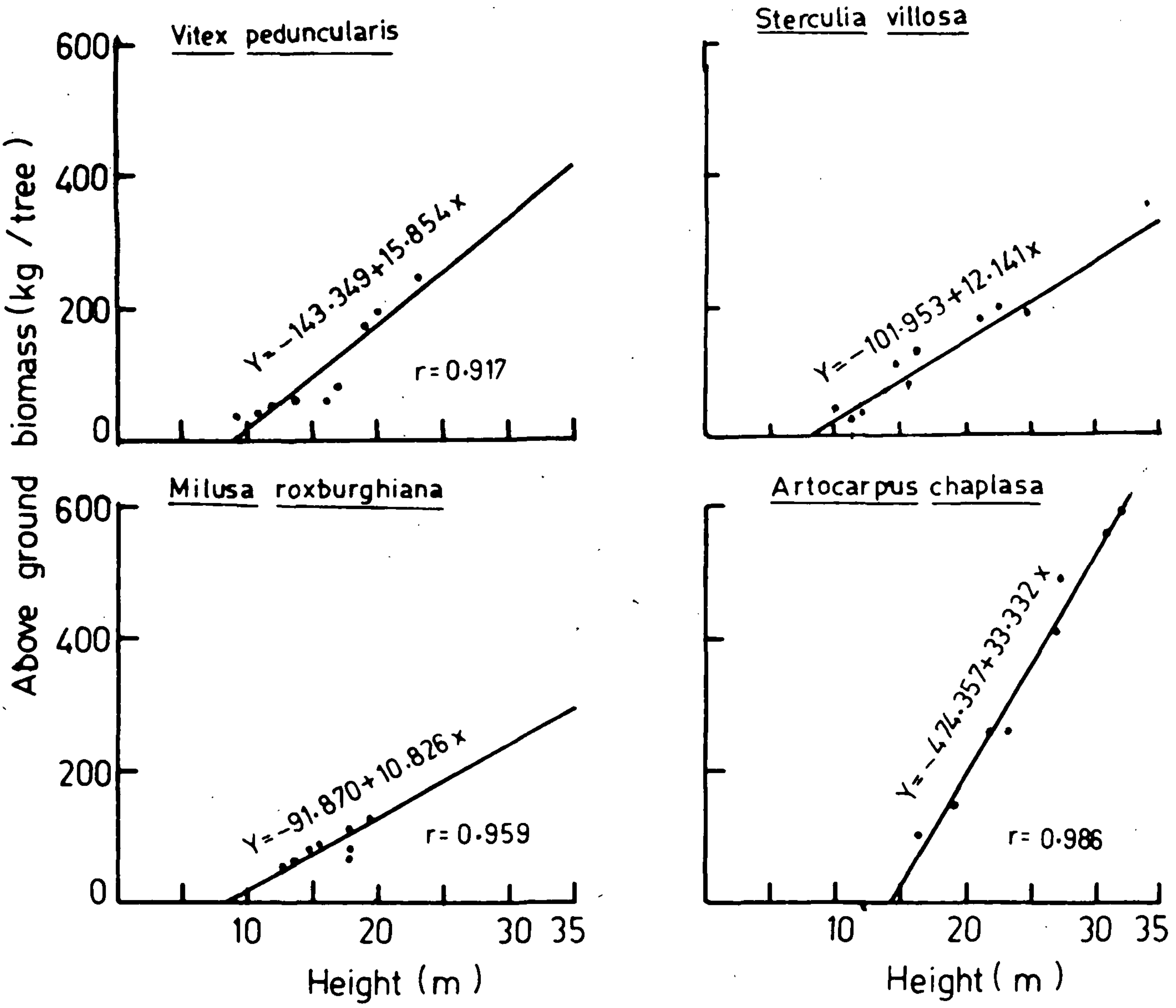

Vitex peduncularis
Y=-143.349+15.854x
r=0.917
Sterculia villosa
Y=-101.953+12.141x
Milusa roxburghiana
Y=-91.870+10.826x
r=0.959
Artocarpus chaplasa
Y=-474.357+33.332x
r=0.986
Above ground biomass (kg / tree)
0
200
400
600
10
20
30
35
Height (m)

Fig. 4-6. Relationship between height and bole biomass of different tree species.

Fig. 4-6

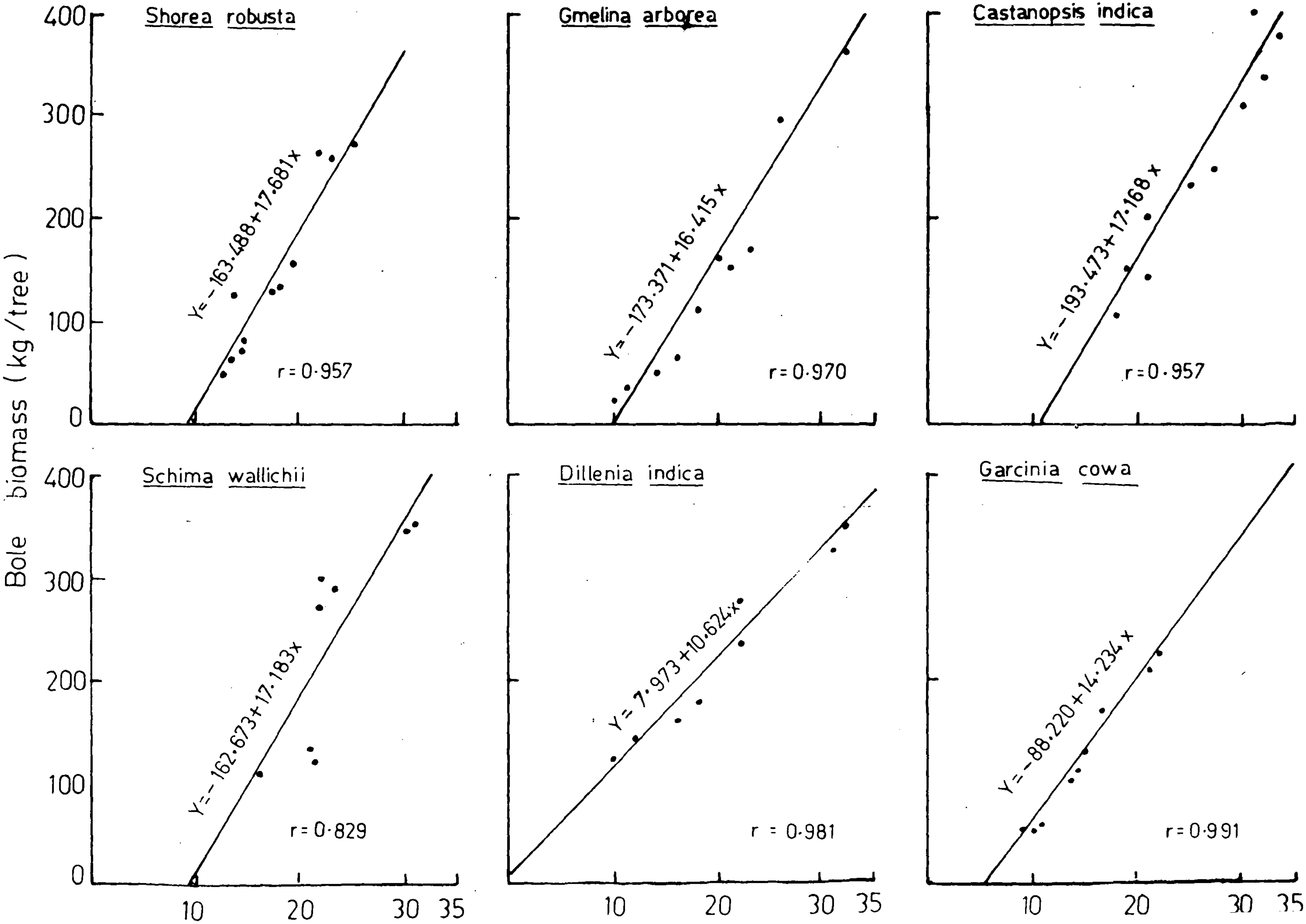

Bole biomass (kg /tree)
Shorea robusta
Y=-163.488+17.681x
r=0·957
Gmelina arborea
Y=-173.371+16.415x
r=0·970
Castanopsis indica
Y=-193.473+17.168x
r=0·957
Schima wallichii
Y=-162.673+17.183x
r=0·829
Dillenia indica
Y=7·973+10.624x
r = 0·981
Garcinia cowa
Y=-88.220+14.234x
r=0·991
400
300
200
100
0
10
20
30
35

Fig.

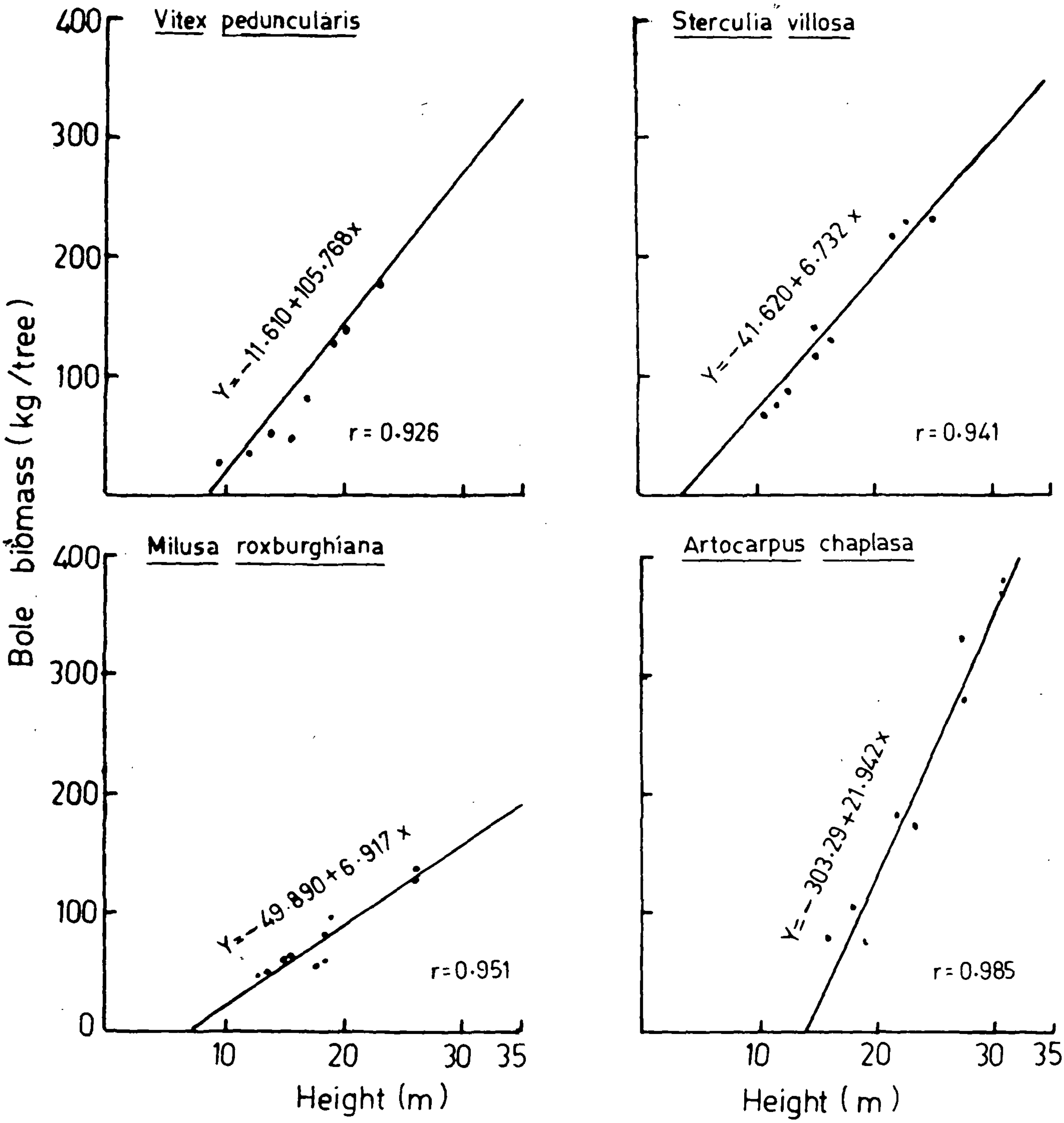

Vitex peduncularis
Y = -11.610+105.768x
r = 0.926
Sterculia villosa
Y = -41.620+6.732 x
r = 0.941
Milusa roxburghiana
Y = -49.890+6.917 x
r = 0.951
Artocarpus chaplasa
Y = -303.29+21.942x
r = 0.985
Bole biomass (kg/tree)
400
300
200
100
0
10
20
30
35
Height (m)
Height (m)

Fig. 4-7. Relationship between height and branch biomass of different tree species.

Fig. 4-7

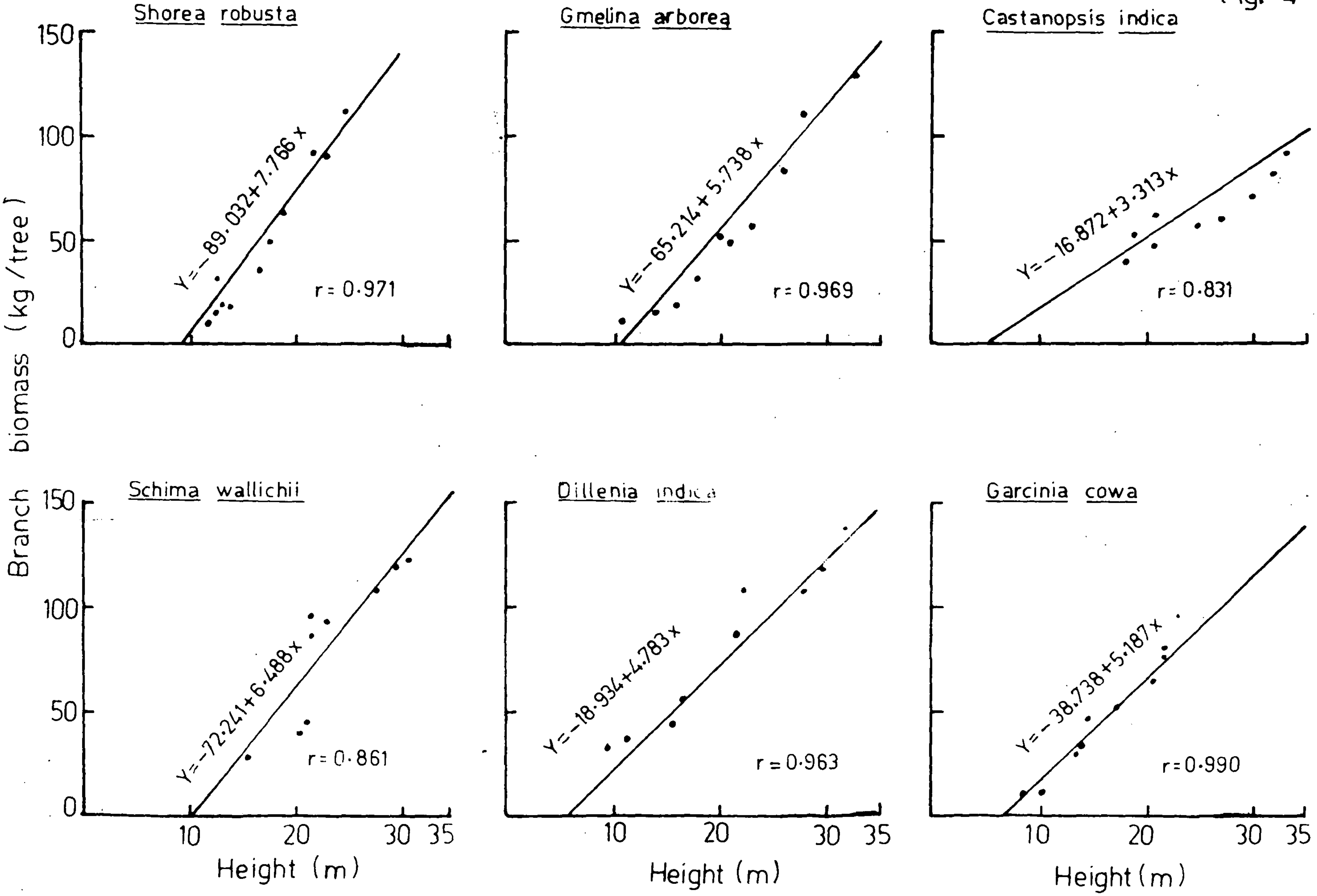

Shorea robusta
Y=-89.032+7.766x
r=0.971
Gmelina arborea
Y=-65.214+5.738x
r=0.969
Castanopsis indica
Y=-16.872+3.313x
r=0.831
Schima wallichii
Y=-72.241+6.488x
r=0.861
Dillenia indica
Y=-18.934+4.783x
r=0.963
Garcinia cowa
Y=-38.738+5.187x
r=0.990
Branch biomass (kg/tree)
0
50
100
150
10
20
30
35
Height (m)

Fig. 4

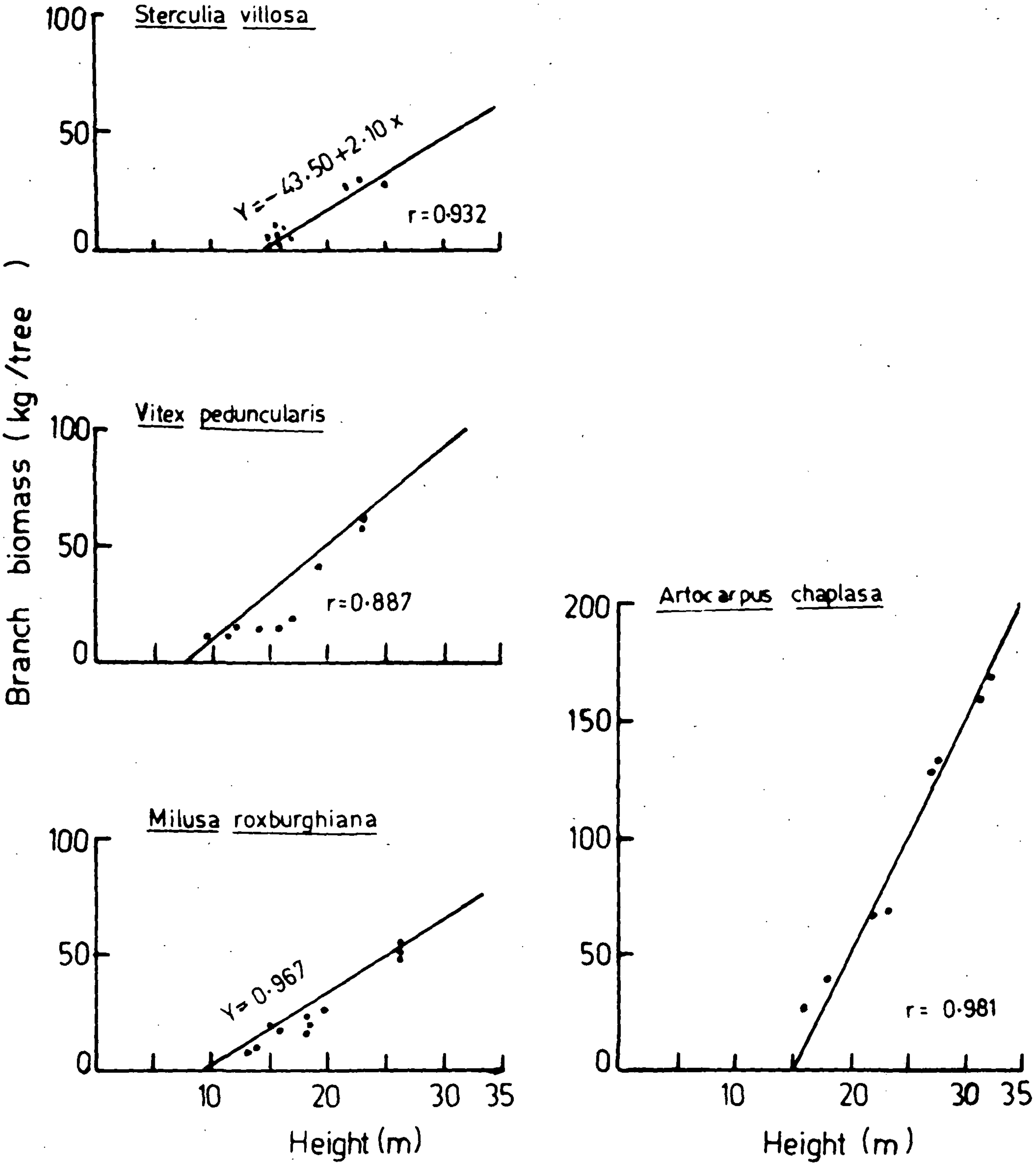

Sterculia villosa
Y=-43.50+2.10x
r=0.932
Vitex peduncularis
r=0.887
Milusa roxburghiana
Y=0.967
Artocarpus chaplasa
r= 0.981
Branch biomass (kg/tree)
Height (m)
Height (m)
0
50
100
150
200
10
20
30
35

Fig. 4-8. Relationship between height and leaf biomass of different tree species.

Fig. 4-8

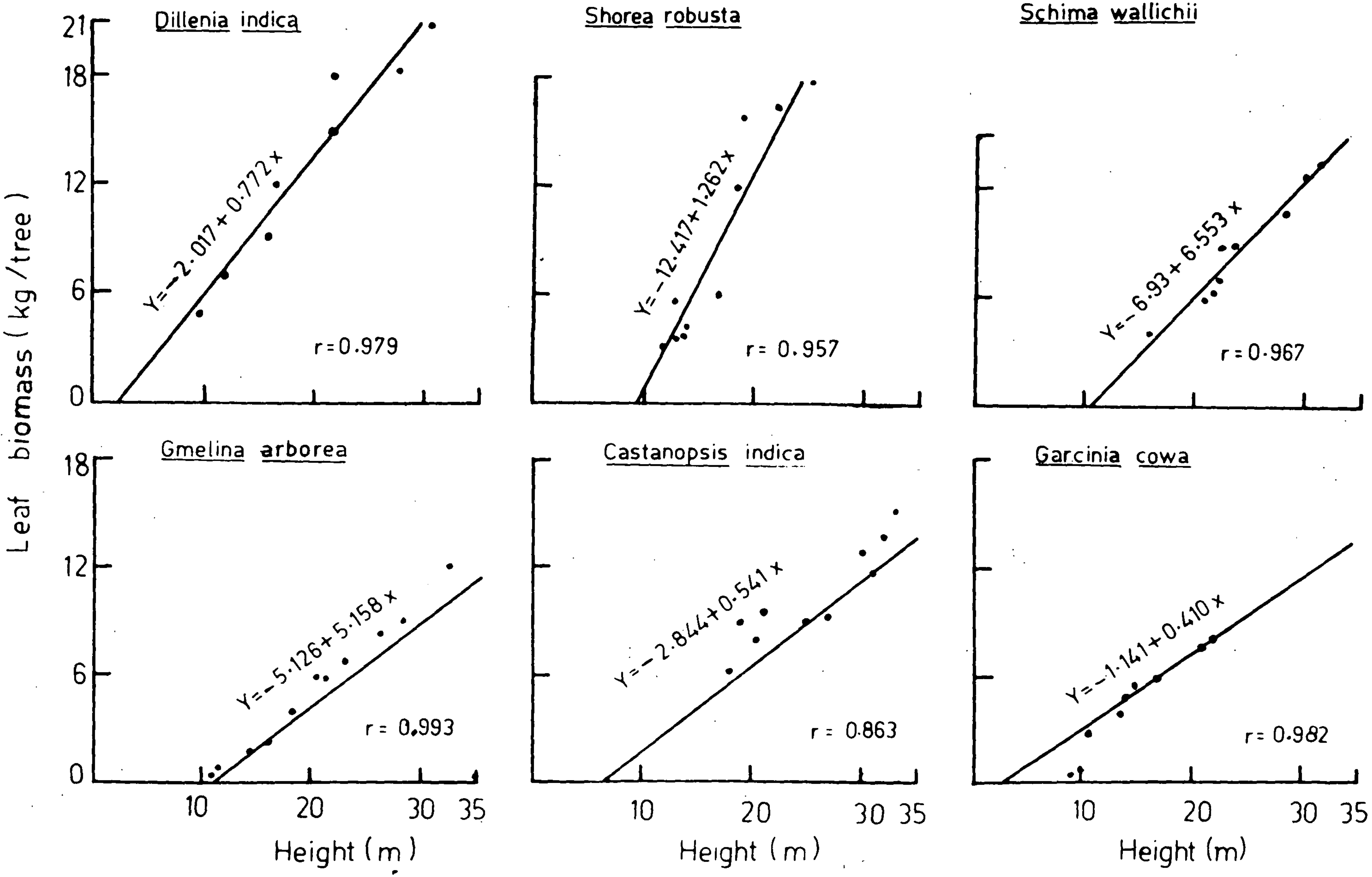
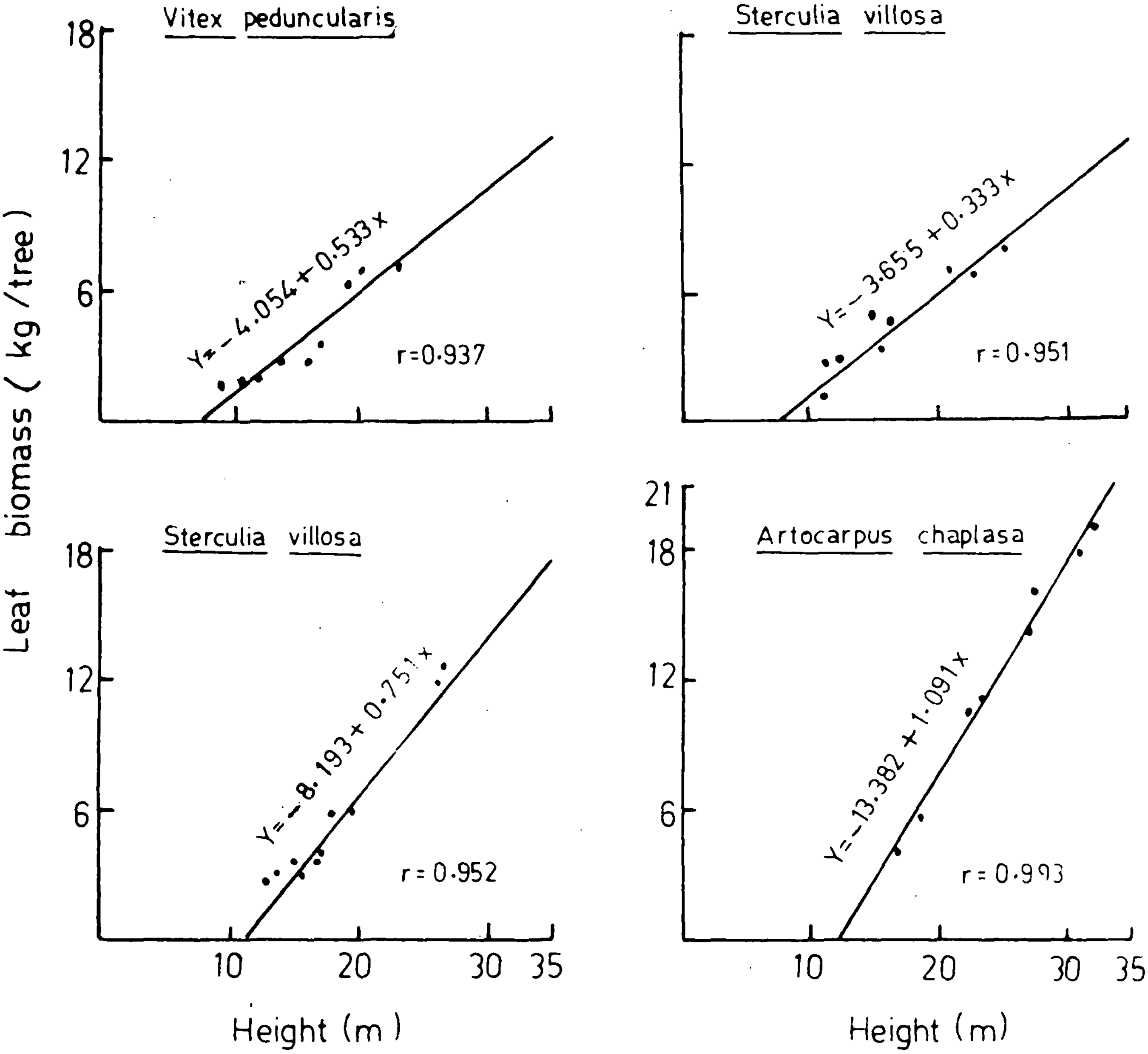

Leaf biomass (kg /tree)
Dillenia indica
21
18
12
6
0
Y= –2.017 + 0.772 x
r = 0.979
Shorea robusta
Y= –12.417+1.262x
r = 0.957
Schima wallichii
Y= – 6.93 + 6.553 x
r = 0·967
Gmelina arborea
18
12
6
0
Y=–5.126+5.158 x
r = 0.993
10
20
30
35
Height (m)
Castanopsis indica
Y=–2.844+0.541 x
r = 0.863
10
20
30
35
Height (m)
Garcinia cowa
Y=–1.141+0.410 x
r = 0·982
10
20
30
35
Height (m)

Fig. 4-



Leaf biomass (kg /tree)
Vitex peduncularis
18
12
6
Y=-4.054+0.533x
r=0·937
Sterculia villosa
Y=-3·655+0·333x
r=0·951
Sterculia villosa
18
12
6
Y=-8.193+0·751x
r=0·952
10
20
30
35
Height (m)
Artocarpus chaplasa
21
18
12
6
Y=-13.382+1·091x
r=0·993
10
20
30
35
Height (m)

Fig. 4-9. Relationship between d^2h and above ground biomass of different tree species.

Fig. 4-9

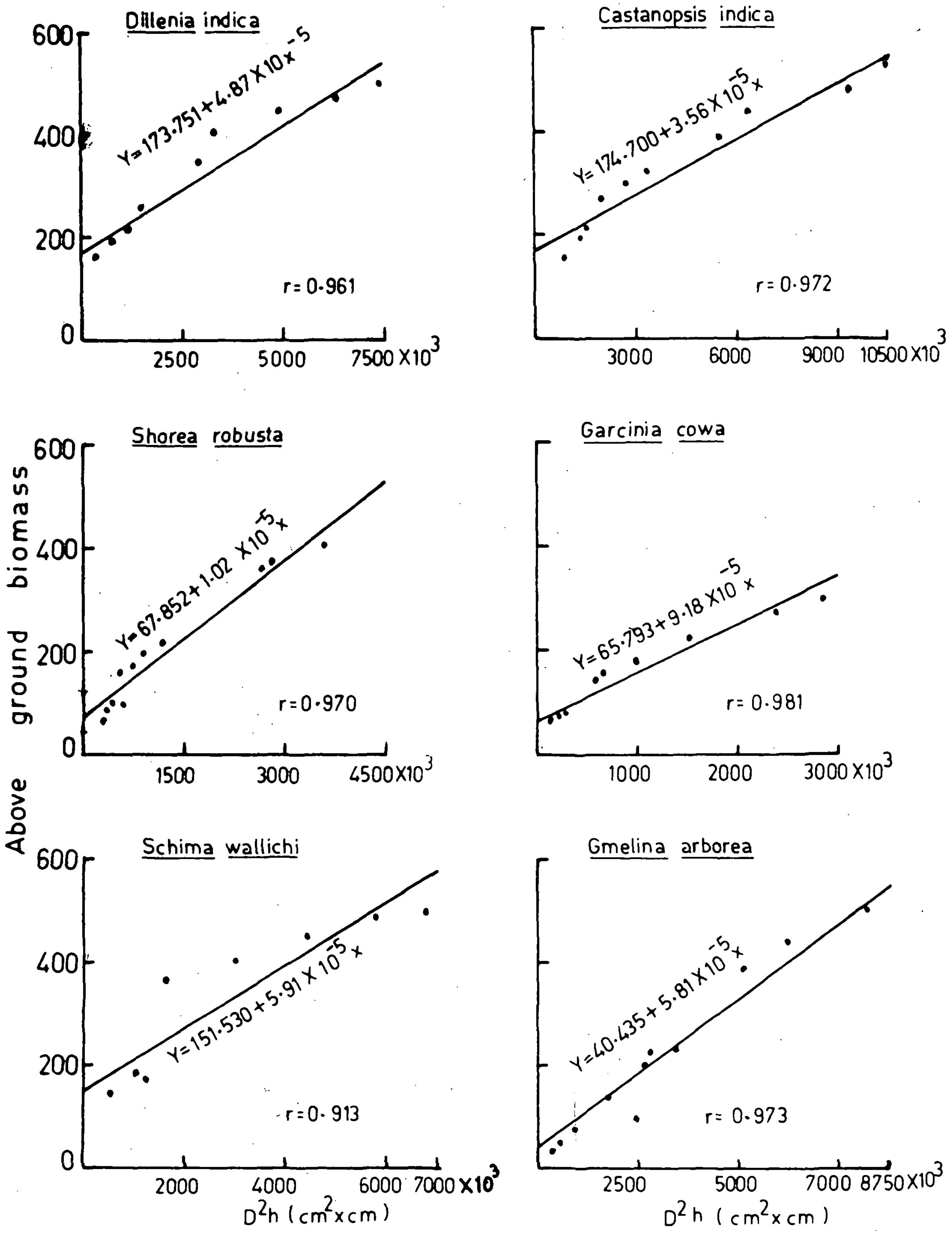

Dillenia indica
Y=173·751+4·87 X 10 x^-5
r= 0·961
600
400
200
0
2500
5000
7500 X10^3
Castanopsis indica
Y= 174·700+3·56 X 10^-5 x
r= 0·972
3000
6000
9000
10500 X10^3
Shorea robusta
Y=67·852+1·02 X10^-5 x
r=0·970
1500
3000
4500X10^3
Garcinia cowa
Y=65·793+9·18 X10^-5 x
r= 0·981
1000
2000
3000 X10^3
Schima wallichi
Y=151·530+5·91 X 10^-5 x
r=0· 913
2000
4000
6000
7000 X10^3
Gmelina arborea
Y=40·435+5·81X10^-5 x
r= 0·973
2500
5000
7000
8750X10^3
Above ground biomass
D²h (cm² x cm)
D² h (cm² x cm)

Fig. 4-9

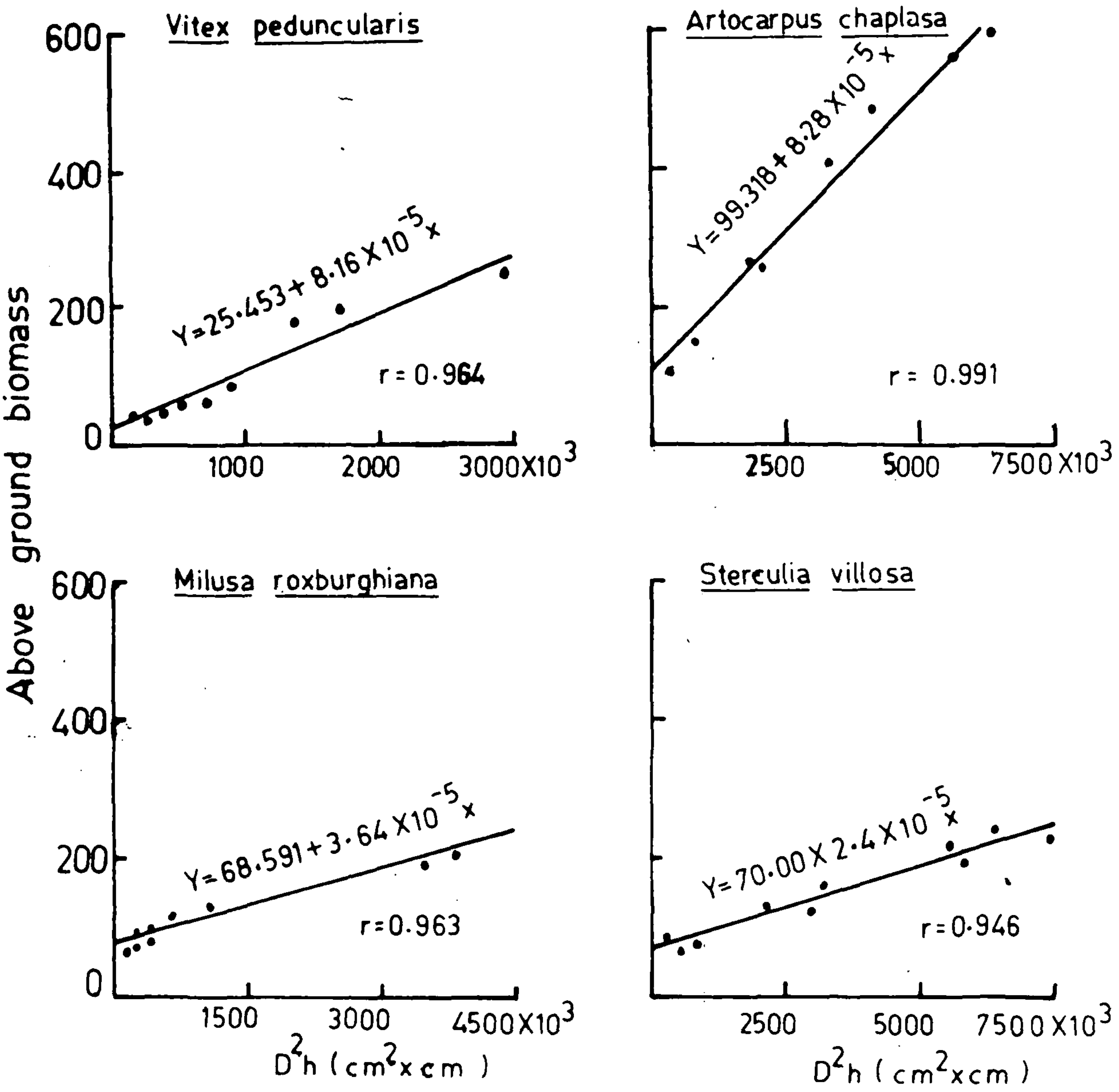

Above ground biomass
Vitex peduncularis
600
400
200
0
1000
2000
3000X10^3
Y=25·453+8·16X10^{-5}x
r = 0·964
Artocarpus chaplasa
2500
5000
7500X10^3
Y=99.318+8·28X10^{-5}x
r = 0.991
Milusa roxburghiana
600
400
200
0
1500
3000
4500X10^3
Y=68·591+3·64X10^{-5}x
r=0·963
D^{2}h (cm^{2}xcm)
Sterculia villosa
2500
5000
7500X10^3
Y=70·00X2·4X10^{-5}x
r=0·946
D^{2}h (cm^{2}xcm)

Fig. 4-10. Relationship between d^2h and bole biomass of different tree species.

Fig. 4-10

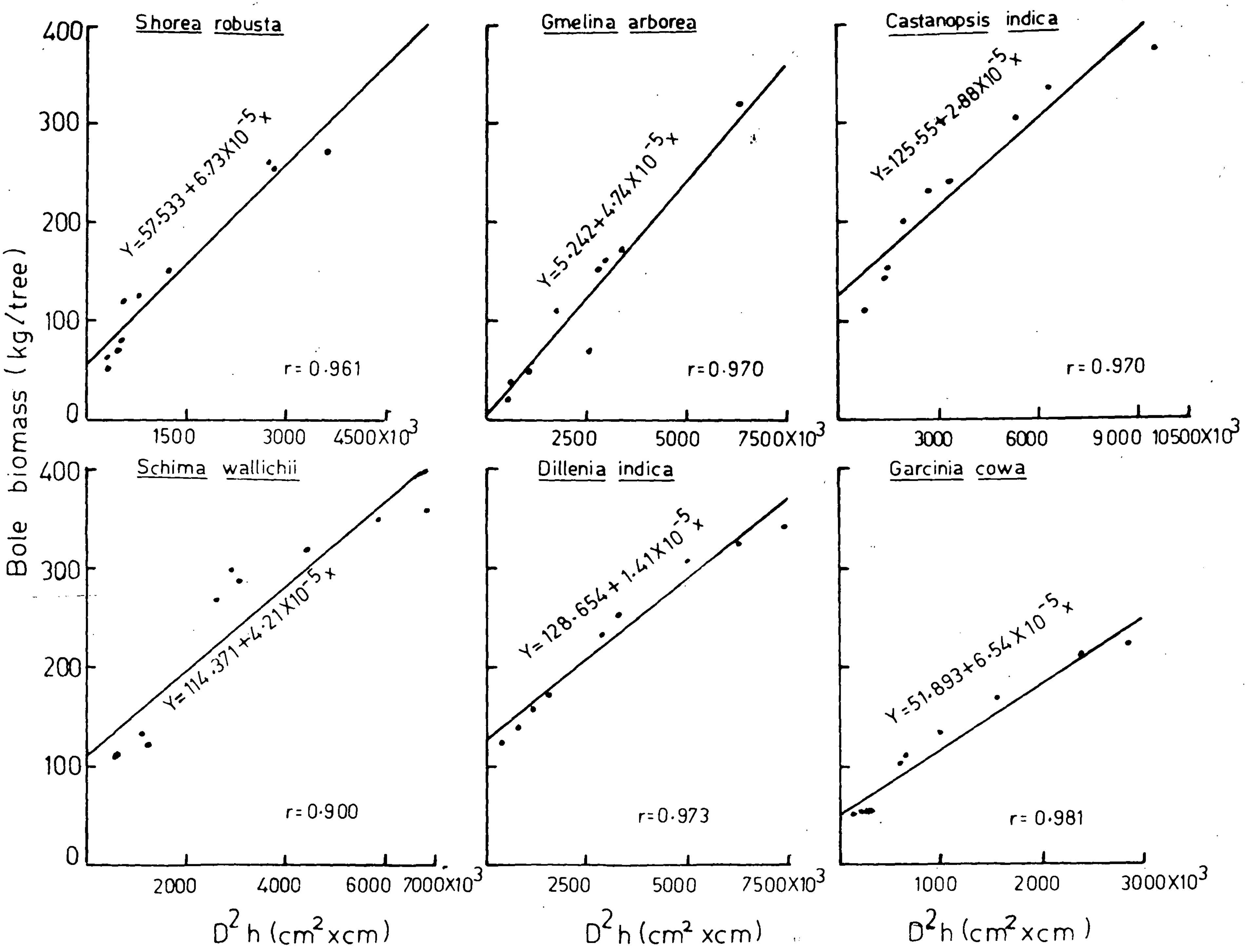

Shorea robusta
Y=57.533+6.73X10^-5 x
r=0.961
Gmelina arborea
Y=5.242+4.74X10^-5 x
r=0.970
Castanopsis indica
Y=125.55+2.88X10^-5 x
r=0.970
Schima wallichii
Y=114.371+4.21X10^-5 x
r=0.900
Dillenia indica
Y=128.654+1.41X10^-5 x
r=0.973
Garcinia cowa
Y=51.893+6.54X10^-5 x
r=0.981
Bole biomass (kg/tree)
0
100
200
300
400
1500
3000
4500X10^3
2500
5000
7500X10^3
3000
6000
9000
10500X10^3
2000
4000
6000
7000X10^3
1000
3000X10^3
D^2h (cm^2xcm)

Fig. 4-1

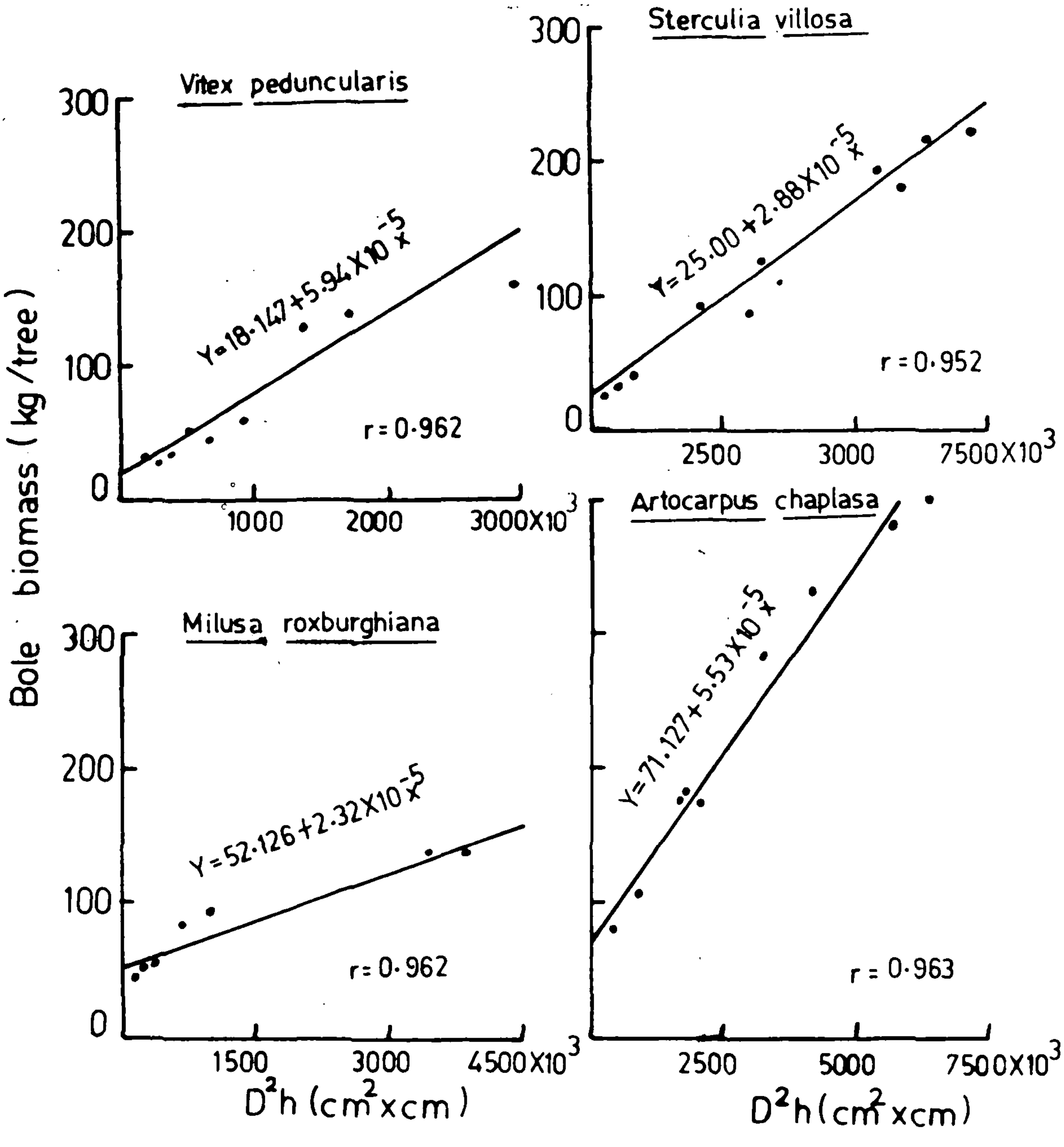
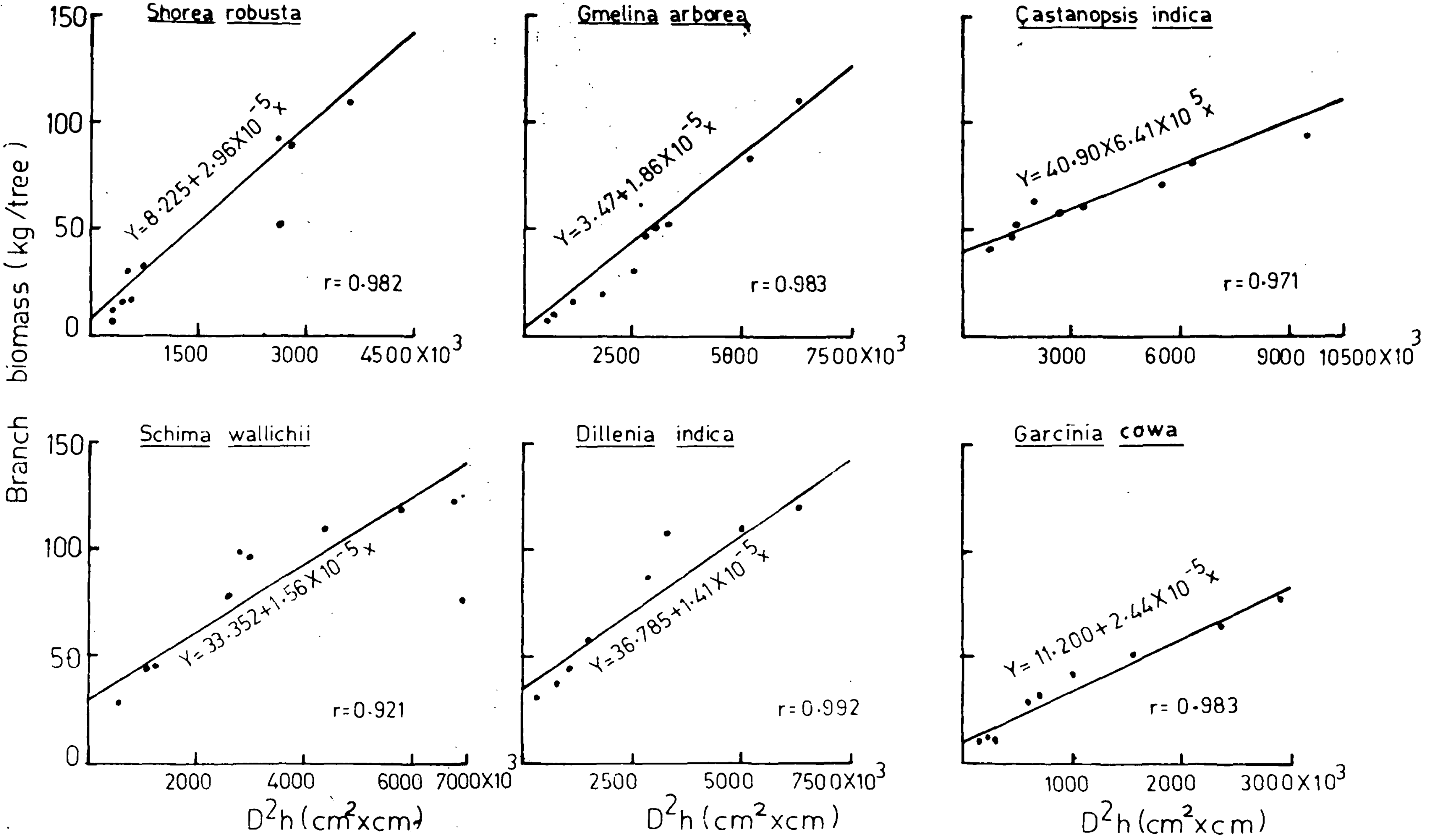

Vitex peduncularis
Y=18·147+5.94X10^-5 x
r=0·962
Sterculia villosa
Y=25.00+2.88X10^-5 x
r=0·952
Milusa roxburghiana
Y=52·126+2·32X10^-5 x
r=0·962
Artocarpus chaplasa
Y=71.127+5.53X10^-5 x
r=0·963
Bole biomass (kg/tree)
D²h (cm²xcm)
0
100
200
300
1000
2000
3000X10³
2500
3000
7500X10³
1500
3000
4500X10³
2500
5000
7500X10³

Fig. 4-11. Relationship between d^2h and branch biomass of different tree species.

Fig. 4-11



Shorea robusta
Y=8.225+2.96X10-5x
r=0.982
Gmelina arborea
Y=3.47+1.86X10-5x
r=0.983
Castanopsis indica
Y=40.90X6.41X105x
r=0.971
Schima wallichii
Y=33.352+1.56X10-5x
r=0.921
Dillenia indica
Y=36.785+1.41X10-5x
r=0.992
Garcinia cowa
Y=11.200+2.44X10-5x
r=0.983
Branch biomass (kg/tree)
0
50
100
150
1500
3000
4500X103
2500
5800
7500X103
3000
6000
9000
10500X103
2000
4000
6000
7000X103
2500
5000
7500X103
1000
2000
3000X103
D2h (cm2xcm)

Fig. 4-11

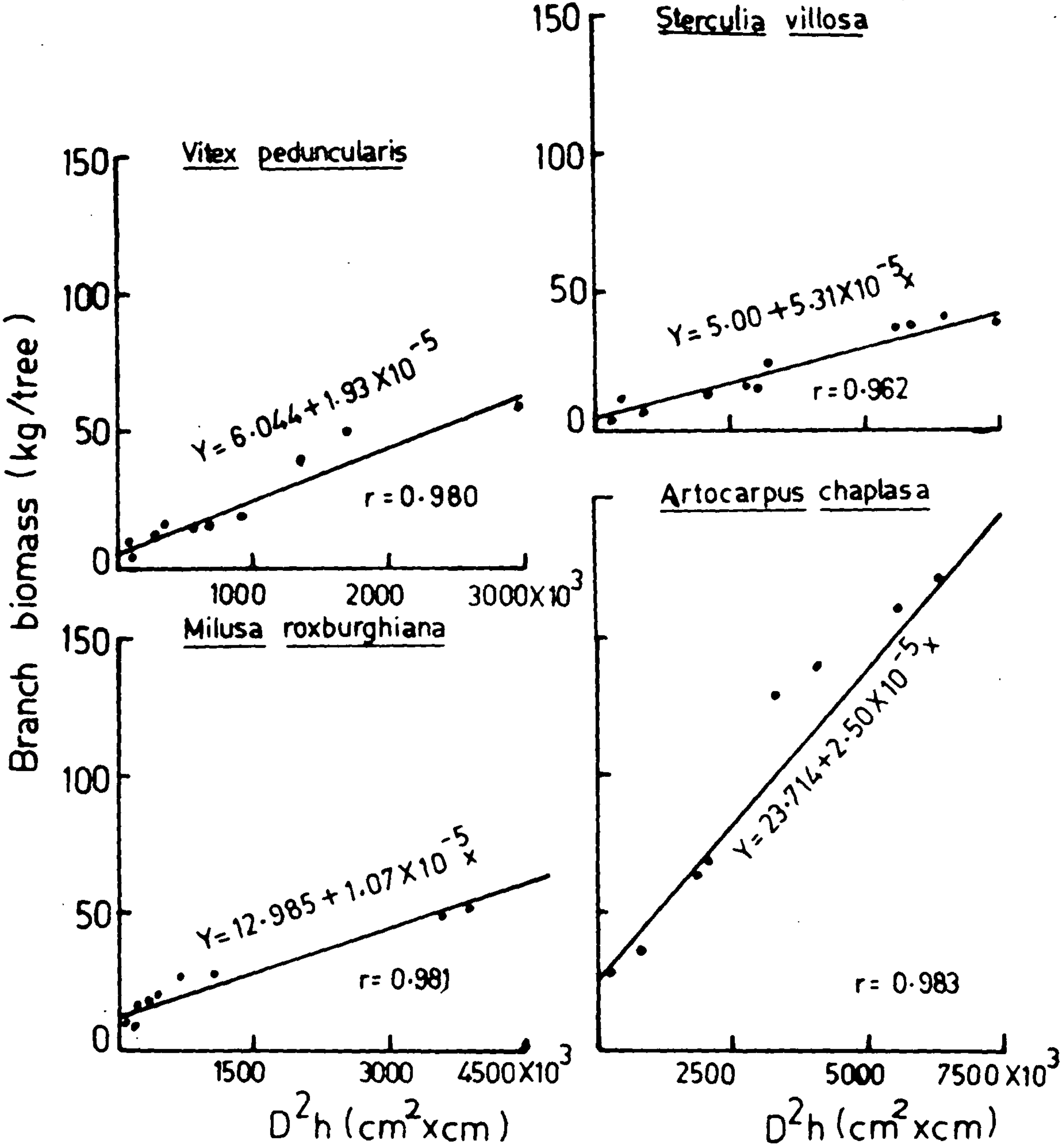

Vitex peduncularis
Y = 6.044 + 1.93 X10^-5
r = 0·980
Sterculia villosa
Y = 5.00 + 5.31X10^-5 x
r = 0·962
Milusa roxburghiana
Y = 12·985 + 1.07 X10^-5 x
r = 0·981
Artocarpus chaplasa
Y = 23·714 + 2.50 X10^-5 x
r = 0·983
Branch biomass (kg/tree)
150
100
50
0
1000
2000
3000X10^3
1500
3000
4500X10^3
2500
5000
7500 X10^3
D^2h (cm^2xcm)
D^2h (cm^2xcm)

Fig. 4-12. Relationship between d^2h and leaf biomass of different tree species.

Fig. 4-12

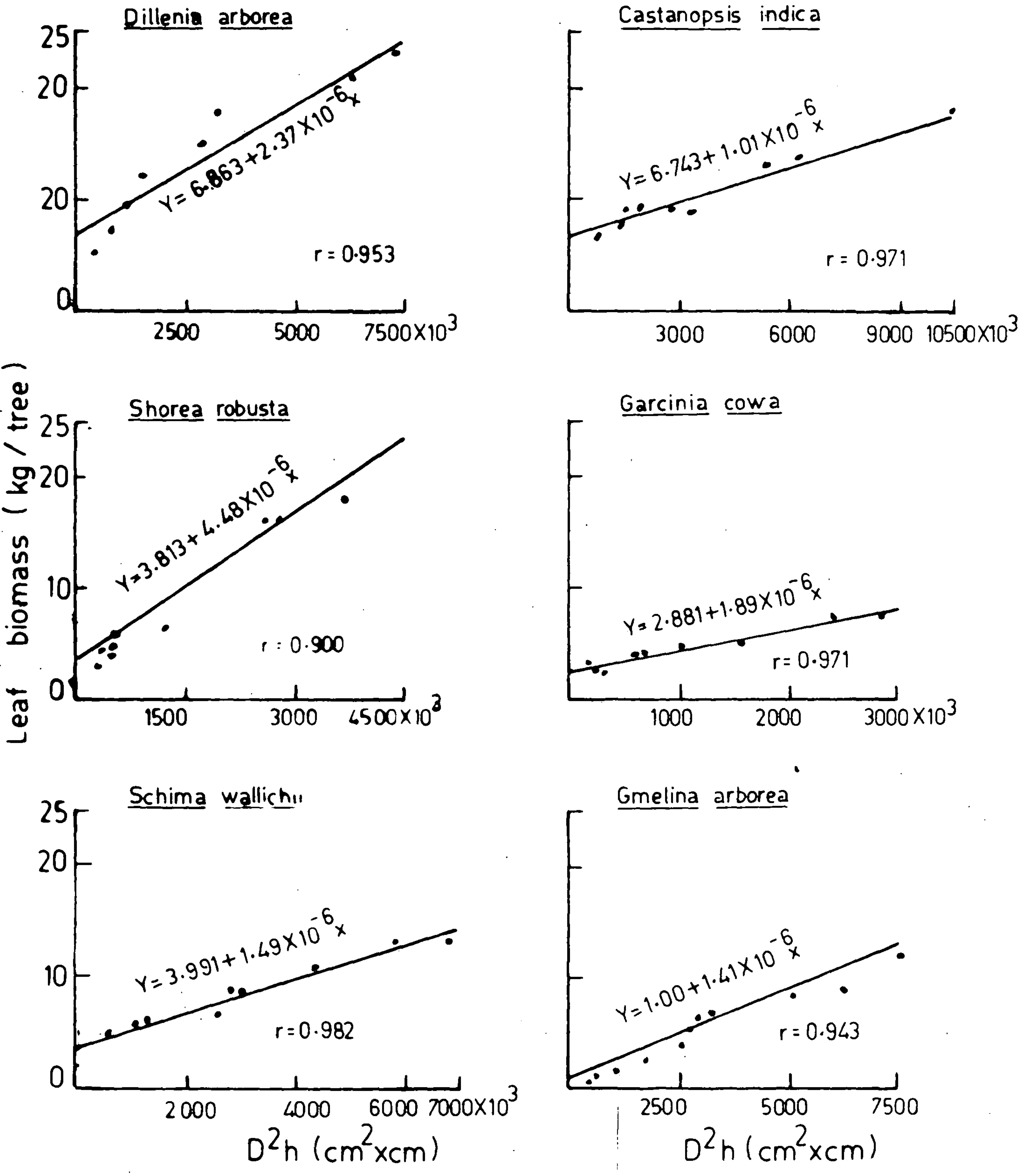
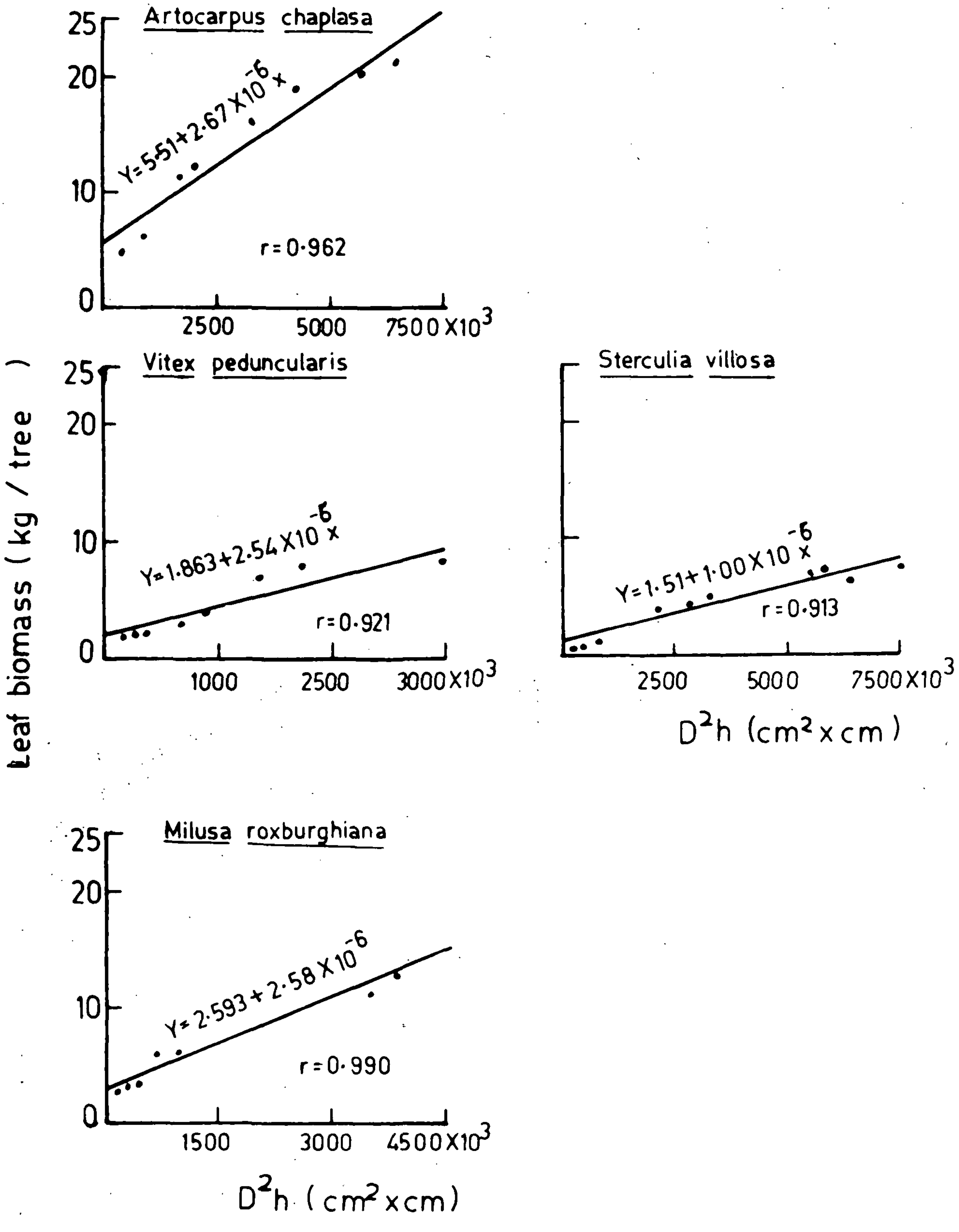

Dillenia arborea
25
20
20
0
Y= 6.863+2.37X10^{-6}x
r = 0·953
2500
5000
7500X10^3
Castanopsis indica
Y= 6·743+1·01X10^{-6}x
r = 0·971
3000
6000
9000
10500X10^3
Leaf biomass (kg / tree)
Shorea robusta
25
20
10
0
Y=3.813+4.48X10^{-6}x
r : 0·900
1500
3000
4500X10^3
Garcinia cowa
Y= 2·881+1·89X10^{-6}x
r= 0·971
1000
2000
3000X10^3
Schima wallichii
25
20
10
0
Y=3·991+1·49X10^{-6}x
r=0·982
2000
4000
6000
7000X10^3
D^{2}h (cm^{2}xcm)
Gmelina arborea
Y=1·00+1·41X10^{-6}x
r= 0·943
2500
5000
7500
D^{2}h (cm^{2}xcm)

Fig. 4-12


Leaf biomass (kg / tree)
Artocarpus chaplasa
$Y=5.51+2.67\times10^{-6}x$
r = 0·962
0
10
20
25
2500
5000
7500 X10^3
Vitex peduncularis
$Y=1.863+2.54\times10^{-6}x$
r = 0·921
0
10
20
25
1000
2500
3000 X10^3
Sterculia villosa
$Y=1.51+1.00\times10^{-6}x$
r = 0·913
2500
5000
7500 X10^3
D^2h (cm^2 x cm)
Milusa roxburghiana
$Y=2.593+2.58\times10^{-6}$
r = 0·990
0
10
20
25
1500
3000
4500 X10^3
D^2h (cm^2 x cm)

CHAPTER 5

LITTER DYNAMICS

LITTER DYNAMICS

INTRODUCTION

Studies on litter production and its decomposition are quite important for proper understanding of energy flow, nutrient cycling and primary production in woodland ecosystems (Ovington, 1962; Newbould, 1967). The litter consists of dead or decaying leaves, twigs, branches, flowers, fruits, bark and other debris. Out of these, leaf happens to be the major source of litter which may fall seasonally as in the case of deciduous trees or it may continuously accumulate throughout the year as in evergreen forests. Thus the nutrient locked in the litter are once again made available to plants.

Considerable emphasis has, therefore, been made on the studies related to litter accumulation and its decomposition in various parts of the world. Although there is a large volume of information on this aspect, much of the published work was reviewed by Ovington (1962), Olson (1963), Bray and Gorham (1964) and Rodin and Bazilevich (1967). But most of the work on litter production has been done in temperate forests. Lack of data on annual litter production in tropical forests is evident from the fact that a comprehensive review of world literature by Bray and Gorham (1964) contained only few references on tropical forests. In tropical Africa nutrient content of litter fall was studied by Laudelout and Meyer (1954), Nye (1961), Hopkins (1966), Bernhard (1970) and Egunjobi (1974). For purposes of facilitating comparison of data from many different ecosystems, total annual litter budgets are preferred by many workers, though submodel budgets for major litter components usually are available in most recent studies (Carlisle et al, 1966a; Sykes and Bunce, 1970; Gosz et al, 1972). In most of the litter production studies of the world, much emphasis has been given on the leaf litter only but a few attempts have been made to account also for wood litter production (Carlisle et al, 1966a; Duvigneaud et al, 1969; Anderson, 1970; Hughes, 1970; Rockhow, 1974; Nielsen, 1977; Christensen, 1977, 1978).

The litter which fall on the ground is decomposed slowly and forms the major source of energy and nutrients for the plants and soil organisms of the ecosystems. Decomposition itself is a very complex and often prolonged process and the rate constants varying with the nature of the substrata and the characteristics of the environment (Satchell, 1971). Much attention has recently been made to different techniques devised for the study of decomposition and to estimate the rate of decomposition of different types of plant litter in different climatic zones (Edwards and Heath, 1963; Wiegert and Evans, 1964; Witkamp, 1966b; Edwards et al, 1970; Van Cleave, 1971; Gosz et al, 1973; Millar, 1974; Suffling and Smith, 1974; Lousier and Parkinson, 1976).

Related to the phenomenon of decomposition is another process called soil respiration which has long been considered as an index of soil metabolism. The degree to which carbon dioxide escapes from soil is often taken as a measure of the microbiological activity occuring in the soil (Mina, 1962; Witkamp and Frank, 1969; Macfadyen, 1970; Anderson, 1973b). It is noteworthy that in many of the publications a direct relationship between microbiological activity, CO_2 production, temperature and moisture has been shown by a number of workers. (Witkamp, 1966 a, b; Wiant, 1967a; Reiners, 1968).

Although the study of litter production is of great significance in forest ecology not much work has been done on this aspect under Indian conditions. In India estimation of annual litter production in deciduous and some evergreen forests has been made by Champion (1936), Puri (1953), Upadhyaya (1955), Singh (1962a, b), Seth et al (1963) and Singh (1969). The present study is an attempt to estimate the leaf and wood litter production and decomposition rates in a humid sub-tropical forest at an elevation 296 m at Lailad (25°45" and 26°0"N latitude and 91°45" and 92°0" E longitude) which is a 50 year old stand in the successional series.

METHODS OF STUDY

Preliminary observations showed that litter traps (Newbould, 1967), were damaged by wild animals which are very common in these forests. In the study area 20 $1m^2$ permanent quadrats were marked randomly. Harbaceous species along with all accumulated old litter was removed at the very beginning. All the quadrats were demarcated using Wooden frames. The litter accumulated in these frames were collected at regular intervals of one month in polythene bags and brought to the laboratory. The wood litter was separated from the leaf litter and the latter was sorted out in to different tree species. The litter from some of the rarer tree species, all shrubs and climbers was bulked under a miscellaneous category. The litter was oven dried to a constant weight at 80°-85°C and weighed. It was ground, passed through a 20 mesh secreen and stored at room temperature in sealed plastic containers.

The litter accumulated and that partly decomposed on the forest floor in the month of April 1977 was weighed (after oven drying at 80°-85°C for 24 hours) from 30 randomly placed $1m^2$ quadrats. The ratio of the mean litter on the ground divided by the annual litter fall gave an approximate idea of the rate of decomposition of the litter (Hopkins, 1966).

For detailed study of the rate of decomposition of leaf litter of individual species litter bag method was adopted (Shanks and Olson, 1961). The fresh leaf litter was collected in April when the maximum litter fall occured and sorted out into five important tree species, namely, *Shorea robusta*, *Schima wallichii*, *Castanopsis indica*, *Dendrocalamus hamiltonii* and *Artocarpus chaplasa*. The remainder consisting of a mixture of species was bulked into one category as miscellaneous. The litter was air dried in the laboratory for about three weeks. 30g of leaf litter of each species category was kept in nylon bags of 10 X 14cm with 1mm mesh size (Suffling and Smith, 1974). Over 50 bags of each species were prepared and kept on 30th April 1977 on the forest floor after removing the organic layer from the ground. The litter bags were randomly placed atleast 6m away from the nearest tree trunk of that species. The miscellaneous category of litter bags were placed randomly but irrespective of any tree species. The litter bags of different categories of litter were kept apart from each other at a distance of about 10-20 metres. At the end of each month three bags of each category representing three replicates were removed randomly and placed in polythene bags carefully avoiding spillage of decomposed material. In the laboratory the nylon bags were opened carefully and all extraneous matters were removed by washing. The washed litter was oven dried for 48 hours at 80° - 85°C and weighed. The weighed litter was ground and stored for chemical analyses.

To evaluate the rate of decomposition of wood the method given by Yoneda (1975b) was used. Freshly fallen, undecomposed air dried wood pieces of moderate size (3-4 cm. diameter) of five species, i.e. *Shorea robusta*, *Schima wallichii*, *Castanopsis indica*, *Dendrocalamus hamiltonii* and *Artocarpus chaplasa* were collected from the forest floor in the month of April. These wood pieces were cut into 12 cm. long pieces and air dried for about 3-4 weeks. After taking the initial weight of each piece, these were tagged properly. Over 50 wood pieces of each species were taken for the study. These pieces were kept under the canopy of each species on 30 April 1977 after removing the organic layer from the forest floor. They were randomly placed at least 6 m away from the nearest tree trunk of that species. At monthly intervals, three replicates of each species were brought to the laboratory in polythene bags. These were then washed and oven dried at 80° - 85°C for about 48 hours. After weighing, these wood pieces were ground and stored for chemical analyses.

To measure the rate of decomposition by CO_2 evolution process, a method used by Yoneda (1975 I, II) was adopted with slight modification. 50 ml of 1N KOH in a small beaker was kept for 24 hours under a covered metallic cylinder of 16.6cm.diameter under two types of situations. (i) The beaker was directly on top of the mineral soil after removal of the litter and (ii) the beaker was placed directly on the litter layer. One set served as the blank for which the beaker was placed on a wooden platform lined by a layer of polythene sheet. All the experiments were replicated 3 times. After 24 hours the KOH was titrated against normal HCl by using phenolpthaline as indicator.

RESULTS AND DISCUSSIONS

Litter production :

The total leaf litter contributed (1977-78) by the tree species along with that due to the wood is shown in Table 5-1. The total litter production in this mixed natural

Table 5-1. Annual leaf litter contribution by individual tree species and total wood litter contribution (kg/ha) at Lailad forest (1977-78) (Figures in parentheses are percentage of the total litter).

	Annual leaf litter/Wood litter production (kg/ha).
Leaf litter:-	
Artocarpus chaplasa	153.36 (2.79)
Castanopsis indica	368.80 (6.69)
Dendrocalamus hamiltonii	564.40(10.23)
Dillenia indica	29.15 (0.53)
Garcinia cowa	96.90 (1.76)
Machillus khasiana	4.52 (0.81)
Mesua ferrea	27.30 (0.49)
Milusa roxburghiana	226.00 (4.03)
Shorea robusta	470.70 (8.39)
Schima wallichii	555.70 (9.91)
Sterculia villosa	45.50 (0.81)
Vitex peduncularis	40.00 (0.71)
Other species (leaf) (miscellaneous)	1663.27(29.63)
	4046.60
Wood litter:-	
Branches, twigs and barks. (all species)	1267.40(22.80)
Total	5513.00

humid sub-tropical forest was estimated to be 5.5 t/ha/yr/. Out of this total litter, leaf litter alone comes to 77% and the remaining 23% represents wood litter. The amount of total litter seems to be slightly lower than the values obtained for other humid tropical forests. Thus, the litter production was shown to range between 6.8 to 10.0 t/ha/yr/ in the case of humid tropical forests of West Africa (Cornforth, 1970), secondary forest at Koda in Ghana (Rodin and Bazilevich, 1967 and Nye, 1961) and for three Columbian forests (Jenny et al, 1949; Folster and Salas, 1976). Much higher values between 8.3 to 14.4 t/ha/yr/ have also been recorded by Mitchell (cited by Bray and Gorham 1964). However, the value obtained during the present study is much in excess of 3.8 t/ha/yr/ recorded by Carlisle et al (1966a) for a mature sessile Oak (Quercus petreae) woodland of England and the average of values given for temperate forests by Bray and Gorham (1964). The range of values for litter production in tropical and sub-tropical forests obtained by different workers are summarised in Table 5-2.

A number of facts contribute towards determining litter production by different species. Kira and Shidei (1967) pointed out that longer the average life span of leaves, the

Table 5-2. The amount of dry matter (t/ha/yr) in some tropical and sub-tropical forests.

Source	Location	No. of sites	Age of vegetation (years)	Dry weight
Laudelot and Meyer (1954)	Zaire	3	Mature	12.3-15.3*
- -	-	1	Young secondary	14.9*
Nye (1961°	Ghana	1	40	10.5
Klinge and Rodrigues (1968)	Brazil	1	Mature	7.3
Bernhard (1970)	Ivory Coast	4	Mature	7.2-13.4
Ewel (1976)	Guatemala	7	1-14	4.6-10.0
Ewel (1976)	"	1	Mature	9.0
Kitazawa (1967)	Japan	-	Mixed stand	9.25
Singh (1968)	India	5	Mature (undisturbed)	1.0-6.2
Present study (1977-78)	India	1	Mature 50	5.5

* Air dried.

greater the leaf biomass per unit area. The size and weight of the leaf also plays an important role in this regard (Bell <u>et al</u>, 1978). Among the phyto-physiological factors, density, basal cover and canopy exposure are important parameters to assess production of organic matter in the forests (Van Cleve and Noonan, 1975). The maximum percentage of leaf litter in the present case was contributed by <u>Dendrocalamus hamiltonii</u>, <u>Schima wallichii</u>, <u>Shorea robusta</u> and <u>Castanopsis indica</u> with values 10.2%, 9.9%, 8.4% and 6.7% respectively. The higher percentage of leaf litter contributed by <u>D. hamiltonii</u> may be attributed to the fact that it has maximum density (560 per hectare). However, this species mostly restricted to the peripheral zone of the forest where biotic disturbances like felling for firewood and some amount of accidental fire occur. It may be noted that <u>D. hamiltonii</u> is an early successional species during secondary succession and is predominant in the forest only upto a period of 20-25 years. This would explain the predominance of this species along the periphery of the forest. <u>D. hamiltonii</u> in the central zone of the forest is patchy and the production of organic matter is also less (Fig. 5-1). The distribution of total litter in the peripheral and central

Fig. 5-1. Density distrubution of Dendrocalamus hamiltonii in Lailad forest.

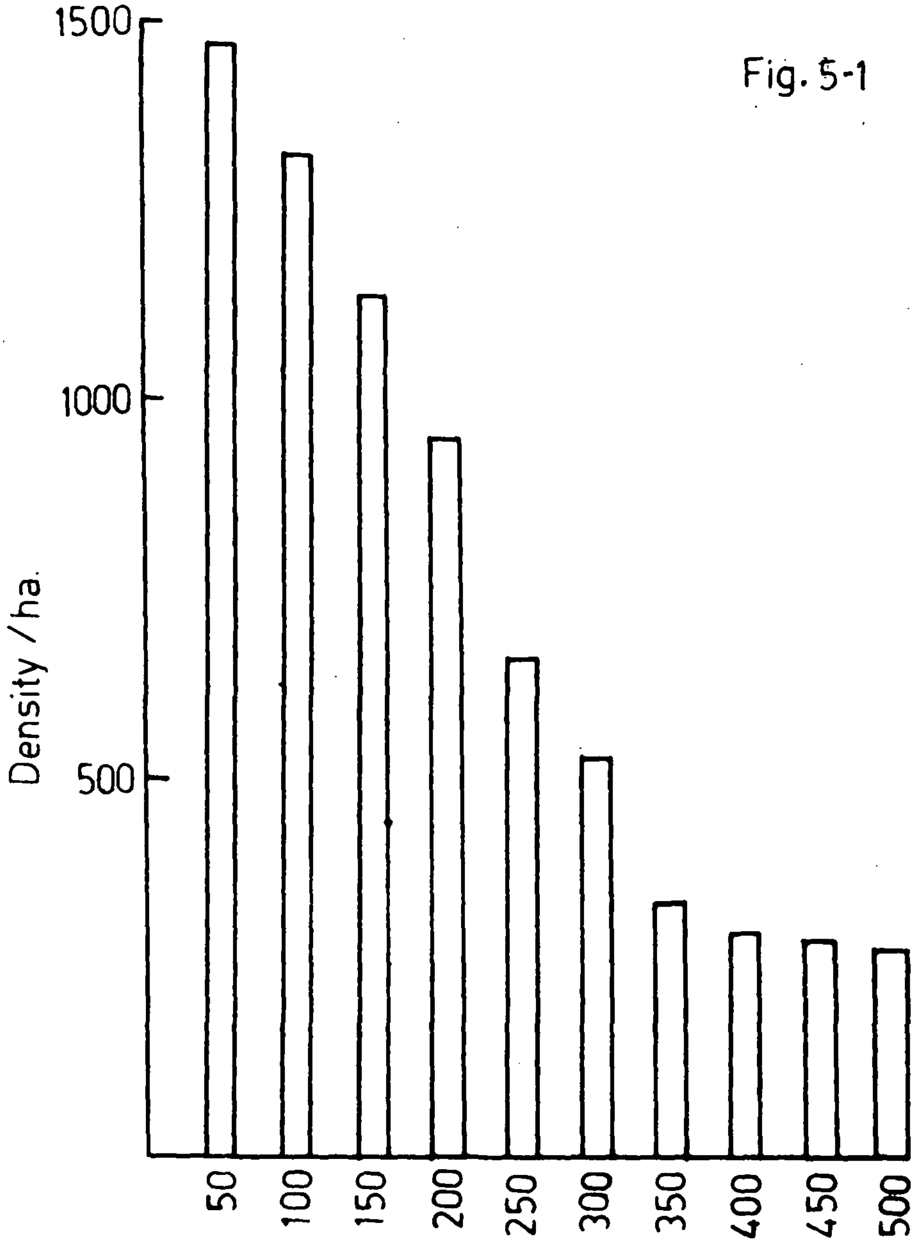


Fig. 5-1

Distance from the peripheral zone to the central zone of the forest (m) zones of the forest showed that out of the total amount (5.5 t/ha/yr) of the leaf and wood litter 40.95% was present in the peripheral zone and the remaining 59.05% was present in the central zone (Table 5-3). Along the peripheral zone *D. hamiltonii* contributed a larger proportion of litter, compared to the central zone, as discussed elsewhere. In the central zone maximum litter production was by *S. robusta*, *S. wallichii* and *C. indica* with percentage contribution of 13.05, 9.88, 7.55 respectively. These represent comparatively late successional species and therefore they are important components of the central zone. In the older and undisturbed central zone of the forest, wood litter production was greater compared to the peripheral zone. Other tree species, namely *S. wallichii*, *S. robusta* and *C. indica* arranged in the order of litter production had densities of 174, 73 and 104 per hectare and basal area cover of 17, 17 and 15 m^2 per hectare. The high litter production in the case of *Shorea robusta* inspite of comparatively lower density and basal cover values may be due to greater leaf size and leaf dry weight as indicated in Table 5-4. In general, litter fall pattern followed the IVI values given in Table 3-1 and agrees with similar correlation reported by Bormann *et al* (1970).

Table 5-3. Distribution of litter along the periphery and central zones of the sub-tropical forest at Lailad (kg/ha/yr) (Figures in paranthesis represents the percentage of the total litter in each zones).

Species	Peripheral zone	Central zone
<u>Leaf</u> <u>litter</u>:-		
Artocarpus chaplasa	102.24 (2.26)	204.48 (3.14)
Castanopsis indica	245.84 (5.44)	491.76 (7.55)
Dendrocalamus hamiltonii	846.60 (18.75)	282.20 (4.31)
Dillemia indica	25.16 (0.56)	33.14 (0.51)
Garcinia cowa	48.80 (1.08)	145.00 (2.23)
Machillus khasiana	4.04 (0.09)	5.00 (0.08)
Mesdua ferrea	40.20 (0.89)	14.40 (0.22)
Milusa roxburghiana	311.34 (6.89)	140.66 (2.16)
Shorea robusta	261.86 (5.80)	849.54 (13.05)
Schima wallichii	297.80 (6.59)	643.60 (9.88)

Table 5-3 cont'd.

Species	Peripheral zone	Central zone
Sterculia villosa	64.66 (1.43)	26.34 (0.40)
Vitex peduncularis	36.60 (0.81)	43.40 (0.67)
Other species (leaf) (miscellaneous)	1530.54 (33.88)	1796.00 (27.61)
<u>Wood litter</u>:-		
Branches, twigs, barks. (all species)	701.00 (15.52)	1833.80 (28.16)

Table 5-4. Annual leaf litter production, individual leaf area and dry weight of leaves of some important tree species alongwith standard errors at Lailad forest.

Species	Litter production ($gm/m^2/yr$)	Individual leaf area (cm^2)	Dry weight/leaf (gm)
Artocarpus chaplasa	15.34±0.73	300±65.55	2.500±1.30
Castanopsis indica	36.88±1.06	108±40.00	0.943±0.14
Dendrocalamus hamiltonii	56.44±1.21	218±57.72	1.560±0.85
Dillenia indica	2.91±0.28	250±60.38	1.850±0.76
Garcinia cowa	9.69±0.44	75±15.00	0.450±0.15
Machillus khasiana	0.45±0.34	20±6.80	0.350±0.10
Messua ferrea	2.73±0.15	18±3.80	0.300±0.12
Milusa roxburghiana	22.60±0.38	23±5.50	0.083±0.05
Shorea robusta	47.07±1.36	138±30.40	1.649±0.85
Schima wallichii	55.57±1.99	71±17.65	0.500±0.25
Sterculia villosa	4.55±0.30	201±55.88	0.750±0.35
Vitex peducularis	4.00±1.04	20±4.33	0.250±0.10

The seasonal pattern for leaf and wood litter is shown in Fig. 5-2. Although the litter continuously fell throughout the year a clear monthly pattern of litter fall exists. Leaf litter fall (56.5%) was maximum during the dry months of February, March and April. During the rest of the period leaf fall was very much less and more or less uniform. This pattern is in agreement with that reported by Nye (1961) for moist tropical forest of Ghana. The maximum shedding of leaf litter during these months may be due to the formation of abscicion zone during the winter season which itself is a dry period and which gets accentuated during the succeeding summer months of February, March and April. The young secondary rain forest in Zaire shows two periods of maximum litter fall that come at the end of the two drier seasons (Laudelout and Meyer, 1954) while only one peak period which coincides with the dry season was observed in other forests. The differences between forests in this respect may be related to the severity of the drought stress in the dry season. For example, in the Amazonian lowland forest the litter fall was twice as high in the dry months as it was in the wettest months (Klinge and Rodrigues, 1968).

Bray and Gorham (1964) has shown an inverse linear

Fig. 5-2. Monthly litter production in a humid sub-tropical forest at Lailad (1977-78). Leaf litter, ● ; wood litter, ○ .

Fig. 5-3. Comparison of expected and observed values of leaf litter production for Lailad forest, (after Bray and Gorham, 1964).

Fig. 5-2

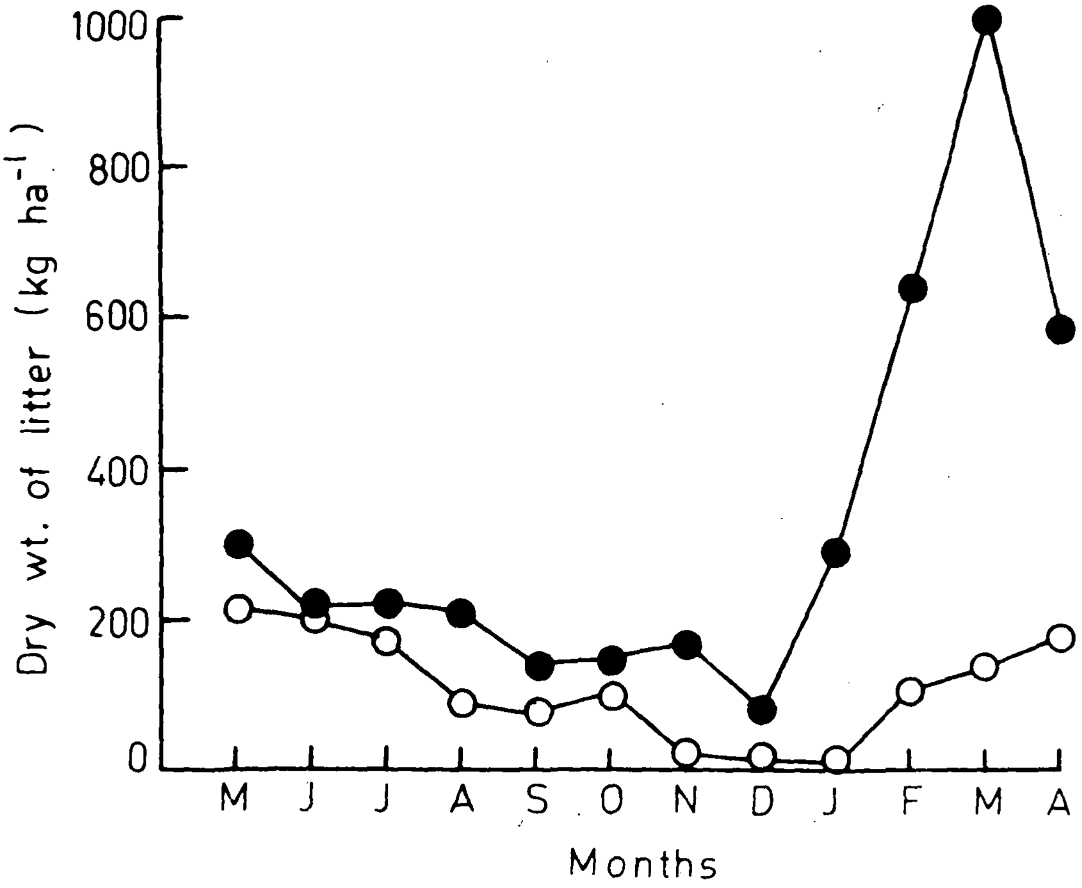
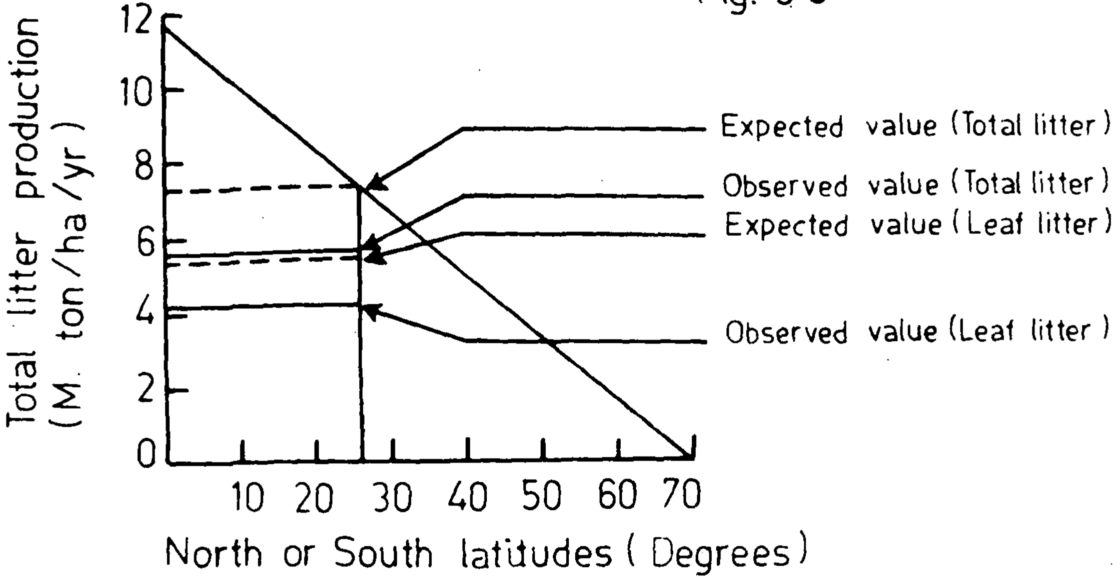

Dry wt. of litter (kg ha^{-1})
1000
800
600
400
200
0
M
J
J
A
S
O
N
D
J
F
M
A
Months

Fig. 5-3


Total litter production (M. ton/ha/yr)
12
10
8
6
4
2
0
10
20
30
40
50
60
70
North or South latitudes (Degrees)
Expected value (Total litter)
Observed value (Total litter)
Expected value (Leaf litter)
Observed value (Leaf litter)

relationship between the amount of annual litter production of forests and the latitudinal zone they occupy. Of the total litter, leaf litter alone, according to them, constitute roughly 70%. Accordingly, the total annual litter production in the present case works out to 7.6 t/ha of which 5.43 t/ha is leaf litter. It may be noted that the calculated values of leaf litter production very closely approximates the average of actually determined values in this study area (Fig. 5-3).

The total wood litter fall during this study was 1261 kg/ha which represents 23% of the total litter. For temperate forests a range of 22-78% has been shown (Carlisle et al, 1966a; Anderson, 1970; Sykes and Bunce, 1970; Hughes, 1971). Low wood litter production in this forest in comparison to higher range of values quoted above could be related to the age of the forest which in the present case is only about 50 years, so that the trees have not yet attained maturity. However, wood litter production has been related to management practices, topography, species composition etc. (Christensen, 1975).

Wood litter fall also showed a yearly pattern with peak fall occuring during May, June and July. However, this pattern is different from leaf litter fall in that whilst leaf litter fall is greatest during the dry months of February, March and April which is late winter/early summer period and that of wood litter fall occured during May, June and July which is the monsoon period. This may be due to the delay due to inadequate storm action though abscission might have occurred during the dry winter months. In a study of woody litter fall in a mountain range forest in New Guinea also this coincides with the rainy season (Edwards, 1977).

Litter decomposition :

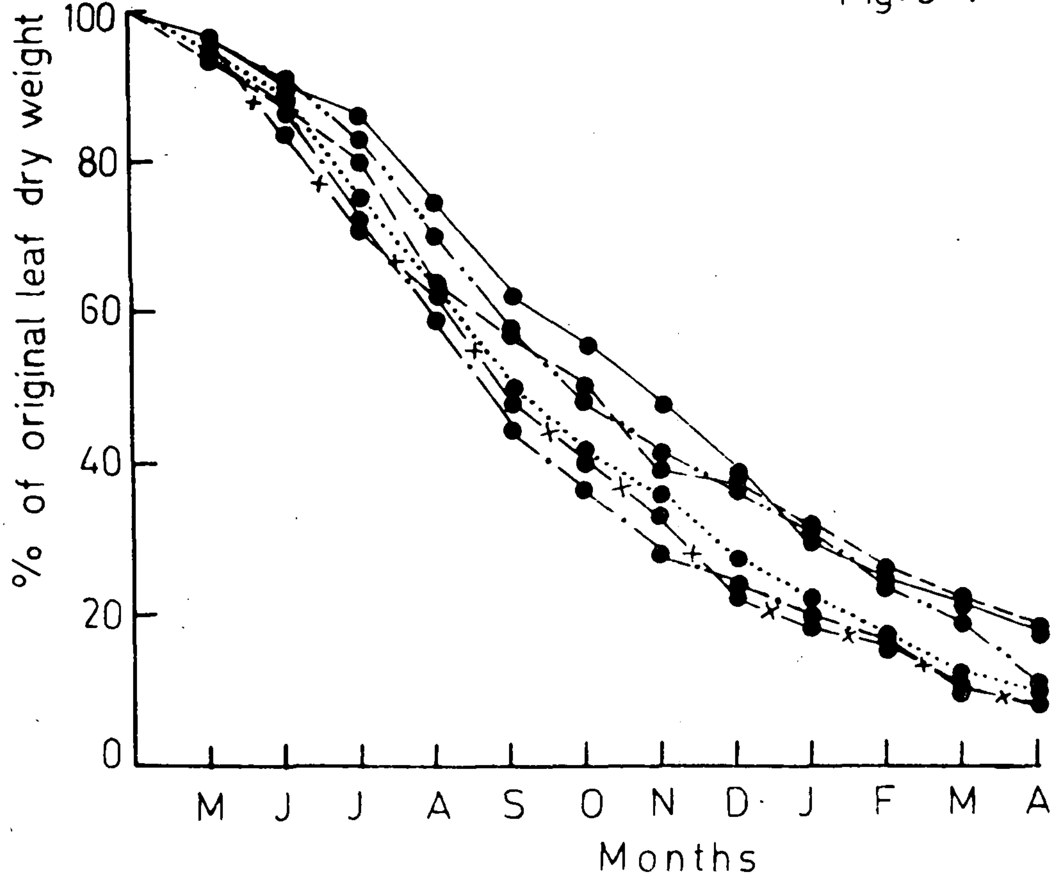
The rate of decomposition of leaf litter over a period of one year has been expressed in Fig. 5-4 as a percentage of the original dry weight of the leaf litter. It is seen from this that *S. robusta* deco-mposes much more slowly compared to others. On the other hand, the rate of decomposition of *D. hamiltonii* was most rapid.

Olson (1963) described equations for the rate of decay under various situations which may be used to compare differences between species. Confining litter in mesh bags and measuring its rate of loss is a special case of decay with essentially no addition of material from outside. Most of the workers who have considered the rate of decay of litter (Jenny *et al*, 1949; Olson, 1963) have assumed that there is

Fig. 5-4. Rate of decomposition of leaf litter expressed as percentage of the original dry weight of leaves remaining after various periods of decomposition.

S. robusta, ●———●; *S. wallichii*, ●— , —●;
C. indica, ●----●; *D. hamiltonii*, ●— X —○;
A. chaplasa, ●— ••—●; Miscellaneous, ●•••• ●;

Fig. 5-4


% of original leaf dry weight
100
80
60
40
20
0
M
J
J
A
S
O
N
D
J
F
M
A
Months

an exponential loss in weight as a result of decay, i.e. $X/X_0 = e^{-kt}$, where X = weight remaining at time t, X_0 = original weight, e is the base of natural logarithms and k is the decomposition constant. This model expresses the loss as a negative exponential function of the fraction. After one year of decay this fraction remaining would be $X/X_0 = e^{-k}$. This exponential model also helps to calculate the "half time" (0.693/k) or time required to lose 95% (3/k). The decay parameters and the time parameters for all the species used for decomposition study are shown in Table 5-5.

It is clear from this table that the ratio of decomposition is rapid in *D. hamiltonii* and *S. wallichii* (high k values) while it is less in *S. robusta* and *C. indica* (low k values). The rate of decomposition of leaf litter in the present study was found to be lower than the values reported by Singh (1969) in deciduous forests at Varanasi (India) with unconfined litter. This may partly be accounted as due to smaller mesh size of the litter bags which does not allow the larger fauna to enter (Gilbert and Bocock, 1962; Edwards and Heath, 1963; Olson, 1963). It may also be related to species composition and other environmental parameters. Nitrogen content of the litter also plays an important role in decom-

Table 5-5. Decay constants and time required for the loss of one-half and 95% of the original leaf dry weight in different species.

Species	Decay parameter. K	Time parameters (years)	
		Half-time $\frac{(0.693)}{K}$	95% $\frac{(3)}{K}$
Artocarpus chaplasa	1.998	0.347	1.501
Castanopsis indica	1.866	0.371	1.608
Dendrocalamus hamiltonii	2.170	0.319	1.382
Shorea robusta	1.867	0.371	1.607
Schima wallichii	2.176	0.318	1.379
Other species (miscellaneous)	2.167	0.320	1.384

position (Melin, 1930; Broadfoot and Pierre, 1936). However, Singh (1969) correlated various chemical constituents and the rate of decomposition in tropical tree species and found that not only nitrogen but numerous chemicals interact to affect the rate of decomposition. The nitrogen content of leaf litter (Table 5-6) in S. robusta, C. indica and A. chaplasa is quite high but still low rate of decomposition was observed in these species. This may be due to decay resistant petiole and midrib of the leaves which contain high concentration of lignin (Singh, 1969).

An exceptionally higher rate of loss in weight (40-45%) was observed in the first 4-5 months starting from May. This rapid decay may be attributed to the fact that high precipitation, temperature and soil moisture accelerate microbial activities. Subsequently, the rate of loss slowed down and during the last 3 months the rate of loss was extremely slow.

Fig. 5-5 shows the rate of decomposition over a 1 year period of wood of the different species expressed as percentage loss of dry weight. Maximum rate of decomposition of wood was observed for D. hamiltonii (77.8% loss) and the least for S. robusta (56.2% loss). This is also evident from the k values of these two species (Table 5-7) and may be due to

Table 5-6. Chemical composition of leaf litter collected in April 1977 from Lailad forest.

Species	N(%)	P(%)	K(%)	(Ca(%)	Mg(%)
Artocarpus chaplasa	0.67	0.35	0.35	2.50	0.66
Castanopsis indica	0.82	0.46	0.36	1.88	0.59
Dendrocalamus hamiltonii	0.68	0.32	0.22	1.15	0.31
Shorea robusta	0.85	0.63	0.63	1.12	0.51
Schima wallichii	0.76	0.54	0.44	1.93	0.65
Other species (miscellaneous)	0.79	0.56	0.46	2.08	0.67

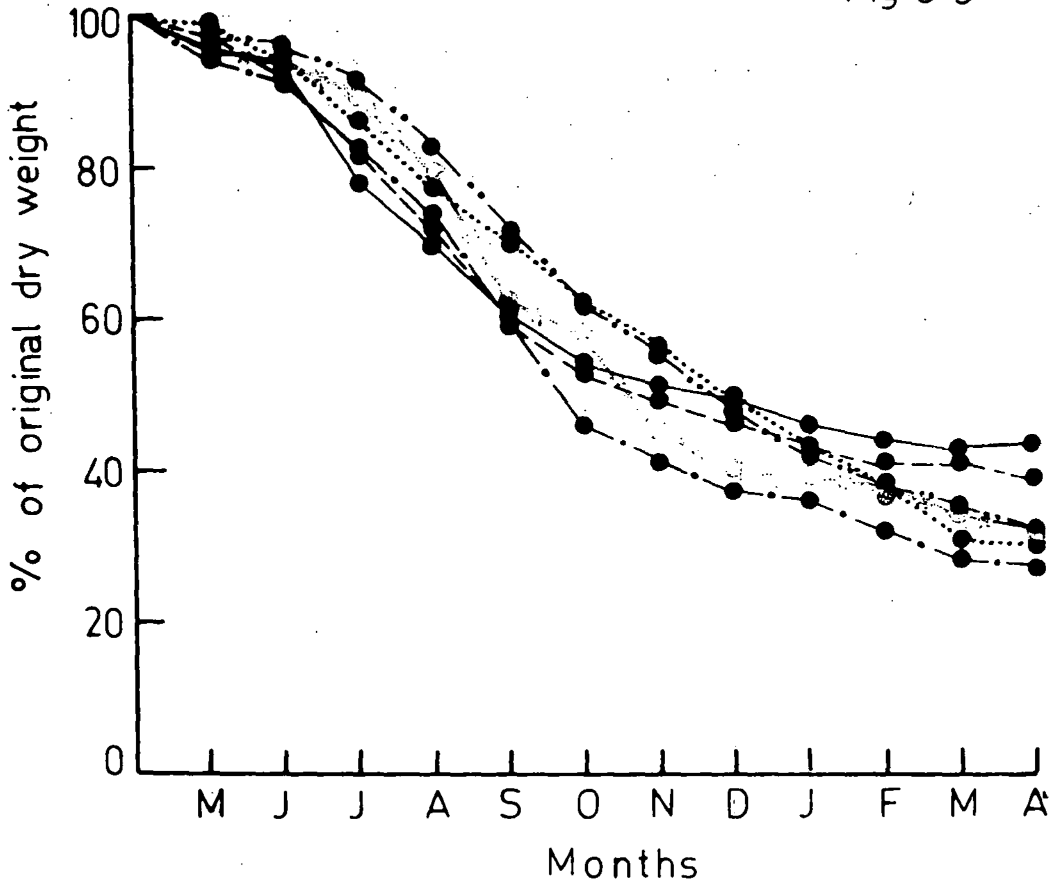
Table 5-7. Decay constants and time required for the loss of one-half and 95% of the original wood dry weight in different species.

Species	Decay parameters K	Time parameters (years)	
		Half-time $\left(\frac{0.693}{K}\right)$	95% $\left(\frac{3}{K}\right)$
Artocarpus chaplasa	0.794	0.873	3.778
Castanopsis indica	1.097	0.632	2.735
Dendrocalamus hamiltonii	3.630	0.191	0.826
Shorea robusta	0.756	0.917	3.968
Schima wallichii	1.189	0.583	2.523

Fig. 5-5. Rate of decomposition of wood litter expressed as percentage of the original dry weight remaining after various periods of decomposition.

S. robusta, ●———●; *S. wallichii*, ●····●; *C. indica*, ●—··—●; *D. hamiltonii*, ●—·—●; *A. chaplasa*, ●---●.

Fig. 5-5

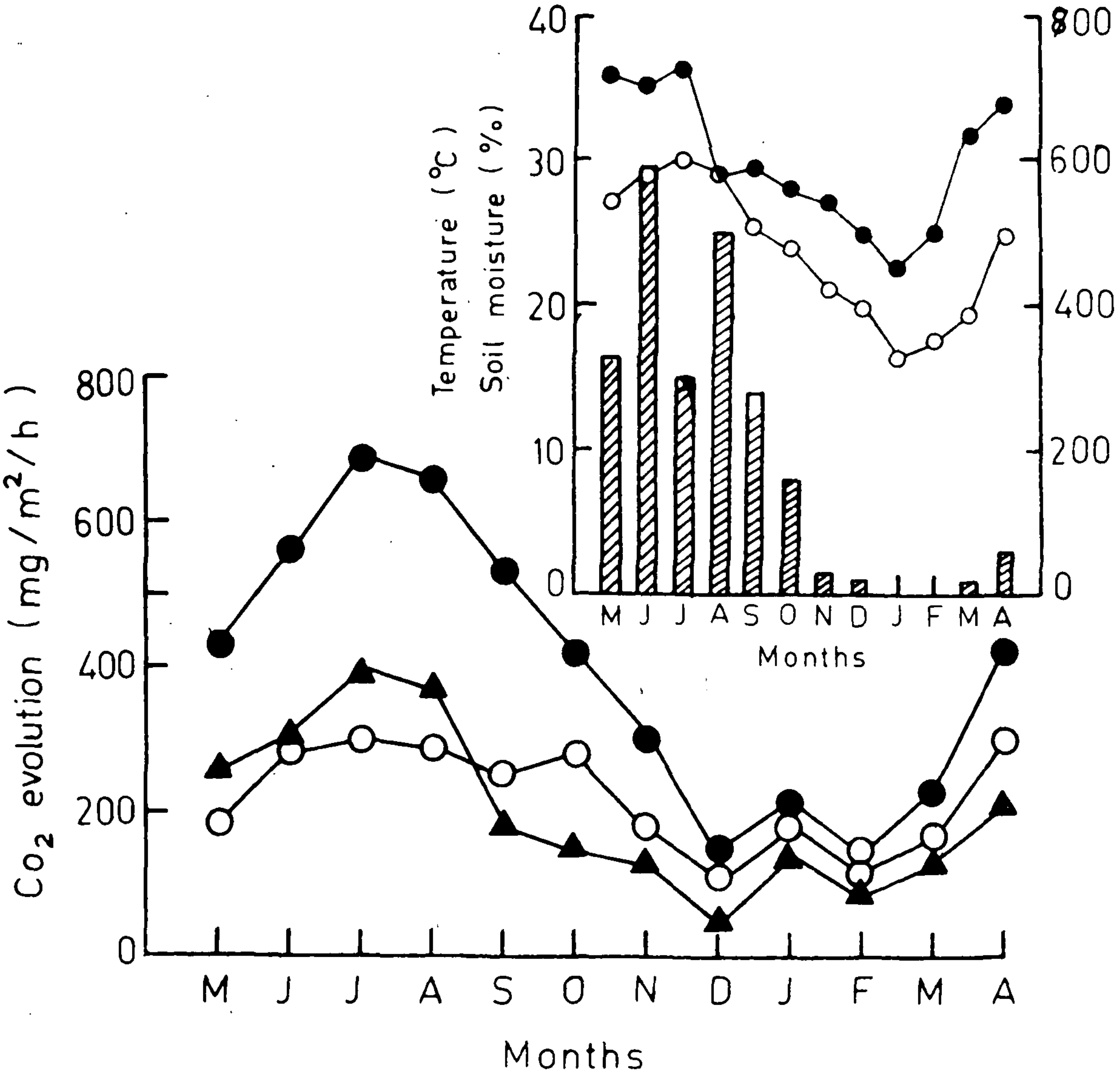


the high cellulose content in the former and higher lignin content in the wood of the latter. During the first 3-4 months starting from May, it was found that the decomposition was high in *S. robusta*, *A. chaplasa* and *S. wallichii* as is also the case for leaf litter. This could be due to more favourable temperature and humidity conditions prevailing at this time which facilitated early decomposition of easily susceptible thick bark on wood.

Organic matter decomposition on the forest floor was also evaluated on the basis of carbon dioxide production. The seasonal pattern of CO_2 evolution from the litter (which includes leaf and branch litter on the soil surface) and the mineral soil as shown in Fig. 5-6 indicates that highest rate of decomposition of the litter occurred during the period of May-September which is hot humid monsoon period. During the dry winter months (November-February) rate of decomposition was very slow. The low level of activity during winter months is due to low temperature and low moisture status of the soil. During March-April due to slight increase in moisture and due to warmer temperature conditions, microbial activity increased. Such a relationship between temperature, moisture status of the soil and CO_2 evolution has also been shown by

Fig., 5-6. Monthly pattern of CO_2 evolution from the forest floor at Lailad. Forest floor, ● ; litter, ○ ; soil, ▲ ; (Inset figure shows the pattern of rainfall (histogram) alongwith maximum temperature, ● ; and soil moisture, ○).

Fig. 5-6



40
30
20
10
0
800
600
400
200
0
Temperature (°C)
Soil moisture (%)
M J J A S O N D J F M A
Months
800
600
400
200
0
Co₂ evolution (mg/m²/h)
M J J A S O N D J F M A
Months

other workers (Stevenson, 1956; Soulides and Allison, 1961; Van Schreven, 1967). The present values (159-700 mg $CO_2/m^2/h$) of CO_2 evolution from the forest floor was higher than the values reported by some other workers in tropical forests (Schulze, 1967; Wanner, 1970 and Medina and Zelwer, 1972) and temperate forest (Witkamp, 1966a; Reiners, 1968; Kirita, 1971d; Lieth and Oullette, 1962). This high rate of CO_2 evolution from the forest floor in the present case may be due to more favourable temperature conditions combined with high rainfall and humidity conditions which favours faster decomposition.

Turn over rate :

The seasonal litter fall on the ground reached a maximum in the month of March. Decomposition at this time was extremely slow, if any, due to the dry conditions prevailing at this time. With the onset of rain the decomposition rate is accelerated due to high temperature and humidity. The rate of litter decay under steady state conditions can be expressed as a constant k or the fraction of litter that decomposes during a unit of time (Jenny et al, 1949; Olson, 1963 and Koelling and Kucera, 1965) which may be expressed as :

$$K = A/A + F$$

where A is the annual litter fall and F is the residue litter from previous years. The k values for this sub-tropical forest works out to 1.10 (leaf and branch litter included) whereas the k values for leaf litter alone was 1.33. The k value for total litter is lesser due to slower decomposition of the wood fraction compared to leaf litter decomposition. A comparison of values obtained by the present worker with those for other tropical and temperate forests given in Table 5-8 indicates that the present values for k is closer to the values obtained for other tropical forest (Jenny *et al*, 1949; Cornforth, 1970 and Edward, 1977) but much higher than that for a temperate Oak (Reiners and Reiners, 1970) or Pine (Olson, 1963) forest.

SUMMARY

The total litter production in the forest at Lailad was found to be 5 t/ha/yr. Out of this total amount; 77% was contributed by leaf litter and the remaining 23% was due to wood litter. In the forest as a whole maximum contribution of leaf litter was by *Dendrocalamus hamiltonii*, *Schima wallichii*, *Shorea robusta* and *Castonopsis indica* with values of 10.2%, 9.9%, 8.8% and 6.7% respectively out of total litter fall.

Table 5-8. Estimated rates of disappearance of litter in various tropical and temperate forests.

Forest types and approximate altitudes	Location	Litter production (t/ha/yr)	Forest floor litter (t/ha)	Annual decay constant (K)	Authority
<u>Tropical</u> <u>forests</u>:-					
Lowland forests					
Rain forest (30 m)	Columbia	8.5	5.04	1.69	Jenny <u>et</u> <u>al</u>. (1949)
Semi evergreen					
Young secondary (390 m)	Zaire	12.3	3.89	3.16	Laudelot and Meyer (1954)
Secondary	Ghana	10.5	2.26	4.65	Nye (1961)
Plateau (100 m)	Ivory Coast	-	-	3.30	Bernhard (1970)
Valley (50 m)		-	-	4.20	- do -
Mora excelsa (200 m)	Trinidad	6.8	4.16	1.64	Cornforth (1970)
Lower Montane forests (1630 m)	Columbia	10.1	16.5	0.61	Jenny <u>et</u> <u>al</u>. (1949)
Central site of radiation study (460 m)	Puerto Rico	4.8	5.11	0.94	Wiegert ~~(196~~ (1966
(2400 - 2500 m)	New Guinea	7.55	6.46	1.20	Edwards ~~(197~~ (1977)
Sub-tropical forests 50-year old (296 m)	Meghalaya (India)	5.5	6.4	1.10	Present stud
<u>Temperate</u> <u>forests</u> :-					
Oak forests	Minnesota	-	-	0.018	Reiners and Reiners ~~(197~~ (1970)
Pine forests	Minnesota	-	-	0.017	Olson (1963)
Pine forests (P. sylvestris)	England	-	-	0.093	Kendrick (1959)

The seasonal pattern for leaf and wood litter showed that maximum leaf litter was produced in the months of February-April (56.5% of the total) andd wood litter in the months of May-July (43.8% of the total). In the forest as a whole 59% of the total leaf litter production was in the undisturbed central zone of the forest. Along the peripheral zone maximum leaf litter was contributed by D. hamiltonii (about 18% of the total) while in the central zone of the forest, S. wallichii, S. robusta and C. indica contributed more.

The rate of decomposition of leaf litter of D. hamiltonii and S. wallichii was faster which was evident from their k values of 2.170 and 2.176 respectively in comparison to other species where the k values were low. The rate of decomposition was faster during the monsoon months of June-August when temperature conditions were warmer with high humidity. Wood litter of D. hamiltonii and S. robusta showed faster rates of decomposition compared to others with yearly losses of 78% an d 56% respectively. The soil respiration rates were also faster during June-August when the rate of litter decomposition was maximum.

CHAPTER 6

RAINFALL INTERCEPTION, THROUGHFALL, STEMFLOW AND LOSS THROUGH RUN-OFF AND PERCOLATION

RAINFALL INTERCEPTION, THROUGHFALL, STEM FLOW AND LOSS THROUGH RUN-OFF AND PERCOLATION.

INTRODUCTION

Atmosphere is a source of chemical inputs to terrestrial ecosystems as well as a source of water vapour for precipitation. Of the precipitation coming down, some reaches the ground through the canopy as throughfall, some of it comes along the tree trunks as stemflow and a part is retained by the canopy which never reaches the ground but subsequently evaporates to the atmosphere which is called as intercepted water. Interception of precipitation by canopy cover is an important aspect of hydrological cycle influencing the water budget and nutrient movement in the ecosystems. Most of the studies on interception patterns by forest canopy pertain to temperate forests (Ovington, 1954; Carlisle et al, 1965; Zinke, 1967; Leonard, 1967; Rowe, 1974 and Szabo,1975) whereas studies of a similar nature on tropical forest are meagre (Jackson, 1971).

Along with other processes occurring in forest ecosystem, the pattern of water circulation is decisive from several viewpoints. To understand the quantitative and qualitative course of productivity or to explore the bioelement cycle and to understand the whole ecosystem balance itself, the knowledge of water circulation pattern in time and space is indispensable (Szabo, 1975).

It has been reported by many workers that rain water removes considerable amount of nutrient from the crowns of trees (Tamm, 1951; Mes, 1954; Madgwich and Ovington, 1959; Carlisle *et al*, 1967 and Cole *et al*, 1968) and interception by the canopy affect the chemistry of the throughfall and stemflow in a number of ways (Ovington, 1954; Carlisle *et al*, 1965; Gosz *et al*, 1972; Eaton *et al*, 1973). The amount of different nutrients discharged from forest ecosystems is of great importance to understand the nutrient budget and very little amount of work has been done in this regard so far (Bormann *et al*, 1968, 1969; Likens *et al*, 1969).

In India the work on interception loss, stemflow and throughfall has been done only in plantations (Dabral and Subba Roa, 1968, 1969; and George, 1978) and no attempt has so far been made in respect to mixed forests. The present study was made in order to assess ~~t~~the pattern of water circulation through stemflow, throughfall, interception loss, surface run off and percolation in a 50 year old mixed subtropical forest at Lailad at an elevation of 292 m in Meghalaya.

METHODS OF STUDY

Stemflow was sampled using a spiral polythene gutter of 6 cm diameter fitted to each stem and sealed with paraffin wax. The gutter was fixed at a height of 1.5m above the soil surface on the tree trunk. A plastic funnel was attached to the two cut ends of the gutter and connected to a polythene container of 5l capacity. A nylon filter of 1mm mesh size was placed in the mouth of the funnel to prevent entry of extraneous matter. Three replicates each for two girth classes namely 30 and 90cm were selected for each of the following species : (i) *Shorea robusta*, (ii) *Schima wallichii*, (iii) *Castanopsis indica*, (iv) *Gmelina arborea* and (v) *Artocarpus chaplasa*.

Input precipitation by throughfall and incident rainfall were collected in polythene containers, the mouth of each being fitted with 20cm diameter funnel which was provided with 1mm mesh nylon filter to prevent entry of foreign matter. 3 containers were kept outside the forest in open places to collect the water from incident rain. Another 12 containers of the same size were kept under the forest canopy to measure the throughfall. As the forest is a mixed one and is stratified with many layers no attempt was made to collect throughfall from a particular tree species. In order to measure the atmospheric precipitation two standard rain gauges were kept in the open. All the containers were kept 50cm above the soil surface on a wooden platform to avoid splashing of soil particles into the funnels. 2ml toluene was added to the container to prevent microbial activity. Sampling was done at intervals ranging from 2 to 7 days depending upon the intensity and frequency of rainfall during the monsoon. At the time of sampling, 500ml of well homogenised water from stemflow/throughfall/incident rain was brought to the laboratory and the samples were filtered through a Whatman No. 44 filter paper, and chemically analysed.

For studies pertaining to run-off water and sedimentation the loss from a confined area of 1 X 10m along the slope was collected in large drums of 200l capacity and periodically removed for analyses. Percolation studies were done using a simple lysimeter of the Russian type (Buckman and Brady, 1960). The soil was cut out vertically to expose the profile. A small tunnel was excavated at a depth of 40cm (this is the depth at which root density is high) and a collector of 30 X 30 X 15cm was placed inside the tunnel. By pressing from below, the rim of the collector was firmly inserted into the undisturbed soil above. The water percolating through the soil is tapped out into receptacles from time to time. This method was found to be quite satisfactory for comparative purpose, though the values may be somewhat low.

RESULTS AND DISCUSSION

Throughfall :

A summary of the seasonal results (Table 6-1) shows that the percentage of rainwater coming as throughfall is maximum in the month of March and April with 84.8 and 74.0% of the total respectively while in other months it was much less with minimum percentage value in December. The high proportions of throughfall in March-April is due to reduced crown density at this time when 41.0% leaf fall occurred. As the crown density increased during subsequent months the proportion of throughfall showed a gradual decrease. It may be noted that January and February were rainless. Similar relationship between crown density and throughfall was also reported by Szabo (1975) though the difference were less marked. The very low proportion of throughfall during October-November may also be due to the fact that in these months the crown remain dry and infrequent storms interrupted

Table 6-1. Throughfall, stemflow and interception loss at Lailad forest for the year 1977-78 with standard errors.

Month	Gross rainfal (mm)	Throughfall (mm)	(%)	Stemflow (mm)	(%)	Interception loss (mm)	(%)
April	188.5	139.5±2.8	74.0	25.0±1.3	13.3	24.0±1.8	12.7
May	292.5	190.0±2.0	64.9	30.0±1.1	10.3	72.5±1.9	24.8
June	187.5	105.5±1.8	56.3	21.5±0.8	11.5	60.5±1.7	32.3
July	463.0	264.5±1.7	57.1	45.0±0.7	9.7	153.5±1.7	33.1
August	440.0	253.5±0.7	57.6	40.0±0.5	9.1	146.5±0.9	33.3
September	375.0	209.5±1.8	55.9	27.0±0.7	7.2	138.5±1.7	36.9
October	160.0	80.0±1.6	50.0	12.0±1.0	7.5	68.0±1.5	42.5
November	26.5	12.0±1.6	45.3	1.0±1.2	3.4	13.5±1.6	50.9
December	14.5	5.5±2.5	37.9	-	-	9.0±2.3	62.1
March	18.5	15.7±2.4	84.9	1.5±0.7	8.1	1.3±2.1	7.0

by several rainless intervals permit more water to be transmitted from the canopy to the atmosphere with less water to the ground. The average value of 58.4% throughfall during the course of this study was higher than the values obtained for other broad leaved forests (Miller, 1963; Dabral and Subba Rao, 1969 and Aldridge and Jackson, 1973) but lower than a few others (Ovington, 1954; Eidmann, 1959; Leonard, 1961; Aussenac, 1968; Nihlgard, 1970; Szabo, 1975; Bultot et al 1977). The quantity of throughfall is directly proportional to the gross rainfall and this relationship is indicated in Fig. 6-1 and was found to be very significant ($P > 0.05 = 0.991$).

Stemflow :

The average stemflow during the period of study was measured to be 8.0% of the precipitation (Table 6-1). Expressed as a projection of the canopy or the entire forest surface, stemflow amounts only to a small portion of the precipitation in comparison to the throughfall and interception loss. Minimum proportion of stemflow was measured in the month of November due to lesser intensity and frequency of rain. On the other hand reduced canopy density in the month of March and April allows more water to flow from the stem. The gradual decline in percentage stemflow from May-October is related to high canopy density which in turn results in greater proportion of interception losses.

The observed mean value of stemflow of 8.0% was found to be higher than the values reported by Ovington (1954); Rowe (1974); and Szabo (1975) which ranged from 0.12-3.10% but lower than the values reported by a few others (Eidmann, 1959; Aldridge and Jackson, 1973).

The stemflow pattern is probably related to tree architecture particularly to branching pattern, canopy, orientation and surface characteristics of tree species, which would be an interesting study. Stemflow in different species as well as in different girth classes of the same species varied considerably (Table 6-2). Preliminary studies showed that the bark surface of S. robusta and S. wallichii was very rough whereas that of C. indica, A. chaplasa and G. arborea was smooth. Thus much of the water is absorbed by the rough stem surface in the former two species (Voigt, 1960; Leonard, 1961; Rutter, 1963).

Table 6-2. Amount of stemflow from different tree species of different diameter classes (mm/tree/year).

Species	Diameter class (cm)		
	0-10	10.1-20.0	20.1 and above
Shorea robusta	3.5	6.6	12.7
Schima wallichii	4.4	8.6	14.2
Castanopsis indica	11.6	18.6	21.1
Artocarpus chaplasa	12.6	17.3	21.8
Gmelina arborea	11.4	16.9	22.3

Fig. 6-1. Relationship between gross rainfall and throughfall.

Fig. 6-2. Relationship between gross rainfall and stemflow.

Fig. 6-3. Relationship between gross rainfall and interception loss.

Fig. 6-1

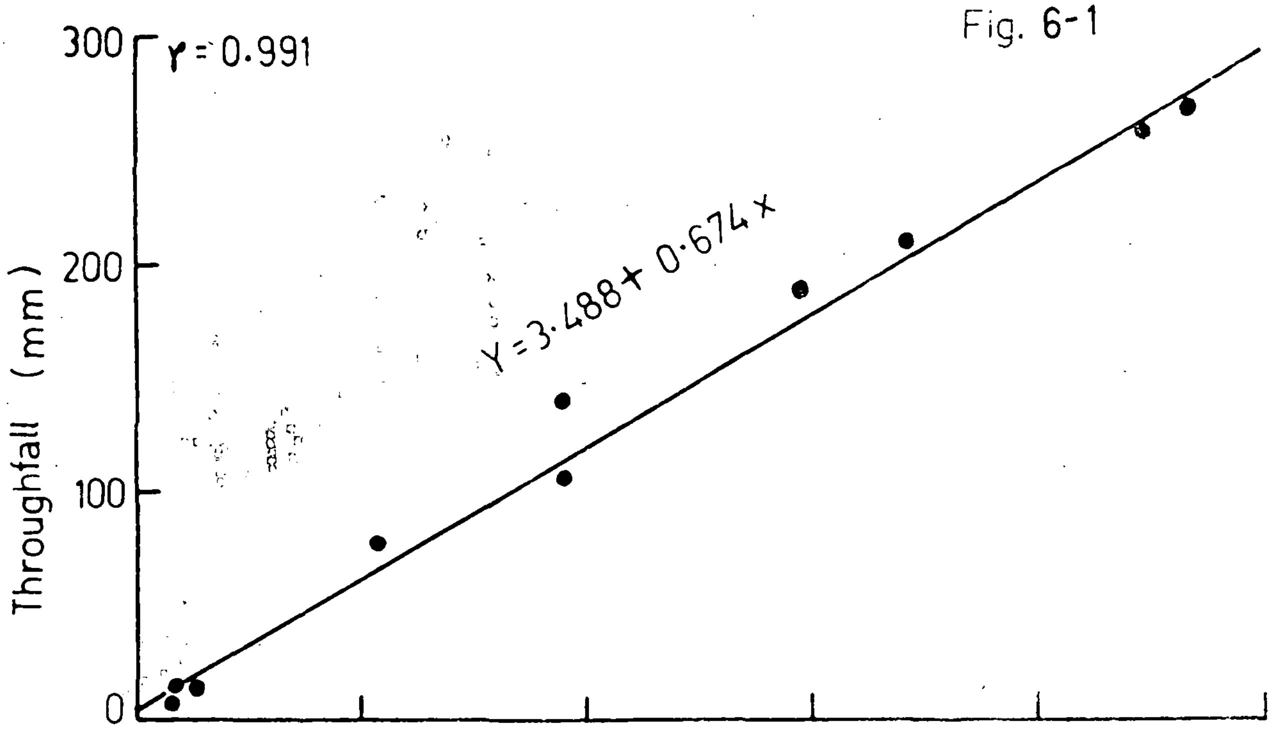


Fig. 6-2

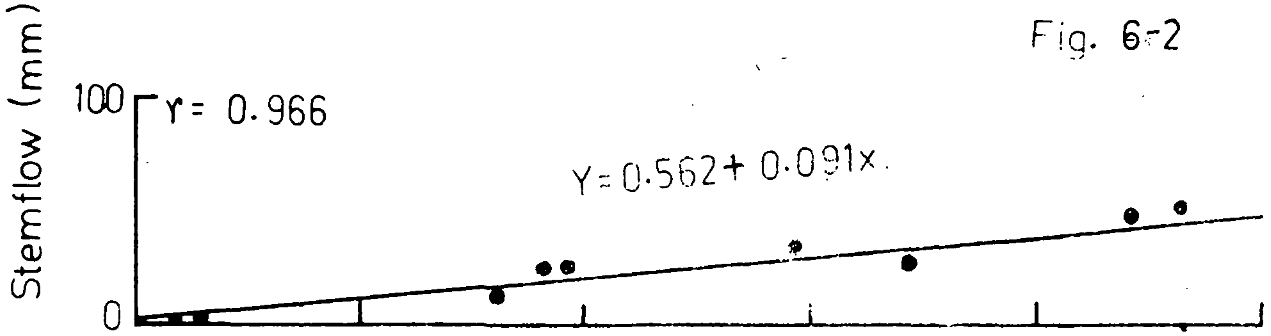
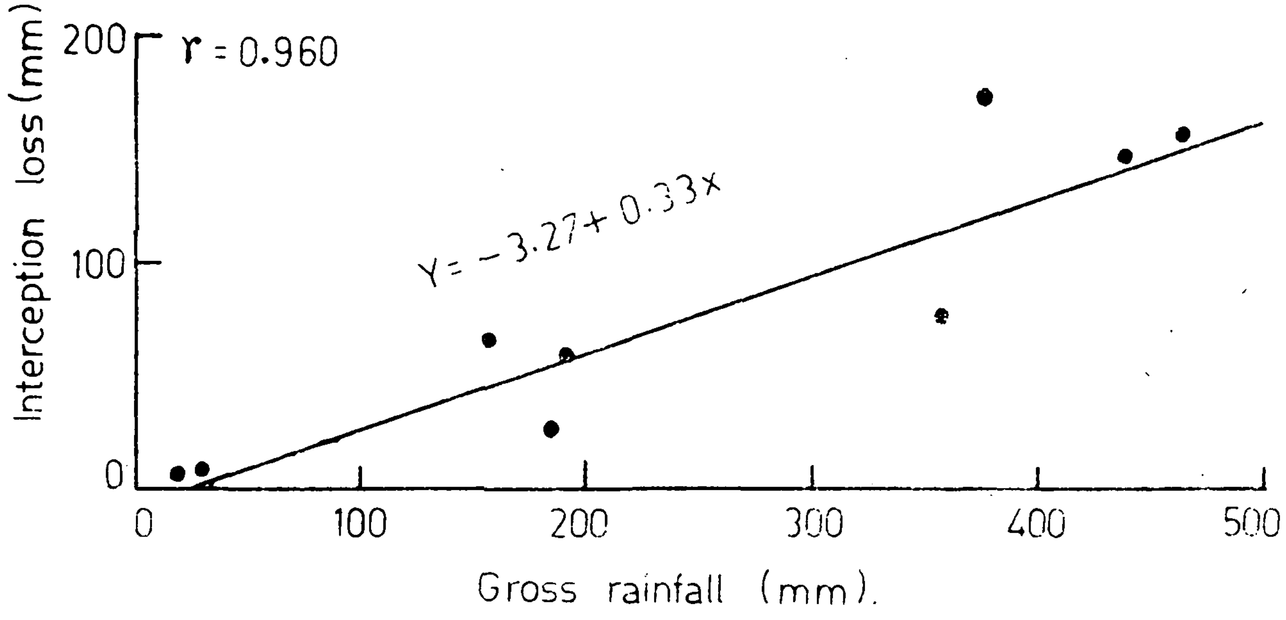


Fig. 6-3



Further in all the species stemflow increased with increase in the girth of the stem. The relationship between gross rainfall and stemflow was found to be highly significant ($P.> 0.05 = 0.966$) which is expressed by a linear regression line (Fig. 6-2).

Interception loss :

The proportion of the rainfall intercepted by the canopy was inversely related to the proportion of throughfall and stemflow with maximum percentage values recorded in December and minimum in the month of March. This high percentage of water transmission from the canopy during October-December may be attributed to the fact that the rainfall in these months was not very regular in comparison to the monsoon months (April-September) and the vegetation often remained dry. The quantity of water necessary to wet the vegetation account to a larger percentage of the gross precipitation as interception loss. Further rapid evaporation occurred from the crown during the several rainless intervals in these months. The low interception values during March and April was due to reduced crown density due to maximum leaf fall during this period. Development of new leaves starting in the month of April in many of the species permit more interception of rain water from then onwards. Szabo (1975) working in a Hungarian Oak forest ecosystem also showed that the interception was reduced from 21.2% to 14.9% with leaf fall. It may be mentioned here that according to many others (Beall, 1934; Trimble and Weitzman, 1954 and Delfs, 1967) interception does not decrease or decreases only to a small extent with defoliation.

The relationship between gross rainfall and interception loss which follow the same pattern as stemflow and throughfall is shown in Fig. 6-3. In conclusion it may be mentioned that the factors which contributed to a larger extent in interception loss are the total quantity, duration and intensity of rainfall, wind velocity, temperature and canopy saturation capacity.

<u>Water balance of the ecosystem</u> :

The total amount of water and percentage values given in Table 6-1 are based on the estimation in site in the forest where the canopy was entirely closed. But in order to explain the total quantity of water in one hectare forest surface, the forest gaps are to be considered. The total canopy coverage in the present forest was 90% and the rest 10% was gap where the precipitation could reach the forest floor almost directly without any interruption. After making allowances for gaps in the forest canopy, the percentage distribution of the incident rainfall in a forest of one hecater is shown in Fig. 6-4.

In one year the total distribution of the precipitation of 21.66 X 10^6 litre arriving at one hectare is as follows :

Throughfall = 11.481 X 10^6 litre (= 52.993%)
Stemflow = 0.188 X 10^6 litre (= 0.868%)

Amount of the rain which comes directly to the soil surface through the opening of the forest
= 3.910 X 10^6 litre (= 18.047%)

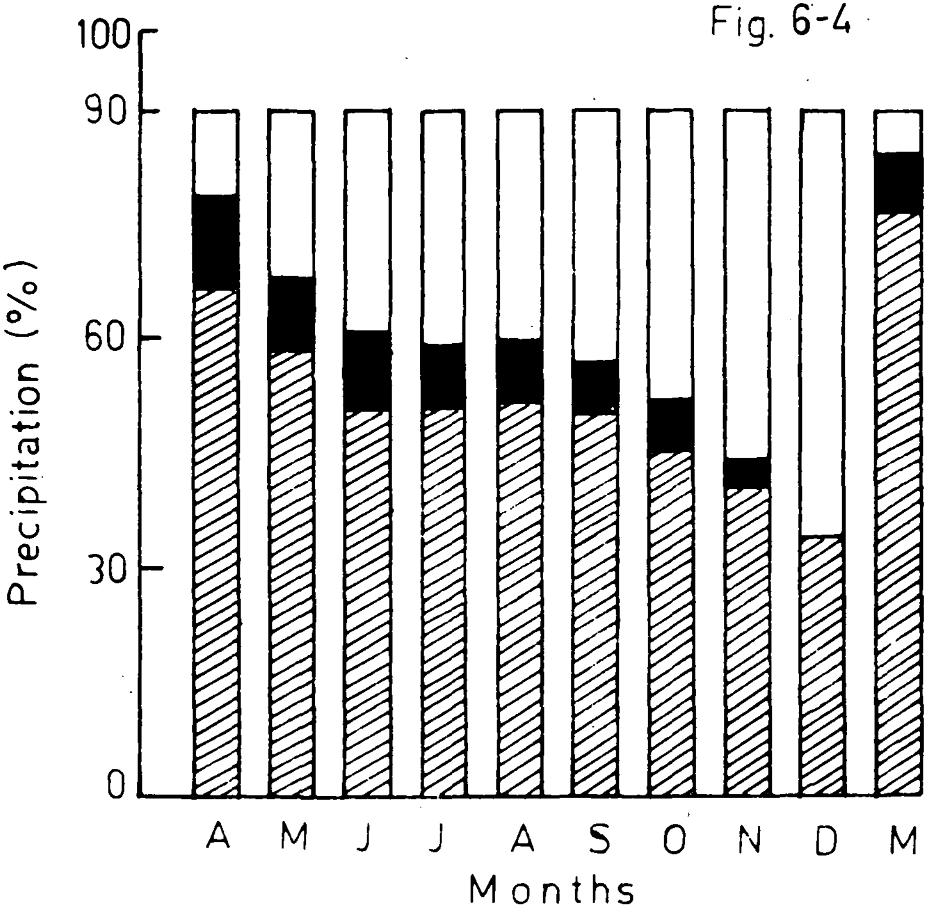
Intercepted water = 6.086 X 10^6 litre (= 28.091%)

Loss through run-off and percolation :

Studies on surface run-off and percolation losses of rainwater at Lailad forest showed that they represented 19.6% and 6.78% respectively of the total annual rainfall during the year. The monthly pattern of losses of water

Fig. 6-4. **Distribution of precipitation in the forest (per hectare). Hatched columns, throughfall; closed columns, stemflow; open column,** intercepted loss.

Fig. 6-4



could be related to the rainfall pattern with maximum run-off and percolation losses occurring during May-September (with 87% and 37% of the total run-off and percolation losses respectively) with peak values in the month of July (Fig. 6-5). Both the high frequency and intensity of rainfall during monsoon, contribute to heavy losses during this period. At this time the soil is over saturated with rain water allowing more water to be discharged from the ecosystem. Further high evapo-transpiration during warm months when the forest crown cover was at its peak of development also curtailed downward movement of water through the soil. During the rest of the period percolation and surface run-off losses were negligible partly due to low rainfall but also due to dryness of the soil which restricted movement of water.

A comparison of the present result on run-off and percolation losses with a deforested site nearby (deforestation was done for shifting agriculture which locally is known as 'Jhum') showed that these losses are much heavier after clear cutting and burning the slash. Clear cutting not only removes the protective plant cover but also tends to loosen the soil resulting in heavy losses. Deforestation had a pronounced effect on the amount of sediment export from the

Fig. 6-5. Monthly pattern of surface run-off and percolation loss of Lailad forest.

Surface run-off, ● ;

percolation loss, ○ .

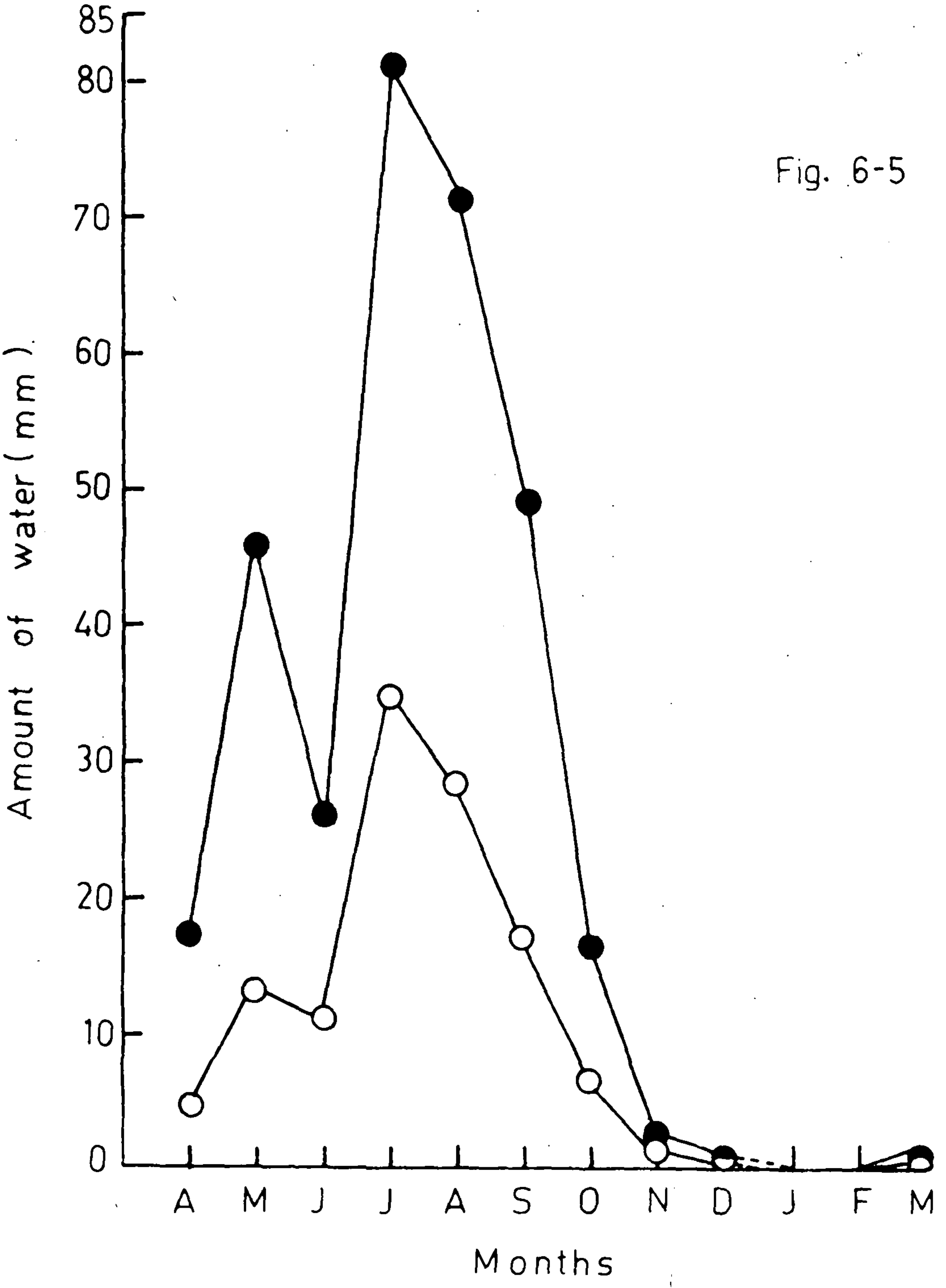

85
80
70
60
50
40
30
20
10
0
Amount of water (mm)
A
M
J
J
A
S
O
N
D
J
F
M
Months

Fig. 6-5

ecosystem. It has been reported that the loss of a sediment from freshly burnt and cropped land was about 22 to 30 m ton/ha/yr (Toky and Ramakrishnan, unpublished). But this loss was heavily reduced to 0.76 and 0.23 in ton/ha/yr under 10 and 50 year old fallows respectively. The reduction in the sediment loss in forested ecosystem was mainly due to the plant cover and also accumulation of litter in the soil surface. It has also been shown by other workers (Lull and Reinhart, 1967; Likens _et al_, 1970a and Pierce _et al_, 1970) that deforestation and disturbance of forest floor are mainly responsible for heavy sediment loss from the ecosystems.

SUMMARY

Out of the total amount of rainwater (21.66×10^6 1/ha/yr) measured during the period of study 11.48×10^6 1/ha/yr reached the soil as throughfall, 0.19×10^6 1/ha/yr as stemflow and 6.09×10^6 1/ha/yr went as interception loss from the canopy during the period of study. A high proportion of water 76% was accounted as due to throughfall in the months of March-April due to reduced canopy cover as maximum leaf fall occurred during these months. Throughfall was minimum in the months of October-December which may be due to the dryness of the season and a consequent dry canopy. In the months of November minimum stemflow occurred (3.4%) due to lesser intensity and frequency of rain while maximum stemflow (21.4%) was recorded in the months of March-April. Interception losses were heavy in the months of December being 62% of the rainfall and it was minimum (7%) in the month of March. The relationships between gross rainfall and throughfall, stemflow and interception loss was established.

The losses of water through surface run-off and percolation during the period of study showed that they represented 19.6% and 6.8% of the total rainfall respectively. Maximum surface run-off and percolation losses (87% and 37% of the total rainfall respectively) were recorded during the months of May-September. A comparison of the results of surface run-off and percolation was made with the deforested sites which showed that these losses were much heavier after clear cutting and burning the slash in comparison to a 50 years old forested ecosystem at Lailad.

CHAPTER 7

NUTRIENT CYCLING

NUTRIENT CYCLING

INTRODUCTION

Nutrient cycling is a vital function of any forested ecosystem. From an applied view point, a nutrient cycling is essential to meet the high demands for forest resources. This basic information is also important because it defines the relationship between soil and plants. A vital characteristics of ecosystem is the continuous flow of nutrient and energy through the system and thus in the broadest sense ecosystems are open systems. Several workers have evaluated the size and rate of exchange between various nutrient pools in forest ecosystems (Duvigneud and Denaeyer-De Smet, 1964; Ovington, 1965; Cole et al, 1968; Bormann and Likens, 1970; Jorgensen et al, 1975). Quantitative approach in nutrient input-output budgets for a terrestrial ecosystem may be determined by measuring the meteorologic, geological and biological inputs and outputs of the ecosystems (Bormann and Likens,1967).

Geological inputs and outputs are generally referred to the dissolved or particulate matter which are added or leave the system by water or colluvial action or both (Hart et al, 1962; Pierce, 1966; Likens et al, 1967; Fisher et al, 1968; Bormann and Likens, 1967; Bormann et al, 1968;

Hornbeck and Pierce, 1969; Hornbeck et al, 1970) and also to weathering of the mineral soil and the subsequent release of nutrient depending upon the soil type, rock type, climate and vegetation. The meteorological inputs enter the ecosystems through the atmosphere in the form of gaseous and dissolved or particulate matter in precipitation, dust and wind. Only in the last two decades the study of the nutrients input and deposition from the atmosphere by the way of precipitation has received some serious attention (Tamm, 1951; Madgwick and Ovington, 1959; Tukey and Tukey, 1959; Carlisle et al, 1965; Bormann and Likens, 1967; Ulrich et al, 1971; Reiners, 1972; Szabo, 1975).

Accumulation of nutrients in the forest ecosystem through biotic sources occurs as a result of successional process (Odum, 1969) as the amount of biomass in the system increases. The work of nutrient accumulation in the standing crop of biomass has been reviewed by many workers (Rodin and Bazilevich, 1967; Ovington, 1968; Duvigneud and Denaeyer-De Smet, 1970). The comprehensive reviews and synthesis of data by Bray and Gorham (1964), Bakuzis (1964), Major (1970) Larcher (1975) and Lieth and Whittaker (1975) have brought considerable attention to the process of nutrient cycling and production in forest ecosystems.

Another important feature of nutrient cycling in the forest ecosystem is the annual return of nutrients to the soil through leaf and wood litter from the vegetal and its subsequent decomposition (Tarrent et al, 1951; Owen, 1954; Nye, 1961; Witkamp and Olson, 1963; Olson, 1963; Bray and Gorham, 1964; Bernhard, 1970; Gosz et al, 1972; Anderson, 1973a; Louisier and Parkinson, 1978). The importance of soil organic matter in mature forest was emphasized by Rodin and Bazilevich (1967), Likens et al (1970a), Pierce et al (1972), Whittaker et al (1974) and Gosz et al (1976).

The present study on nutrient cycling is intended to obtain base line information on nutrient status of the standing crop, release of nutrients through leaf and wood litter, input and output nutrient budget through water circulation and the status of nutrients in the forest soil in a 50 year old mixed humid sub-tropical forest at Lailad at an elevation of 296 m (25°45" and 26°0" N Latitude and 91°45" and 92°0" E Longitude) in Meghalaya in the north eastern part of India.

METHODS OF STUDY

Different plant components of dominant tree species and shrubs were collected during biomass studies for chemical analyses. Herbaceous species however, were not considered individually. Leaf and wood litter collected in litter frames of 1m^2 and the decomposed leaf and wood litter plaaed in the month of April, 1977 were collected at monthly intervals during 1977-78. Water samples of throughfall, stemflow, incident rainfall, soil percolation and soil surface run-off were also collected at monthly intervals. Water samples and oven dried samples of bole, branches, leaves, fresh litter and decomposed litter were chemically analysed for nitrogen, phosphorus, potassium, clacium and magnessium using standard methods as described by Paech and Tracey (1956), Jackson (1958) and Allen (1974). Thus, nitrogen was determined by micro-kjeldahl method and phosphorus was estimated colorimetrically by molybdenum blue method. After dry ashing the samples, calcium and magnessium were analysed by EDTA titration method and potassium by flame emission method.

Soil samples were collected from depths of 0-10, 10-40, 40-70 and 70-100 cm. and were based on 3 replicates thoroughly mixed together to give one composite sample. Soil colour was determined by Munsel soil colour chart. Mechanical composite was done by International pipette method as described by Piper (1947) and soil samples were placed in different textural classes. Soil pH was measured by electrometric method in a soil-water suspension of 1:5. Analyses of total nitrogen, organic carbon and available phosphorus were done by standard methods described by Jackson (1958). Nitrogen was estimated by Kjeldahl method, carbon by Walkley-Black method and Po_4-p colorimetrically by molybdenum blue method. Calcium and magnesium were analysed by EDTA titration method while potassium was estimated by flame emission method after extracting the exchangeable cations with 1N Ammonium acetat at pH 7. The soil bulk density was used for subsequent conversion of analytical data to field weight per unit area.

RESULTS AND DISCUSSION

Nutrient budget in standing crop :

An analysis of the concentration of N,P,K,Ca and Mg in different plant components (bole, branches,and leaves) showed that the leaf material, contained higher percentage of N,P,K and Mg while bole along with bark contained higher levels of Ca in all the species except D. hamiltonii where the concentration of Ca was found to be more in leaves. The lower concentration of Ca in the bole of this species may be due to the absence of bark in the sense that the dicot trees have. It may be noted here that Seth et al (1963) and Woodwell et al (1975) observed that bark of trees hold very high levels of Ca compared to other tissues. Next to the leaves, the branches had higher levels of N,P,K and Mg and the bole had the least concentration. On the other hand, Ca concentration was the least in branches with intermediate values for leaves (Table 7-1).

On a hectare basis, the total amount of different elements contributed by different tree species (Table 7-2) showed that S. wallichii, C. indica and S. robusta contributed maximum with respect to N,P,K, Ca and Mg. This was directly related to the large biomass in the standing crop of these tree species in the same order as given above. Among other species a great variation was observed with regard to percentage contribution of different elements which may be partly due to nutrient concentration. Thus, D. hamiltonii stands next to A. chaplasa and M. roxburghiana in biomass but contributed more in terms of P,K and Mg due to higher concentration of these three elements in the plant tissue. Because of low Ca concentration in the tissue coupled with low biomass, the

Table 7-1. Concentration of different nutrients in different compartments of different tree species at Lailad.

Species	Compartment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Artocarpus chaplasa	Bole	0.41	0.12	0.31	3.00	0.14
	Branches	0.61	0.23	0.32	0.82	0.49
	Leaves	2.10	0.64	0.59	2.96	0.77
Dillenia indica	Bole	0.40	0.12	0.37	2.20	0.30
	Branches	0.51	0.24	0.58	0.68	0.48
	Leaves	1.90	0.55	0.74	1.80	0.70
Dendrocalamus hamiltonii	Bole	0.64	0.14	0.58	0.84	0.47
	Branches	0.70	0.28	0.52	0.69	0.70
	Leaves	1.76	0.59	0.83	1.99	0.88
Castanopsis indica	Bole	0.85	0.14	0.26	2.90	0.18
	Branches	0.90	0.28	0.40	1.00	0.34
	Leaves	1.90	0.49	0.66	2.40	0.79
Gmelina arborea	Bole	0.48	0.12	0.49	2.50	0.22
	Branches	0.70	0.23	0.50	0.63	0.82
	Leaves	1.90	0.60	0.82	1.95	1.02
Garcinia cowa	Bole	0.45	0.20	0.24	2.40	0.33
	Branches	0.60	0.32	0.41	1.00	0.43
	Leaves	1.35	0.61	0.85	1.76	0.79
Milusa roxburghiana	Bole	0.58	0.15	0.26	2.80	0.29
	Branches	0.75	0.28	0.65	1.00	0.83
	Leaves	1.65	0.47	0.85	3.20	1.09

Species	Compartment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Schima wallichii	Bole	0.59	0.16	0.48	3.36	0.26
	Branches	0.62	0.31	0.63	0.70	0.45
	Leaves	1.86	0.66	1.19	2.60	0.67
Shorea robusta	Bole	0.42	0.11	0.34	2.40	0.30
	Branches	0.82	0.26	0.44	0.88	0.68
	Leaves	1.90	0.76	1.20	1.78	1.08
Sterculia villosa	Bole	0.53	0.18	0.35	2.00	0.37
	Branches	0.80	0.42	0.47	0.69	0.67
	Leaves	1.65	0.59	0.98	1.60	1.01
Vitex peduncularis	Bole	0.68	0.12	0.47	2.60	0.41
	Branches	0.70	0.30	0.57	0.78	0.52
	Leaves	1.86	0.65	0.84	1.98	0.73

Table 7-2. Amount of different elements contributed by different species alongwith percentage Contribution of the total for the forest given in parenthesis.

Species	Nutrients (kg/ha)				
	N	P	K	Ca	Mg
Artocarpus chaplasa	34.70 (3.81)	11.25 (4.03)	21.15 (3.59)	135.81 (4.77)	17.17 (3.88)
Dendrocalamus hamiltonii	32.42 (3.56)	21.99 (7.88)	31.72 (5.39)	36.10 (1.35)	29.17 (6.59)
Dillenia indica	23.69 (2.60)	8.12 (2.91)	21.10 (3.58)	74.57 (2.65)	10.31 (2.33)
Gastnopsis indica	291.66 (32.02)	61.35 (21.98)	102.53 (17.41)	439.87 (25.69)	79.30 (17.93)
Gmelina arborea	18.77 (2.06)	5.22 (1.87)	16.57 (2.81)	63.81 (2.04)	12.66 (2.86)
Gercinia cowa	18.12 (1.99)	8.49 (3.04)	10.52 (1.79)	61.21 (2.24)	12.81 (2.90)
Milusa roxburghiana	27.74 (3.05)	10.92 (3.91)	11.70 (1.99)	113.14 (4.70)	25.30 (5.72)
Schima wallichii	346.71 (38.07)	114.97 (41.19)	294.04 (49.92)	1086.65 (45.47)	174.00 (39.34)
Shorea robusta	83.72 (9.19)	25.21 (9.03)	58.07 (9.86)	181.68 (8.89)	61.00 (13.79)
Sterculia villosa	23.11 (2.54)	9.06 (3.25)	14.63 (2.48)	53.96 (1.90)	16.81 (3.62)
Vitex peduncularis	10.09 (1.11)	2.55 (0.91)	7.00 (1.19)	22.43 (0.90)	3.79 (0.68)

contribution by D. hamiltonii as far as this nutrient is concerned was far less than that of A. chaplasa and M. roxburghiana.

Fig. 7-1 shows the pattern of distribution of the nutrient in the different tree compartments. Bole contained maximum amount of all nutrients followed by branches and leaves. This is inspite of the higher concentration of N,P, K and Mg in the leaf tissue. It may be worth noting here that leaf biomass is much less than that contributed by bole. This compartmentalization of nutrient is highly exaggerated for Ca due to the fact that this nutrient also had highest concentration in the bole.

Fig. 7-2 indicates the percentage contribution (per hectare) by the different elements in the different compartments of the standing crop. The quantities of the different nutrients in the three compartments of the tree, in a decreasing order, are as follows :

Ca>N>K>Mg>P

As noted earlier, it is also evident that maximum storage of Ca is in the bole.

The pattern of distribution of nutrients by trees, shrubs and herbs along the periphery and the centre of the forest was found to be different. About 60% of the total

Fig. 7-1. Pattern of compartmentalisation of nutrients in trees at Lailad forest. Open column, bole; hatched column, branches; closed column, leaves.

Fig. 7-2. Proportion of different nutrients in different components in living biomass of trees (percentage of the total amount in kg/ha). Closed column, N; strippled column, P; hatched column, K; open column, Ca; cross hatched column, Mg.

Fig. 7-1

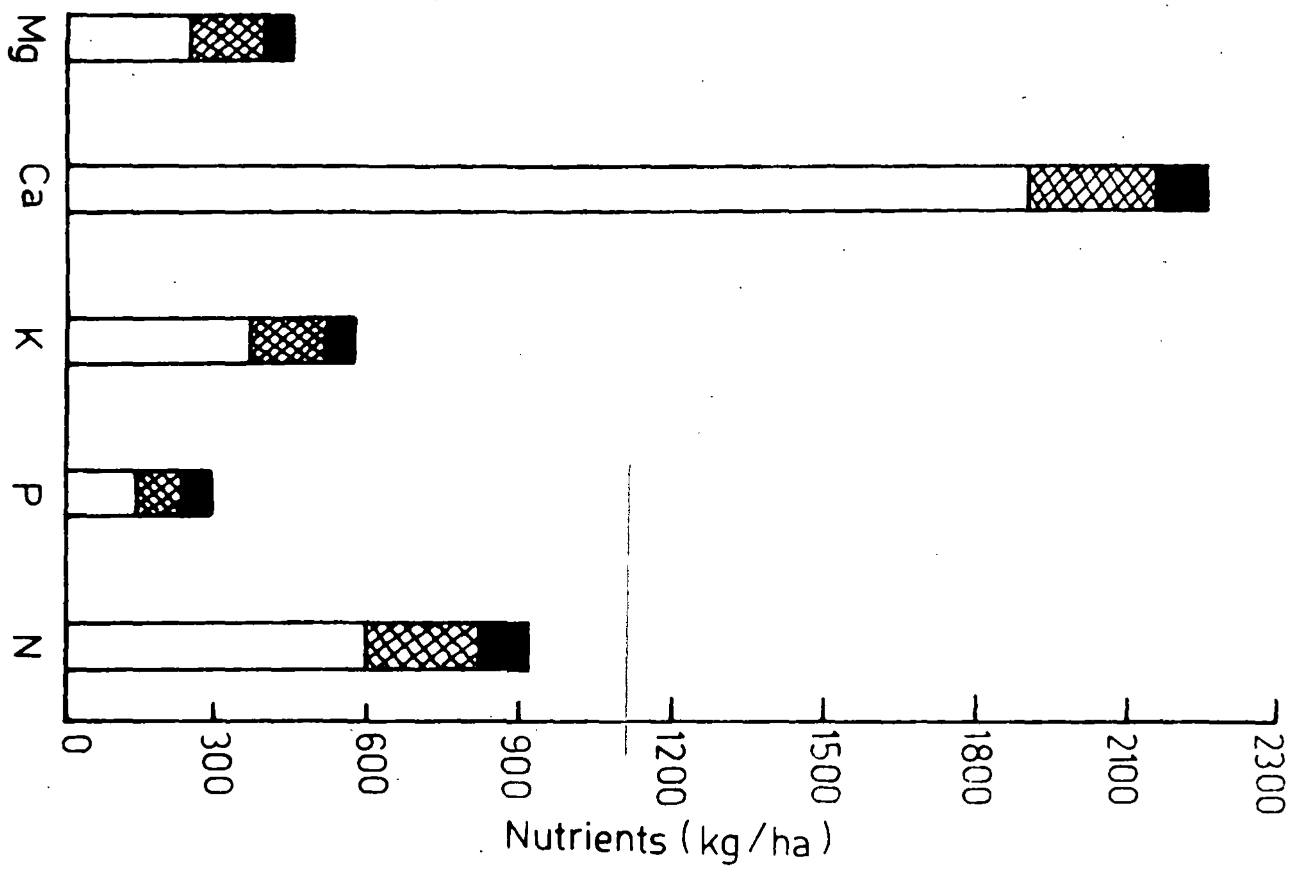
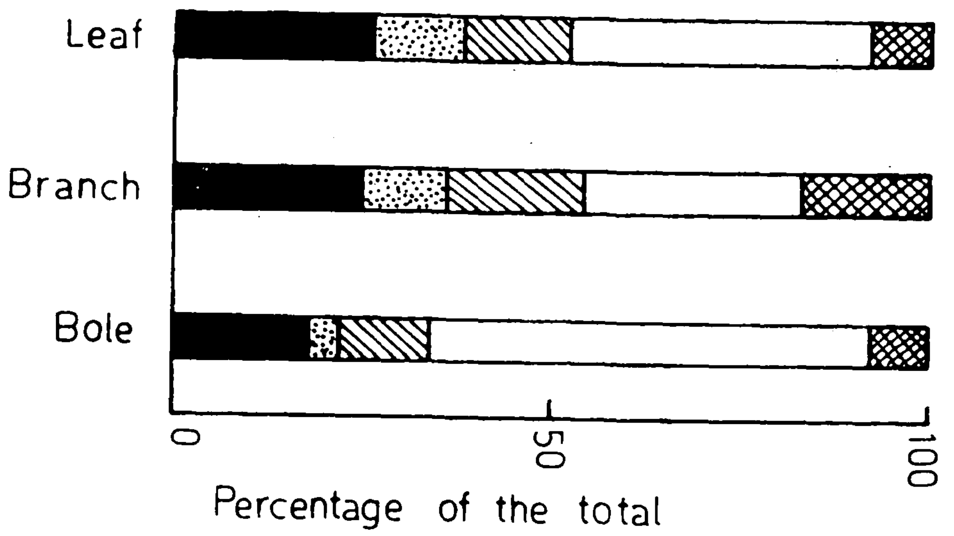

Mg
Ca
K
P
N
0
300
600
900
1200
1500
1800
2100
2300
Nutrients (kg/ha)

Fig. 7-2


Leaf
Branch
Bole
0
50
100
Percentage of the total

nutrient pool in the living biomass was in the undisturbed central zone of the forest, the rest along the disturbed peripheral zone. (Table 7-3). However, along the peripheral zone the contribution by shrub and herb species was more (0.87 and 0.35% respectively) in comparison with the central zone (0.74 and 0.17% respectively). Tree species contributed more to the nutrient pool of the living biomass (59.90%) in the central zone than along the peripheral zone (37.97%) of the forest. It may be mentioned here that the disturbed peripheral zone of the forest had preponderance of shrubs and herbs.

The total standing crop of nutrients (particularly nitrogen, phosphorus and calcium) was much more than the values reported for some temperate forests (Table 7-4). However, the value for nitrogen was lower than that reported by some of the workers on tropical forests. The value for calcium is closer to that obtained for tropical forests in Ghana by Greenland and Kowal (1960) but is lower than that reported for some Indian forest types (Desh Bandhu, 1970; Faruqi, 1972). The same holds true for phosphorus budget except that the values reported on higher level than that of tropical forests of Ghana (Greenland and Kowal, 1960).

Nutrient content in litter :

The percentage concentration of N,P,K,Ca and Mg on

Table 7.3. Distribution of different elements in the peripheral and in the central zones of the forest by trees, shrubs and herbs (kg/ha).

Elements	Peripheral zone			Central zone			
	Trees	Shrubs	Herbs	Trees	Shrubs	Herbs	Mean value
Nitrogen	609.34	34.40	13.86	1212.12	29.20	6.82	952.77
Phosphorus	194.68	4.74	1.88	363.58	4.02	0.94	284.92
Potassium	417.90	8.94	3.54	760.16	7.60	1.20	599.67
Calcium	1920.88	25.80	10.24	2577.58	21.90	5.00	2280.70
Magnesium	326.28	6.02	2.38	558.36	5.12	1.20	449.68

Table 7-4. Nutrient content within the living biomass of trees in different forest communities.

Forest community	Nutrients (kg/ha)					Authority
	N	P	K	Ca	Mg	
Pinus sylvestris (55 yrs.)	453	41	-	272	-	Ovington (1959)
Quercus robar (47 yrs.)	464	40	-	292	-	- do - (1958)
Betula verrucosa (55 yrs.)	543	34	-	651	-	- do - (1959)
Second. Douglas fir stand	320	66	-	333	-	Cole *et al.* (1967)
Douglas fir stand (450 yrs.)	313	42	242	620	-	Grier *et al.* (1974)
Tropical forest (Ghana)	2050	150	-	2700	-	Greenland and Kowal (1960)
Mixed deciduous forest	1260	85	-	1648	-	Duvigneaud *et al.* (1964)
Tropical dry deciduous (India)	1708	436	-	3707	-	Desh Bandhu (1970)
Shorea robusta (India)	7909	650	-	9960	-	Faruqi (1972)
Mixed sub-tropical forest (50 yrs.)	910.73	279.13	589.03	2269.23	442.32	Present study

oven dry weight basis in leaf litter of different species (Table 7-5) showed that N and Ca content was highest in *M. ferrea* and *M. roxburghiana* while P and Mg concentration was found to be highest in *S. robusta*, *A. chaplasa* gave high Mg values. For other tree species a great variation in concentration of different elements was observed. Generally speaking the percentage of nutrients in wood litter of the different species was comparatively lower. Although *D. hamiltonii* is not a tree species in the strict sense it accounts for a considerable proportion of the different elements as seen from a comparison of Tables 7-5 and 7-6.

Analyses of nutrient contents of the leaf and wood fallen on the soil surface in different months is shown in Figs. 7-3 and 7-4. This seasonal variation in concentration of N, P, K, Ca and Mg was well marked during the period of study. This may be explained as due to a number of factors like translocation of nutrients from leaves before senescence approached, the extent of leaching of soluble organic and inorganic nutrients from the leaves, extent of decomposition of leaves before fall and the contribution of leaf by different species which may affect the concentration and total content of the respective elements (Gosz *et al*, 1972; Van Cleve and

Table 7-5. Nutrient content (%) in leaf litter of different species and wood litter (Composite sample for all species).

Species	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Leaf litter :-					
Artocarpus chaplasa	0.685	0.354	0.354	2.920	0.656
Castanopsis indica	0.846	0.461	0.361	2.281	0.591
Dendrocalamus hamiltonii	0.736	0.324	0.224	1.391	0.359
Dillenia indica	0.637	0.239	0.541	1.856	0.281
Garcinia cowa	0.525	0.398	0.308	1.650	0.351
Machillus khasiana	0.849	0.399	0.299	1.980	0.651
Mesua ferrea	0.990	0.270	0.470	3.235	0.581
Milusa roxburghiana	0.870	0.222	0.322	3.156	0.650
Shorea robusta	0.861	0.626	0.626	1.351	0.512
Schima wallichii	0.767	0.538	0.438	2.310	0.656
Sterculia villosa	0.662	0.299	0.399	1.330	0.423
Vitex peduncularis	0.575	0.328	0.228	1.810	0.351
Other species (Miscellaneous)	0.789	0.560	0.460	2.510	0.673
Wood litter :-					
Branches, twigs and barks (all species)	0.601	0.384	0.280	0.730	0.451

Table 7-6. Amount of different elements contributed through leaf and wood litter by different species alongwith percentage contribution of the total for the forest given in parenthesis.

Species	Nutrients (kg/ha/yr)				
	N	P	K	Ca	Mg
Leaf litter:-					
Artocarpus chaplasa	1.05 (2.54)	0.54 (2.15)	0.54 (2.56)	4.48 (4.29)	1.01 (3.31)
Castanopsis indica	3.12 (7.54)	1.70 (6.73)	1.33 (6.28)	8.41 (8.07)	2.18 (7.18)
Dendrocalamus hamiltonii	4.14 (10.04)	1.83 (7.24)	1.26 (5.96)	7.84 (7.52)	2.03 (6.67)
Dillenia indica	0.19 (0.45)	0.07 (0.28)	0.16 (0.74)	0.54 (0.52)	0.08 (0.27)
Garcinia cowa	0.51 (1.23)	0.30 (1.18)	0.30 (1.40)	1.60 (2.45)	0.34 (1.12)
Machillus khasiana	0.04 (0.09)	0.02 (0.07)	0.14 (0.07)	0.09 (0.09)	0.03 (0.10)
Milusa roxburghiana	1.96 (4.75)	0.50 (1.99)	0.73 (3.43)	8.72 (8.36)	1.47 (4.84)
Mesua ferrea	0.27 (0.65)	0.07 (0.29)	0.13 (0.60)	1.02 (0.98)	0.16 (0.52)
Shorea robusta	4.52 (10.92)	2.95 (11.67)	2.95 (13.89)	6.35 (6.09)	2.41 (7.94)
Schima wallichii	4.22 (10.30)	2.99 (11.88)	2.41 (11.37)	12.84 (12.31)	3.61 (11.90)
Sterculia villosa	0.30 (0.73)	0.14 (0.07)	0.18 (0.86)	0.61 (0.58)	0.19 (0.63)
Vitex peduncularis	0.23 (0.56)	0.13 (0.56)	0.09 (0.43)	0.72 (0.69)	0.14 (0.46)
Other species (trees shrubs and herbs)	13.13 (31.75) 33.68	9.15 (36.42) 20.39	7.52 (35.45)	41.76 (40.03)	10.99 (36.23)
Wood litter: (twigs and barks)	7.62 (18.45)	4.87 (19.47)	3.60 (16.96)	9.25 (8.81)	5.72 (18.83)

Fig. 7-3. Monthly variation in concentration of different nutrients in leaf litter at Lailad forest.

N, ● ; P, ○ ; K, ▲ ; Ca, △ ;
Mg, ■ .

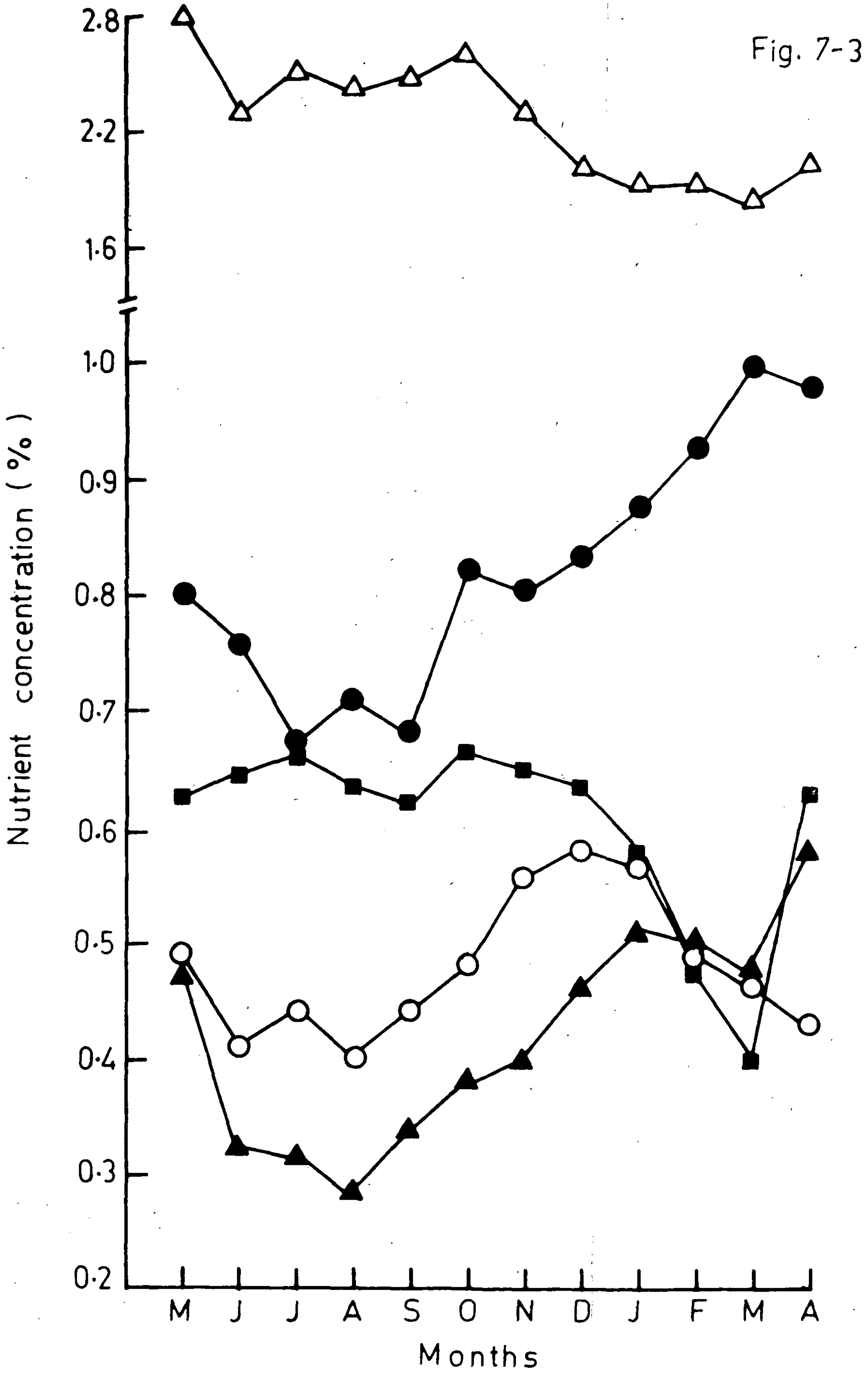
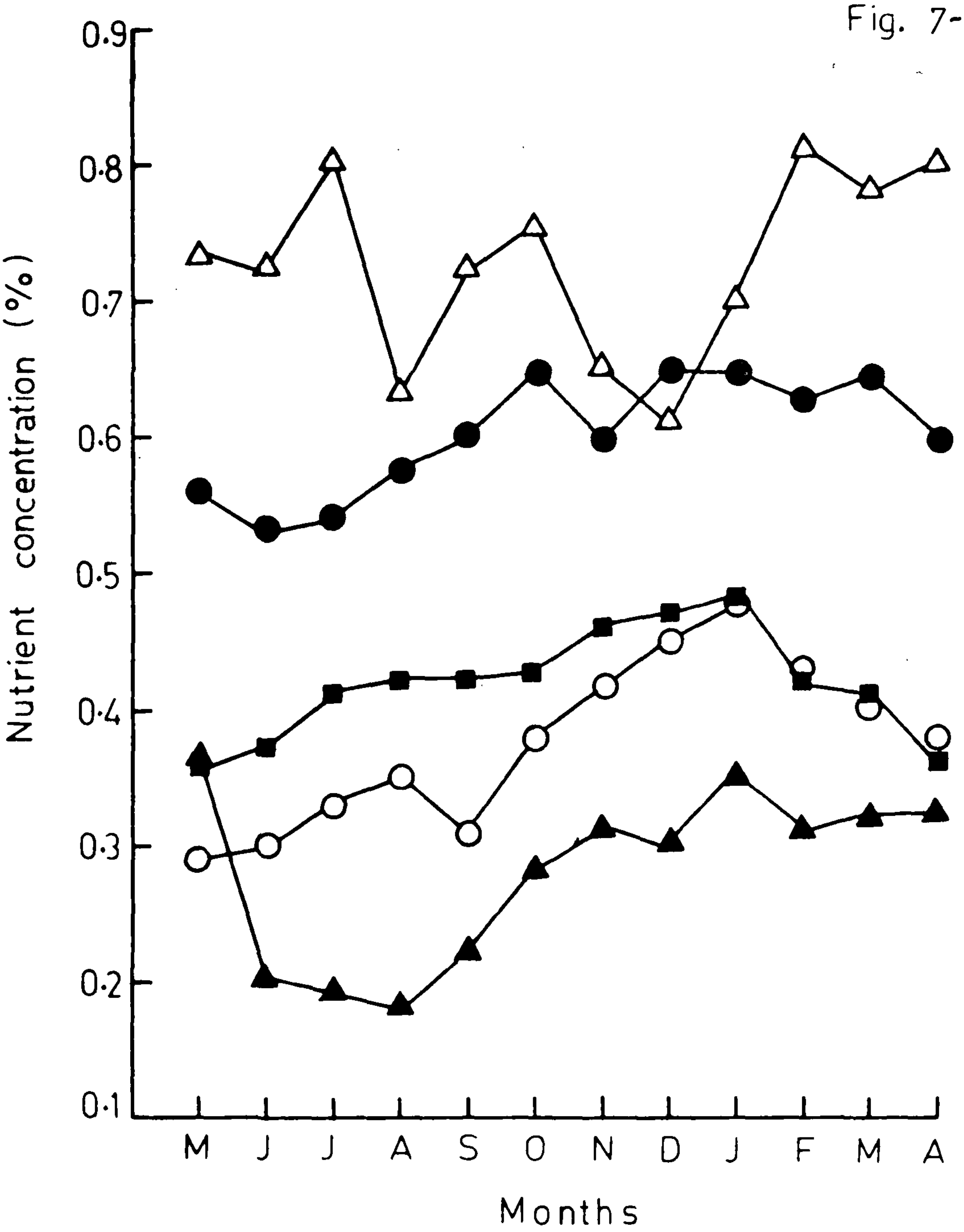


Fig. 7-3
Nutrient concentration (%)
2·8
2·2
1·6
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
M
J
J
A
S
O
N
D
J
F
M
A
Months

Fig. 7-4. Monthly variation in concentration of different nutrients in wood litter at Lailad forest.

N, ● ; P, ○ ; K, ▲ ; Ca, △ ;
Mg, ■ ;

Fig. 7-4



0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
Nutrient concentration (%)
M
J
J
A
S
O
N
D
J
F
M
A
Months

Noonan, 1975). The role of soluble organic and inorganic constituents from the leaf material affecting the nutrient content of senescing foliage has also been emphasized by Tukey (1970). In the present study it was found that the senescent leaf material generally showed higher concentration of more mobile elements like N,P and K while lower concentration of less mobile elements such as Ca and Mg. It may be noted that leaves becomes senescent for most of the species during dry winter months of December-January and leaf fall is maximum in March. Leaf fall may extend to April but with simultaneous production of new leaves. The high concentration of nutrients like N and P may be due to the fact that retranslocation of these nutrients is not so active compared to some others. However, these mobile elements are subject to leaching by precipitation from attached leaves. Hence in the months of May-August the level of these nutrients tend to be low. Potassium is leached much more readily than other mobile elements as was shown by a number of workers (Madgwick and Ovington, 1959; Miller, 1963; Tukey, 1970; Egunjobi,1971). This is also the case in the present study. The pattern for Ca and Mg showed that the concentration is at its lowest at the time of leaf fall probably due to their withdrawal into the wood. The low level of N, and K in the months of February-March may be due to some leaching that may occur from senescent leaves due to occasional showers at this time. During the growing season (April-September) a shift in nutrient concentration was observed in the case of N,P and K towards the lower side but with increased Ca and Mg levels. This is explained due to the mobility of the N,P and K due to leaching during May-September by rain while Ca and Mg are not susceptible to be leached to the same extent (Fig.7-3).

The wood litter analysis for Ca showed a somewhat reverse trend at the time of leaf fall in the month of March-April with higher levels which is to be expected due to withdrawal from leaf which showed a corresponding decreased level. A low level of N,P and K was also observed in the wood litter during the rainy season of May-August due to high mobility of these and consequent leaching (Fig. 7-4).

The percentage contribution by different species to the total amount of different elements not only depends upon litter biomass of the species concerned but also on the nutrient concentration. Thus, even though D. hamiltonii had greatest litter biomass contribution in the forest as a whole, yet there were other species like S. robusta which contributed higher amount of P through litter. In contrast, a species like M. ferrea which had high nutrient level in the leaf tissue for N and Ca, had very low total contribution of these through litter because of smaller litter contribution to the forest floor. High percentage contribution of the different nutrients through litter in the case of three important tree species like S. robusta, S. wallichii and C. indica in that order is both due to high litter production and high nutrient concentration in the leaf tissue (Table 7-6).

The pattern of distribution of litter nutrients along the peripheral and the central zones of the forests is different both in terms of species contribution as well as the total amounts. Generally speaking, the total contribution of different elements per unit area per year is higher in the central zone of the forest compared to that along the peripheral zone (Table 7-7). This is related to greater maturity of the forest in the central zone due to comparatively low disturbance and the consequent species diversity and denser plant cover. The peripheral zone of the forest, as mentioned elsewhere, are highly disturbed which may be considered as 20-25 years of age due to preponderance of D. hamiltonii. It may be mentioned here that studies by Ramakrishnan et al (1980) have shown that this species of bamboo is typical of

Table 7-7. Contribution of nutrient elements by different tree species in the peripheral and central zones of the forest at Lailad (kg/ha/yr).

Species	Peripheral zone					Central zone				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Leaf litter:										
Artocarpus chaplasa	0.700	0.362	0.362	2.996	0.670	1.400	0.724	0.724	5.970	1.342
Castanopsis indica	2.080	1.134	0.888	5.608	1.454	4.160	2.266	1.774	10.216	2.906

disturbed forests less than 20 years of age. Consequent to the age difference of the forest along the peripheral zone due to disturbance, the contribution of nutrients through litter by D. hamiltonii is significantly higher compared to the contribution by the same species in the central zone of the forest. To a lesser degree the same pattern holds good for M. roxburghiana. On the other hand, species like S. robusta, S. wallichii and C. indica showed a reverse trend with higher nutrient distribution by these species in the central zone (Table 7-7). Of all the nutrients returned to the forest floor through litter calcium showed very high values and the value for potassium was the least (Table 7-8). The amounts of various elements returned to the forest ecosystem by litter in the present case, was in the order of :-

Ca>N>Mg>P>K.

A comparison of the nutrients contribution through litter for different forest types both temperate and tropical along with that obtained in the present study is shown in Table 7-9. This showed that almost all nutrients except probably nitrogen is released in larger quantities in tropical forests compared to temperate ones. This is most obvious for phosphorus which had somewhat comparable situation only in one other forest type at Varanasi (Singh, 1968). The value obtained for other tropical forests are all much lower than that obtained in the present study. Potassium values are comparable

Table 7-8. Distribution of total mineral nutrients in litter along the peripheral and central zones of the sub-tropical forest at Lailad (kg/ha/yr).

Nutrients	Peripheral zone	Central zone	Mean value
Nitrogen	34.368	48.350	41.359
Phosphorus	20.076	30.434	25.255
Potassium	17.008	25.412	21.210
Calcium	90.322	118.128	104.225
Magnesium	24.776	35.940	30.358

Table 7-9. Amount of mineral nutrients returned through litter fall in some tropical, sub-tropical and temperate forests of the world.

Vegetation	Locations	Nutrients (kg/ha/yr)					Source
		Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	
Mixed tropical	Zaire	154-224	7-9	48-87	84-105	44-53	Laudelot and Meyer (1954)
Mixed tropical	Kade Ghana	199.4	7.2	68.3	206.1	44.8	Nye (1961)
Mixed moist evergreen	Ivory Coast	104-107	4.2-13.6	26-81	61-105	22-51	Bernhard (1970)
Amazonian tropical rainforest	Brazil	106	2.1	13	18	13	Klinge and Rodrigues (1968)
Tropical deciduous	Gautemala	169	5.8	20	88	64	Ewel (1976)
Birch forest	U.S.S.R.	66	5	13	54	19	Russian authors cited by Ovington(1965)
Scot Pine forest	England	125	10	57	49	9	Ovington (1959)
Temperate forest Pinus caribae	Nigeria	7.3	0.4	6.9	11.4	2.7	Egunjobi,and Fasehum (1972)
Sessile Oak forest	England	21-27	1-9	7-4	14-15	2-2.8	Carlisle <u>et al</u> (1966)
Mixed tropical deciduous forest	Varanasi (India)	18-54	1-28	6-31	15-184	44-30	Singh (1968)
Mixed tropical forest	Meghalaya (India)	41.36	25.26	21.21	104.22	30.36	Present study

to other tropical forests and only in one temperate mixed forest in USSR a high value is reported. Calcium also was higher than in temperate forests and was comparable to other tropical situations. The same holds true for magnesium also.

Nutrient release through decomposition :

The concentration of nitrogen in leaf and wood litter of different species kept for decomposition at the beginning of the experiment ranged between 0.70 - 0.85% in the leaf tissue and between 0.58 - 0.75% in wood tissue. As decomposition progressed, between 2-7 months after the start of the experiments, there was a rapid fall in N content of the decomposed leaf material probably due to rapid leaching of nitrogen (Fig. 7-5). This trend was also noticed in wood litter (Fig. 7-6) though the ultimate left over N in the leaf litter was about 4% of the original and that for wood litter was about 14%. This is due to the slower rate of decomposition of the latter. In the case of D. hamiltonii however, the rate of release and removal of N was more rapid than that of others.

Phosphorus ranks next to N with respect to release and leaching of this element from decomposed tissues. The original concentration of P was lower in leaf and wood litter

Fig. 7-5. Loss of nitrogen from leaf litter through decomposition.

S. robusta, ●——●; *S. wallichii*, ●–··–●;
Q. indica, ●-·-·-●; *D. hamiltonii*, ●–X–●;
A. chaplasa, ●····●; Miscellaneous, ●----●;

Fig. 7-5

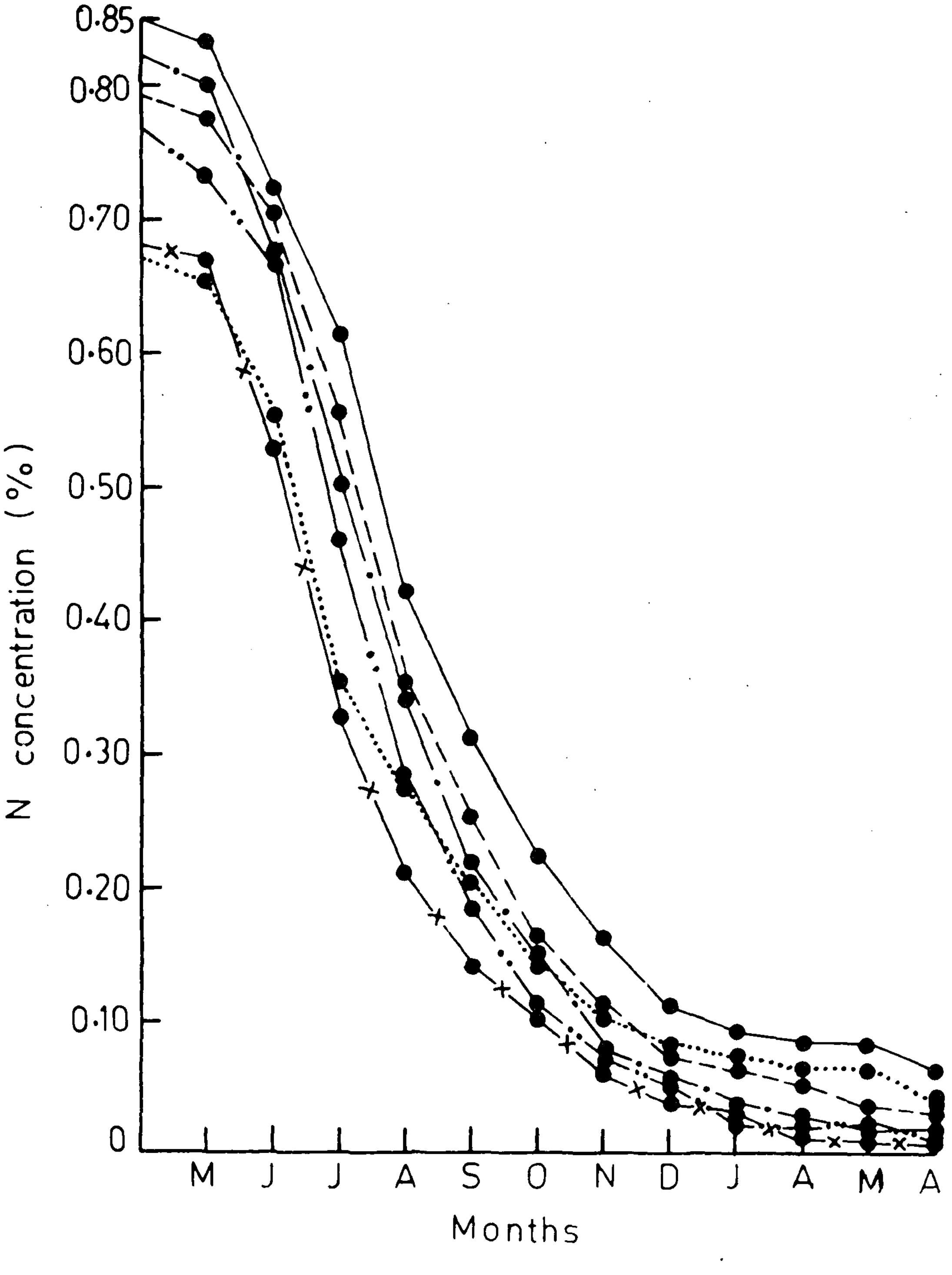
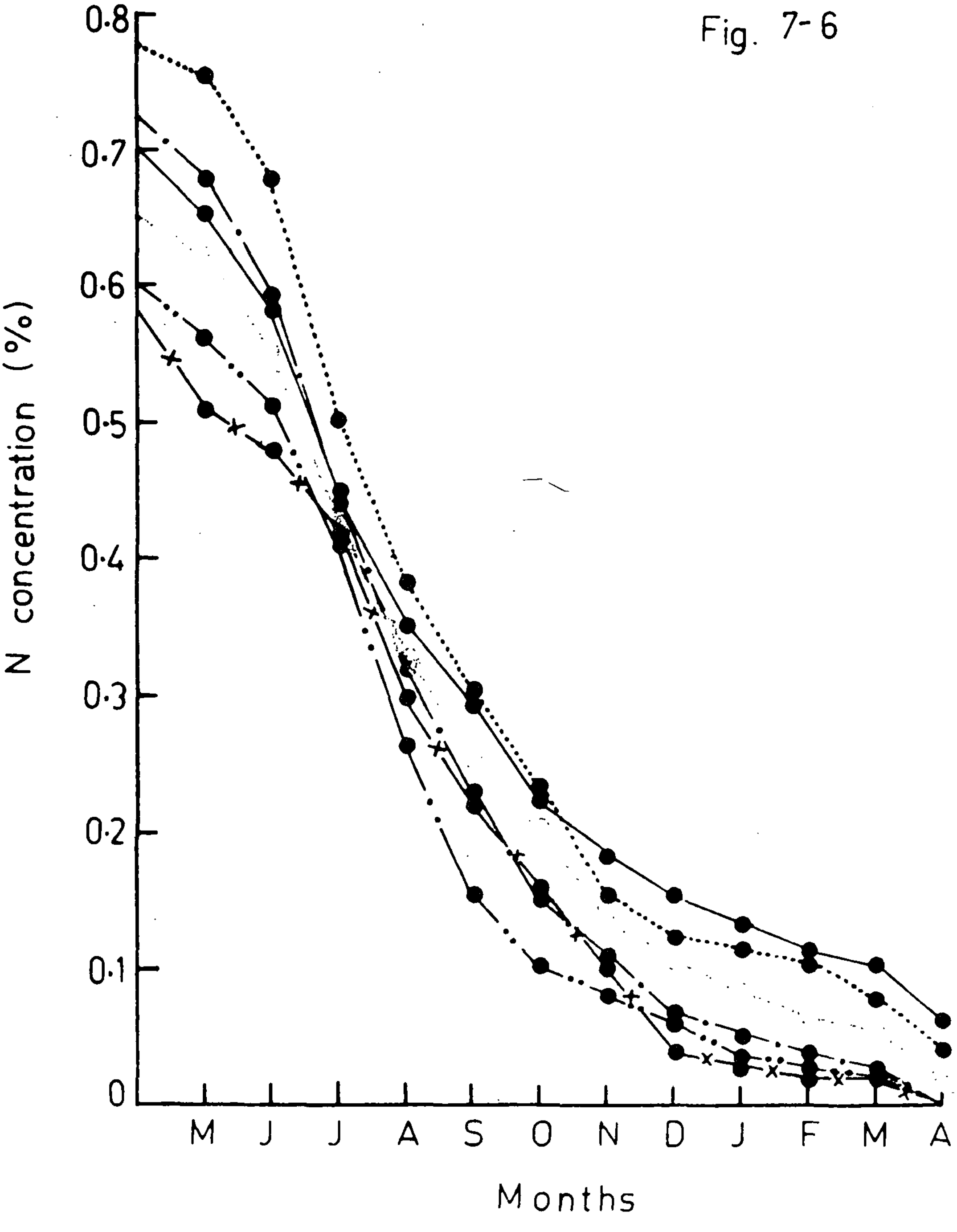

N concentration (%)
0.85
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
M
J
J
A
S
O
N
D
J
A
M
A
Months

Fig. 7-6. Loss of nitrogen from wood litter through decomposition.

S. robusta, ●——●; *S. wallichii*, ●-··-●; *C. indica*, ●-•—●; *D. hamiltonii*, ●—X—●; *A. chaplasa*, ●····●.

Fig. 7-6



compared to nitrogen level. Rapid loss of P occured in the first 3-4 months after which the loss slowed down. Further in most of the species very little P remained in the leaf tissues after 1 year period except in the case of *S. robusta* and *C. indica* (Fig. 7-7). Because of slower rate of decomposition of wood litter about 5% of the original remained after 1 year of study. Wood litter of *A. chaplasa* and *S. robusta* was more hard than that of other species (Fig. 7-8).

The pattern of loss of potassium from leaf and wood litter was quite different from that of N and P. Loss of K was most rapid in the first 2-3 months and slowed down markedly during the rest of the year. Thus during the first 2-3 months as much as 75% of K was leached out from the decomposed tissues (Fig. 7-9). After 7 months of decomposition, leaf litter lost almost all K from it, except in the case of *S. robusta* where a very small amount remained. This was due to slow rate of decomposition in this species. Wood litter had comparatively more K remaining at the end of one year (Fig. 7-10).

Loss of calcium was slower compared to some of the more mobile nutrients like N,P and K as was also observed by Tukey (1970). Species like *S. robusta* and *D. hamiltonii* lost Ca from leaf litter rather slowly, preceded by species like *S. wallichii* and *C. indica*; rate of loss of Ca was too steep

Fig. 7-7. Loss of phosphorus from leaf litter through decomposition.

S. robusta, ●———●; *S. wallichii*, ●–••–●;
C. indica, ●– • –●; *D. hamiltonii*, ●–X–●;
A. chaplasa, ●••••●; Miscellaneous, ●----●.

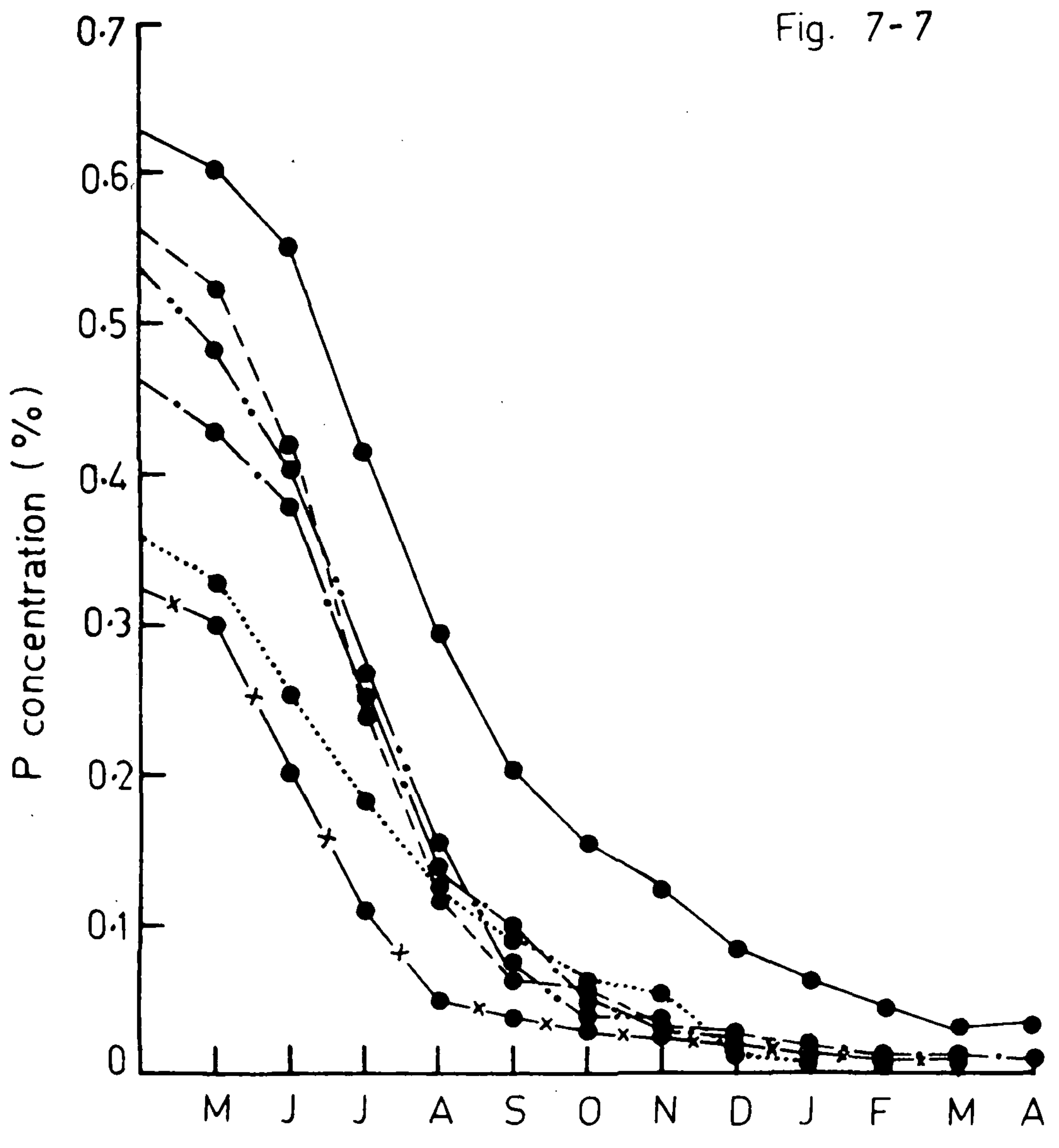


Fig. 7-7
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
P concentration (%)
M
J
J
A
S
O
N
D
J
F
M
A
Months

Fig. 7-8. Loss of pphosphorus from wood litter through decomposition.

S. robusta, ●———●; *S. Wallichii*, ●···–●; *C. indica*, ●—·—●; *D. hamiltonii*, ●–X–●; *A. chaplasa* ●····●.

Fig. 7-8

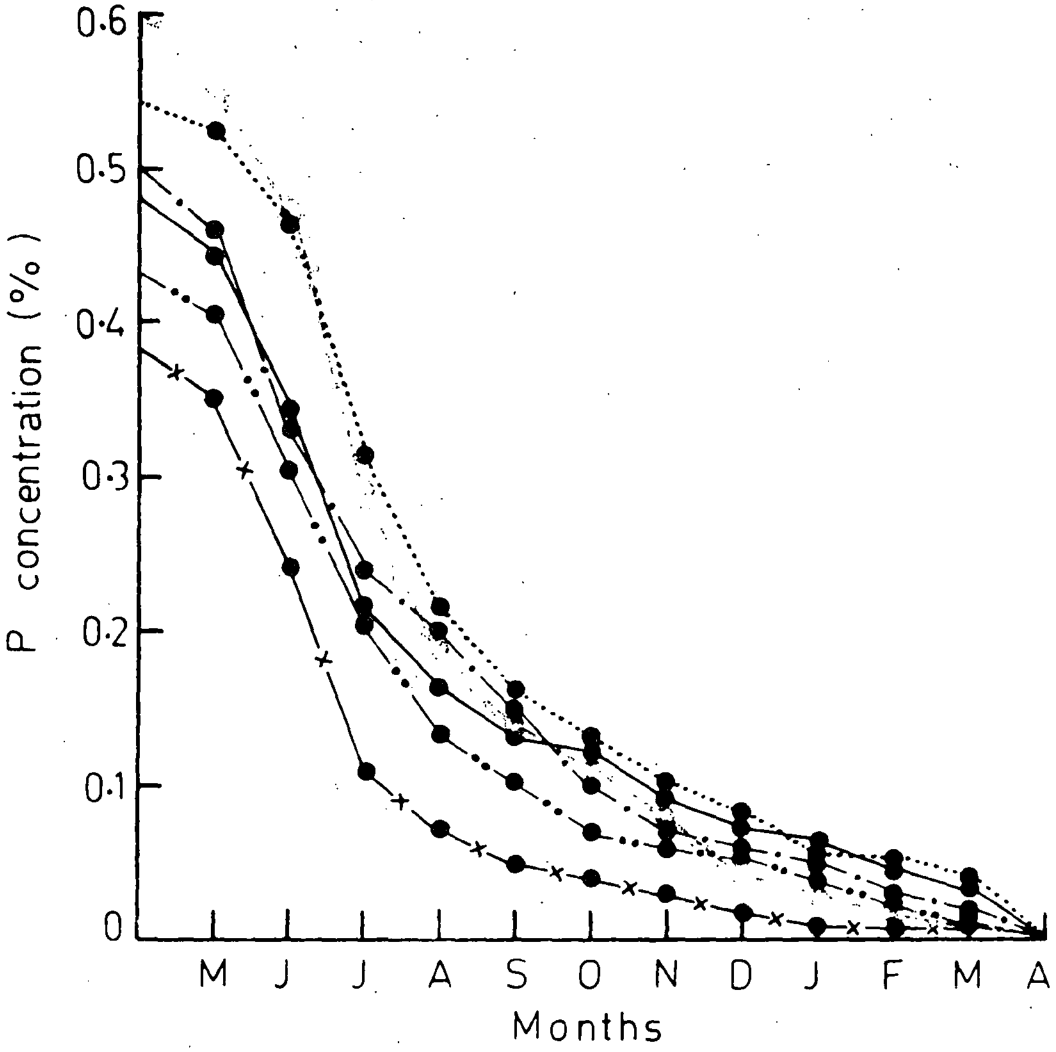


Fig. 7-9. Loss of potassium from leaf litter through decomposition.

_S_. _robusta_,●—●; _S_. _wallichii_,●-:-●;
_C_. _indica_,●-·-●; _D_. _hamiltonii_,●-X-●;
_A_. _chaplasa_,●····●; Miscellaneous,●---●.

Fig. 7-9

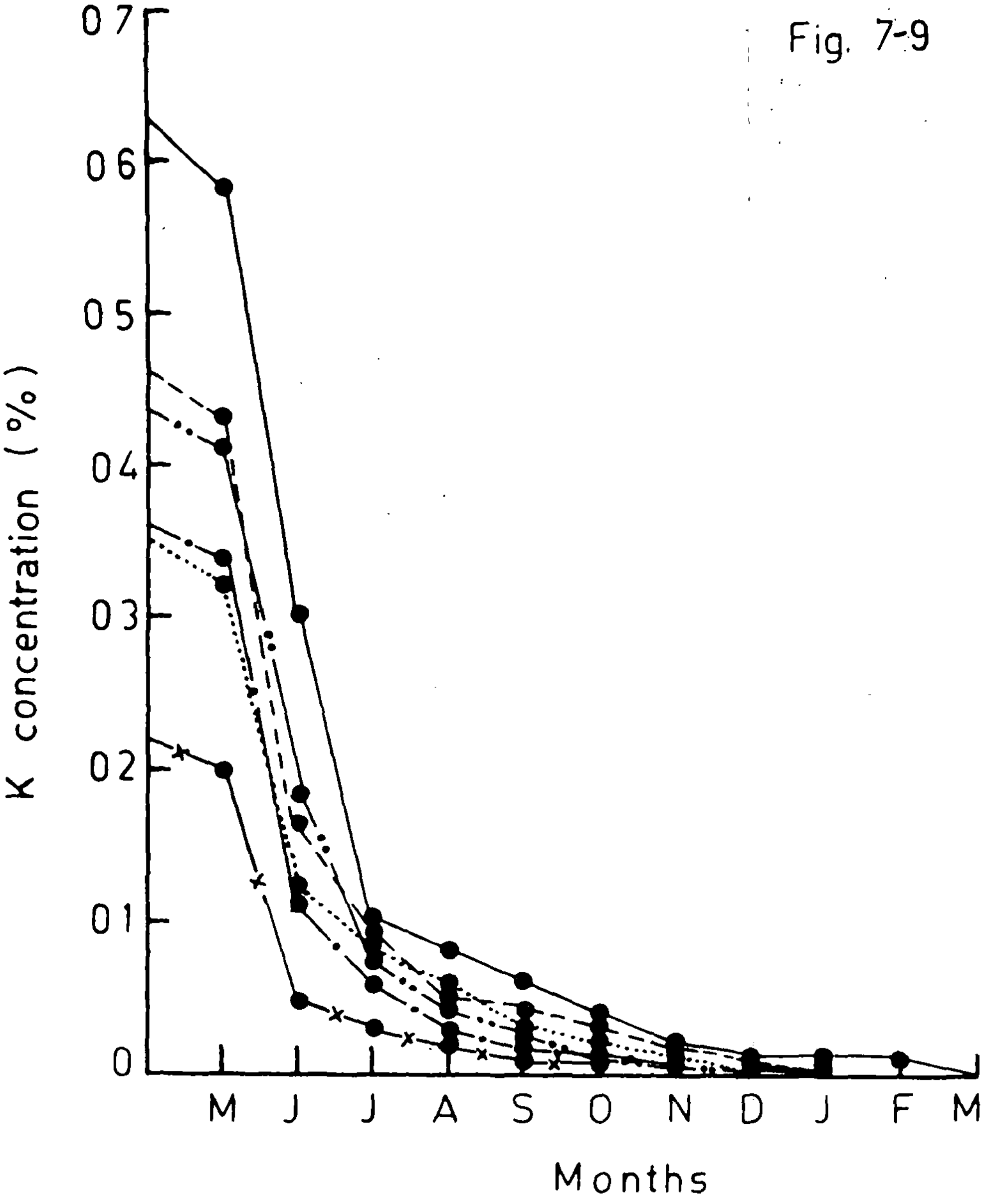


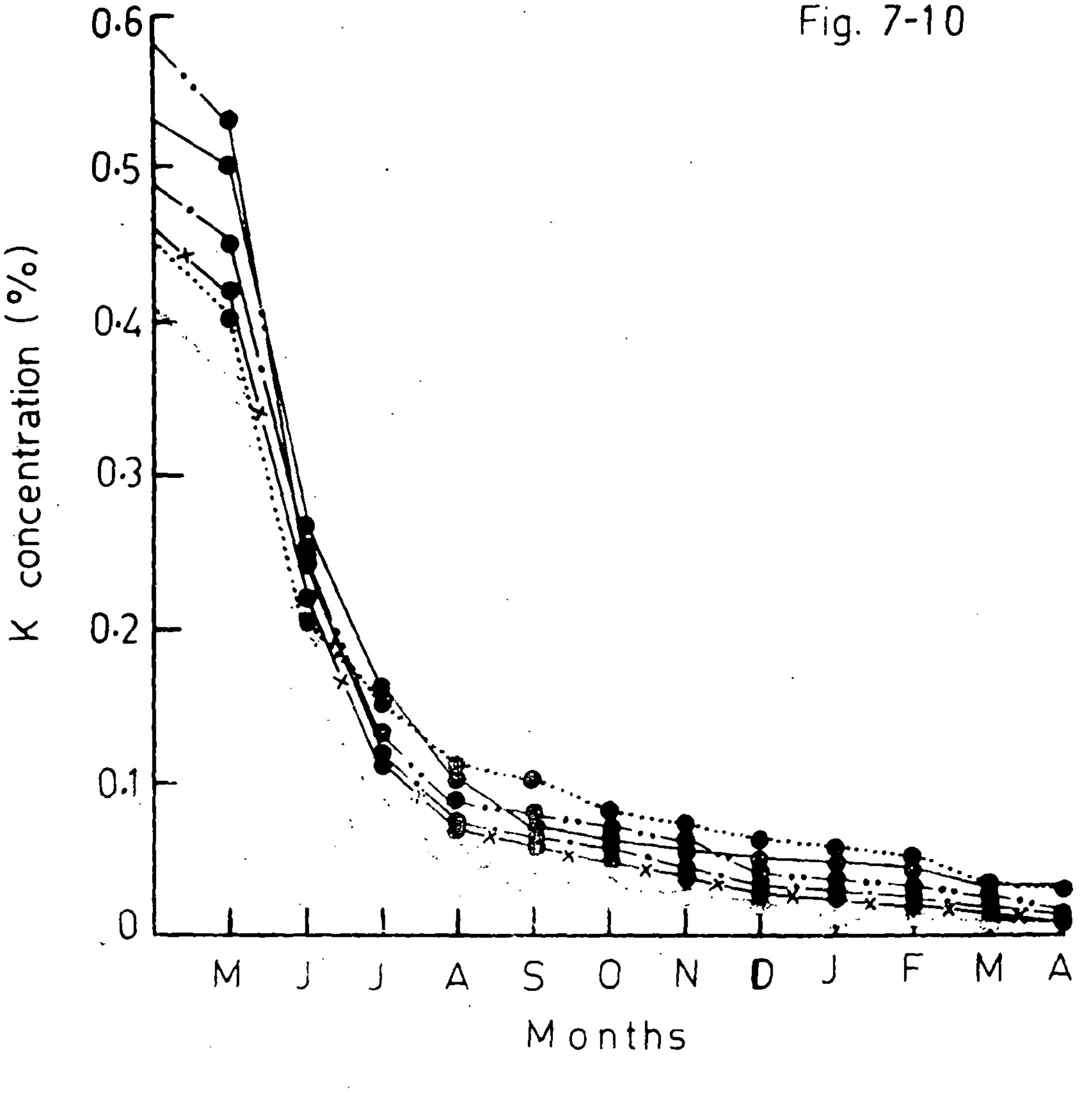
Fig. 7-10. Loss of potassium from wood litter through decomposition.

S. robusta, ●——●; *S. wallichii*, ●-··-●;

C. indica, ●-·-●; *D. hamiltonii*, ●-X-●;

A. chaplasa, ●···-●;

Fig. 7-10



in the case of A. chaplasa which continued upto 8 months from the start. Further, a fairly high level of Ca ramained in the leaf litter in all the species and ranged between 7 to 9% of the original concentration (Fig. 7-11). Rate of loss of Ca from the wood litter of S. robusta was much more rapid though this was not true for leaf litter. Similarly A. chaplasa which had rapid release of Ca from leaf tissue showed slow release from wood litter. D. hamiltonii had lower levels of Ca to start with, compared to other species and also released this nutrient slowly. Whilst Ca level in the original wood tissue was lesser than in leaf litter, the amount remaining was of the order of 7 to 12% of the original concentration. (Fig. 7-12) Loss of Ca from wood was more rapid in the initial stages of decomposition because of rapid decomposition of bark which hold much of calcium (Seth et al, 1963; Woodwell et al, 1975).

Magnessium loss from the decompesing leaf and wood litter was rapid during the first 7-8 months. Whilst species like A. chaplasa and S. wallichii started with higher Mg level in the leaf tissue and lost it more rapidly, D. hamiltonii had the least concentration of this element compared to other species and the rate of loss was somewhat slower. Whereas

Fig. 7-11. Loss of calcium from leaf litter through decomposition.
S. robusta, ●——●; *S. wallichii*, ●-··-●;
C. indica, ●-·-●; *D. hamiltonii*, ●-X-●;
A. chaplasa, ●···●; Miscellaneous, ●--●.

Fig. 7-11

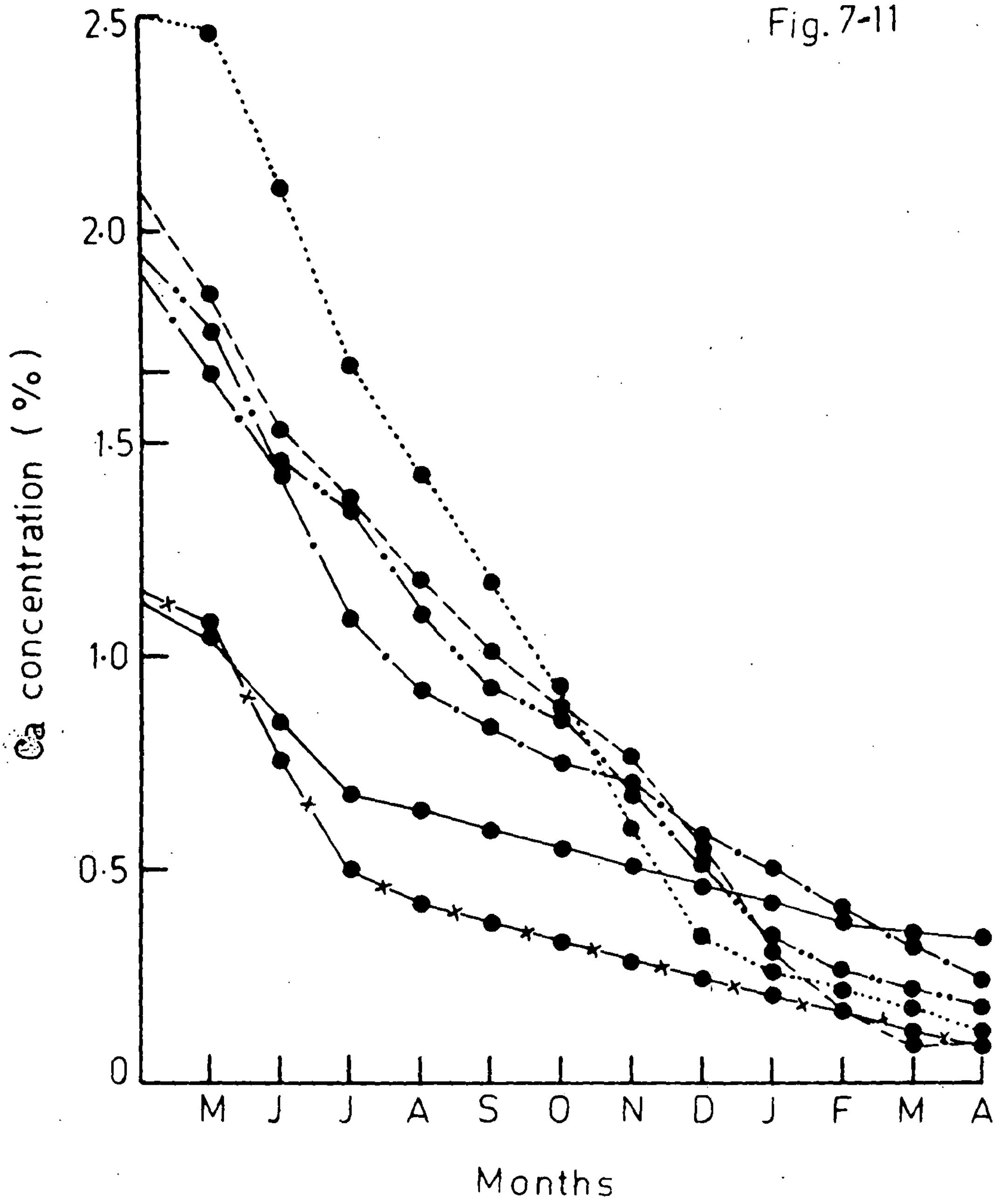


Fig. 7-12. Loss of calcium from wood litter through decomposition.

S. robusta, ●——●; *S. wallichii*, ●-··-●;
C. indica, ●-·-●; *D. hamiltonii*, ●-X-●;
A. chaplasa, ●·····●;

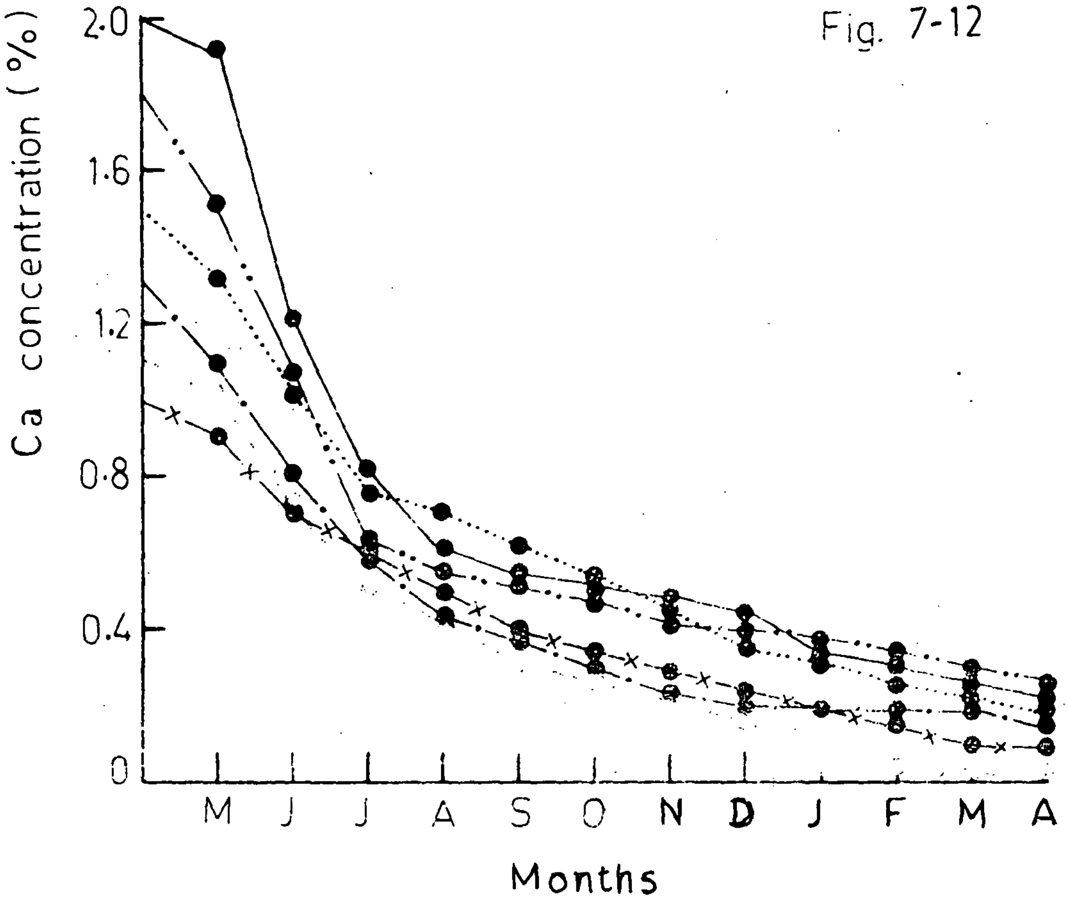


Fig. 7-12
Ca concentration (%)
2.0
1.6
1.2
0.8
0.4
0
M
J
J
A
S
O
N
D
J
F
M
A
Months

leaf litter of *S. robusta* showed 8% of the original concentration remaining at the end of one year period, *D. hamiltonii* had only 3% remaining at the end of the experiment (Fig.7-13). Magnesium released from wood litter was generally slower and the amount remaining at the conclusion of the experiment out of the original concentration ranged between 4 to 6% (Fig.7-14).

The pattern of loss of nutrients through decomposition was found to be somewhat similar to the work done by Ewel (1976) for a tropical forest in Ghana. Folster and De-Las Salas (1976) reported that the cations are more leacheable than of N and P. The present study however, showed that N, P and K are lost much more earlier than Ca and Mg. Amongst cations the loss of Ca from leaf and wood tissues was much less than that of K or Mg, a feature reported by Attiwill (1967) and Thomas (1969) also. However, it may be noted that the pattern of release of Ca is also a specific characteristic in that the release of this element from the leaf tissue of *A. chaplasa* was more rapid than that of other tree species. Nutrient release from leaf tissue is more rapid than that from wood litter due to slower decomposition of the latter, a pattern also reported by Gilbert (1957), Alexander (1961) and Gosz *et al* (1972).

Fig. 7-13. Loss of magnesium from leaf litter through decomposition.

S. robusta,●——●; *S. wallichii*,●-··-●;
C. indica,●-·-●; *D. hamiltonii*,●-X-●;
A. chaplasa,●·-·●; Miscellaneous,●---●.

Fig. 7-13

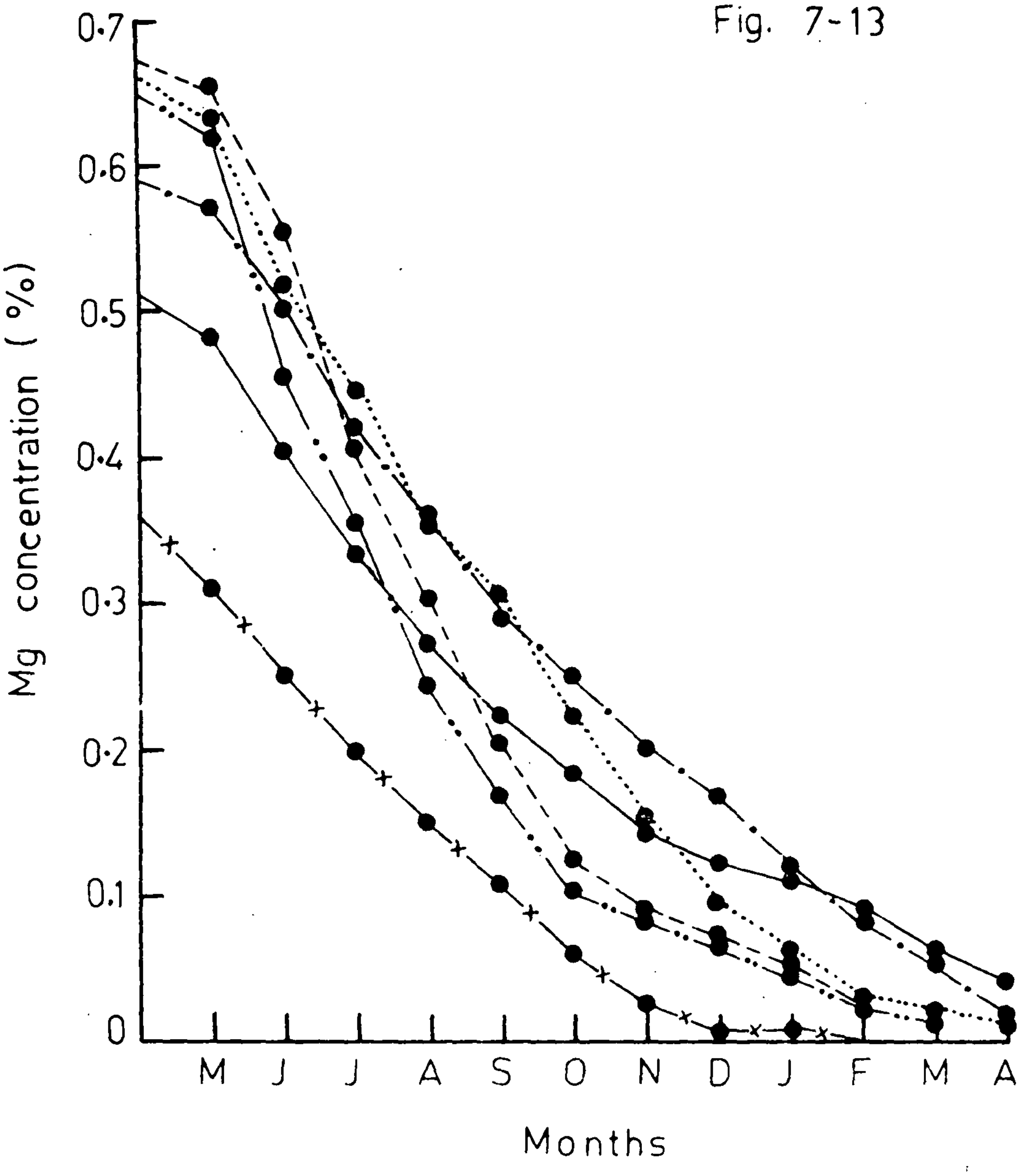
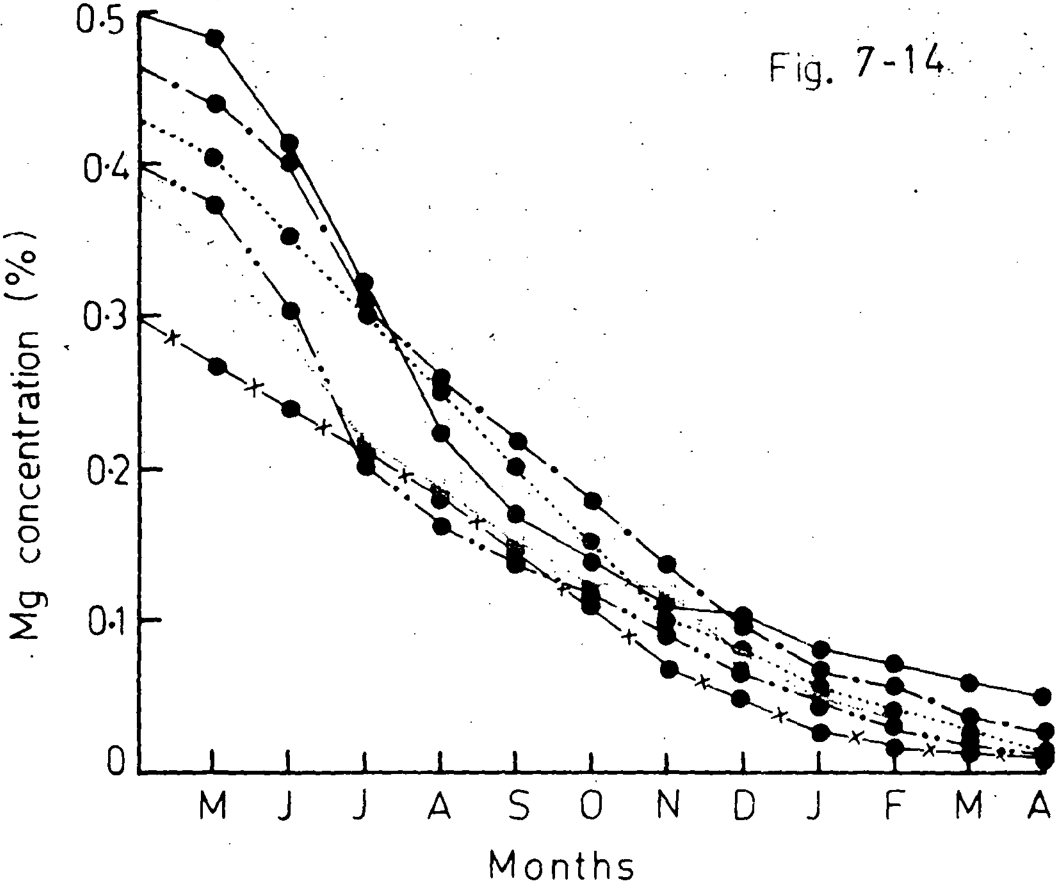


Fig. 7-14. Loss of magnesium from wood litter through decomposition.

S. robusta, ●——●; *S. wallichii*, ●-··-●;
C. indica, ●-·-●; *D. hamiltonii*, ●-X-●;
A. chaplasa, ●···●.

Fig. 7-14



Nutrient return by throughfall, stemflow and incident rainfall :

The mean monthly concentration (mg/l) of the various elements found throughout the study period in throughfall, stemflow and incident rainfall are shown in Fig.7-15, 16,17,18 and 19. The concentration of total nitrogen in throughfall and stemflow was low during March-May, followed by a steady rise reaching the maximum towards the end of the year. This steady rise in concentration may be related to the maturity of the leaves. Before the formation of abscission layer in December the concentration reached its peak when the leaves were fully matured. A similar increase in N concentration in throughfall with increased maturity of the leaves and a subsequent sharp decline after the formation of abscission layer is also reported by Tukey _et al_ (1958). No throughfall occurred after December as the winter months were dry. A more or less similar pattern for stemflow was also observed during the study period. During December - February no stemflow could be recorded due to comparatively dry period. However, the concentration of N in stemflow was generally more than that of throughfall. This high concentration in stemflow may be due to : (i) release of nutrient during bark decay during the rainy season (ii) the wash out

Fig. 7-15. Monthly variation in concentration of nitrogen in different water samples. Throughfall, ● ; stemflow, ○ ; incident rainfall, ▲ .

Fig. 7-16. Monthly variation in concentration of phosphorus in different water samples.

Throughfall, ● ; stemflow, ○ ; incident rainfall, ▲ .

Fig. 7-15

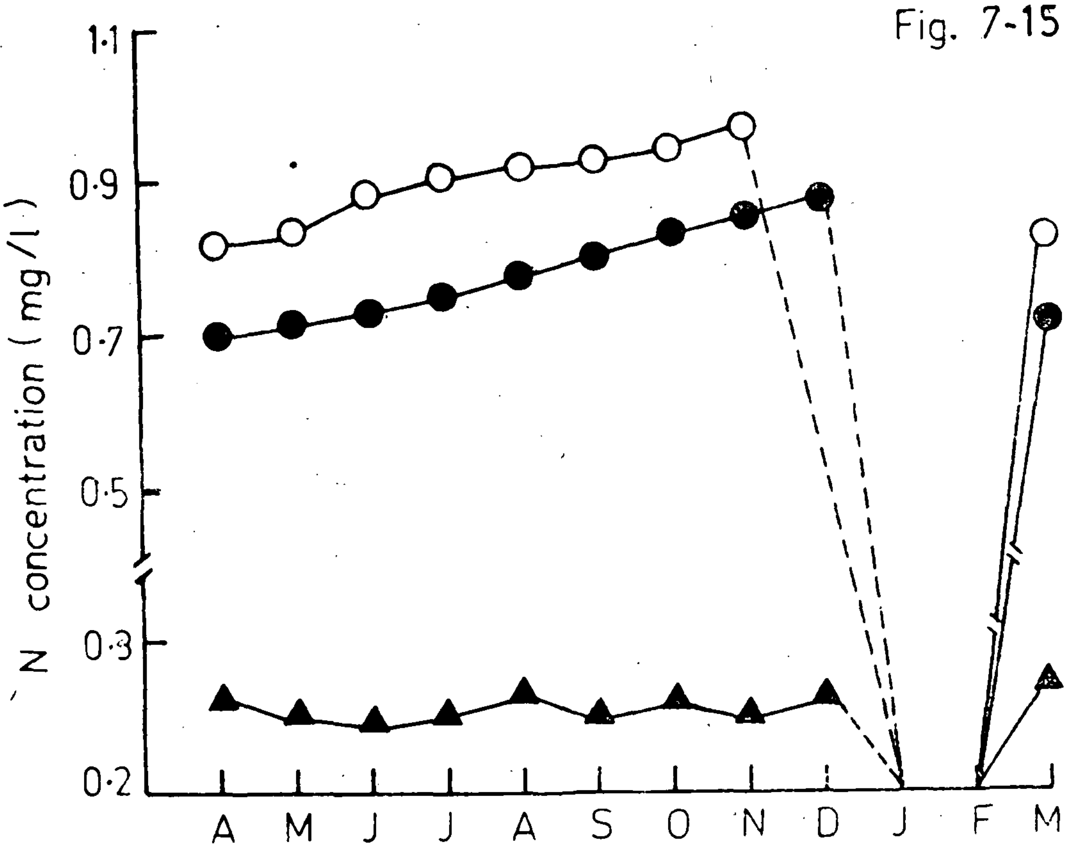


Fig. 7-16

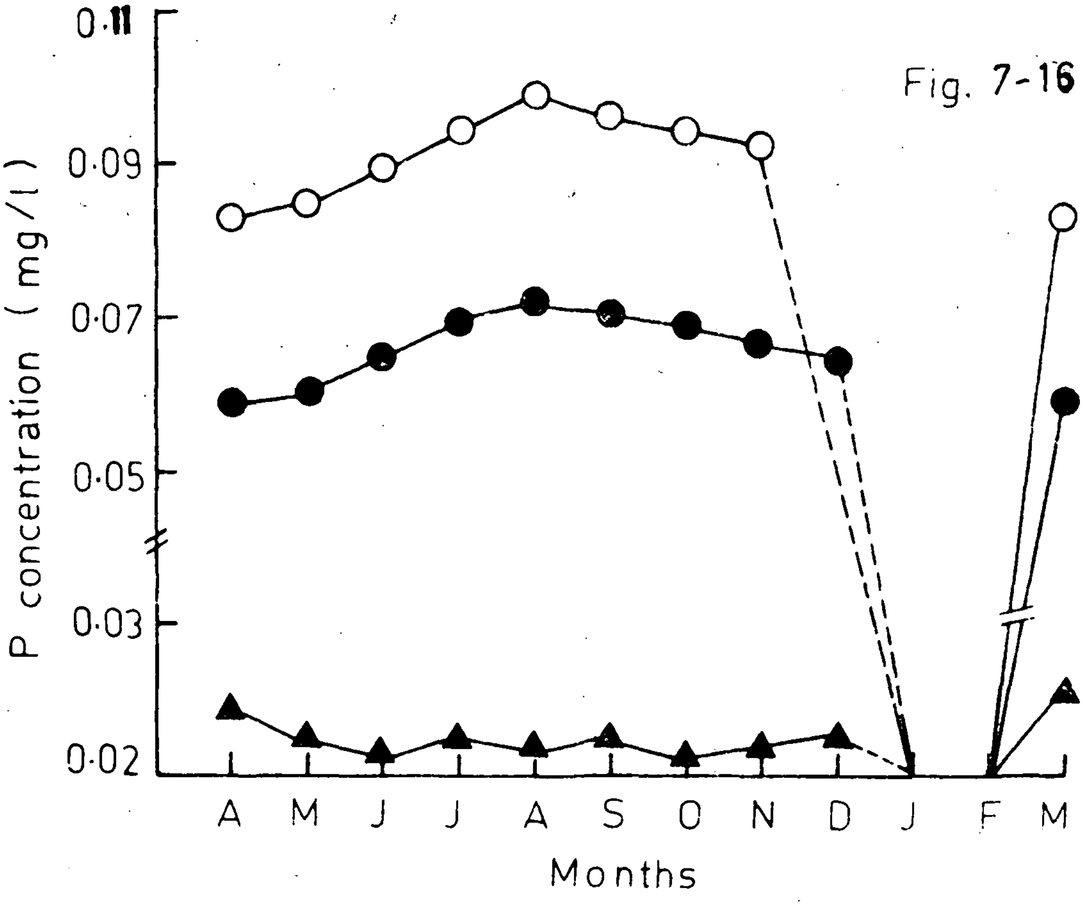
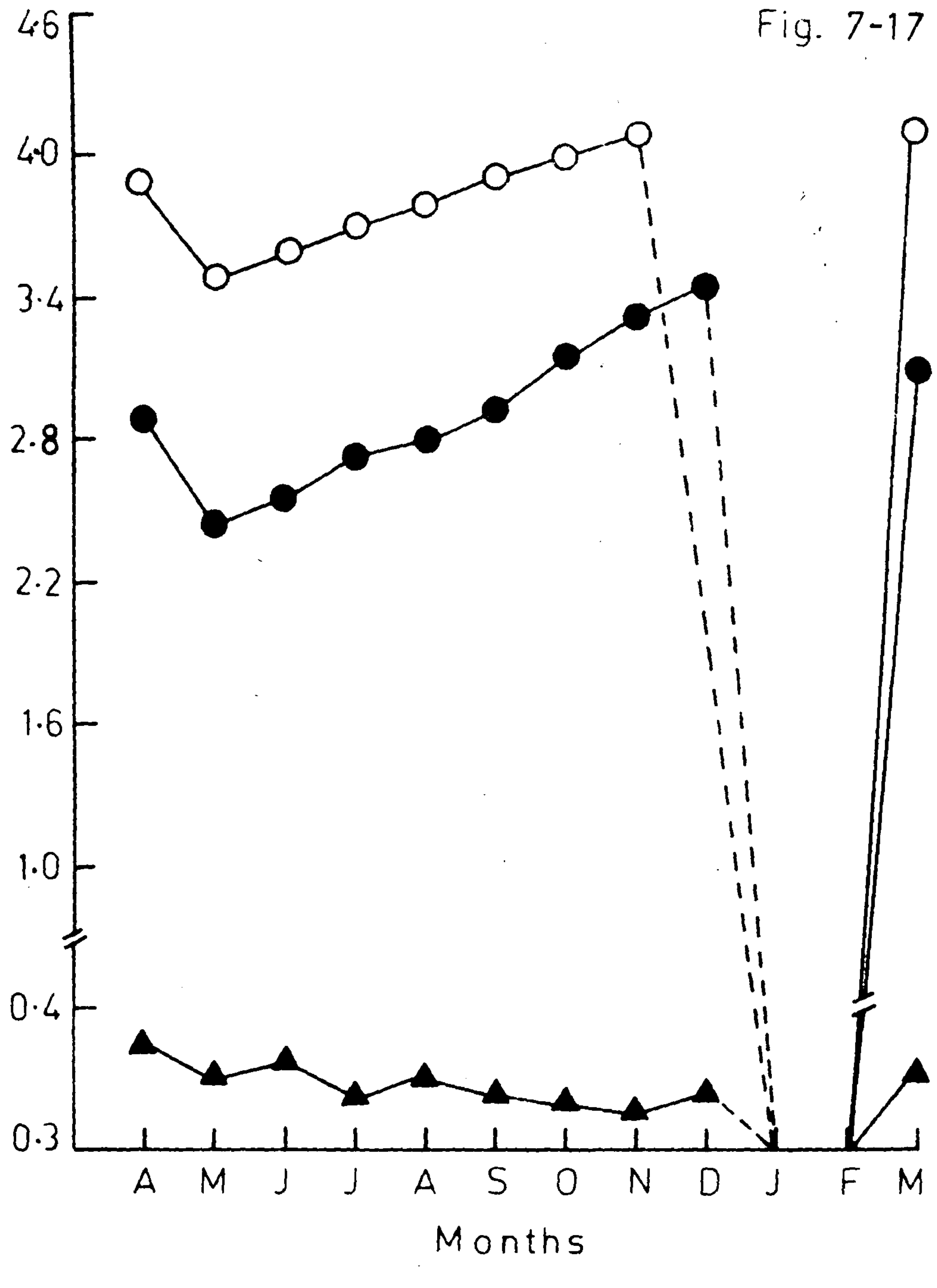


Fig. 7-17. Monthly variation in concentration of potassium in different water samples. Throughfall, ● ; stemflow, ○ ; incident rainfall, ▲ .

Fig. 7-17



4·6
4·0
3·4
2·8
2·2
1·6
1·0
0·4
0·3
k concentration (mg/l)
A
M
J
J
A
S
O
N
D
J
F
M
Months

Fig. 7-18. Monthly variation in concentration of calcium in different water samples. Throughfall, ● ; stemflow, ○ ; incident rainfall, ▲ .

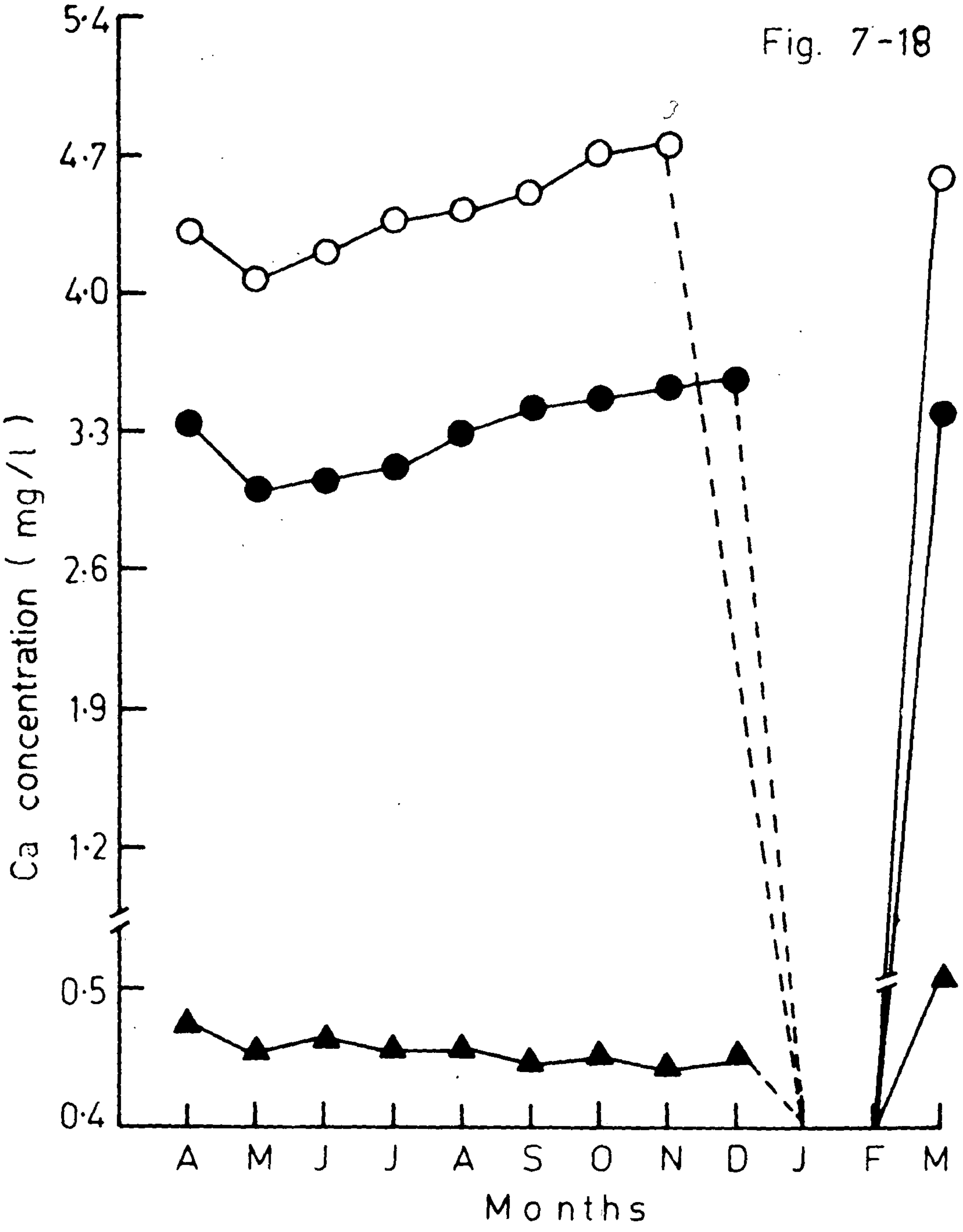
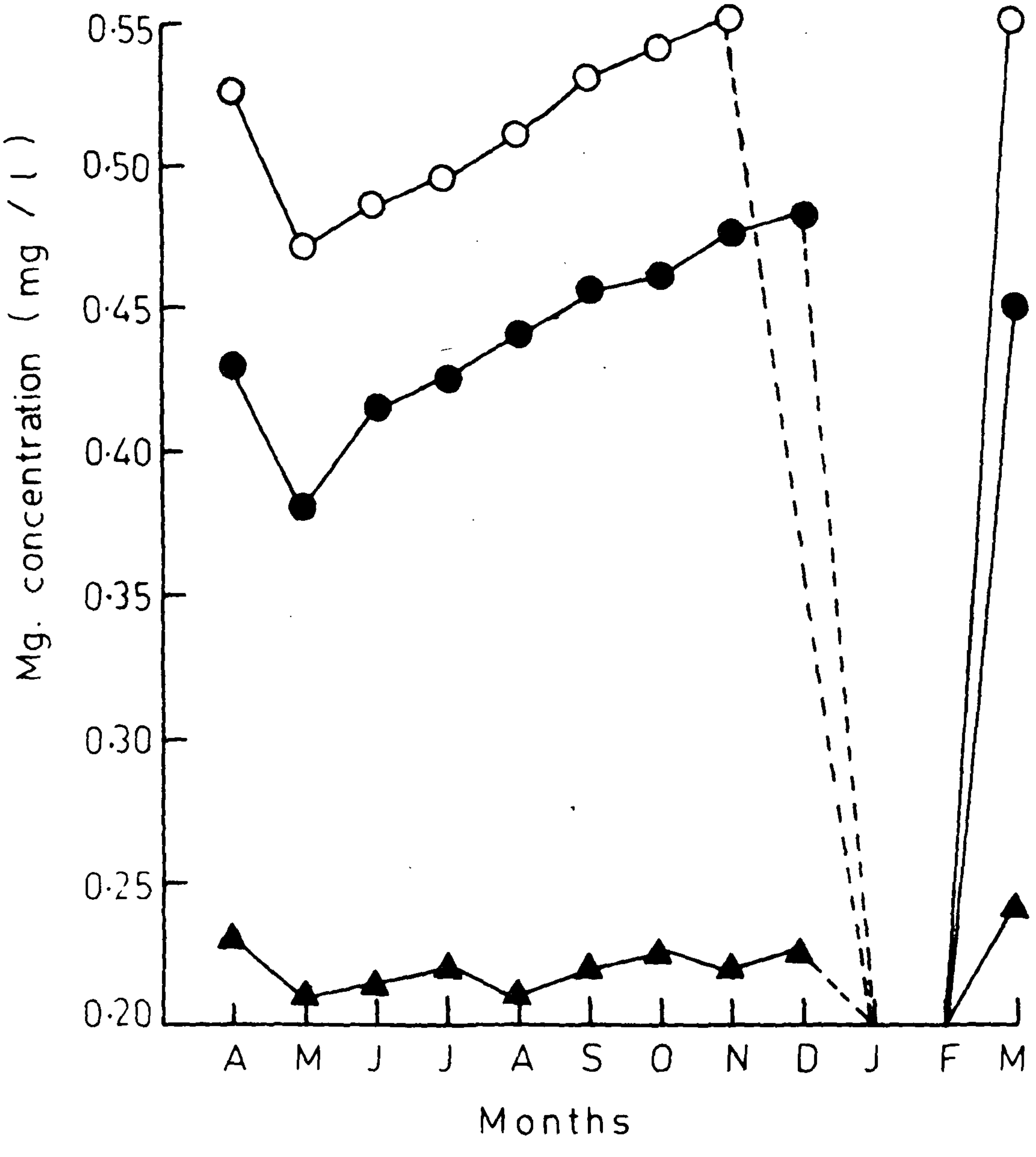


Fig. 7-18
Ca concentration (mg/l)
5·4
4·7
4·0
3·3
2·6
1·9
1·2
0·5
0·4
A
M
J
J
A
S
O
N
D
J
F
M
Months

Fig. 7-19. Monthly variation in concentration of magnesium in different water samples. Throughfall, ● ; stemflow, ○ ; incident rainfall, ▲ .

Fig. 7-19



0·55
0·50
0·45
0·40
0·35
0·30
0·25
0·20
Mg. concentration (mg / l)
A
M
J
J
A
S
O
N
D
J
F
M
Months

of nutrient from leaves which further gets enriched from the bark of the stems and (iii) low quantities of water in stemflow and the consequent high concentration of nutrients. A significant monthly variation could be observed in the concentration of N in the incident rain, which was very low compared to that in the throughfall and stemflow.

Incident rain had very low concentrations of phosphorus during the rainy season. The slightly higher level of P in the incident rain during March-April may be due to (i) high level of dust particles in the atmosphere during the preceding dry period, (ii) presence of partly burnt particles of organic matter due to burning of slash in the neighbourhood during this period due to shifting agriculture and (iii) low rainfall during this period with lesser dilution of this element. The concentration of P in throughfall is on the average three times more than that in incident rain. In throughfall P concentration gradually increased reaching a maximum in August followed by a slow decrease in subsequent months. The gradual increase in concentration up to August may be attributed to the presence of high pollen concentration in the canopy due to flowering of many species that occurred in the forest and also due to the production of new leaves during this period which may have higher level of phosphorus. Similar observations were also made by Carlisle et al (1967) working on sessile oak forest in England. During the leaf fall period of March-April the level of phosphorus was low in comparison to other months of the year. A similar monthly pattern was also observed for stemflow except that the concentration of P on the average was two times higher than that for throughfall. This higher level of P in stemflow could be accounted as due to the additional release of this nutrient due to bark decay along with that comes from the leaves, as discussed earlier.

The monthly pattern for potassium, calcium and magnessium concentrations in throughfall, stemflow and incident rainfall was similar (Fig. 7-17,18,19). The gradual increase in concentration from the month of May to December is probably related to gradual maturation of the new leaves produced in April and the consequent increase in release of some of these nutrients from more mature leaves an observation also made by Tukey et al (1958), Will (1959) and Deneyer-De Smet (1966).

The concentration of K, Ca and Mg was very low in the incident rain and was very high in the stemflow, the concentration in throughfall was intermediate between the two. Higher concentration of these elements in stemflow is similar to that observed for N and P for reasons already given earlier. Between these three elements, the concentration of calcium was more in stemflow due to high levels of this in the bark, as discussed elsewhere. In March the concentration in the incident rainfall was higher, decreasing in April and May after which it remained steady. High concentrations in March-May may partly be due to low rainfall and the wash out from dust particles. Throughfall and stemflow for these three elements showed a similar pattern through the rainy season. The concentration was higher in March reaching very low values in May after which the concentration increased gradually upto December. After the formation of abscission layer in December a sharp decrease in concentration would be expected as reported by Tukey et al (1958). However, the high concentration found in throughfall and stemflow in March and April is due to atmospheric dust and blow off of ash etc. from slash and burn agriculture discussed earlier.

The total amount of nutrients (kg/ha/yr) contributed through stemflow, throughfall and incident rain (Table 7-10) showed that throughfall contributed 98% of all the nutrients in comparison to that through stemflow. This low addition through stemflow is inspite of the high concentration of nutrients in the stemflow water, as the total quantity of stemflow is far less than that due to throughfall. It may be recalled that stemflow accounted only 8% of the total rainfall whereas throughfall was 53% of the total.

Amongst the cations, calcium and potassium were highly leachable with heavy wash out through stemflow and throughfall. Between nitrogen and phosphorus, leaching of the former was far greater. The high amount of some of the nutrients in incident rain might be due to contamination of these elements due to slash and burn as well as due to heavy dust accumulation in the atmosphere during the preceding drier winter months. The total quantities of different nutrients reaching the soil by throughfall, stemflow and incident rain was in the order of : ca>k>N>Mg>P.

Comparison of present values regarding nutrient leaching showed that return of nitrogen to the forest ecosystem by throughfall was more than the values reported by George (1979) for an *Eucalyptus* plantation but lower than

Table 7-10. Nutrient return through stem flow, throughfall and rainwater at Lailad forests.

	Nutrients (kg/ha/yr)				
	N	P	K	Ca	Mg
Stem flow	0.17	0.02	0.71	0.84	0.10
Throughfall	8.39	0.89	31.28	35.19	5.03
Total	9.56	0.91	31.99	35.93	5.13
Rainwater	4.33	0.43	7.80	9.96	4.77
Difference	5.23	0.48	24.19	24.97	0.63

the values reported for Hubbard Brook ecosystem (Table 7-11). It was comparable to those of other temperate forests. Phosphorus values in this throughfall study was more than that reported for an Eucalyptus plantation in India and that obtained for some temperate forests ; it was lower than the values reported by Carlisle et al (1966b) and Szabo and Csortos (1975). However, the values for potassium, calcium and magnesium in throughfall in this study in general was higher than that obtained by other workers. The stemflow release of different nutrients obtained in this study was more than that reported in most of the earlier ones. These differences may be related to differences between forest types, quantity and pattern of rainfall and even to atmospheric factors like dust, pollutants etc.

In conclusion it may be mentioned here that the leaching of elements from the stem and forest canopy by precipitation is dependent on a number of factors. Eaton et al (1973) reported that nutrients are generally recognized as being associated with organic molecules (N,P) moved more slowly from the forest canopy, while nutrients commonly found in ionic form (K) move more rapidly. Further nutrients

Table 7-11. Nutrient inputs by throughfall, stemflow and precipitation in different forest communities of the world.

Community	Locality	Water source	Nutrients (kg/ha/yr)					Authority
			N	P	K	Ca	Mg	
Oak forest	Hungary	Throughfall	17.28	2.08	27.02	23.28	4.55	Szabo and Csortos (1975)
		Stemflow	-	-	-	-	-	
		Precipitation	20.09	1.32	7.43	17.40	2.31	
Temperate forest (Hubbard Brook Ecosystem)	U.S.A.	Throughfall	10.60	0.63	26.94	6.98	1.98	Eaton *et al* (1973)
		Stemflow	1.11	0.10	3.51	0.64	0.19	
		Precipitation	2.43	0.05	0.37	0.89	0.17	
Sessile Oak forest	England	Throughfall	8.82	1.31	28.14	17.18	9.36	Carlisle *et al.* (1966)
		Stemflow	-	-	-	-	-	
		Precipitation	9.54	0.43	2.96	7.30	4.63	
Oak Forest	England	Throughfall	-	-	24	14	4	Madgwick and Ovington (1959)
		Stemflow	-	-	-	-	-	
		Precipitation	-	-	30	24	10	
Black spruce forest	Minnesota	Throughfall						

in young growing tissues are quickly metabolized within the cells and are therefore difficult to leach while in older tissues the nutrients are in an exchangeable form and therefore could be more easily released. Aerosols and dust may adhere to leaves, branches and stems and thus add significantly to the chemical concentration of throughfall and stemflow (Carlisle et al, 1967; Duvigneaud and Deneyer-De Smet, 1964). Intensity of rain, leaf composition weight of leaves and branches etc. are some of the important overriding factors in determining nutrient return by rain.

Run-off and percolation losses through water :

The concentrations of different mineral elements namely nitrogen, available phosphorus and cations like potassium, calcium and magnessium, lost through run-off showed much fluctuation in different months. The high concentration of N in run-off water in the month of March-April (Fig. 7-20,21,22,23 and 24) may be due to lesser rainfall in these months and the consequent lesser dilution effect. The peak in concentration was reached during August-September and this may be related to greater release of nutrients from fastly decomposing litter on the forest floor. It may

Fig. 7-20. Monthly variation in concentration of nitrogen in different water samples. Surface run-off, ● ; percolation, ○ .

Fig. 7-21. Monthly variation in concentration of phosphorus in different water samples. Surface run-off, ● ; percolation, ○

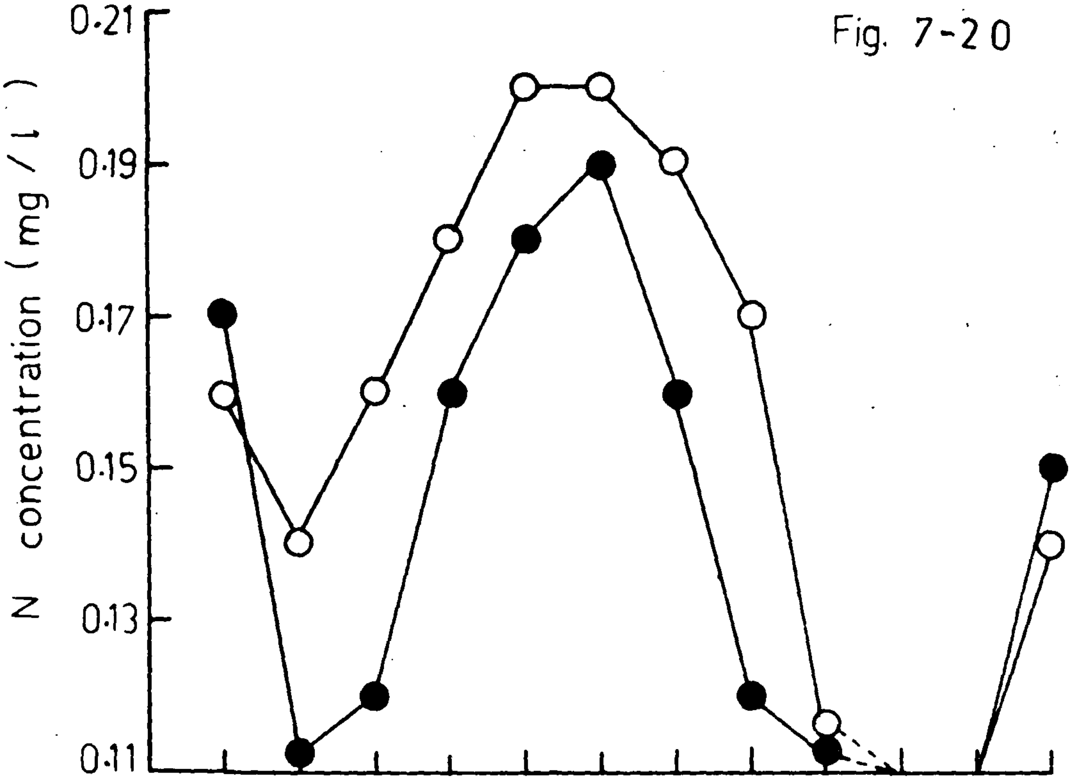


Fig. 7-20

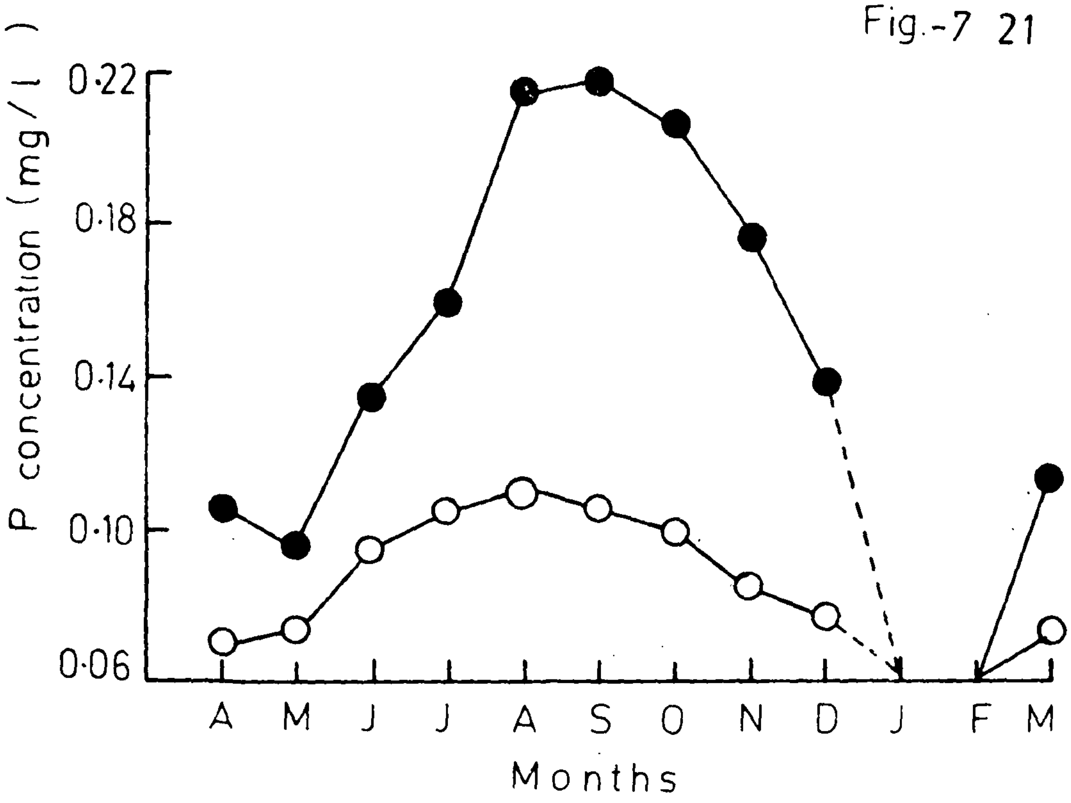


Fig.-7 21

Fig. 7-22. Monthly variation in concentration of potassium in different water samples. Surface run-off, ● ; percolation, ○ ;

Fig. 7-23. Monthly variation in concentration of calcium in different water samples. Surface run-off, ● ; percolation, ○ .

Fig. 7-22

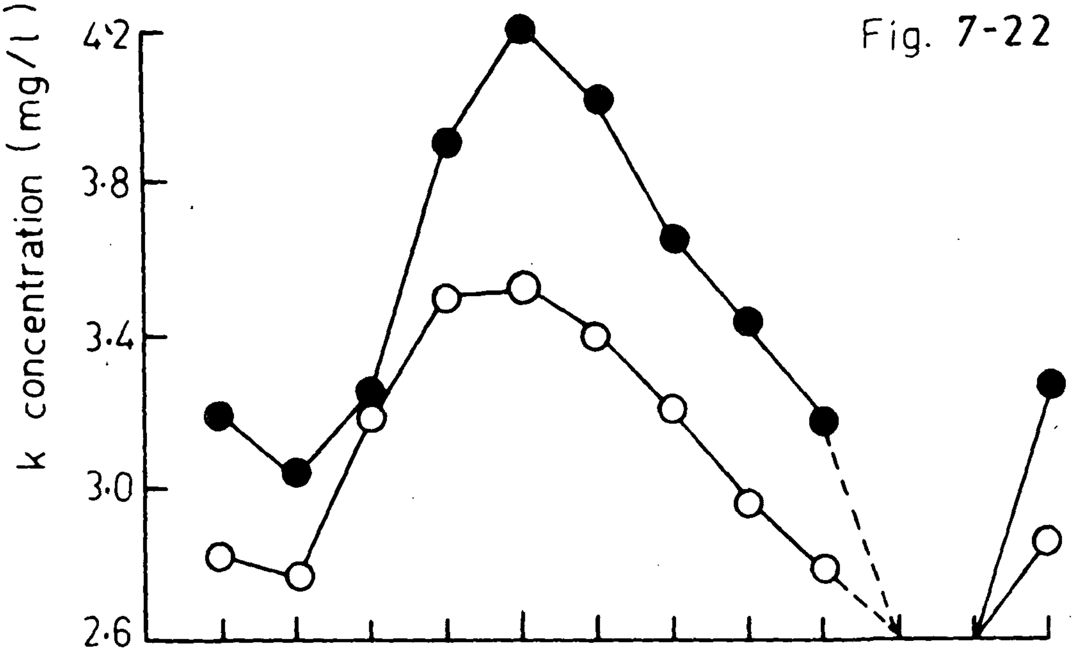


Fig. 7-23

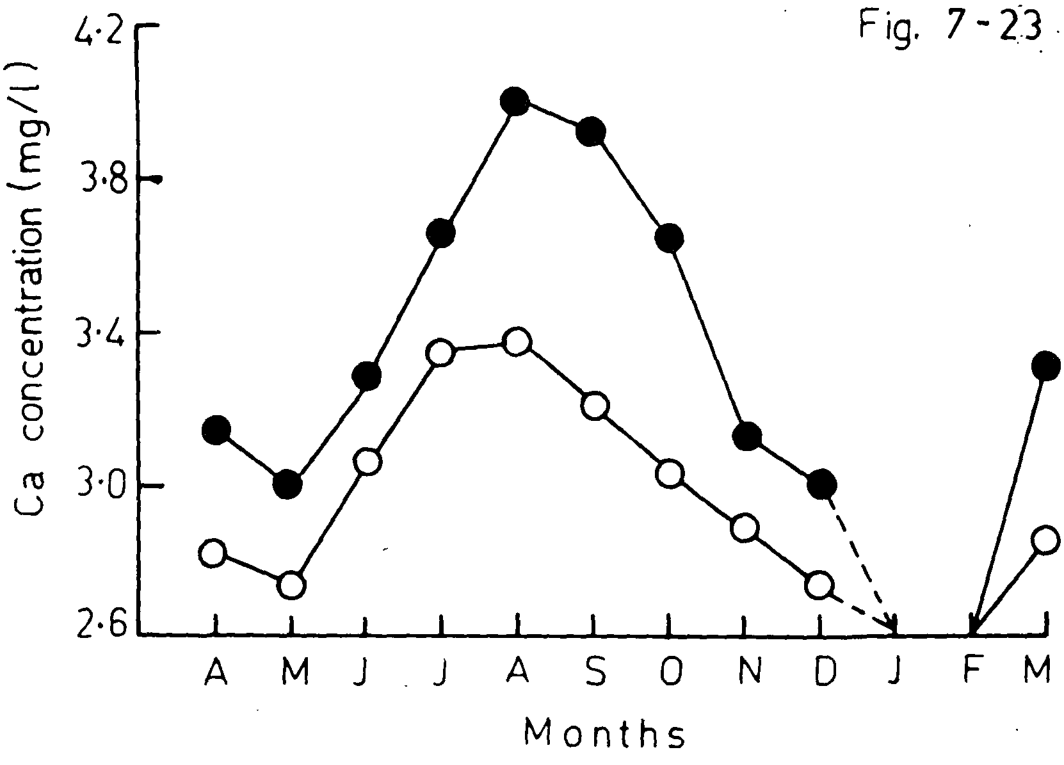
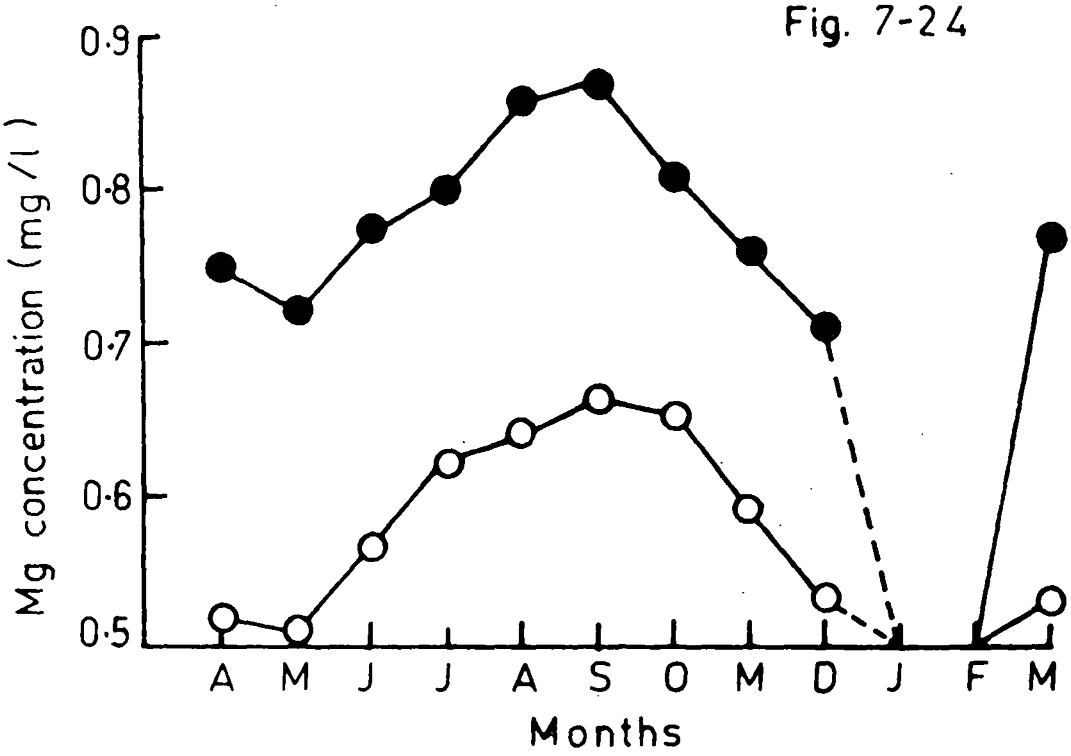


Fig. 7-24. Monthly variation in concentration of magnesium in different water samples.

Surface run-off, ● ;

percolation, ○ .

Fig. 7-24



be noted that the litter deposited during March-April gets ideal conditions during the early monsoon period of May-July with high temperature, humidity and rainfall. Part of this nutrient pool released from litter thus may increase the concentration in the run-off and percolation water during the subsequent months with a peak in August-September. January and February are practically rainless and dry with no run-off and percolation losses. Whereas concentration of most of the nutrients was more in the run-off water, N concentration was in general higher in percolation water. The concentration of nutrients in percolation water also followed a similar pattern as that in the run-off water, in that peak values were higher during July-September with a minor peak during March-April (Fig. 7-20,21,22,23,24).

Potassium and calcium losses on the forested ecosystem were heavier compared to other nutrients losses. Run-off water loss being much higher compared to percolation loss of water, the losses of nutrients through run-off is also expected to be heavy as was found in the present case.

The results presented for clear cut forest, represents a site which was clear cut, burnt and cultivated for one year before being left a fallow. It is interesting to note that nutrient losses are extremely heavy from this deforested area. In fact even though the quantity of water lost through run-off and percolation is not more than 2 - fold and 3 - fold respectively compared to the Lailad forest, nutrient losses increased 7 - fold and 6 - fold respectively compared to the forested site. This is partly due to sudden increase in nutrient pool due to burn and also due to rapid nitrification of the soil initiated after clear cutting and burning.

Nutrient status of forest soil :

Along the soil profile the soil colour changed from dark brown at the top getting lighter through depth and was reddish at a depth of 70-100 cm. The dark colour of the soil in the upper layers is due to humus in this region. The upper layers of the profile are sandy loam becoming sandy at lower depths. Moisture content throughout the profile was not very different (Table 7-12). However, moisture level in the soil was higher during the monsoon compared to drier winter months. The soil moisture was slightly more in peripheral zone, compared to central zone of the forest

Table 7-12. Physical properties of soil.

Soil depth (cm)	Soil colour	Textural class	Moisture content (%)	Bulk density (g/cc)	Porosity (%)
0 - 10	Dark brown	Sandy loam	22.83 ± 5.469	1.61	38.077
10 - 40	Light brown	Sandy loam	21.25 ± 4.653	1.78	31.538
40 - 70	Reddish brown	Sandy	21.18 ± 4.284	1.72	33.846
70 - 100	Reddish	Sandy	21.90 ± 3.806	1.70	34.614

(Fig. 7-25). Bulk density was less in the upper layer of the profile but increased in the region of 10-40 cm. due to more compact and loamy soil. At still lower layers, bulk density decreased as the soil was sandy.

The soil pH was slightly acidic with a great monthly variations. In general, pH decreased with increase in soil depth throughout the year. During dry winter months (December-February) the soil was less acidic (pH 6.65-6.70) but during rainy season the pH decreased to 5.90. This decrease in soil pH during the rainy period of May-July could be related to heavy material from the surface layers of the soil. The slight increase in pH at a depth of 100 cm may be related to increase of some of the cations like calcium at lower depths of soil. The soil pH was not significantly different in the peripheral zone and central zone of the forest though slightly less acidic in the central zone (Fig. 7-26).

Organic carbon was maximum in the surface layer of the soil (0.10 cm) and drastically decreased with increase in depth (Table 7-13, Fig.7-27). The level of organic carbon was lesser in the dry season but increased during the rainy season due to rapid decomposition of organic matter.

Table 7-13. Chemical properties - pH, Carbon-Nitrogen status, and available phosphorus concentration (mean values) with standard error.

Soil depth (cm)	pH			C/N	Available Phosphorus (ppm)
		Organic carbon	Total Nitrogen		
0-10	6.35±0.379	2.390±0.231	0.254±0.021	9.409±2.131	107±21.481
10-40	6.08±0.272	0.848±0.191	0.141±0.031	6.014±3.462	56±26.064
40-70	5.80±0.289	0.346±0.014	0.086±0.008	4.023±1.011	30±23.823
70-100	6.07±0.211	0.178±0.027	0.046±0.007	3.870±1.000	13±4.621

Fig. 7-25. Monthly and depth variation in soil moisture in (a) central and (b) peripheral zones of the forest at Lailad.

0 - 10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 7-25

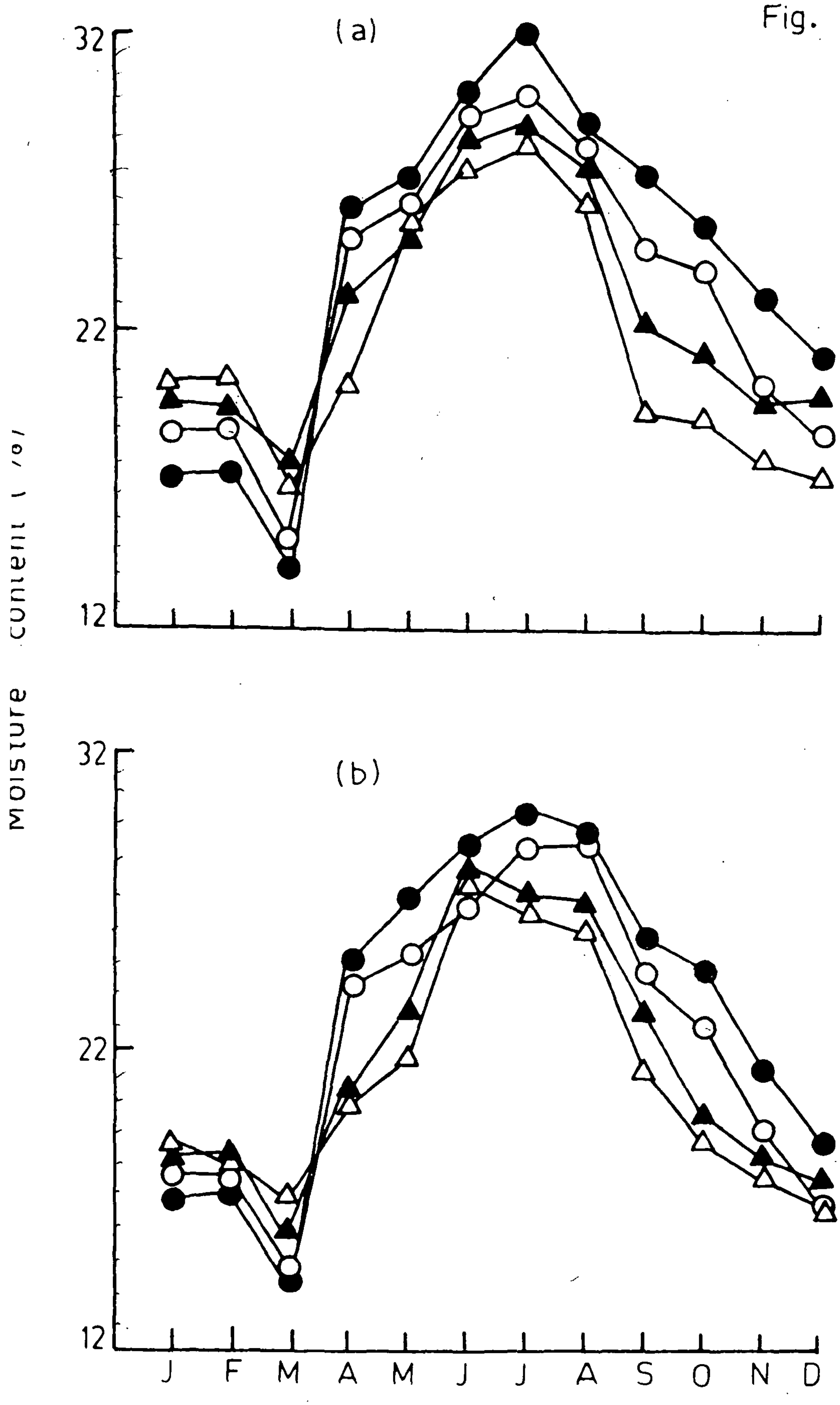
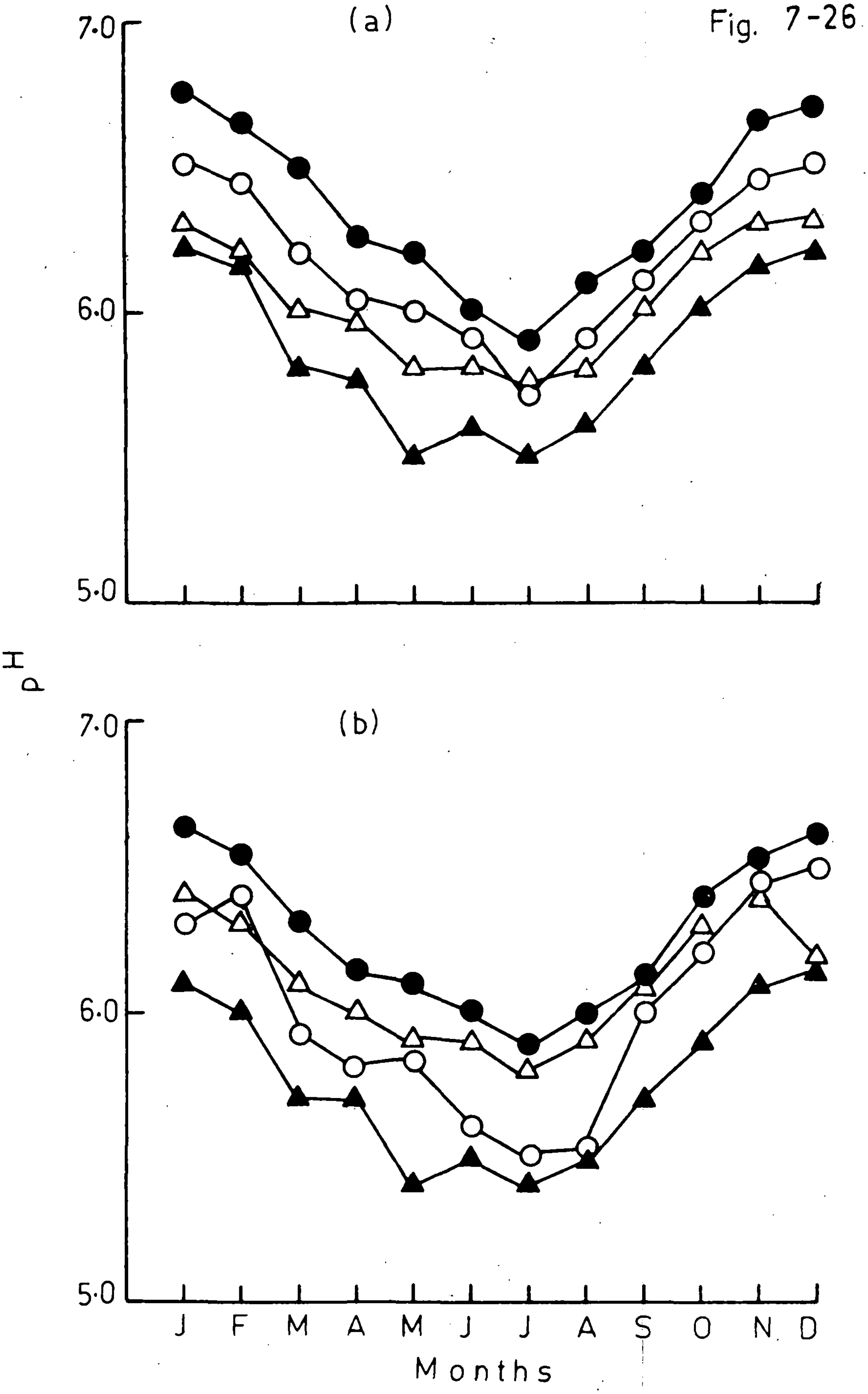


Fig. 7-26. Monthly and depth variation in soil pH in (a) central and (b) peripheral zones of the forest at Lailad.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 7-26



Organic carbon was in general, more in the central zone of the forest than along the peripheral zone due to more mature forests in the central zone and the consequent higher production of organic matter (Fig. 7-27). The pattern of distribution of nitrogen down the soil profile as well as monthly pattern are closely similar to that of organic carbon. (Table 7-13, Fig. 7-28). The fluctuation in the monthly pattern was least in the lower layers of the soil.

The C/N ratio of 9.4 in the surface layers obtained during the present study was found to be lower than 11.0 indicating rapid decomposition of organic matter (Lutz and Chandler, 1946). It may be noted here that the C/N ratio of temperate forests in general is very high due to slow decomposition of organic matter. For example, Geist and Stickler (1970) reported a ratio of 22.0 for the pine forests in U.S.A. It may be noted that C/N ratio decreased markedly with increase in depth of the soil due to low concentration of organic carbon (Table 7-13).

Phosphorus in the soil decreased markedly with depth. The monthly pattern showed that the concentration reached maximum during the rainy season (May-August) which

Fig. 7-27. Monthly and depth variation in concentration of organic carbon in (a) central and (b) peripheral zones of the forest.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 7-27

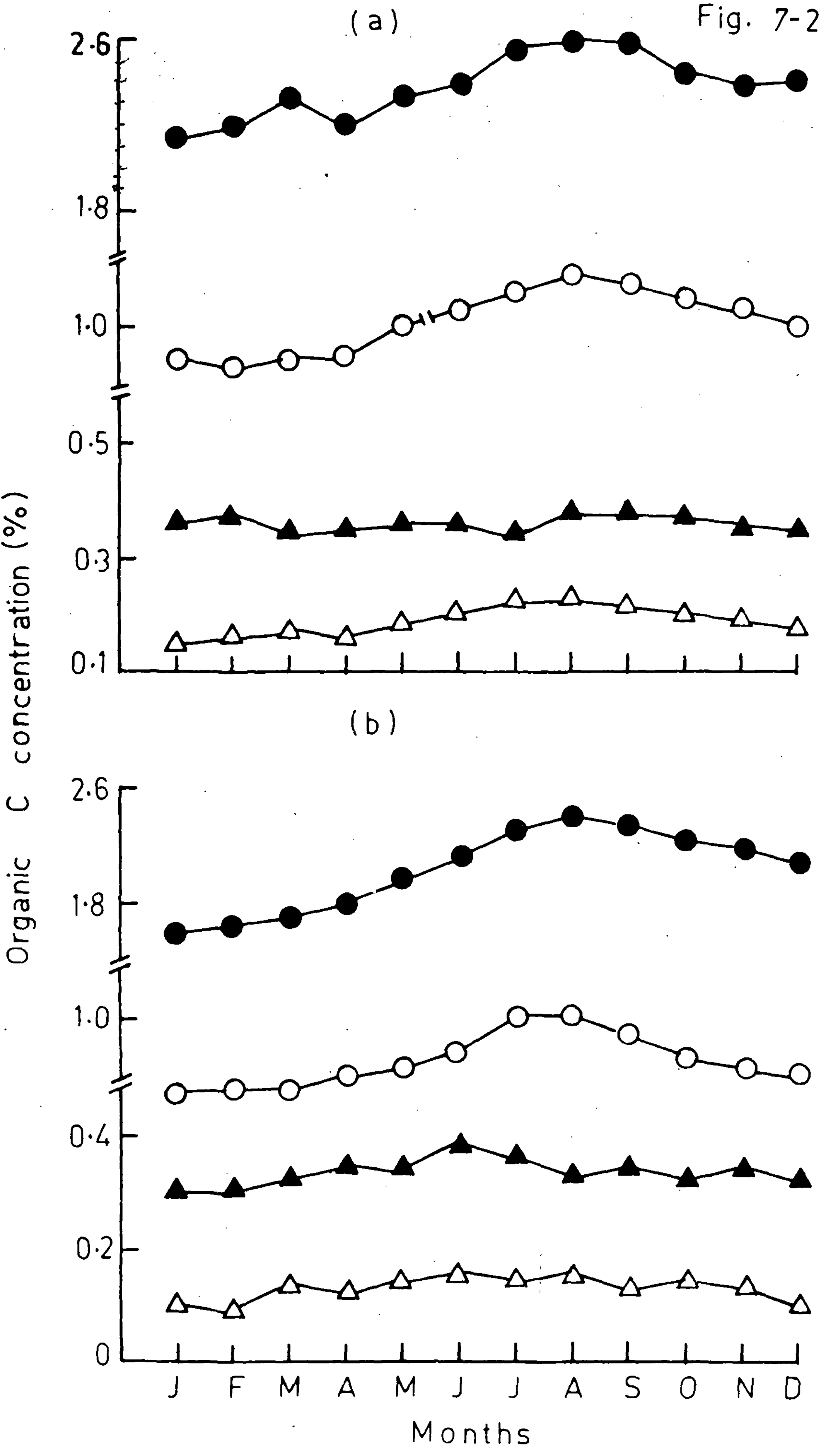
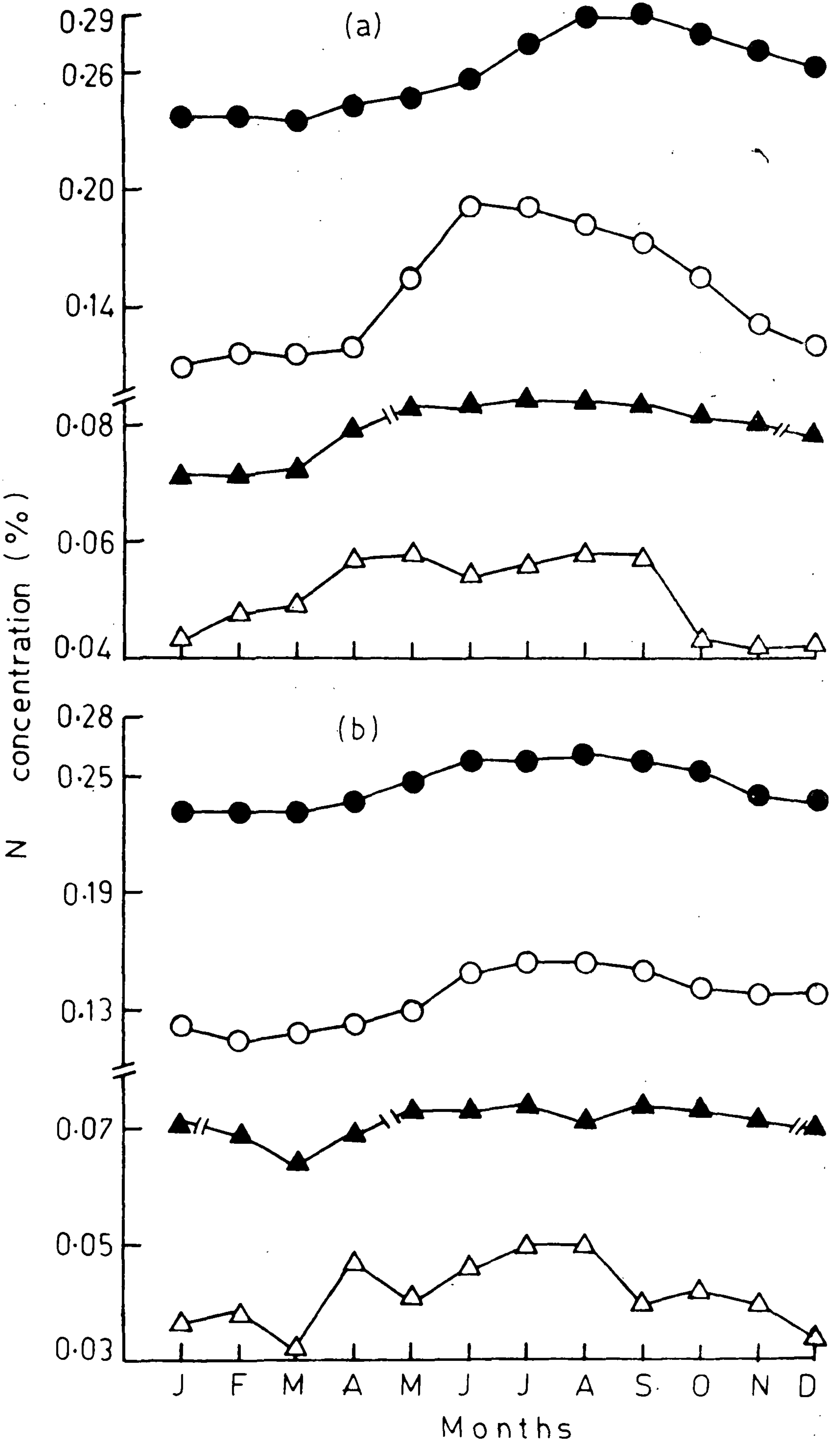

(a)
2·6
1·8
1·0
0·5
0·3
0·1
(b)
2·6
1·8
1·0
0·4
0·2
0
Organic C concentration (%)
J
F
M
A
M
J
J
A
S
O
N
D
Months

Fig. 7-28. Monthly and depth variation in concentration of total nitrogen in (a) central and (b) peripheral zones of the forest.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 7-28


(a)
0·29
0·26
0·20
0·14
0·08
0·06
0·04
(b)
0·28
0·25
0·19
0·13
0·07
0·05
0·03
N concentration (%)
J
F
M
A
M
J
J
A
S
O
N
D
Months

may be related to rapid release of this nutrient from the litter and declined during the dry winter months. This fluctuation was more pronounced in the upper layers of the soil. At a depth of 70-100 cm, the monthly fluctuation was the least (Table 7-13, Fig. 7-29). The concentration of available phosphorus was slightly more in the central zone of the forest than along the peripheral zone.

The concentration of the three exchangeable cations - calcium, potassium and magnesium was found to be maximum in the surface layer of the soil (0-10 cm) and decreased with increase in soil depth (Table 7-14, Fig. 7-30,31,32). This decrease was more marked in the case of potassium compared to calcium; magnesium was intermediate between the other two.

The monthly fluctuation in concentration of the three exchangeable cations followed a similar pattern in that the concentration was lower during dry winter months and significantly higher during the rainy season. But the increase in level of potassium (Fig. 7-30) during rainy season was more rapid reaching a high peak during July-September before the decline in concentration. This rapid rise in concentration of this element may be due to the

Table 7-14. The concentration of exchangable cations in forest soil (mean values).

Soil depth (Cm.)	Milli-equivalents per 100 gms.			Total
	Potassium	Calcium	Magnesium	
0 - 10	1.40 ± 0.615	1.05 ± 0.250	1.27 ± 0.271	3.72
10 - 40	0.98 ± 0.421	0.26 ± 0.210	0.57 ± 0.233	1.81
40 - 70	0.36 ± 0.208	0.21 ± 0.153	0.33 ± 0.165	0.90
70 - 100	0.09 ± 0.039	0.27 ± 0.110	0.34 ± 0.116	0.70

Fig. 7-29. Monthly and depth variation in concentration of available phosphorus in (a) central and (b) peripheral zones of the forest.

0-10 cm, ● ; 10-40 cm, ○ ;

40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 7-29

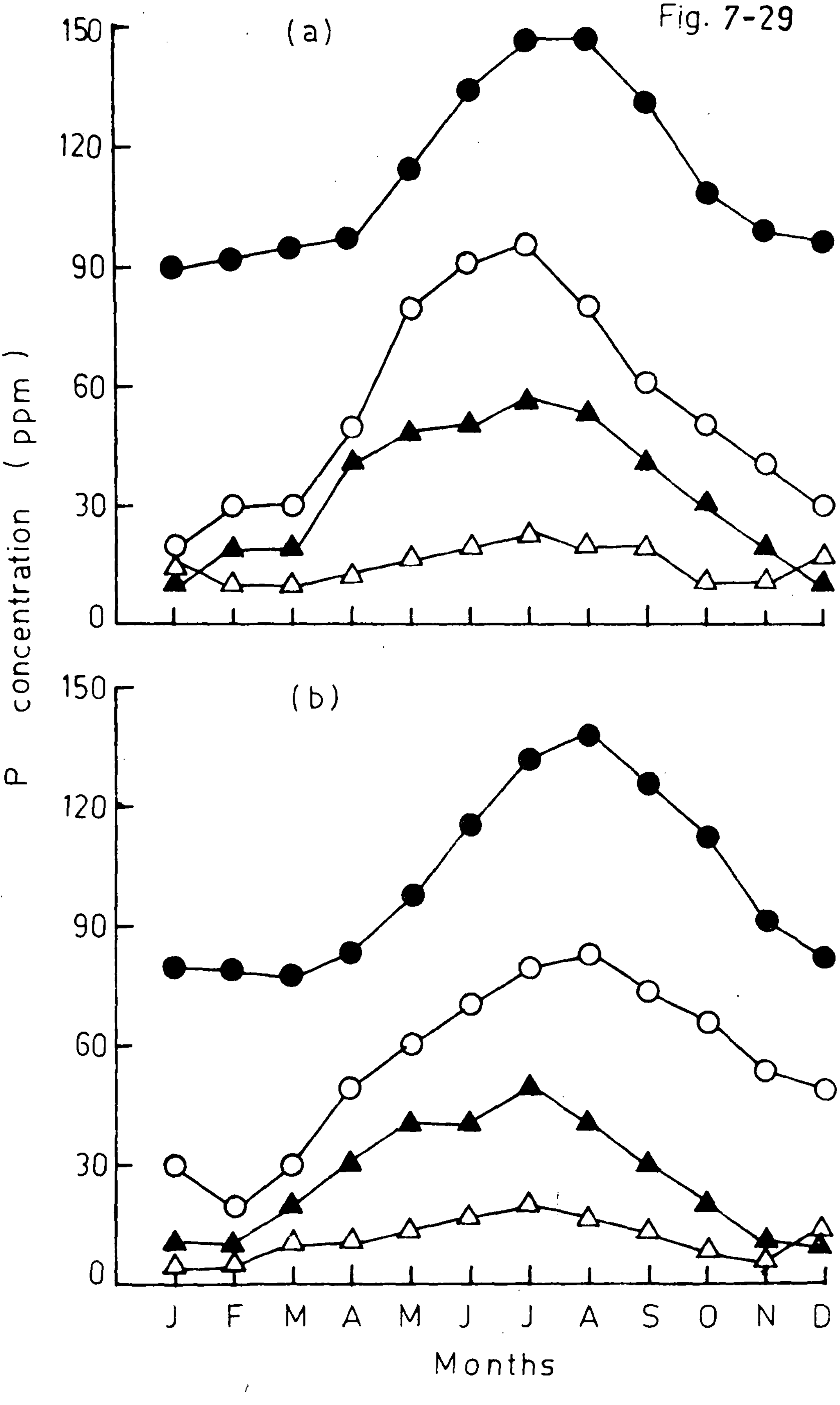

(a)
(b)
P concentration (ppm)
150
120
90
60
30
0
J
F
M
A
M
J
J
A
S
O
N
D
Months

Fig. 7-30. Monthly and depth variation in concentration of exchangeable potassium in (a) central and (b) peripheral zones of the forest. 0-10 cm, ● ; 10-40 cm, ○ ; 40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 7-30

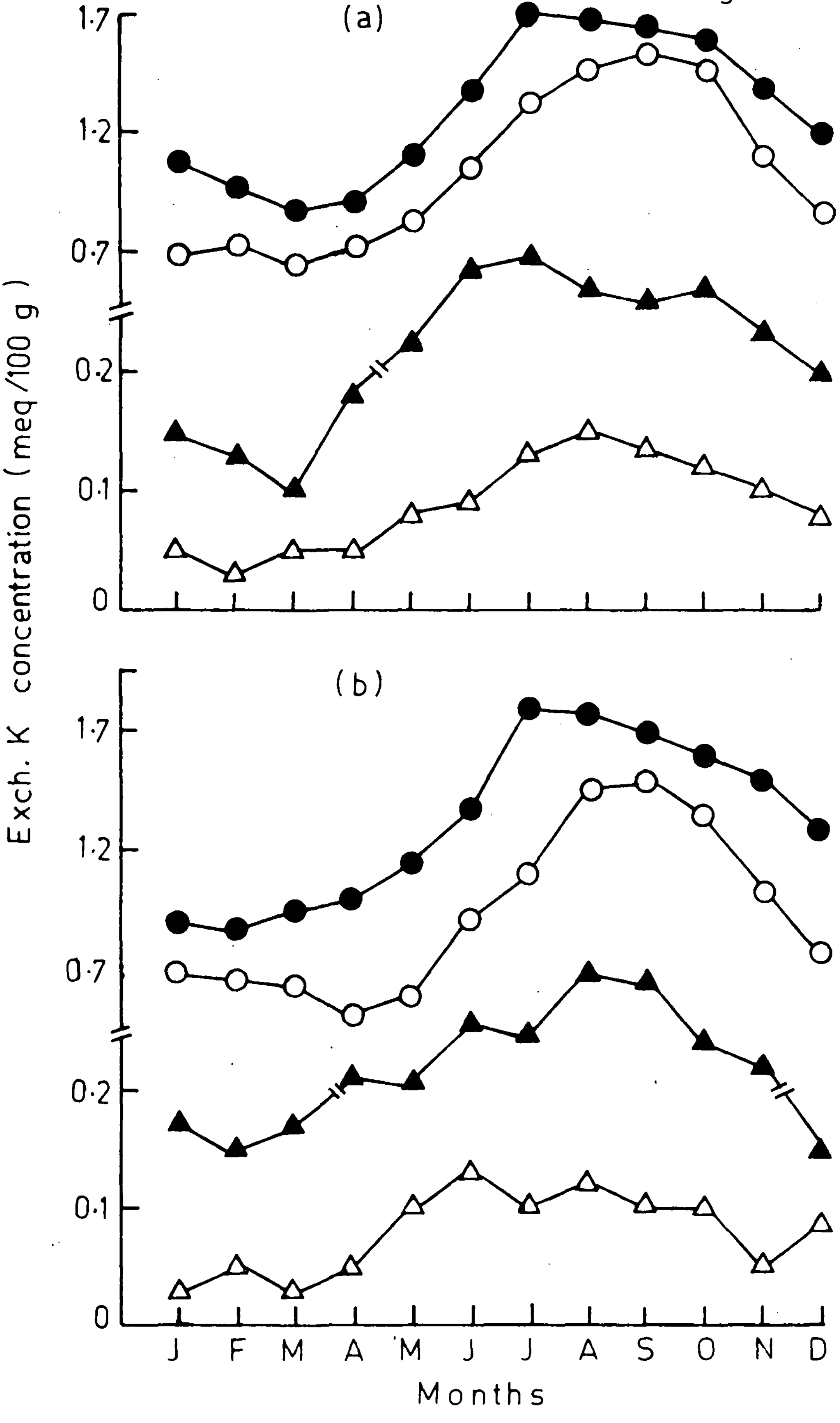

(a)
(b)
1·7
1·2
0·7
0·2
0·1
0
Exch. K concentration (meq/100 g)
J
F
M
A
M
J
J
A
S
O
N
D
Months

Fig. 7-31. Monthly and depth variation in concentration of exchangeable calcium in (a) central and (b) peripheral zones of the forest. 0-10 cm, ● ; 10-40 cm, ○ ; 40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 7-31

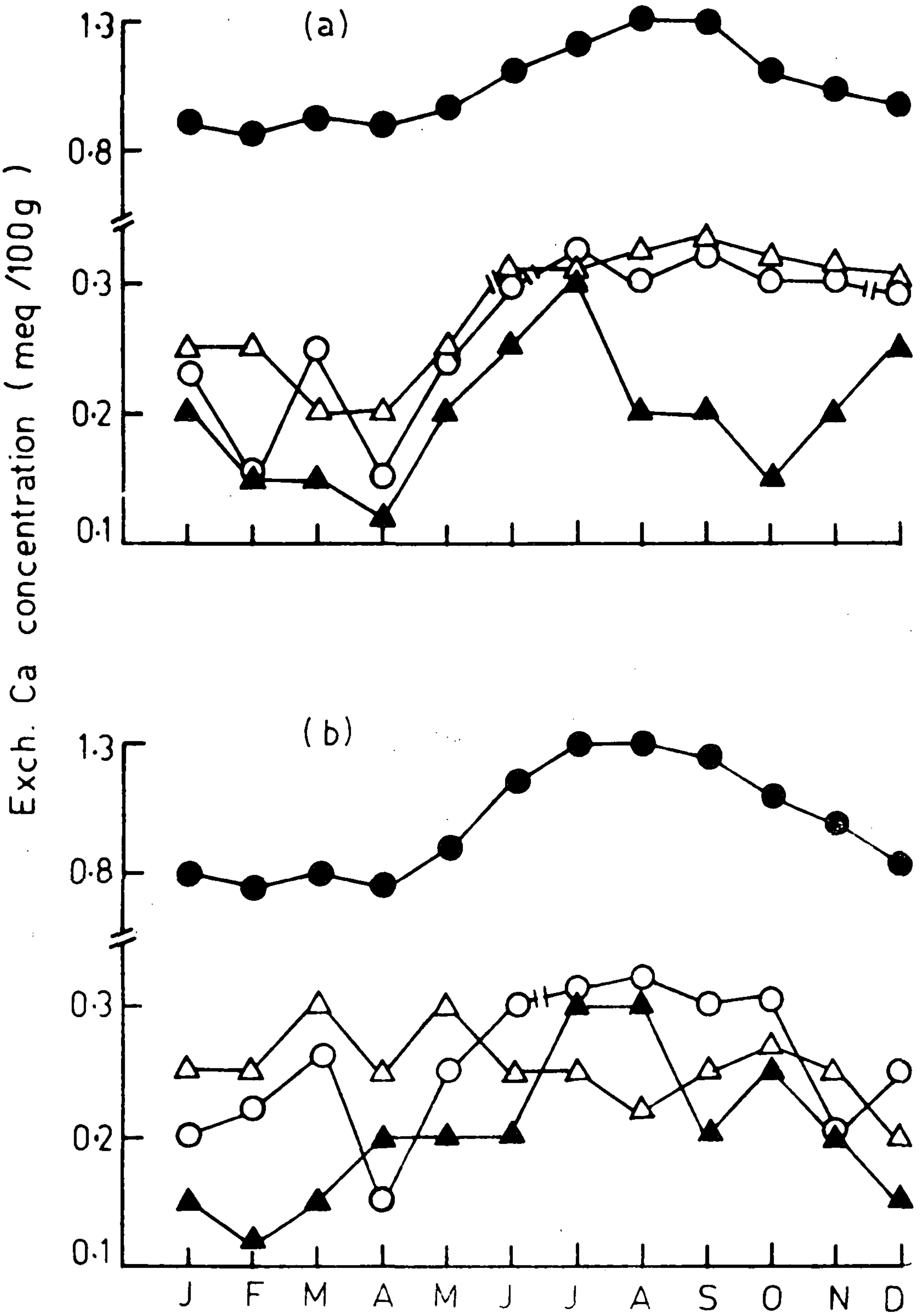

(a)
(b)
1·3
0·8
0·3
0·2
0·1
Exch. Ca concentration (meq /100g)
J
F
M
A
M
J
J
A
S
O
N
D
Months

Fig. 7-32. Monthly and depth variation in concentration of exchangeable magnesium in (a) central and (b) peripheral zones of the forest.
0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

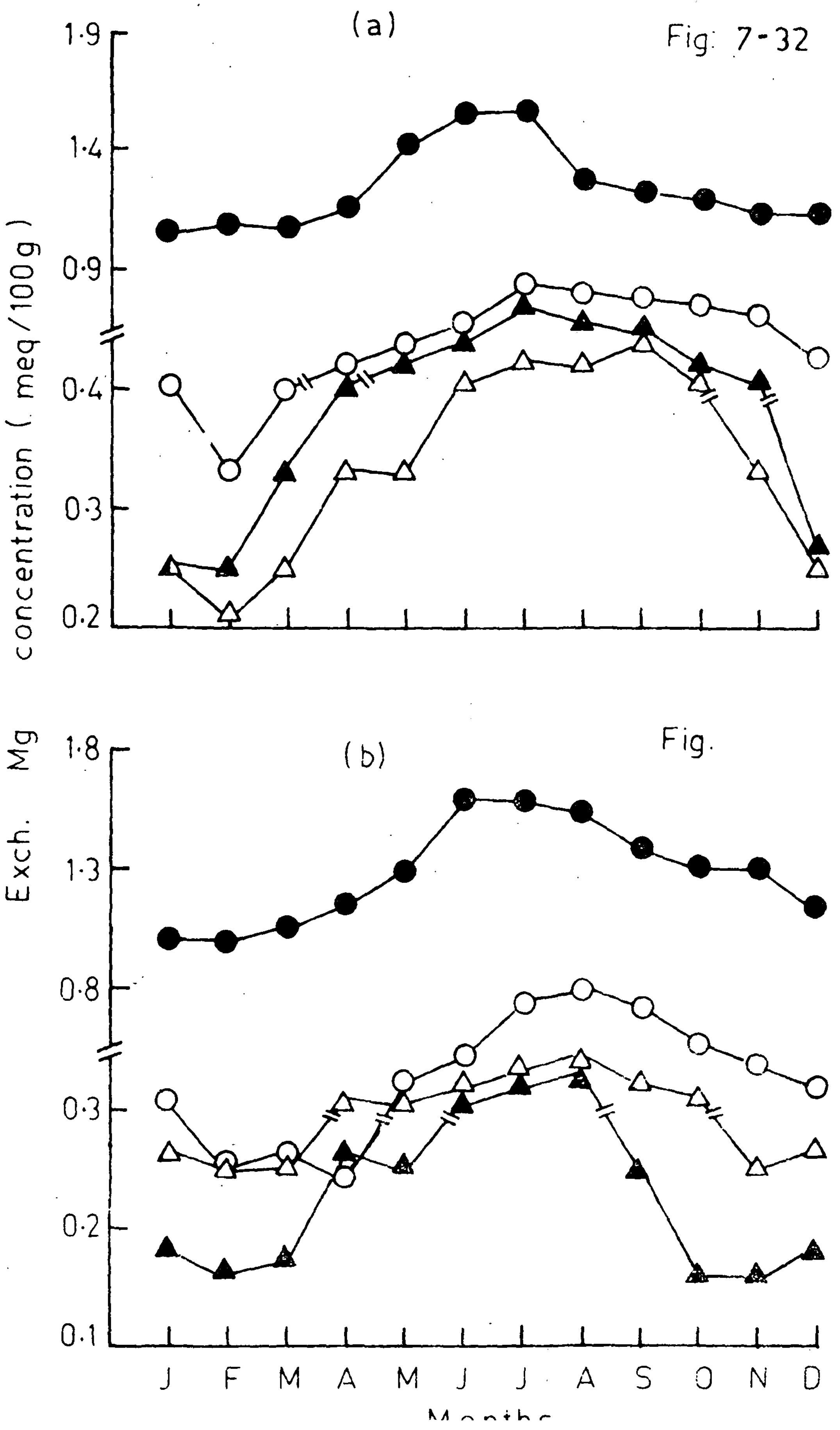


Fig: 7-32

Fig.

(a)
(b)
Exch. Mg concentration (meq/100g)
1·9
1·4
0·9
0·4
0·3
0·2
1·8
1·3
0·8
0·3
0·2
0·1
J
F
M
A
M
J
J
A
S
O
N
D
Months

more rapid release of this nutrient from decomposing organic matter and also due to higher levels in the throughfall (Tukey et al, 1958). The increase in level of calcium and magnessium in the soil during the rainy season was less prohounced compared to potassium. In general, the monthly fluctuation of cations was marked in the surface layers of the soil only. The slightly higher concentration of the cations along the peripheral zone of the forest particularly during the month of May-August may be related to leaching down of the nutrient from higher elevations of the central zone of the forest and the deposition along the peripheral zone.

The total amount of different elements (kg/ha) (Table 7-15) showed that the soil is rich in organic carbon and total nitrogen and the present values of these two elements were found to be higher than the values reported by Singh (1967) for a sub-tropical forest at Varanasi (India). But the amount of phosphorus was somewhat comparable to that reported by the above author. Amongst the cations the maximum amount was represented by potassium which was followed by calcium and magnessium (Table 7-15). The accumulation of a high amount of potassium and depletion of calcium

Table 7-15. Mineral status of forest soil at Lailad (kg/ha) (mean values).

Soil depth (cm)	Organic carbon	Total nitrogen	Phosphorus	Potassium	Calcium	Magnesium
0 - 10	38479.000	4089.400	172.270	861.350	325.220	296.240
10 - 40	45283.200	7529.400	299.040	2050.560	261.660	368.460
40 - 70	17853.600	4437.600	154.800	675.960	216.720	356.040
70 - 100	9078.000	2346.000	66.300	161.200	255.000	209.100

in an older tropical forest as was found in the present case was also reported by Zinke *et al* (1978). The low amount of calcium in the present case also can be explained on the basis of parental rocks. The soil of the study area was lateritic in origin which was rich in nitrogen but poor in cations.

The amount of nutrients held are greater in the surface layers of the soil. The profile analysis data as present in Table 7-15 shows that 10-40 cm depth is a layer of accumulation for all nutrients except calcium below which nutrient concentration decline drastically.

Nutrient circulation in the forest ecosystem :

In a forest ecosystem, the amount and distribution of nutrients depends upon the balance between the different processes concerned in the nutrient cycling. The build up of total amount of different nutrients like nitrogen, phosphorus, potassium, calcium and magnesium in a 50 year old forested stand at Lailad is shown in Table 7-16. It was found that maximum amount of nutrients in the living biomass is stored in the tree compartment due to its larger biomass. Amongst all the nutrients Ca represented 50% of the total probably due to its accumulation in the bole as discussed earlier and was followed by N,K,Mg and P with 21%, 13%,10% and 6% respectively. Within the tree compartment, the

Table 7-16. Distribution of nutrients in different components in a 50 year old forest ecosystem at Lailad.

Component		Nutrient elements (kg/ha)			
	N	P	K	Ca	Mg
<u>Standing crop</u> :					
a. Tree - Bole	604.99	146.92	379.56	1904.68	247.04
Branches	224.30	94.33	164.18	255.00	153.77
Leaves	81.44	37.88	45.29	109.57	41.51
b. Shrubs and herbs	42.04	5.79	10.64	31.47	7.36
Total	952.77	284.92	599.67	2300.72	449.68
<u>Soil</u> : 0-10 cm	4089.10	172.27	861.35	325.22	296.24
10-40 "	7529.40	299.04	2050.56	261.66	368.46
40-70 "	4437.60	154.96	675.96	216.72	356.04
70-100 "	2346.00	66.30	161.20	255.00	209.10
Total	18402.10	692.57	3749.07	1085.60	1229.84
<u>Input/year</u> :Litter	41.36	25.25	21.21	104.22	30.36
Precipitation	4.33	0.43	7.80	9.96	4.77
Stemflow and throughfall	5.23	0.48	24.19	24.97	0.63
Total	50.92	26.16	53.20	139.15	35.76
<u>Output/year</u>:					
Surface run-off	0.46	0.50	11.05	10.68	2.45
Percolation	0.21	0.11	3.84	3.73	0.72
Total	0.67	0.61	14.89	14.41	3.17

distribution of different nutrients in different organs like in the bole accounted for 72% of the total compared to 20% in branches and 8% in the leaves.

The most important feature of the nutrient cycling in forest ecosystem is the regular input of nutrients to the ecosystem through litter and precipitation. Litter which is shed over the forest floor throughout the year is derived from the trees, shrubs and herbs. Leaves are usually the largest components but bark, branches, stems, inflorescences and seeds also contribute to some extent. The litter which is continuously falling on the forest floor is very heterogenous being composed of organic material, differing greatly in structure and chemical composition. The total amount of litter fall in a year was estimated to be 5.5 t/ha in which the amount of Ca was maximum followed by N, Mg, P and K. Another important pathway for nutrient input into the ecosystem is precipitation, either direct or via throughfall and stemflow. However, the input of nutrients through precipitation was less than that added through stemflow and throughfall. Ca and K came through this pathway in larger quantities whereas the quantity of P was the lowest. While 72.7% of the total input of nutrients was through litter, 27.3% came through precipitation, stemflow and throughfall.

The gain of nutrients to forest ecosystem as a result of precipitation is offset to some extent by minerals which are carried away in water draining from the forest through surface run-off and percolation. Run-off losses are heavier compared to percolation losses (Table 7-16). K and Ca losses are heavier than that of other elements.

The nutrients which are added to the system through litter and via precipitation are incorporated into the forest floor. These nutrients along with the nutrients recovered through physical and chemical weathering of parental rocks and minerals soil enrich the soil. The surface layers of the soil contained more nutrients compared to deeper layers due to the surface deposition of nutrients through litter and through precipitation. The circulation of nutrients from one compartment to another as presented in Fig. 7-33 show the rate and magnitude of movement of nutrients, which differs greatly within the system. Thus, the ecosystem is not a closed circuit, since nutrients are continuously being added to or removed from the nutrient pools by various natural and artificial processes. The forest nutrient cycle has three segments, an input, an intracycle or system within which nutrient movement takes place, and an output. The input into the system is that comes through precipitation the rate of which has been estimated while inputs through biological nitrogen fixation and through soil weathering could not be estimated. The input through solids though likely to be negligible could not be calculated. The annual losses are chiefly through surface run-off and percolation of water within the soil which has been quantified. The rate of transfer of nutrients from the soil pool to the vegetation has been calculated on the basis of approximate estimations of productivity based on biomass increment data available for differently aged fallow developing during secondary succession after jhum (Toky and Ramakrishnan, unpublished). One of the major transfer routes from the vegetation to the soil is through litter, the annual rate of which is also available. The release of nutrients through root decay could not be estimated. The nutrient cycling in the Lailad forest on the basis of the present available information could be represented as in Fig. 7-33.

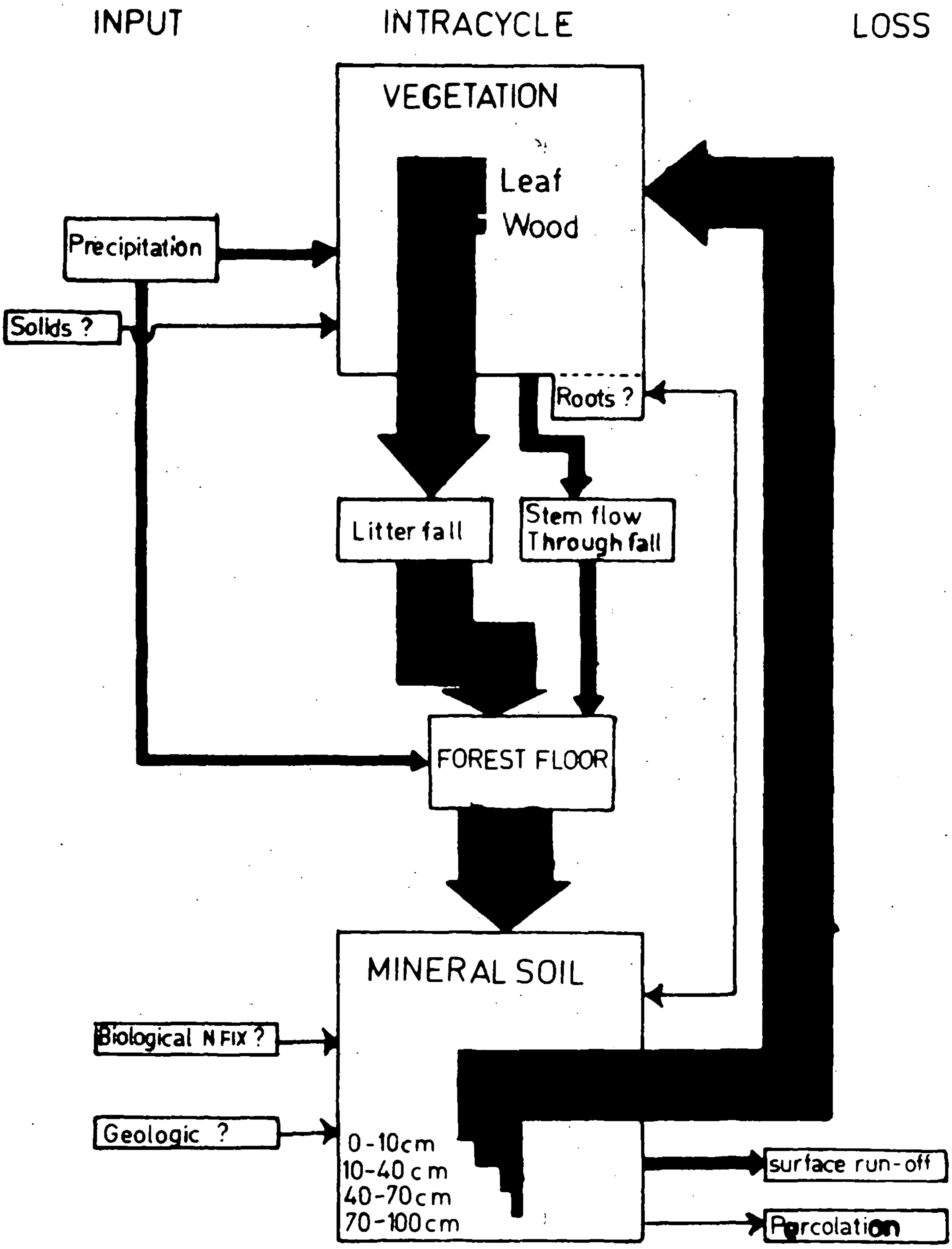
SUMMARY

The concentration of nutrients in different tree species and in different organs like bole, branches and leaves of the same species varied greatly. Total amount of nutrients present in the standing crop of the forest trees, shrubs and herbs were: N, 953; P, 284; K, 600; Ca; 2281 and Mg, 450 kg/ha, Out of this about 60% was in the central zone and the remaining 40% was present in the peripheral zone of the forest. *Sehima wallichii*, *Castanopsis indica*, *Shorea robusta* andd *Dendrocalamus hamiltonii* contributed more nutrients to the living compartment of the forest due to their greater biomass. The annual input of nutrients through leaf and wood litter of different tree species was found to be: N, 41; P, 25; K, 21; Ca, 104 and Mg, 30 kg/ha. A large proportion of these nutrients (about 50%) was through litter of the central zone of the forest. However, the monthly concentration of different elements in leaf and wood litter varied. Among the species *D. hamiltonii* contributed more to the peripheral zone, while in the central zone species like *S. wallichii*, *C. indica* and *S. robusta* contributed more. Nutrient addition through precipitation, throughfall and stemflow amounted to: N, 9.56; P, 0.91, K, 31.99; Ca, 34.93 and Mg, 36.39 kg/ha/yr. The input by stemflow and throughfall was more than that through precipitation. Comparison of nutrient discharge from the forested ecosystem through surface run-off and percolation with that after clear-cutting showed that in the deforested ecosystem the nutrient losses were about 6-7 times more than that from a forested ecosystem.

Soil was lateritic sandy loam with a pH ranging from 5.8 to 6.3. Concentration of soil nutrients was high during the rainy season due to their release from decomposing litter. The fluctuation in concentration of nutrients were well marked in the upper layers of the soil only. Soil nutrient pool had: N, 18402; P, 692; K, 3749; Ca, 1085 and Mg 1229/kg/ha up to a depth of 100 cm. The nutrient pool in the different compartments and their transfer within the system has been discussed.

Fig. 7-33. Nutrient cycling in a 50-year old forest at Lailad.

Fig. 7-33


INPUT
INTRACYCLE
LOSS
VEGETATION
Leaf
Wood
Precipitation
Solids ?
Roots ?
Litter fall
Stem flow
Through fall
FOREST FLOOR
MINERAL SOIL
Biological N FIX ?
Geologic ?
0-10cm
10-40 cm
40-70cm
70-100cm
surface run-off
Percolation

CHAPTER 8

GENERAL CONSIDERATIONS RELATED TO SHIFTING AGRICULTURE (JHUM) AROUND LAILAD

GENERAL CONSIDERATIONS RELATED TO SHIFTING AGRICULTURE (JHUM) AROUND LAILAD

Shifting cultivation which is locally known as Jhum is a traditional form of agricultural practice of the tribal population of the hill areas of the north eastern India (Ramakrishnan et al, 1980) and is also prevalent in many parts of the world (Nye and Greenland, 1960; Zinke et al, 1978; Ewel, 1976). An area of over one million hectares in the north-east is estimated to be under Jhum (Roy and Verma, 1976). This practice consists of cutting down the forests of various stages of development allowing the slash to dry for a few months and burning the slash before cultivation. After cultivation for sometime the land is left fallow, again to be cultivated in a few years. This Jhum cycle was formerly fairly long of about 30 years when the population pressure was not so great, but during recent times the higher population densities and reduced acreage has led to as short a cycle as 4-5 years which has adversely affected the quality of environment both in terms of soil fertility as well as forested vegetational cover.

The present study on a 50 year old forested vegetation at Lailad (25°45"N and 26°0" Latitude and 91°45" and

7

92°0" E Longitude) is one in the series of secondary successional communities that develop in the lower elevations of the Khasi Hills of Meghalaya, subsequent to Jhum cultivation. In the following account, this 50 year old forest community has been considered as one in the sequence of successional changes both from the point of view of biotic and abiotic events.

Secondary succession :

During secondary succession after jhum cultivation the vegetation underwent a number of qualitative and quantitative changes. The pattern of secondary succession in the fallows during the first few years when weedy species dominate varies considerably depending upon the jhum cycle and the agricultural practices. The most dominant weedy species are Eupatorium odoratum, Imperata cylindrica, Mikania micrantha, Saccharum spontaneum and Borreria hispida. Under short cycles and when cropping is done only during the first year, rhizome of bamboo, Dendrocalamus hamiltonii remain in the soil and sprout. Due to the more rapid growth of bamboo sprouts, they soon suppress other herbaceous weeds.

Under a long cycle, the herbaceous early colonizers dominate the fallow upto about 5 years after which the sprouts of D. hamiltonii take over (Table 8-1). The regeneration is mainly from fire resistant underground rhizome which store a lot of reserve food. Seedling regeneration also occurs, though sporadic. The broad picture of the population dynamics of bamboo is given in Table 8-2. Thus, this species progressively becomes dominant and reaches its peak in terms of both density and frequency in a 20 year fallow. Regeneration from sprouts is more or less steady upto about 20 years and then declines. Conversely the proportion of dead individuals progressively increased and reached a maximum in a 50 year fallow.

In a 20 year fallow, broad leaved species which are shade intolerant such as Vitex peduncularis, Schima wallichii, Terminalia ballerica, Bauhinia alba and Dillenia indica, are also frequent. In a 50 year fallow, besides a few shade intolerant trees like Schima wallichii, others like Shorea robusta, Castanopsis indica, Garcinia cowa and Eugenia communis also become established but none is able to achieve dominance in the community. The broad pattern of succession is given in Table 8-3.

A study of the secondary successional communities

Table 8-1 I.V.I. values of important species in jhum fallows of different ages (partly based on Toky and Ramakrishnan, unpublished).

Name of species	Age of fallow (year)				
	0	5	10	20	50
Grewia elastica	71.2	-	-	-	-
Thysanolaena	35.9	-	-	-	-
Imperata cylindrica	23.9	48.8	-	-	-
Eupatorium odoratum	30.8	53.3	-	-	-
Arundinella bengalensis	19.7	28.5	-	-	-
Ficus hispida	11.5	-	26.1	16.7	-
Panicum khasianum	10.3	12.1	-	-	-
Panicum maxima	9.6	11.2	11.0	-	-
Ensete superba	9.3	-	-	-	-
Carex cruciata	-	11.3	-	-	-
Setaria glauca	-	10.3	-	-	-
Cymbopogon khasiana	-	9.2	-	-	-
Dendrocalamus hamiltonii	-	1.9	33.8	53.8	10.0
Cyperus globqosus	-	-	28.8	-	-
Litsaea sp.	-	-	11.4	-	-
Maesua sp.	-	-	6.9	-	-
Combreqtum sp.	-	-	6.0	-	-
Macaranga sp.	-	-	6.4	-	-
Melia arborea	-	-	6.5	-	3.0
Machillus sp.	-	-	5.4	-	-
Vitex peduncularis	-	-	-	38.5	23.0
Schima wallichii	-	-	-	35.3	32.0

Terminalia bellerica	-	-	-	33.8	-
Vitex glabrata	-	-	-	28.3	-
Bauhinia alba	-	-	-	27.8	-
Dillenia indica	-	-	-	27.8	-
Careya arborea	-	-	-	26.7	-
Castanopsis indica	-	-	-	-	27.0
Carcinia cowa	-	-	-	-	25.0
Eugenia communis	-	-	-	-	13.0
Prunus aminata	-	-	-	-	10.0
Psychotria sp.	-	-	-	-	9.0

Note : stump sprouts not included

Table 8-2 Analysis of bamboo (Dendrocalamus hamiltonii) vegetation in jhummed areas (partly based on Toky and Ramakrishnan, unpublished).

	Age of fallow (year)				
	5	10	15	20	50
Frequency	25	80	85	100	40
Density (Individual No./10m^2)	3.0	7.2	45.0	56.0	15.0
% of Dead shoots	0%	0%	3%	10%	58%
% of New shoots	45%	23%	41%	43%	9%
Circumference of shoot (cm)	5	15	29	30	45

Table 8-3 Pattern of secondary succession after jhum at Burnihat (relative IVI % values in parenthesis) (partly based on Toky and Ramakrishnan, unpublished).

Age of fallow (year)	
1	Imperata cylindrica (87%) - Monocot weeds
	↓
2	Imperata cylindrica (32%) - Eupatorium odoratum (55%)
	↓
5	Eupatorium odoratum (69%) - Dicot trees (20%) - Imperata cylindrica (6%)
	↓
10	Dicot trees - Dendrocalamus hamiltonii (20%)
	↓
15	Dendrocalamus hamiltonii (35%) - Shade intolerant Dicot trees (21%) - Shade tolerant Dicot trees
	↓
20	Dendrocalamus hamiltonii (68%) - Dicot trees (Shade intolerant and shade tolerant) (19%)
	↓
50	Dicot trees (shade tolerant (81%) - Dendrocalamus hamiltonii (10%)

for diversity and dominance patterns indicates that there is little diversity in the early successional stages and progressively increases upto a 50 year fallow (Table 8-4). Dominance was maximum in a 5 year fallow where Imperata cylindrica and Eupatorium odoratum dominated. The present results are in agreement with those Mellinger and McNaughton (1975) who showed that species diversity increased and dominance decreased with progression of old field succession in New York. These results also seem to be in general agreement with the basic hypothesis of Margalef (1963, 1968) that succession is accompanied by increased biological diversity and reduced dominance.

Litter fall :

Total litter production in different successional communities is directly related to the age of the stands. Table 8-5 represents the total annual litter production in different successional communities which shows that litter production increased sharply from a 1 year fallow to a 10 year fallow followed by a gradual increase subsequently upto 20 years of age. After this, the litter production declined sharply in the mature stand of 50 years. This pattern of increase in litter production could be related to the rapid

Table 8-4 Species diversity and dominance in successional stands from younger to older fallows (partly based on Toky and Ramakrishnan, unpublished).

Successional ages of fallows (year)	Diversity	Dominance
0	0.12	0.215
5	0.21	0.705
10	1.01	0.519
15	1.48	0.556
20	1.50	0.501
50	2.58	0.115

Table 8-5 Total litter and biomass production in different successional ages of fallows (partly based on Toky and Ramakrishnan, unpublished).

Successional ages of fallows (year)	Litter production (t/ha/yr)	Biomass production (t/ha)
1	1.177	4.808
5	4.893	23.206
10	7.076	57.406
15	7.685	103.846
20	9.970	147.590
50	5.513	137.764

rate of growth of the community during the early stages of succession. The sharp increase in litter production upto 5 years may be due to rapid death and elimination of herbaceous species at this stage of development of the community. The high level of litter production in a 20 year fallow compared to that in a 50 year fallow could be due to (i) the presence of larger proportion of deciduous species in the early stages of succession (ii) the rapid growth of the early successional species which being shade intolerant tend to capitalize upon the light energy that is available in plenty at this stage and (iii) the rapid turn over of the entire vegetation at earlier stages of succession so that the whole individual may contribute to the litter on the forest floor due to their death and decay. A decline in litter production of more mature communities as compared to early successional ones has also been noted by Laudelout and Meyer (1954) and Ewel (1976).

Biomass :

The standing crop of biomass also increased with the increase in the age of different successional communities (Table 8-5). The total biomass of 4.808 t/ha in a 1 year fallow sharply increased upto 20 years. The data presented shows a slight decline in standing biomass in a 50 year fallow compared to that in a 20 year one. This seems to be an exaggeration as in a 50 year fallow the biomass contribution of the community was based on 11 dominant tree species only out of a total 28 tree species in the community alongwith the total biomass of all shrubs and herbs. If all the minor tree species in the community is considered then the value for a 50 year stand may equal to or slightly exceed that of a 20 year one. In any case it is apparent that the increase in biomass of a 50 year fallow is not likely to be as sharp as compared to communities of younger age. The sharp increase upto about 10 years compared to the level in a 1 year fallow could be accounted as due to a shift in species composition from herbs to bamboo in later stages. Another sharp increase from 10 to 20 year stand may be chiefly due to the peak dominance attained by bamboo in a 20 year stand.

Hydrology and nutrient losses :

Regrowth of vegetational cover during different successional stages after clear cutting and burning have great impact on hydrology and nutrient losses in the forest ecosystems. Studies on surface run-off, percolation and sediment losses in different successional fallows showed that these losses were maximum in a 0 year fallow where the cropping was done after clear cutting and burning the slash. These losses were sharply reduced in the fallows (Table 8-6). The slight increase in surface run-off in a 50 year fallow may be due to the slope of the study area. However, percolation losses and sediment losses were reduced to 1/3 and 1/12 in older stand of 50 years. High transpiration, evaporation and absorption of water by the forest reduced the surface run-off and percolation losses in old forested ecosystems (Leonard, 1961; Pierce *et al*, 1970; Bormann *et al*, 1974).

The losses of N, P, K, Ca and Mg from 0, 5, 10 and 50 years old fallows showed that maximum losses occured in a 0 year fallow and decreased sharply with the development of fallows (Table 8-7). The loss of Ca and K from a 50 year fallow as higher compared to other nutrients may be due to greater release of these two nutrients from the vegetation through litter decomposition. Timmons *et al* (1977) working in an Aspen-Birch forest ecosystem also reported that K and Ca losses were heavier in comparison to other elements from mature forests.

Recovery of soil fertility :

A number of physico-chemical changes occured in the

Table 8-6 Loss of water in different successional ages of fallows (partly based on Toky and Ramakrishnan, unpublished).

Age of the fallows (year)	Surface run-off (mm)	Percolation loss (mm)	Sediment loss (m t/ha/yr)
0 (after burning and cropped)	557.89	357.12	45.73
5	410.03	324.67	16.77
10	284.99	216.45	10.16
50	312.60	124.00	2.11

The annual rainfall during the study was 2166 mm.

Table 8-7 Loss of nutrient elements from different fallows (kg/ha/yr)
(partly based on Toky and Ramakrishnan, unpublished)

Nutrients	Age of the fallows (year)							
	0		5		10		50	
	Surface run-off	Percolation loss	Surface run-off	Percolation loss	Surface run-off	Percolation loss	Surface run-off	Percolation loss
N	8.07	14.05	1.23	1.62	0.70	0.76	0.46	0.21
P	1.31	0.09	0.20	0.03	0.08	0.02	0.49	0.11
K	77.74	20.82	1.43	0.81	2.54	0.32	11.05	3.84
Ca	210.35	6.95	3.07	4.06	1.69	2.38	10.68	3.73
Mg	15.24	3.46	2.05	1.30	1.27	0.76	2.45	0.72

soil during the fallow development resulting in the recovery of soil fertility. The total carbon of 9.750 kg/m^2 upto a depth of 40 cm in a 0 year fallow declined markedly after one year of revegetation and subsequently improved upto a 10 year fallow and declined markedly in a 15 year fallow (this is probably related to ground fire at this stage) and again improved slightly in a 50 year fallow but stabilized at a lower level than that of a 10 year one (Fig. 8-1). Accumulation of organic matter and nutrients by the native second growth vegetation is one of the important functions of the fallow period. It is the return of the organic matter to the upper soil depths which accounts for the restoration of soil fertility and the main pathway of it is the litter fall and its subsequent decomposition. The depletion of organic matter in the soil surface continued through the early successional fallows upto about 5 years. This was mainly due to low return of litter during the initial colonization and growth of the vegetation in the fallows dominated by species like Imperata cylindrica and Eupatorium odoratum and also due to faster decomposition in these open sites. This trend in reduction of soil humus upto 5 year fallow period could be one of the reasons against a short jhum cycle which has become so common in present times. Maximum level of soil humus is reached in a fallow of 10 year, though a slightly lower level was maintained in the soil under a 50 year fallow. Laudelout and Meyer (1954) and Ewel (1976) have made similar observations and conclude that organic matter production in mature stand is less compared to a secondary seral forest.

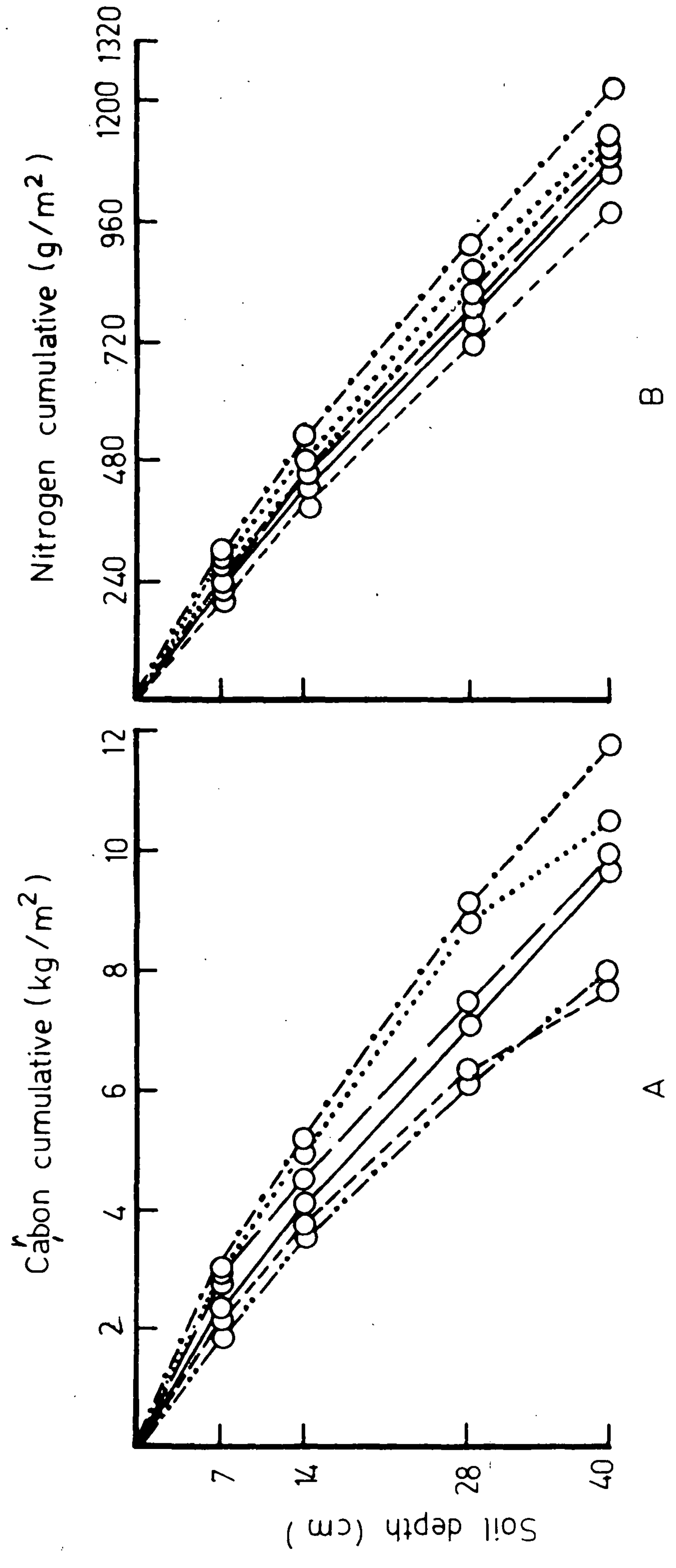
Total nitrogen upto a depth of 40 cm declined in a 1 year fallow when compared with that immediately after cropping (0 year fallow). Subsequently nitrogen status improved and reached its maximum under a 10 year fallow and in 15 and 50 year fallows it stabilised at a lower level (Fig. 8-1). The decline in nitrogen level upto 5 year during revegetation of the fallow could be partly due to low litter production and also due to rapid utilization of nitrogen by the fast growing plant cover. As for carbon, nitrogen level in the soil also reached its peak in a 10 year old fallow. The comparatively low level of both carbon and nitrogen attained in a 15 year fallow compared to a 10 year one could be explained as due to accidental spread of ground fire from slash and burn in adjoining areas.

Total available phosphorus declined in 1 and 5 year fallows and showed marked and steady improvement in 10, 15

Fig. 8-1. Changes in cumulative quantity of carbon (A) and nitrogen (B) within a soil column of 40 cm depth under fallows of various ages.

0 year,○——○; 1 year,○- - -○;
5 year,○-··-··○; 10 year,○-·-·-○;
15 year,○- —— ○;
50 year ○·······○.

Fig. 8-1



Cabon cumulative (kg/m^2)
2
4
6
8
10
12
Nitrogen cumulative (g/m^2)
240
480
720
960
1200
1320
Soil depth (cm)
7
14
28
40
A
B

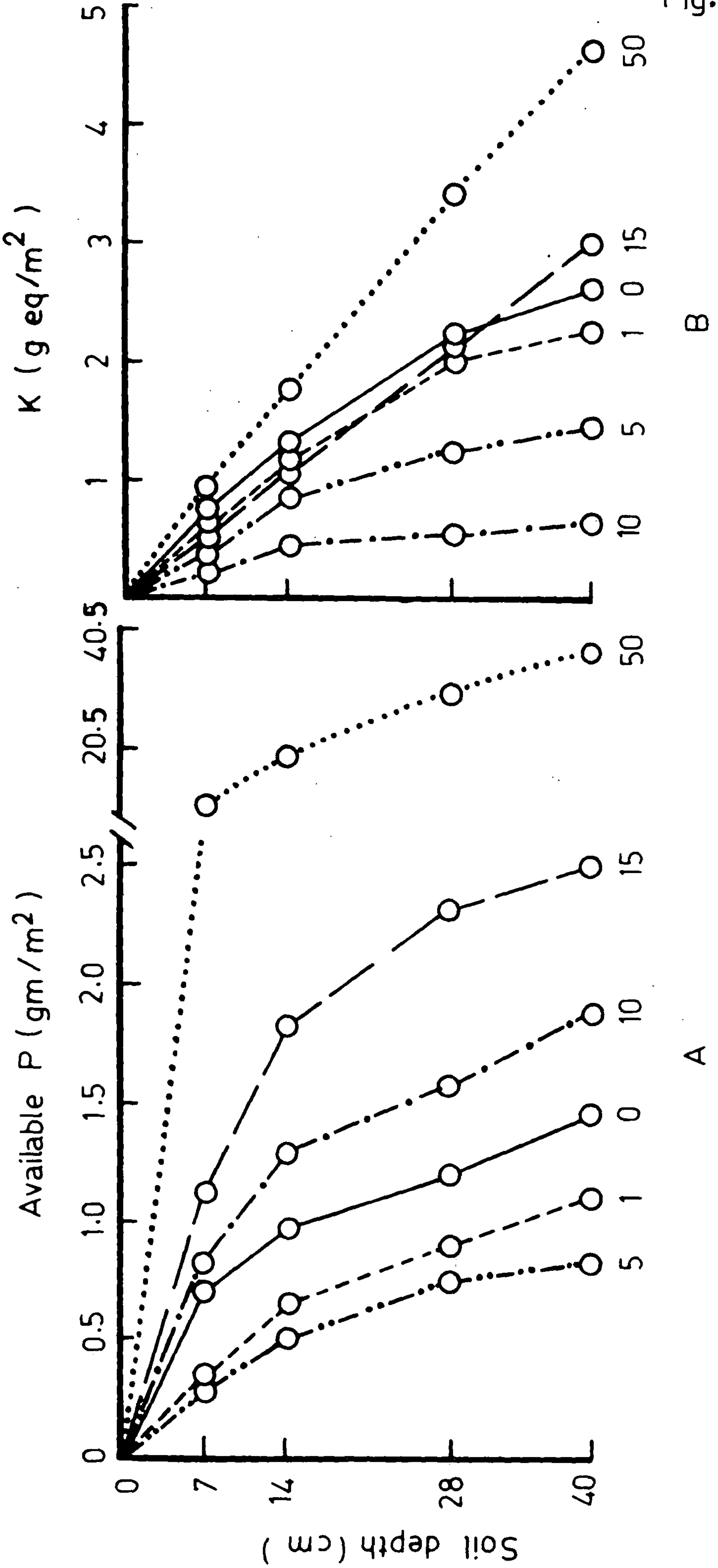
and 50 year fallows. Depletion of available phosphorus and with depth was also maximum in a 5 year fallow (Fig.8-2). During early phases of development of vegetation upto 5 years, there is a gradual depletion in available phosphorus throughout the profile reaching a minimum under a 5 year second-growth fallow. This is followed by a rapid build up through 10, 15 and 50 year fallows. The accumulation of phosphorus particularly in the surface layers of older forests may be due to transfer of phosphorus from the deeper layers of the soil to the upper stratum through litter fall (Nye and Bortheum, 1967; Russel, 1968).

Cumulative amount of calcium and magnesium followed a different trend from that of potassium. In the case of the former two, total level through the soil profile was least in a 50 year fallow and was maximum in 0 and 1 year fallow (Fig.8-3). In a 50 year fallow the depletion of these two nutrients was maximum with increase in depth of the soil. On the other hand, in a 50 year fallow potassium level was maximum and its enrichment through depth was also high. Least level of potassium in the soil was observed in a 10 year fallow (Fig.8-2). The exchangeable cations are depleted from the top column of the soil as the forest fallow develops due to the rapid absorption by the developing vegetation and

Fig. 8-2. Changes in cumulative quantity of available phosphorus (A) and exchangeable potassium (B) within a soil column of 40 cm depth under fallows of various ages.

0 year,○——○; 1 year,○----○;
5 year,○-••-○; 10 year,○-•-•-○;
15 year,○—-○; 50 year○•••••○;

Fig. 8-2

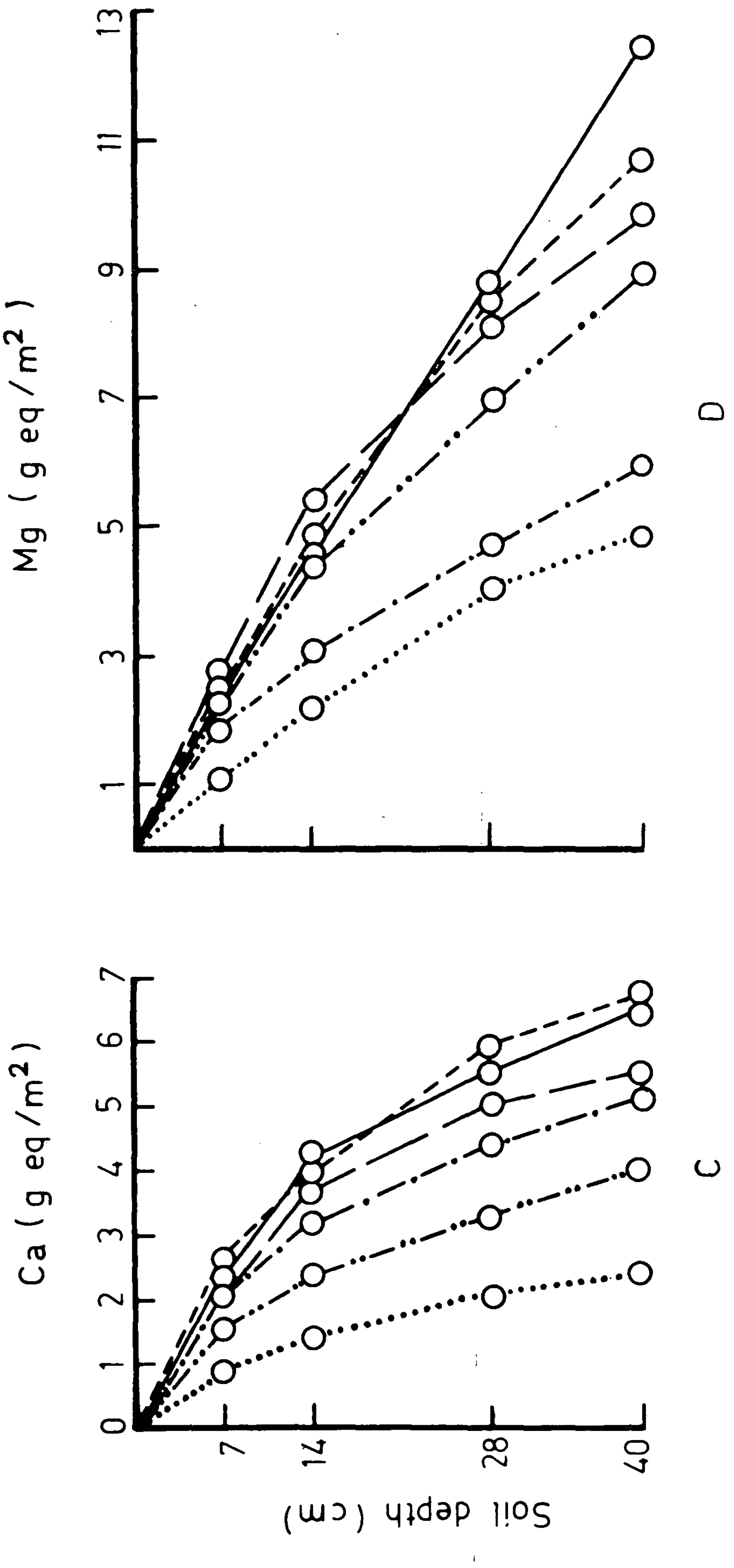


Available P (gm/m^2)
0
0.5
1.0
1.5
2.0
2.5
20.5
40.5
K (g eq/m^2)
1
2
3
4
5
Soil depth (cm)
0
7
14
28
40
50
15
10
0
1
5
A
B

Fig. 8-3. Changes in cumulative quantity of exchangeable calcium (C) and magnesium (D) within a soil column of 40 cm depth under fallows of various ages.

0 year,○——○; 1 year,○- - -○;
5 year,○-··-○; 10 year,○-·-·-○;
15 year,○- — -○; 50 year,○······○.

Fig. 8-3


Ca (g eq/m^2)
0
1
2
3
4
5
6
7
C
Mg (g eq/m^2)
1
3
5
7
9
11
13
D
Soil depth (cm)
7
14
28
40

also due to erosion and percolation losses. Potassium accumulation by D. hamiltonii in a 10 year fallow is an example of rapid transfer of this nutrient from the soil pool to the living biomass component (Toky and Ramakrishnan, unpublished). Valentine (1976) working with the changes in soil chemical characteristics after clear cutting and burning of forest in South Western Australia also reported that the level of exchangeable potassium, calcium and magnesium declined rapidly in the first 7 years after the regeneration burn, which may be due to rapid transfer from the soil pool to the living biomass. As the age of the jhum fallows increased, beyond 10 years, soil cationic level and particularly that of potassium increased due to faster return of nutrients into the soil through litter fall from a mature stand of vegetation containing species like D. hamiltonii.

An old forest stand like a 50 year fallow discussed here, showed low levels of calcium and magnesium in soil and rapid depletion of both with depth which is in contrast to the pattern observed for potassium which maintained very high levels. Thus the recharge of calcium and magnesium in the soil seems to be much more fire dependent whereas potassium release due to litter fall recharges the soil pool resulting in a very high level in a 50 year old fallow. It may be noted here that D. hamiltonii which is a dominant feature in the vegetation only upto about 20 years of regrowth of the forest accumulates potassium in the biomass upto this stage and discharges it into the soil pool when this species dies out and is replaced by dicot trees during the course of succession. Zinke et al (1978) in the 'Lua' forest fallow system concludes that the sum of basic cations is highest at the beginning of the cycle at the time of slash and burn, with a gradual discharge of soil calcium and magnesium as the forest fallow regrows in contrast with potassium which had a high level in the soil under an old forest, an observation similar to the present one.

SECTION - II

STUDIES ON GROWTH, PRODUCTIVITY AND NUTRIENT CYCLING IN *SHOREA ROBUSTA* GAERTN. PLANTATIONS AT UMTESOR

CHAPTER 9

GROWTH ANALYSIS AND PRODUCTIVITY OF *SHOREA ROBUSTA* GAERTN.

GROWTH ANALYSIS AND PRODUCTIVITY OF SHOREA ROBUSTA GAERTN.

INTRODUCTION

The study of growth patterns is a dynamic technique which separates growth into component processesto study the effect of endogenous and exogenous influences. Growth analysis includes the measurement of bud break, leaf development shoot elongations etc., along with productivity estimates. Measurements of productivity of dominant tree species in different woodlands is of great importance because they greatly influence the magnitude and pattern of energy flow, which is stored in trunks, branches, leaves and roots in the form of various organic substances and the material remain in continuous circulation between the biotic and abiotic components of the ecosystem. The measurement of forest productivity in units of stem volume is not compatible with the complete tree utilization system. Detailed information in production and weight relations of various tree species are required to evaluate their usefulness for the maximum yield concept and complete tree utilization (Young, 1978).

Comprehensive reviews of biomass and productivity of temperate, evergreen, sub-tropical and tropical forests of the world has been given by Ovington (1962, 1965), Rodin and Bazilevich (1967, 1968), Kira and Shidei (1967), Tadaki and Hatiya (1968), Satoo (1968, 1970, 1971) and Lieth (1972). In tropical and temperate deciduous woodlands a considerable amount of data on productivity and biomass have been recorded by Westlake (1963), Whittaker (1966), Misra _et al_ (1967), Pandeya _at al_ (1970a) and Whittaker and Woodwell (1971).

The important features in growth pattern studies are the production of leaves, orientation of mature leaves, the shedding pattern of leaves which govern the photosynthetic efficiency of the plant species. The seasonality in the birth and death of leaves and the pattern of shoot growth are two important adaptive strategies of natural selection which ultimately determine the overall architectural pattern of a tree canopy, the study of which is more important for better understanding of the functioning of forest ecosystems (Madgwick, 1970). The growth behaviour of deciduous species showed that rapid growth of the species are not due to their efficient energy conversion but due to their capacity for unrestricted leaf production and economic branching patterns (Coombe, 1960). A number of workers (Kozlowski, 1964; Murray and Sale, 1966; [redacted] and Brown, 1971), have emphasized the factors responsible for shoot growth in various temperate and tropical tree species. Horn (1971) who described the differences in crown geometry and leaf sizes in hardwood temperate species showed that early successional types are soft wooded with smaller leaves and multilayered canopy whereas the late successional species are heavy wooded with large leaves and are generally with monolayered crowns.

The present study tries to relate growth pattern with primary productivity of Shorea robusta Gaertn, which is one of the most important timber yielding tree species which is shade tolerant though requiring light for its germination and establishment (Troup, 1921). This is a late successional, hard wooded tree species with larger leaves, growing up to an altitude of 3000 feet in the north eastern region.

METHODS OF STUDY

A 13-year old open grown Shorea robusta tree of 4.48m height growing in an even aged plantation at Umtasor at an altitude of 760m. was selected in October, 1977 for growth analysis. All the leaves were tagged, the length of the main leader and I, II and III order branches were recorded along-with the dbh of the tree. Observations were made at 30 days interval with respect to various growth parameters, production and growth of the existing main leader and branches and also with respect to new branches that may come out. Bud burst, birth and death rates of leaves were also studied. Leaf area was measured on the main leader and the I, II and III order branches at different canopy positions on the tree along the gradiant of sun light intensity.

9, 11, 13, 15, 17 and 19 years old plantations of Shorea robusta were selected in 1977 and for productivity studies and their dbh, density and basal area per hectare was calculated on the basis of randomly placed 10m^2 quadrats. IVI values were calculated for each stand and was considered as typical. Ten typical individuals were harvested from each of the six stands following the procedure given by Newbould (1967) and observations on height, branch number and leaf number were recorded. The results presented are the mean of all observations. The bole of each individual tree was cut into small pieces and fresh weight was recorded in the field itself. As the branches were small the fresh weight of all the branches were recorded. A small portion of the bole and portions of branches of different thickness were oven dried at 80-85°C and dry weight values for these organs were estimated on this basis. All the leaves of each tree were hand picked and fresh weight was recorded. Fifty leaves randomly collected in polythene bags and oven dried at 80-85°C to calculate leaf dry weight values.

RESULTS AND DISCUSSIONS

Growth Analysis :

The main leader of Shorea robusta is an orthotropic sympodium as the terminal bud of the axis aborted each year at the end of the growing season and the axis continued its growth by subjacent lateral bud. This is also true in the case of the I order branches. The increment in length in a growing season declined as we move from the main leader to different branches of increasing order as discussed below. The growth in this species is continuous during the growing season with no articulation or features of rhythmic growth on the main leader or branches, but with continuous leaf production. A well defined period of winter dormancy of about 5 months was found and during this period leaf shedding occurred.

New growth started in the month of April and continued for about 7-8 months. The leaves are spirally arranged, branches being produced in some of the leaf axils.

Figure 9-1 shows the monthly pattern of leaf fall and leaf production. The leaf fall started in the month of November and extended upto the month of May. Peak leaf fall occurred during February-March when about 65.9% of the total was shed. Maximum leaf fall at this time may be related to water stress as this period is rainless and dry though other workers have related leaf fall to day length, light intensity or mineral deficiency (Addicott and Lynch, 1955; Kramer and Kozlowski, 1960).

New leaves appeared in the month of April at a time when only 0.72% of the older leaves were still present on the tree. However, these older leaves are soon shed within a week after the appearance of new leaves. In other words, senescence of the old leaves provided the signal for bud break, placing this species in the category of leaf exchanging type (Longman and Jenik, 1974). Though new leaf production started in the month of April it reached its peak in June when about 63.55% of the total leaf production was recorded. The production of new leaves declined sharply in subsequent months and

Fig. 9-1. Monthly pattern of leaf fall and production in *S. robusta*.

Leaf fall, ● ;

Leaf production, ○ .

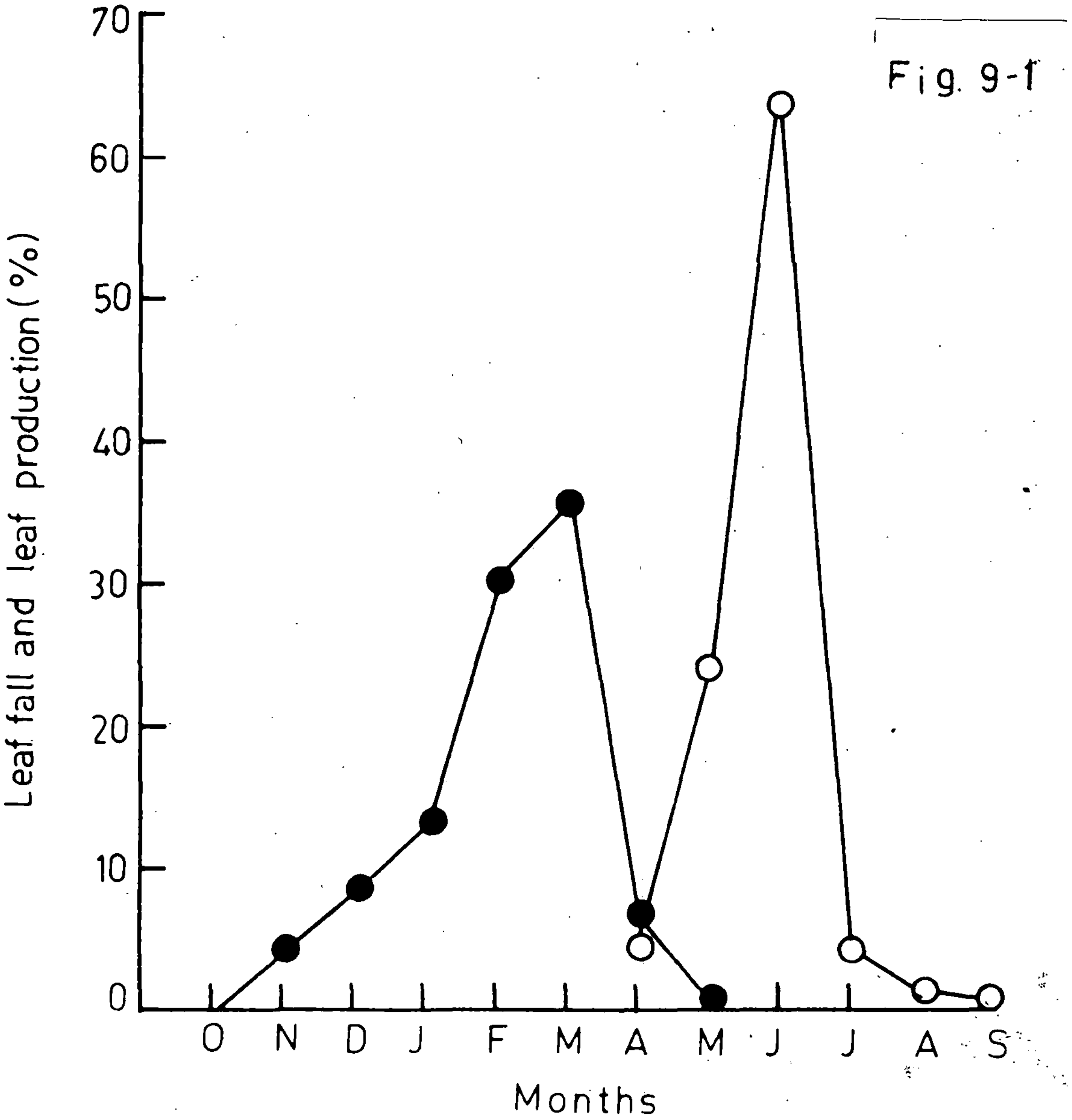


Fig. 9-1
Leaf fall and leaf production (%)
70
60
50
40
30
20
10
0
O
N
D
J
F
M
A
M
J
J
A
S
Months

stopped completely after September. Such a pattern of production of leaves during the growing season of about 6 months only is a feature common with many tropical trees (Longman and Jenik, 1974). This may be related to more favourable environmental conditions like temperature and soil moisture as prevailing at this time. Simon (1914) at Bogor in Western Java, reported that flushing occurred all-through the year where the climatic conditions remained fairly constant. However, increased flushing in certain months as recorded here is also reported in literature (Taylor, 1960; Njoku, 1963; Hopkins, 1970).

Individual leaf area was found to be maximum in the leaves of the main leader and I order branches which decreased in II to III order branches, (Table 9-1). If the tree canopy is divided into 3 levels, the total leaf area was maximum in the middle position (Table 9-2). The branches in middle position of the canopy are older than those at the top to produce more II and III order branches and younger than that at the bottom position of the canopy where most of the branches are slaughed off, (Table 9-3). Since II and III order branches bear more leaves (Table 9-1 and 2) the middle canopy position has larger leaf numbers.

Table 9-1 Branching pattern and leaf numbers and area on the different branch categories of *Shorea robusta*.

Shoot/Branch categories	No. of branches	No. of leaves	Individual leaf area (cm^2)	Total leaf area (cm^2)
Main leader	-	25	220.08	5502.00
I order branch	32	141	212.31	29935.71
II order branch	72	216	187.00	40392.00
III order branch	53	182	180.06	32770.92

Table 9-2. Leaf numbers and area on current year's growth at different canopy positions of *Shorea robusta*.

	Top canopy		Mid canopy		Bottom canopy	
	Number	Area (cm^2)	Number	Area (cm^2)	Number	Area (cm^2)
Main leader	25	5502.00	-	-	-	-
I order branches	60	12738.60	45	9553.95	36	7643.16
II order branches	-	-	130	24310.00	86	16082.00
III order branches	-	-	110	19806.60	72	12964.32
Total	85	18240.60	285	53670.55	194	36689.48

Table 9-3 Distribution of different categories of branches at different canopy positions in *S. robusta*

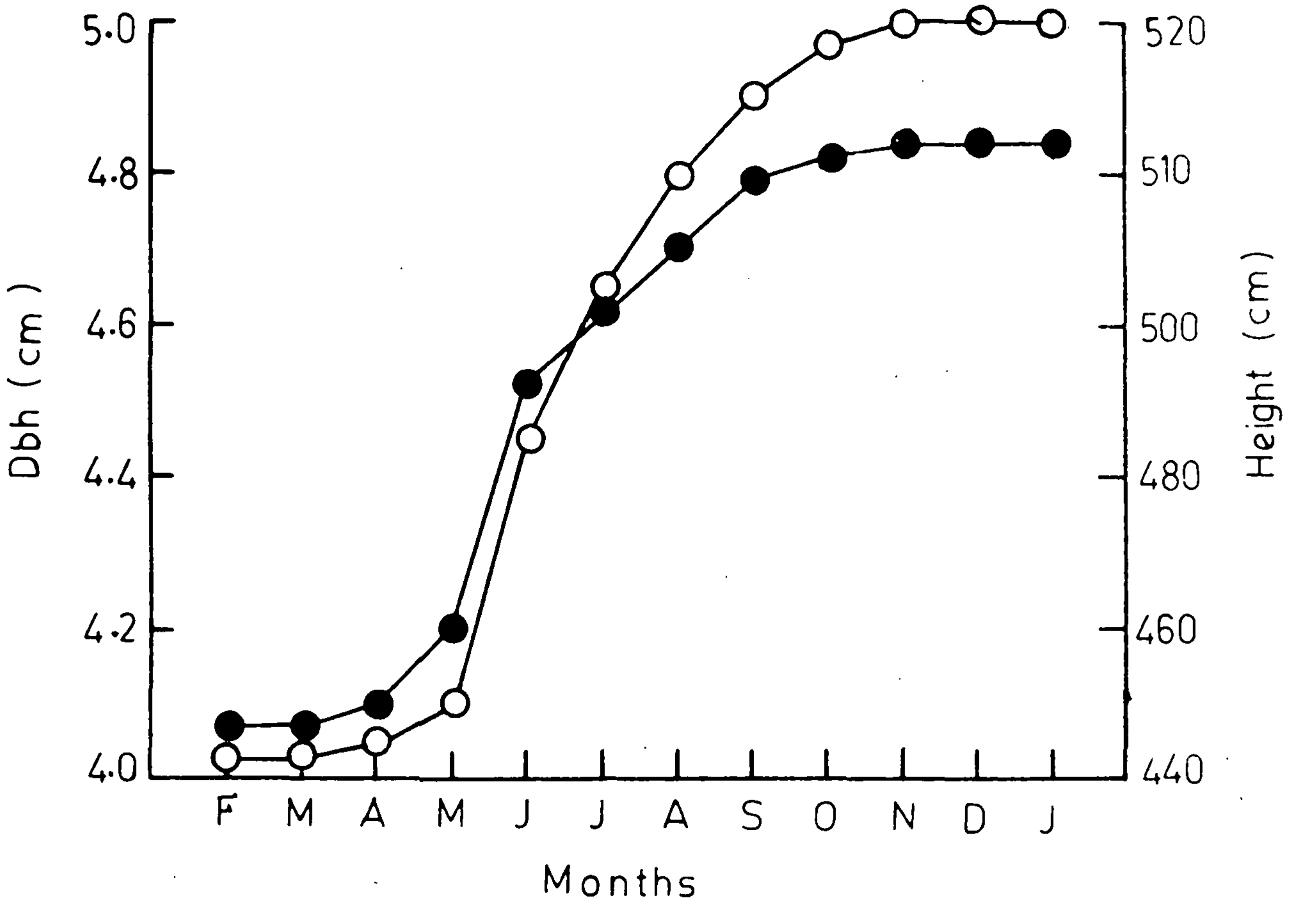
Branch categories	No. of branches		
	Top canopy	Mid canopy	Bottom canopy
I order	13	11	8
II order	-	43	29
III order	-	33	20

The lateral dormant bud subjacent to the abscissed terminal bud burst in the month of April as indicated by leader elongation after 5 months of winter dormancy. The shoot tip abortion is regarded as a natural disease and occurs in many tropical and temperate species (Nitsch, 1957; Garrison and Wetmore, 1961; Romberger, 1963; Millengton, 1963). The abortion of shoot tip results in the discontinuity and yearly renewal of terminal meristem but the development of subjacent lateral bud as new axis does not affect the posture of the main leader because as a consequence of growth it assumes a vertical plane apparently in continuity with the main axis.

The monthly pattern of shoot extension (Fig. 9-2) showed that maximum growth is in the month of June when 33.33% of the total shoot extension occurred. After this peak period extension growth of the main leader decreased but continued upto October. This periodicity in extension growth may be related to better moisture status of the soil and more favourable temperature conditions prevailing during this period. No growth extension occurred during the winter period. The decline in leader growth during August-September may be related to development of moisture deficit in the soil during this period when monsoon is weak. The absence of growth

Fig. 9-2. Monthly pattern of height and dbh increment in S. robusta plant. Height, ● ; dbh, ○ .

Fig. 9-2



5.0
4.8
4.6
4.4
4.2
4.0
Dbh (cm)
520
510
500
480
460
440
Height (cm)
F
M
A
M
J
J
A
S
O
N
D
J
Months

during winter months may partly be related to low temperature conditions and partly to moisture stress at this dry period as also reported for other tropical trees. (Zahner, 1968). The average rate of growth of 0.66 m/year in this species is lesser than that obtained for some pioneer tropical species like <u>Terminalia superba</u> (2.8 m/year) and is somewhat comparable to climax species like <u>Oxystigma oxyphyllum</u> (0.70 m/year) as observed by Lebrun and Gilbert (1954). The rate of growth in girth also followed a similar pattern as for extension growth (Fig. 9-2).

Extension growth of branches in a year decreased through I order to II order at a given position in the canopy. Main leader growth, gave maximum value. Considering the I order branches, the extension growth was more in the top position of the canopy in comparison to the middle and bottom canopy positions (Table 9-4). Probably both the nutrient distribution and light intensity might be responsible for this.

<u>Shorea robusta</u> is a slow growing species with current year's shoot producing branches of the I order only in the following year; the II and III order branches are produced in subsequent two years. This branching pattern along with slower extension growth makes it a comparatively slow growing

Table 9-4 Annual growth extension in main leader and in I, II and III order branches alongwith standard error values in three canopy positions of *S. robusta*.

Shoot/Branch categories	Extension growth (cm)		
	Top canopy	Mid canopy	Bottom canopy
Main leader	66.00	-	-
I order branches	39.60 ± 3.50	24.83 ± 1.75	22.73 ± 3.76
II order branches	-	18.00 ± 2.84	15.05 ± 4.84
III order branches	-	15.30 ± 3.41	13.02 ± 3.65

species typical of a late successional community. Further, as discussed above, branch numbers, leaf numbers and total leaf area are maximum in the middle canopy position. This indicates that Shorea robusta is tolerant of shade to some extent though it is difficult to classify it as a typical shade tolerant species. This is further supported by silvicultural observations that this species need open situation atleast in the initial stages for seed germination and seedling establishment (Troup, 1921).

Productivity :

Height, dbh and basal area increased with the age of the stand and the density of individuals was higher in younger stands, while basal area, height and dbh all increased with increase of age of the stand; leaf area (m^2/ha) reached its maximum in 13 year old stand which is partly related to the age of the tree and partly to density (Table 9-5).

Table 9-6 presents increase in biomass of the ~~individuals~~ tree and the different components within the tree with increase in age with a maximum of 12.74 kg/tree in a 19 year old individual. Misra et al (1967) Faruqi (1972) and Sharma (1976) reported biomass values ranging between 53.9 and 580.0 kg/tree

Table 9-5. Characteristics of S. *robusta* plantations at Umtesor with standard errors.

Variables	Stand age (year)					
	9	11	13	15	17	19
Tree/hectare	8440±6.392	7920±1.403	6630±9.575	4280±10.960	4310±14.335	4620±11.334
Basal area/tree (cm^2)	1.22±1.023	4.02±1.610	12.58±1.522	18.75±1.257	33.38±1.731	38.48±2.097
Basal area/ha (m^2/ha)	1.03	3.18	8.35	8.03	14.38	17.78
Height (m)	1.90±0.225	3.71±0.421	5.57±0.471	6.44±0.512	7.62±0.585	8.35±0.651
Dbh (cm)	1.02±0.333	2.02±0.850	4.00±0.573	5.42±0.690	6.05±0.840	7.00±1.156
Leaf area/leaf (cm^2)	160.00±0.916	198.40±2.603	228.60±4.101	200.10±3.101	184.20±3.841	214.10±2.072
Leaf area (m^2/ha)	7697.28	44969.76	701454.00	48620.80	42130.25	57103.20

Table 9-6. Biomass of plant components in different diameter classes of *S. robusta* plantations (kg/tree) with standard errors.

Stand age (year)	Diameter class (cm)	Plant components			Total
		Bole	Branches	Leaves	
9	1.02	0.115±0.020	0.028±0.004	0.074±0.017	0.217
11	2.02	0.708±0.072	0.162±0.014	0.359±0.030	1.229
13	4.00	3.061±0.246	0.225±0.027	0.551±0.035	3.867
15	5.02	5.984±0.561	0.592±0.184	0.600±0.056	7.176
17	6.05	8.299±0.433	0.434±0.055	0.695±0.111	9.358
19	7.00	11.171±1.428	0.631±0.154	0.942±0.081	12.744

for 15 and 50 year old S. robusta plantations in Varanasi. The low biomass/tree in the present case, may be due to many factors like poor management, soil factors and site quality.

The standing crop biomass (calculated by multiplying the number of tree per hectare) was found to be 58.87 t/ha for 19 year old plantation which was also lower than the values reported by others, for reasons mentioned above. The green biomass was maximum in 13 and 19 year old stands and was low in other stands. This high amount of green biomass may be due to more density as well as leaf biomass. The non-green biomass however, increased gradually from younger towards older stands (Table 9-7).

Each species has its own characteristic biomass increment within the limit of its genetic potential and site quality. In production ecology this biomass increment may be expressed in two ways (i) mean annual increment biomass which can be achieved by division of standing biomass by the age of the plantation and (ii) net primary productivity which is a true measure of forest production can be achieved by measuring the total biomass differences between two stands divided by age intervals, both the values are expressed as

Table 9-7. Production indices of S. robusta plantations

Variables	Stand age (years)					
	9	11	13	15	17	19
Standing crop biomass (t/ha)	1.82	9.73	23.47	30.71	40.71	58.88
Total standing crop biomass (t/ha)	2.64	11.85	26.78	33.21	43.16	61.43
Total leaf litter production (t/ha/yr) (1+3)	0.72	2.12	3.31	2.50	2.45	2.55
Green biomass (t/ha/yr)	0.62	2.85	3.65	2.57	2.99	4.35
Non-green biomass (t/ha/yr)	1.20	6.88	19.82	28.14	37.72	54.53
Mean annual productivity (t/ha/yr)	0.21	0.88	1.80	2.05	2.39	2.89
Net primary productivity (t/ha/yr)	2.54	4.66	7.47	3.22	4.98	9.14

ton/ha/year. The mean annual productivity in present case reached its maximum in a 19 year old stand.

In India, S. robusta is a deciduous tree and parts of its primary production is lost through leaf litter. The leaf litter in the present study, was found to be maximum in 13, 17 and 19 year old stands (Table 9-7) which is partly related to more leaf biomass and individuals per hectare. The net primary productivity reached a maximum of 9.14 t/ha/yr in a 19 year old plantation. This value is lower than that (14.67 t/ha/yr) reported for the species in an 18 year plantation in Gorakhpur, U.P.(Ramam, 1976). The net productivity pattern through different age groups showed that the productivity was low in younger stands increased upto 13 year old stands, again decreased in 15 and 17 year stands and reached its maximum in 19 year old stand. This may be partly related to site quality. Spacing of trees in plantations may also limit tree growth, So that the tree architecture that may emerge out over years of management may probably set a limit to production and distribution of organic matter in the tree components (Ramam, 1976).

The growth pattern of S. robusta discussed earlier could be related to the average productivity values of

9.14 ton/ha/yr. recorded here. Early successional tree species are generally considered to be fast growing with high productivity as is observed for a sub-temperate tree like Pinus kesiya with 15 ton/ha/yr. (Das and Ramakrishnan, unpublished). This high productivity could be related to its growth pattern with more than one flush of leaves appearing during the year and a tree architecture that account for a high photosynthetic efficiency. On the contrary, the production of fewer leaf numbers in a year on the tree alongwith a dormancy period of about 4-5 months when new leaf growth does not at all occur all contribute towards a low production efficiency. This pattern for S. robusta is quite distinct from that for Anthocaphalus cadamba which is an early successional fast growing tree species in the same region (Shukla and Ramakrishnan, unpublished). The productivity of 14.87 ton/ha/yr recorded by Ramam (1976) for forests in Gorakhpur in U.P. is higher than the values recorded by us and this may be ralated to site quality.

SUMMARY

The growth analysis and productivity of Shorea robusta, an important timber yielding tree species was studied. The monthly pattern of leaf fall in a 13 year old plantation of

S. robusta showed that peak fall occurred during February-March when about 65.9% of the total fall occurred. New leaves appeared in the month of April and reached its maximum in the month of June when about 63.55% of the total leaf production occurred. Individual leaf area was found to be maximum in the leaves of the main leader followed by I order branches which decreased in II and III order branches. However, maximum leaf area for the whole tree was recorded in the middle portion of the canopy (53670.55 cm^2). Shoot extension of the main leader was maximum in the month of June when about 1/3 yearly extension growth was completed. Extension growth of branches of the I order showed that it was more in the top canopy than at the based. Extension growth of the tree was characterised by shoot tip abortion and sympodial growth.

Height, dbh and basal area increased with the age of the plantation whereas density decreased with the age of the stand. Maximum leaf area (701454.00 m^2/ha) was recorded in a 13 year old stand which may be related to greater individual leaf area (228.60 cm^2). The biomass of the individual tree which ranged between 0.217 - 12.744 kg/tree increased with the age of the stand and maximum standing crop biomass of 58.8 t/ha was recorded in the oldest 19 year old stand. The net primary productivity reached a maximum of 9.14 t/ha/yr in 19 year old plantation. The productivity for S. robusta which is a late successional species is low and is due to slow growth rate, production of few leaves in a year and an extended period of dormancy of 4-5 months when growth is arrested; branch production is not simultaneous with new leaf growth but is postponed to the following year.

CHAPTER 10

NUTRIENT CYCLING THROUGH THE PLANT AND SOIL COMPARTMENTS IN *SHOREA ROBUSTA* GAERTN. PLANTATIONS AT UMTESOR

NUTRIENT CYCLING THROUGH THE PLANT AND SOIL COMPARTMENTS IN *SHOREA ROBUSTA* GAERTN. PLANTATIONS AT UMTASOR.

INTRODUCTION

Nutrient cycling is one of the vital functional aspects of forest ecosystems. Information on this is especially important because it defines the relationship between the soil and plants. To investigate the nutrient cycling the ecosystem may be divided into three major components (i) mineral soil (ii) forest floor and (iii) vegetation.

Quantitative information on the physical and chemical properties of woodland soil is a relatively young effort. Much of the available soil survey studies are qualitative. The need for information on chemical characteristics of soil is increasing rapidly because of the greater emphasis on the productivity of forests and woodlands.

Measurements of the amount and rate of fixation of energy by photosynthesis, as reflected by accumulation of organic matter or biomass is an essential step leading to the understanding of nutrient cycling in ecosystems. Mature woodland ecosystems are regarded as vast reserves of energy and nutrients. A major part of this energy is stored in roots, trunks, branches and leaves of the trees in the form of various organic substances and the nutrients remain in continuous circulation between plants and soil. But the different woodlands often differ greatly in their biomass and nutrient reserves. Comprehensive reviews on biomass production and nutrient cycling of temperate, sub-tropical and tropical forests of the world have been given by Ovington (1962, 1965), Kira and Shidei (1967), Rodin and Bazilevich (1967, 1968) and Lieth (1972). In India, biomass data from deciduous forests have been collected by Misra et al (1967), Pandeya et al (1970, a,b, 1971), Ramam (1971), Desh Bandhu (1971), Faruqi (1972) and Singh (1975).

Litter is another important component for nutrient cycling in forest ecosystems. Many studies have been done in different parts of the world in its relation to productivity, nutrient cycling and decomposition of forest organic matter (Nye, 1961; Ovington, 1962; Witkamp and Olson, 1963; Bray and Gorham, 1964; Gosz et al 1972, 1973). The litter is the focal point for nutrient cycling and is particularly important in the nutrition of woodlands particularly on soils of low nutrient status where the trees rely to a great extent upon the recycling of litter nutrients. Nutrient content of forest litter from different parts of the world are well studied (Tarrent et al, 1951; Daubenmire, 1953; Ovington, 1959; Frankland et al, 1963 and Carlisle et al, 1966a) though data on Indian forests are scarce (Singh,1969). In India estimation of annual litter production in some evergreen and deciduous forests was done by Puri (1953), Upadhyaya (1955), Seth et al (1963), Singh (1968) and Subba Rao et al (1972).

The present study deals with the physical and chemical properties of the forest soil, the organic matter and litter production, the living biomass of forest stands, and the nutrient cycling between these three compartments in Shorea robusta plantations at Umtesor in Meghalaya at an elevation of 760 m (25°45" and 26°0" N Latitude and 91°45" and 92°0" E Longitude) under Nongkhylum reserve forest.

METHODS OF STUDY

Soil nutrients :

9,11,13,15,17 and 19 year old plantations of Shorea robusta were selected for studies on soil. Monthly soil sampling was done during 1976 from depths of 0-10, 10-40, 40-70 and 70-100 cm. and were based on 3 replicates thoroughly mixed together to give one composite sample. Soil colour was determined by Munsel soil colour chart. Mechanical composition was done by International pipette method as described by Piper (1947) and soil samples were placed in different textural classes. Soil pH was measured by electrometric method in a soil-water suspension of 1:5. Analyses of total nitrogen, organic carbon and available phosphorus were done by standard methods described by Jackson (1958) where nitrogen was estimated by Kjeldahl method, carbon by Walkley Black method and PO_4-P colorimetrically by molybdenum blue method. Calcium and magnesium were analysed by EDTA titration method while potassium was estimated by flame emission method after extracting the exchangeable cations with 1N Ammonium acetate at pH 7. The soil bulk density was used for subsequent conversion of analytical data to field weight per unit area.

Biomass and its nutrients :

Biomass estimations were made in 9,11,13,15,17 and 19 year old stands. Twenty quadrats of $100m^2$ were randomly laid in each stand for measuring diameter at breast height (dbh), density and basal area. Dbh was based on the average of all the trees within these 20 quadrats. In September, 1976 ten typical individuals from a given stand were harvested and observations on height, branch and leaf numbers were recorded. The bole of each individual tree was cut into small pieces and fresh weight was recorded. As the branches were small in size the fresh weight of all branches were taken into account. A small portion of bole and branches were oven dried at 80-85°C and total dry weight values for these organs were estimated on this basis. All the leaves of each tree were hand picked and fresh weight was recorded. Fifty leaves randomly collected in polythene bags and oven dried at 80-85° C were used to calculate leaf dry weight values.

Allometric regression equations were developed between different dependent (bole, branches, leaves and total biomass) and independent variables (height and dbh).

The oven dried material of bole, branches and leaves was ground and passed through a 20 mesh screen. Plant tissue chemical analyses for N,P,K,Ca and Mg were done by standard methods as described by Paech and Tracey (1956) and Allen (1974). Thus nitrogen was determined by micro-kjeldahl method. After dry ashing the samples, calcium and magnesium were analysed by EDTA titration method, potassium by flame emission method and phosphorus by molybdenum blue method.

Litter production and its nutrients :

Twenty 1m^2 permanent quadrats were laid on 30th April, 1976 in all the six plantations (9,11,13,15,17 and 19 year old) where biomass study was performed. The study plots were demarcated using wooden frames after the removal of all the herbaceous species and litter already present in the plots. The litter accumulated in these frames was collected at one month interval in polythene bags. The leaf litter of *S. robusta* was sorted out from the litter of other species and the latter was bulked into one category. The litter was oven dried at 80-85° C and weighed. Dried litter was ground, passed through a 20 mesh screen and stored for chemical analyses. Nitrogen, phosphorus, potassium, calcium and magnesium estimations were done following procedures outlined above.

RESULTS AND DISCUSSION

Mineral soil :

The soil is dark brown in surface layers, getting lighter with depth turning from light red to deep red at depths below 40 cm. The soil is lateritic and the brown colour of the surface layers is due to humus. Texturally the soil was loamy to sandy. The bulk density increased with depth ranging from 1.40-1.45. Mean soil moisture declined with depth and this may be related to the differences in soil texture with depth. Soil was acidic, acidity increasing with depth within a range of 6.5 to 5.9 (Table 10-1). However,

Table 10-1. Physical properties of soil in a 19-year old *Shorea robusta* plantation at Umtesor (mean values) with standard errors.

Soil depth (cm)	Texture Class	Moisture	pH	Bulk density(g/cc)	Colour
0 - 10	Loamy - Sandy	23.57±6.121	6.50±0.351	1.40	Dark brown - Light brown
10 - 40	Sandy - Loamy	22.98±5.10	6.23±0.251	1.40	Light brown - Light reddish
40 - 70	Sandy	22.17±4.281	6.08±0.271	1.42	Light reddish - Reddish
70 - 100	Sandy	21.20±811	5.91±0.211	1.45	Reddish

soil moisture and soil pH fluctuated during the year. Moisture level in the soil was higher during the monsoon compared to drier winter months, for obvious reasons. (Fig. 10-1). Acidity of the soil, however, increased during the monsoon period reaching the highest value in July and decreased during drier part of the year. This may be related to heavy leaching during the rainy season and the upward movement of salts during drier period. (Fig. 10-2).

Generally speaking, the concentration of all the nutrients - C, N, P, K, Ca and Mg levels in the soil was higher during the rainy season of June-September. During the dry winter months and in the dry summer months of March-April the concentration was lower. This is partly so in the surface layers of the soil, whereas at lower depths monthly fluctuation was not marked (Fig. 10-3,4,5,6,7,8). This may be partly related to release of nutrients from the accumulated litter on the forest floor, due to fast rate of decomposition at this time when conditions are most favourable for soil microbial activity. Amongst the cations, this monthly pattern was most marked for K. It may be mentioned here that part of the soil nutrient pool is also due to leaching

Fig. 10-1. Monthly and depth variation in soil pH in a 19-year old S. robusta plantation.

0-10 cm, ● ; 10-40 cm, ○ ;
40-10 cm, ▲ ; 70-100 cm, △ ;

Fig. 10-2. Monthly and depth variation in soil moisture in a 19-year old S. robusta plantation.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

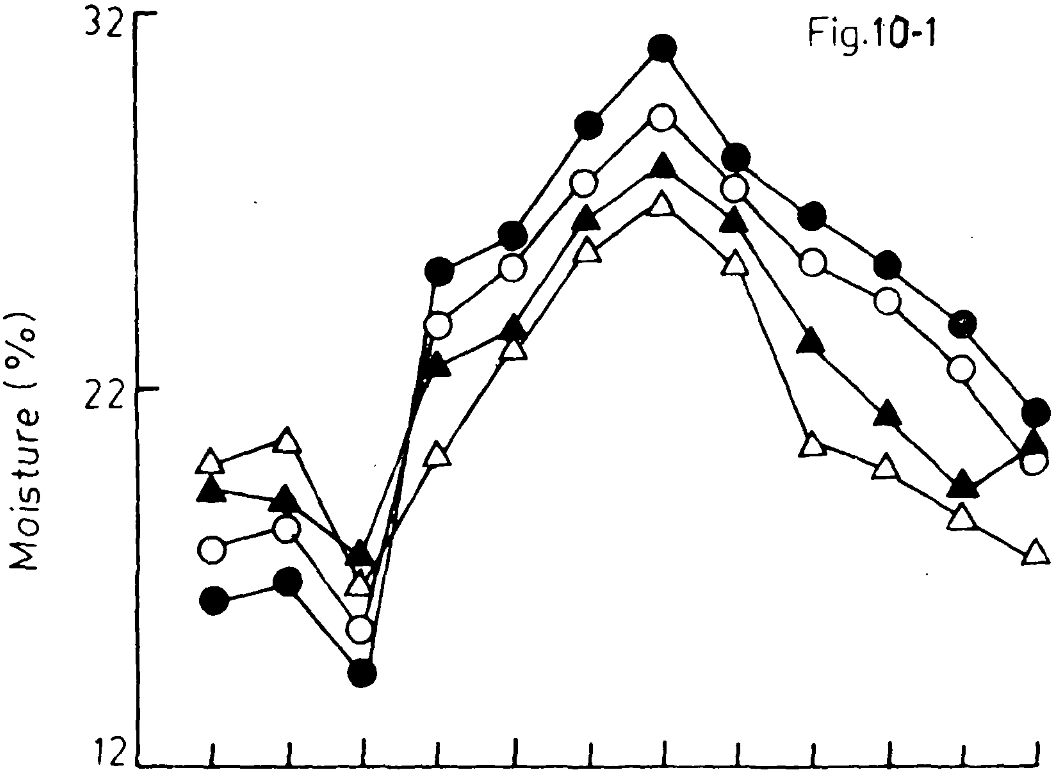


Fig.10-1

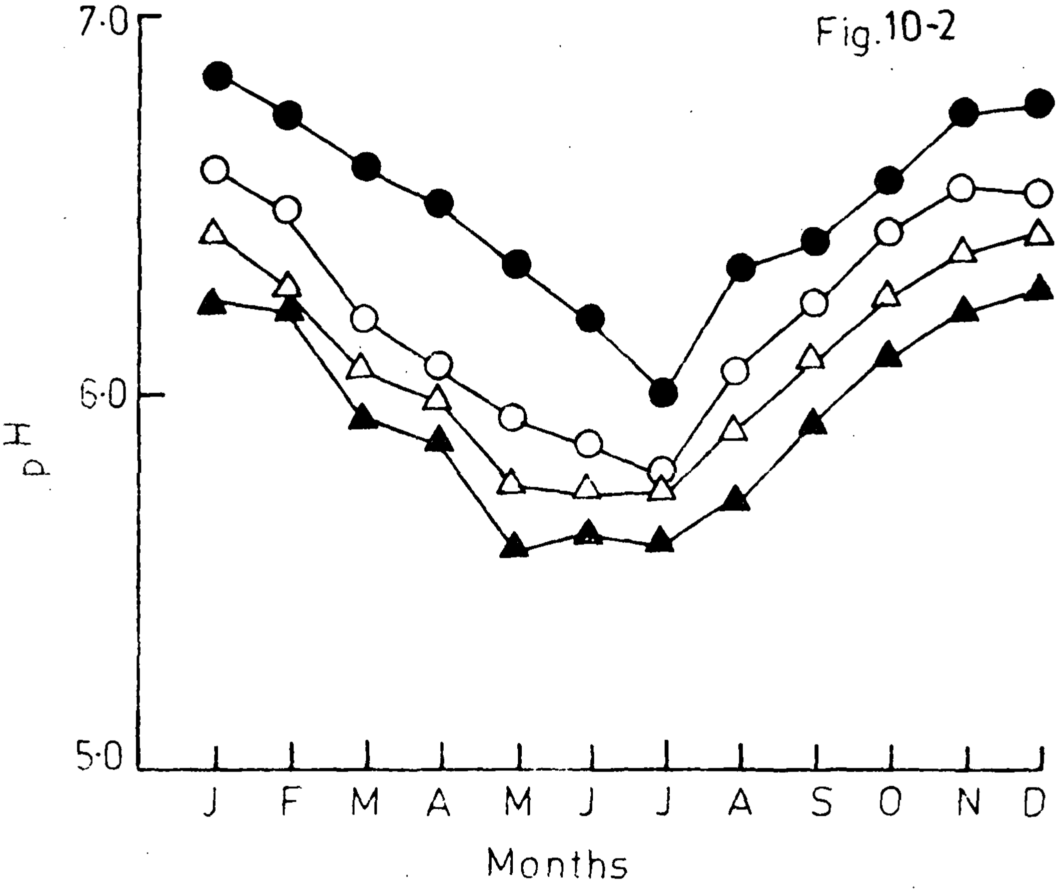


Fig.10-2

Fig. 10-3. Monthly and depth variation in concentration of organic carbon in soil of a 19-year old S. robusta plantation.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 10-4. Monthly and depth variation in concentration of total nitrogen in soil of a 19-year old S. robusta plantation.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

Fig.10-3

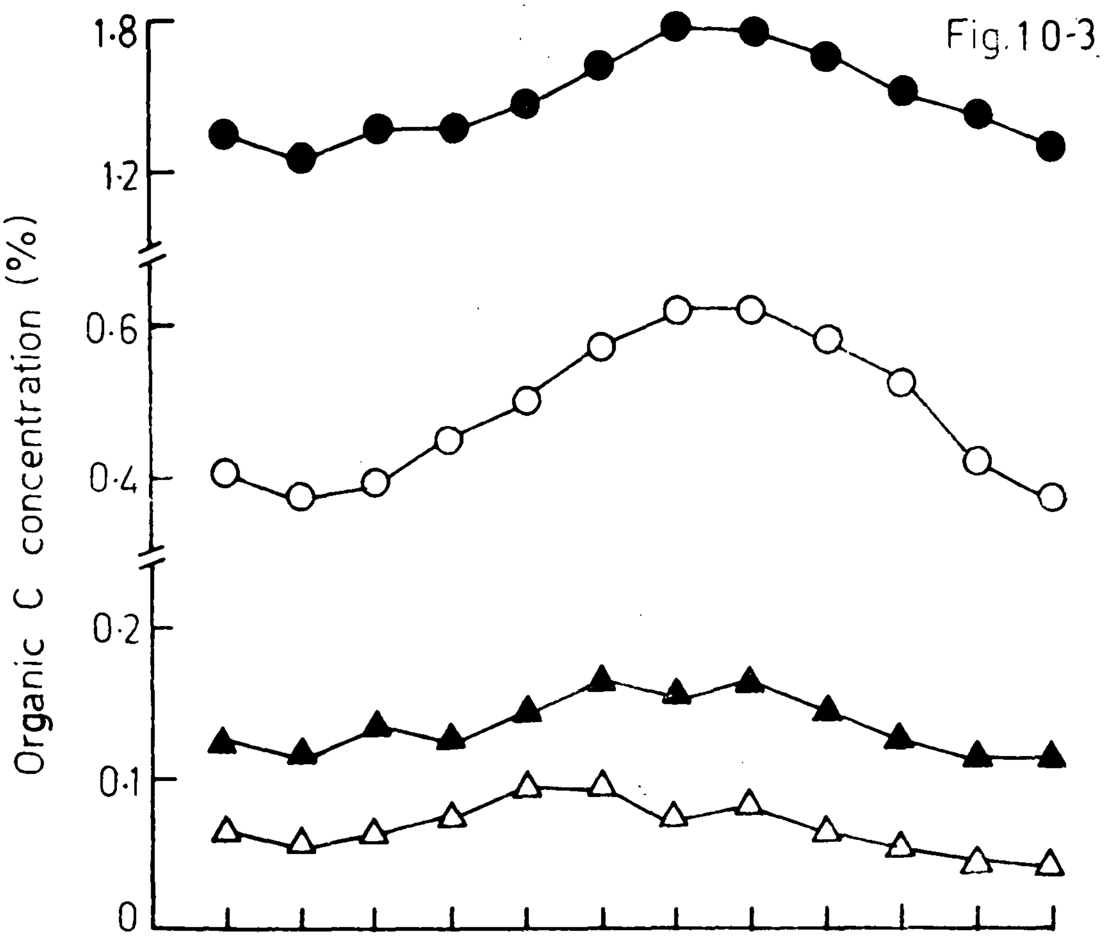


Fig.10-4

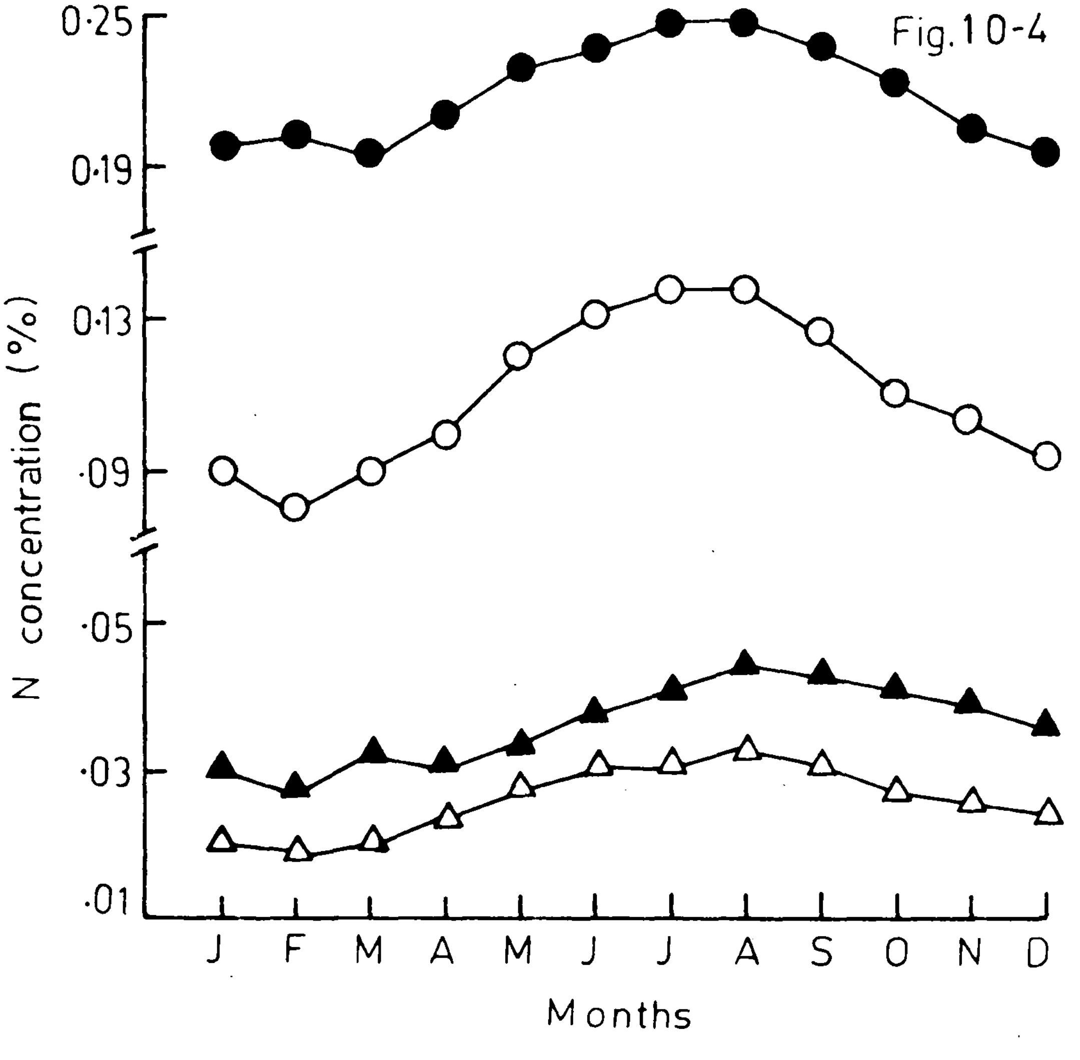


Fig. 10-5. Monthly and depth variation in concentration of available phosphorus in soil of a 19-year old *S. robusta* plantation.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 10-6. Monthly and depth variation in concentration of exchangeable potassium in soil of a 19-year old plantation.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

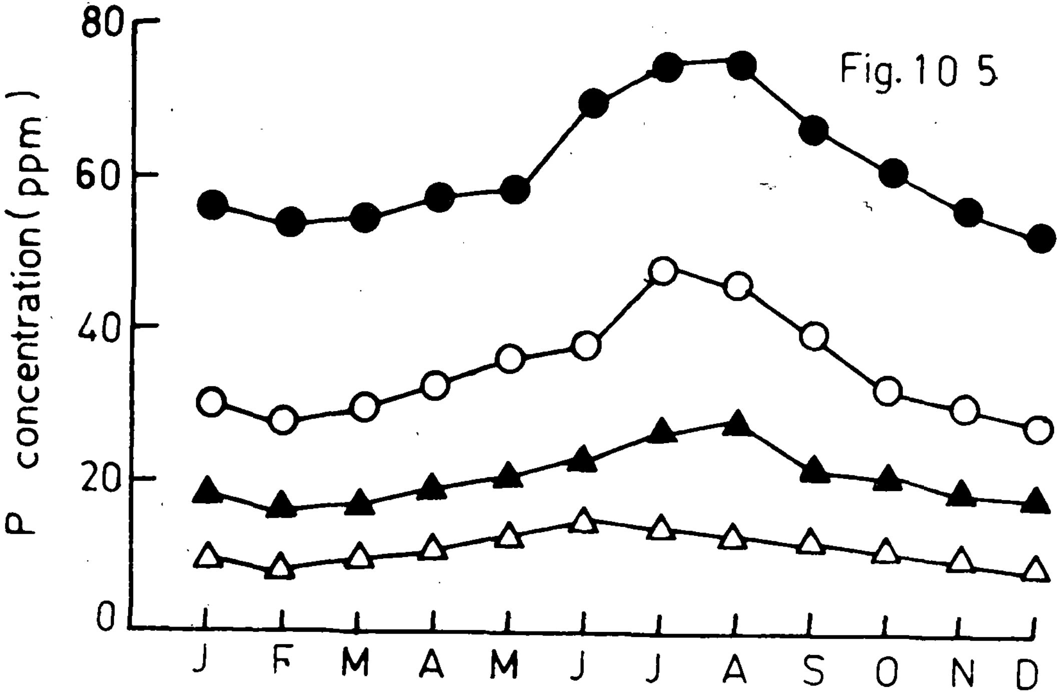


Fig. 10 5

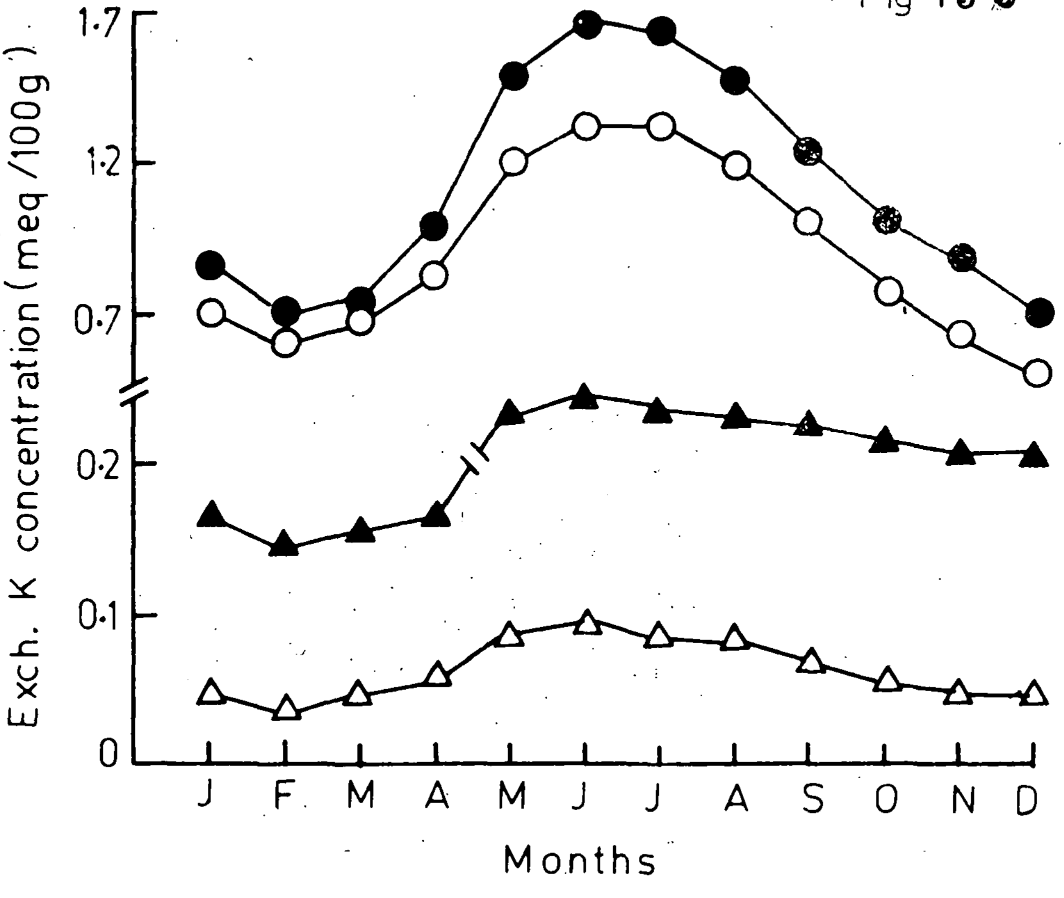


Fig 10·6

Fig. 10-7. Monthly and depth variation in concentration of exchangeable calcium in soil of a 19-year old plantation.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

Fig. 10-8. Monthly and depth variation in concentration of exchangeable magnesium in soil of a 19-year old plantation.

0-10 cm, ● ; 10-40 cm, ○ ;
40-70 cm, ▲ ; 70-100 cm, △ .

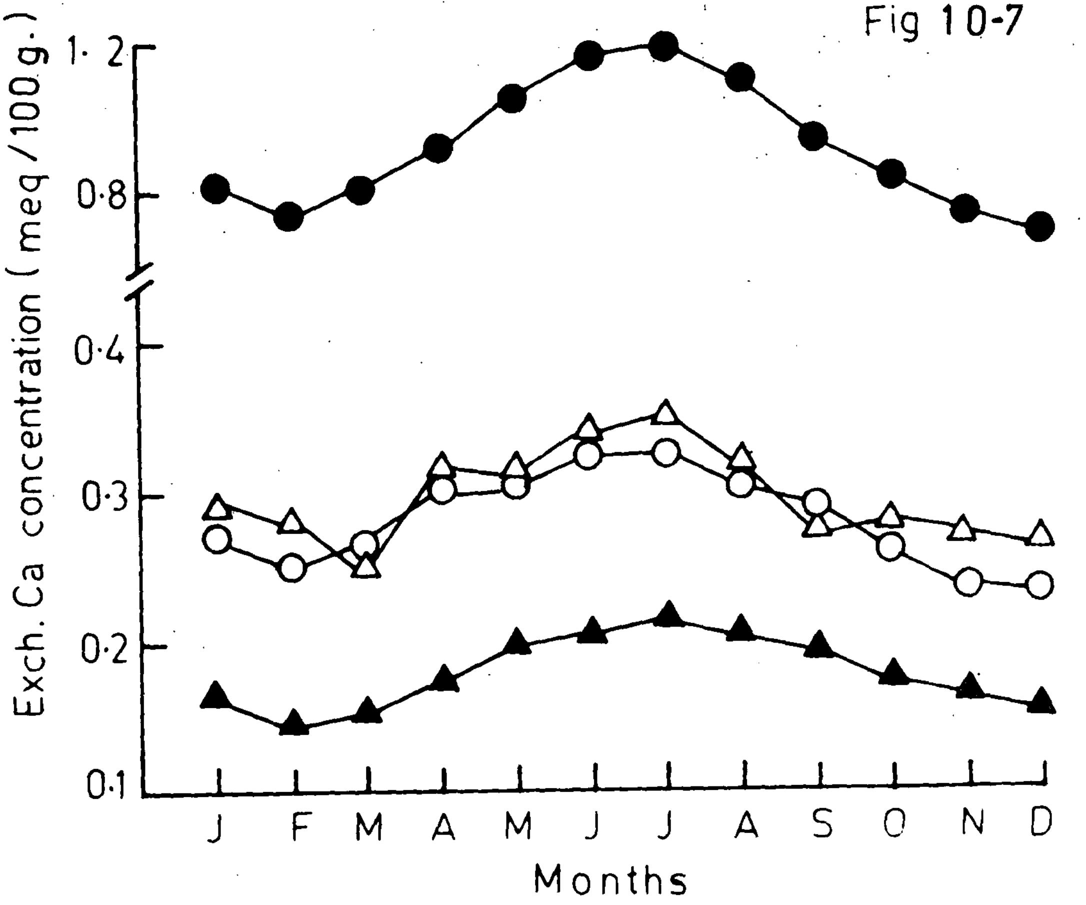


Fig 10-7

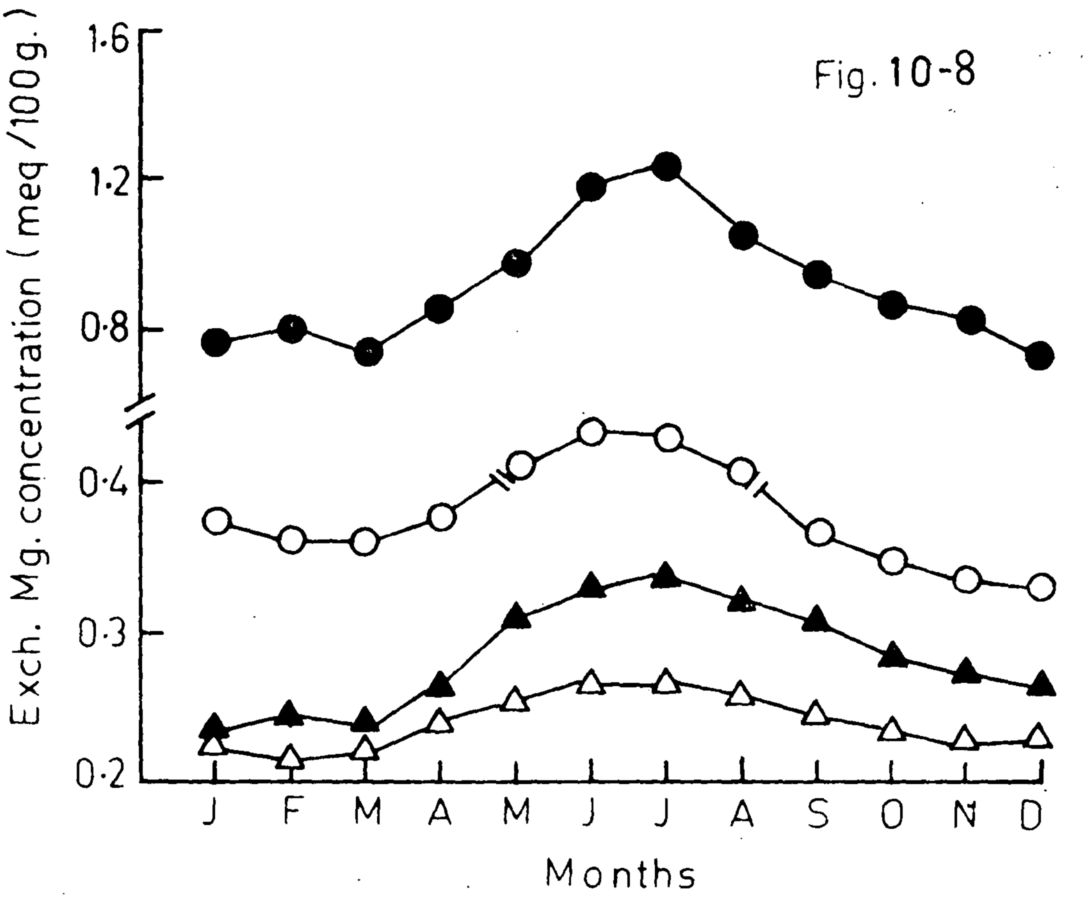


Fig. 10-8

from the forest canopy. This addition to the soil pool is maximum during the monsoon period. This would also explain a higher peak attained by K in the surface soil during the rainy season because K is considered to be more susceptible for addition by throughfall (Tukey <u>et al</u>, 1958).

The mean C/N ratio which was maximum in the upper layer (6.82) decreasing with depth so that at depth of 70-100 cm. it was only 2.33. This is much less than 11.0 indicating rapid decomposition in this woodland (Lutz and Chandlar, 1946). This ratio in temperate forests would be higher indicating slower decomposition in cold climates (Geist and Strickler, 1970).

The mean concentration values for different elements in the soil decreased with depth in all the stands (Table 10-2). However, nutrient concentration at different depths increased with the age of the plantation, which may be due to greater release of nutrients due to weathering, canopy leaching as well as from organic litter on the forest floor. The same trend is indicated by the values for total quantities of nutrients in different layers. The soil is fairly rich in organic carbon and total nitrogen. Amongst the cations, amount of K in the soil was higher followed by Ca

Table 10.2. Percentage concentration (mean values) and total amount (kg/ha) of different nutrients in different soil depths of *S. robusta* plantations at Umtesor with standard errors. (values in parenthesis represent the total amount).

Stand age (year)	Soil depth (cm)	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (ppm)	Cations (mil equ/100 g.)		
					Potassium	Calcium	Magnesium
9	0-10	1.15±0.75 (16100)	0.15±0.07 (2100)	40±20.00 (57.4)	0.82±0.610 (443.87)	0.70±0.210 (199.2)	0.74±0.261 (129.4)
	10-40	0.30±0.21 (12600)	0.06±0.03 (2520)	20±15.65 (100.8)	0.69±0.410 (1154.5)	0.15±0.200 (143.1)	0.25±0.221 (107.2)
	40-70	0.07±0.08 (3045)	0.02±0.03 (852)	10±3.35 (55.4)	0.15±0.210 (266.5)	0.10±0.163 (76.8)	0.16±0.162 (67.3)
	70-100	0.03±0.09 (1278)	0.01±0.03 (435)	10±3.00 (26.1)	0.05±0.036 (68.0)	0.05±0.112 (104.6)	0.08±0.112 (52.9)
11	0-10	1.25±0.87 (17500)	0.18±0.08 (2520)	50±25.00 (70.1)	0.92±0.600 (498.1)	0.80±0.243 (224.4)	0.82±0.268 (137.9)
	10-40	0.38±0.12 (15960)	0.08±0.04 (3360)	30±17.35 (109.2)	0.74±0.420 (1215.2)	0.20±0.210 (168.3)	0.25±0.225 (137.9)
	40-70	0.10±0.09 (4350)	0.03±0.02 (1278)	10±3.50 (65.2)	0.20±0.231 (333.1)	0.05±0.110 (93.9)	0.16±0.182 (88.1)
	70-100	0.04±0.05 (1704)	0.02±0.01 (852)	10±2.80 (30.4)	0.05±0.031 (102.0)	0.20±0.100 (156.9)	0.16±0.110 (68.8)
13	0-10	1.48±0.15 (20720)	0.21±0.51 (2940)	60±31.60 (84.0)	1.10±0.580 (602.1)	0.95±0.240 (260.9)	0.90±0.027 (154.9)
	10-40	0.46±0.25 (19320)	0.10±0.06 (4200)	30±9.00 (136.9)	0.87±0.410 (1428.7)	0.25±0.210 (227.2)	0.41±0.210 (194.1)
	40-70	0.14±0.06 (5964)	0.04±0.02 (1653)	20±5.50 (74.2)	0.25±0.310 (416.4)	0.20±0.115 (153.7)	0.25±0.115 (139.9)
	70-100	0.07±0.03 (2982)	0.03±0.02 (1193)	10±3.80 (39.8)	0.10±0.028 (187.1)	0.25±0.110 (235.4)	0.25±0.110 (121.7)
15	0-10	1.30±0.180 (18200)	0.29±0.09 (2660)	50±28.60 (77.2)	0.95±0.615 (525.5)	0.85±0.264 (235.7)	0.90±0.271 (148.1)
	10-40	0.41±0.035 (17220)	0.07±0.03 (2940)	30±13.60 (128.1)	0.79±0.420 (1313.8)	0.25±0.211 (202.0)	0.33±0.221 (163.4)
	40-70	0.11±0.06 (4785)	0.03±0.01 (1278)	20±7.50 (73.9)	0.23±0.310 (374.2)	0.15±0.151 (128.1)	0.25±0.170 (113.9)
	70-100	0.05±0.02 (2130)	0.03±0.01 (1278)	10±4.00 (34.8)	0.08±0.041 (136.1)	0.20±0.111 (191.8)	0.16±0.121 (100.5)
17	0-10	1.36±0.85 (19040)	0.20±0.06 (2800)	60±31.00 (81.5)	1.02±0.620 (547.4)	0.90±0.260 (252.0)	0.90±0.268 (153.2)
	10-40	0.43±0.07 (18060)	0.09±0.03 (3780)	30±11.50 (132.7)	0.87±0.410 (1412.3)	0.25±0.221 (218.8)	0.33±0.228 (183.9)
	40-70	0.13±0.06 (5538)	0.04±0.02 (1740)	20±6.00 (82.71)	0.26±0.210 (399.7)	0.15±0.135 (136.6)	0.25±0.115 (234.7)
	70-100	0.06±0.01 (2556)	0.03±0.01 (1278)	10±4.50 (44.2)	0.10±0.039 (169.6)	0.25±0.100 (217.9)	0.25±0.100 (111.1)
19	0-10	0.50±0.87 (21600)	0.22±0.20 (3080)	60±29.50 (85.4)	1.10±0.651 (607.6)	0.95±0.274 (263.7)	0.90±0.270 (156.6)
	10-40	0.48±0.35 (20160)	0.11±0.03 (4620)	30±11.80 (145.6)	0.87±0.431 (1445)	0.30±0.210 (235.7)	0.41±0.251 (199.2)
	40-70	0.14±0.06 (5964)	0.04±0.02 (1740)	20±7.60 (86.9)	0.26±0.300 (417.5)	0.20±0.131 (153.7)	0.25±0.110 (150.2)
	70-100	0.07±0.03 (3045)	0.03±0.02 (1278)	10±3.50 (47.6)	0.13±0.036 (204.1)	0.30±0.111 (261.5)	0.25±0.110 (126.9)

and Mg (Table 10-2).

Biomass and its nutrients :

The number of trees/ha decreased with the age of the plantations due to natural thinning only. Artificial thinning was not done in these plantations maintained by the local forest department. While, basal area,height and dbh increased with the age, leaf area/ha reached a maximum in a 13-year old stand, declined sharply in 15 and 17-year old one and showed an increase in a 19-year old stand. This pattern is more due to the density of the stand in different age groups rather than due to leaf area/tree (Table 10-3).

The biomass of the different organs of the tree as well as that of the whole tree increased with increase in age. The green/non-green biomass ratio decreased markedly with age of the plantations in such a way that allocation to wood biomass drastically increased beyond 13-years of age (Table 10-4). The low biomass, generally recorded for this study area compared to that at Varanasi (Misra et al, 1967, Faruqi, 1972 and Sharma, 1976) may be related to poor site quality.

The standing crop biomass (t/ha) of S. robusta as expected, increased with age of the plantations. However, the green biomass increased with the age of the stand upto 13-

Table 10-3. Characteristics of *S. robusta* plantations at Umtesor with standard errors.

Variables	Stand age (year)					
	9	11	13	15	17	19
Tree/hectare	8440±6.392	7920±1.403	6630±9.757	4280±10.906	4310±14.335	4620±11.334
Basal area/tree (cm^2)	1.22±1.023	4.02±1.610	12.58±1.522	18.75±1.257	33.38±1.731	38.48±2.097
Basal area (m^2/ha)	1.03	3.18	8.35	8.03	14.38	17.78
Height (m)	1.90±0.225	3.71±0.421	5.57±0.471	6.44±0.512	7.62±0.585	8.35±0651
Dbh (cm)	1.02±0.333	2.02±0.850	4.00±0.573	5.42±0.690	6.05±0.840	7.00±1.156
Leaf area/tree (m^2)	0.912±0.916	5.678±2.803	10.584±4.101	11.362±3.101	9.775±3.841	12.362±2.073
Leaf area (m^2/ha)	7697.28	44969.76	70172.58	48620.80	42130.25	57103.20

Table 10-4. Biomass of plant components in different diameter classes of *S. robusta* plantations (kg/tree) with standard errors.

Stand age (year)	Diameter Classes (Cm)	Plant components			Total
		Bole	Branches	Leaves	
9	1.02	0.115±0.02	0.028±0.004	0.074±0.017	0.217
11	2.02	0.708±0.072	0.162±0.014	0.359±0.03	1.229
13	4.00	3.061±0.246	0.225±0.027	0.551±0.035	3.867
15	5.02	5.984±0.561	0.592±0.184	0.600±0.055	7.176
17	6.05	8.299±0.433	0.434±0.055	0.695±0.14	9.358
19	7.00	11.171±1.428	0.631±0.154	0.942±0.081	12.744

years after which it decreased in a 15-year stand and again increased in older plantations (Table 10-5). As discussed earlier both density of the species and site quality may account for this decline in 15-year old stand. As noted from Table 10-3, the increase in leaf area/tree in a 15-year stand compared to that in a 13-year one is not commensurate with the marked decline in density of this species. The non-green biomass which contributed anywhere between 1.20 to 54.53 tons/ha increased gradually with age. This pattern which is different from that of the green biomass development with age probably is indicative of the fact that the allocation pattern drastically changes beyond 13-years in such a way that the non-green biomass is significantly higher in proportion to the green biomass production. This is also seen from the values for the non-green/green ratio given here.

On the basis of allometric correlations, a close relationship was found between the weight of the individual tree component and height or diameter af breast height (dbh) (Ovington, 1957; Ogowa et al, 1961, 1965; Young et al, 1964 and Kira and Shidei, 1967). Thus, regressions could be drawn between the dependent and independent variables (Fig. 10-9,10).

Table 10-5. Biomass indices of S. robusta plantations

Variables	Stand age (year)					
	9	11	13	15	17	19
Standing crop biomass (t/ha.)	1.82	9.73	23.47	30.71	40.71	58.88
Green biomass (t/ha.)	0.62	2.85	3.65	2.57	2.99	4.35
Non-green biomass (t/ha.)	1.20	6.88	19.82	28.41	37.72	54.53
Non-green/green ratio	1.94	2.41	5.43	10.96	12.62	12.54

Fig. 10-9. Relationship between height and above ground biomass alongwith biomass of component plant parts of _S. robusta_.

Fig. 10-9

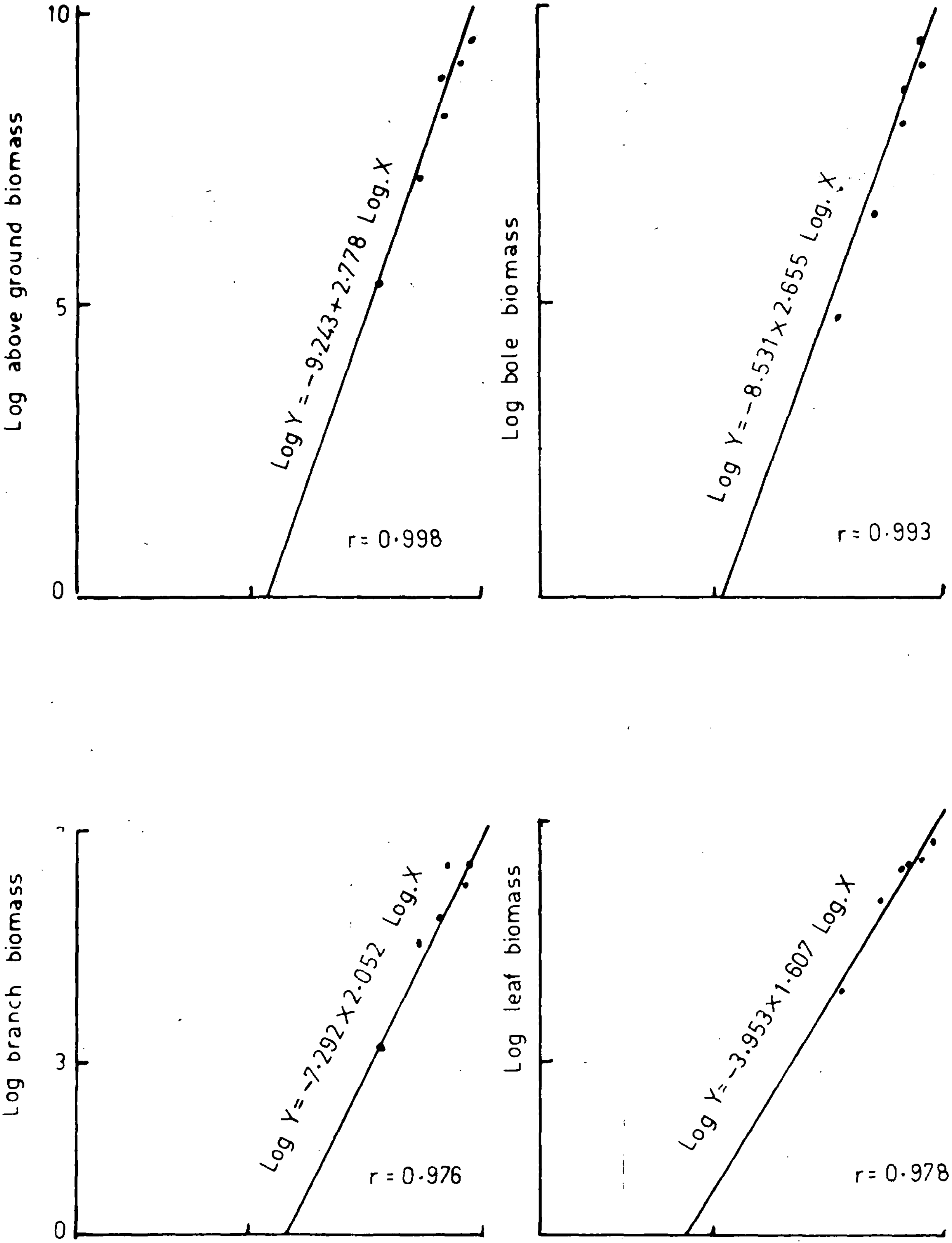
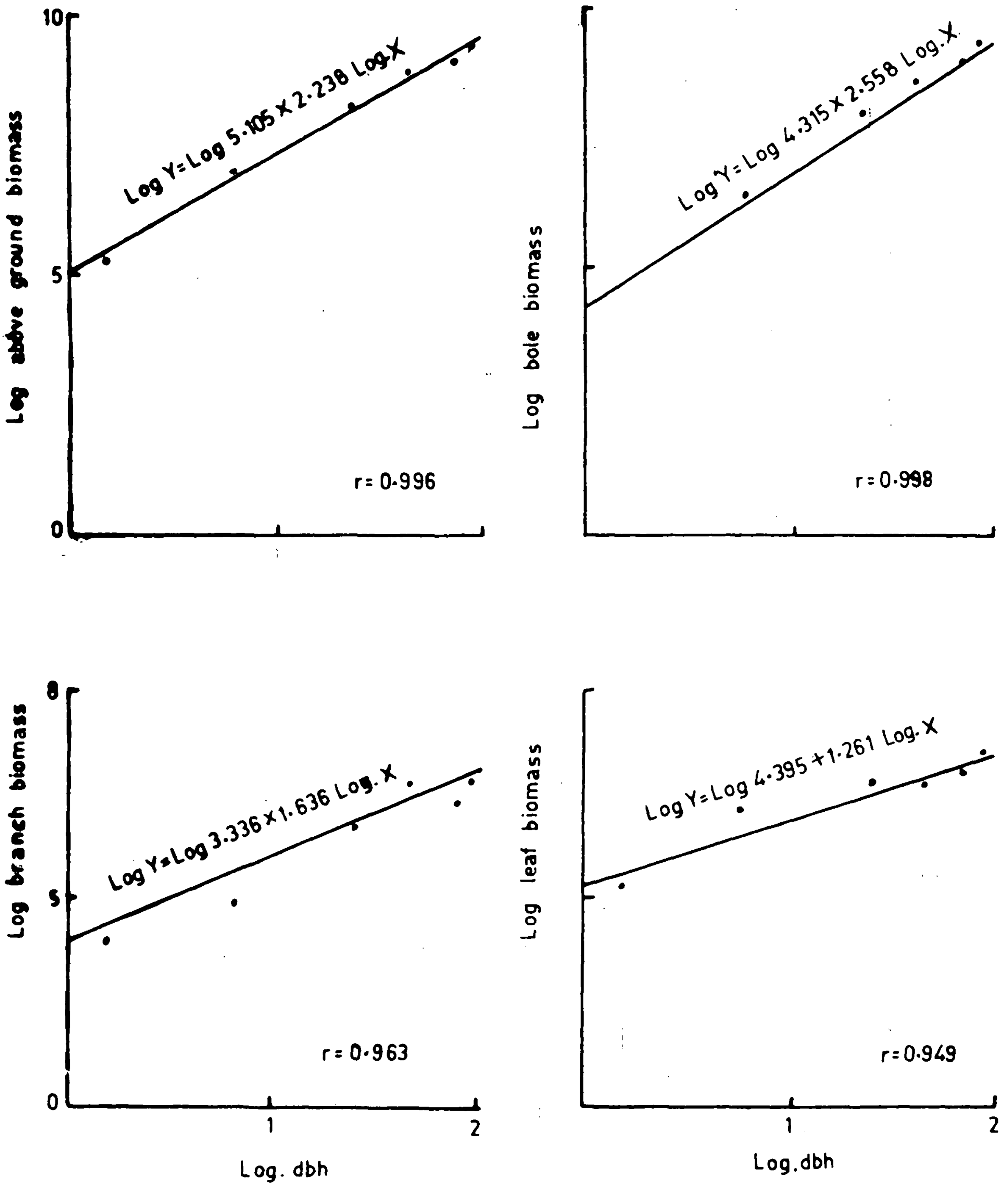

Log above ground biomass
10
5
0
Log Y = −9.243 + 2.778 Log. X
r = 0·998
Log bole biomass
Log Y = −8.531 × 2.655 Log. X
r = 0·993
Log branch biomass
3
0
Log Y = −7.292 × 2.052 Log. X
r = 0·976
3
7
Log. height
Log leaf biomass
Log Y = −3.953 × 1.607 Log. X
r = 0·978
3
7
Log. height

Fig. 10-10. Relationship between dbh and above ground biomass alongwith biomass of component plant parts of S. robusta.

Fig 10-10


Log above ground biomass
10
5
0
Log Y=Log 5·105 X 2·238 Log.X
r= 0·996
Log bole biomass
Log Y=Log 4.315 X 2.558 Log.X
r=0·998
Log branch biomass
8
5
0
Log Y=Log 3.336 X 1.636 Log.X
r= 0·963
1
2
Log. dbh
Log leaf biomass
Log Y=Log 4·395 +1·261 Log.X
r=0·949
1
2
Log.dbh

The percentage concentration of nutrient elements like N,P,K,Ca and Mg was more in the leaves compared to that in branches and bole, in all age groups (Table 10-6). However, the concentration of Ca was more in the wood compared to the leaves. It may be noted that high level of calcium in the wood is related to its accumulation in the bark (Woodwell *et al*,1975). The standing crop of all nutrient elements increased with the age of the stand which is obviously related to the living biomass. The amount of calcium was maximum in all the stands followed by nitrogen, phosphorus, potassium and magnessium (Table 10-7).

Table 10-8 shows the pattern of nutrient distribution in the living biomass of different forest types of the world. While N and P values are comparable to that obtained for many temperate forests, they are much lower than that recorded for tropical forests. This is particularly so in comparison with *S. robusta* plantation studies done by Faruqi (1972) in Varanasi, U.P. whose values seems to be on the higher side. The values for Ca in this study, though more than that recorded for temperate forests is about 19 times more for the *S. robusta* plantation study done at Varanasi (Faruqi, 1972) which again seems to be too high.

Table 10-6. Percentage concentration of different elements in bole, branches and leaves of *S. robusta* plantations.

Stand age (year)	Components	Concentration (%)				
		N	P	K	Ca	Mg
	Bole	0.64	0.04	0.16	1.03	0.18
9	Branches	0.83	0.06	0.39	0.51	0.20
	Leaves	1.41	0.13	1.76	1.31	0.46
	Bole	0.58	0.05	0.18	1.10	0.20
11	Branches	0.80	0.06	0.38	0.61	0.28
	Leaves	1.46	0.13	0.72	1.41	0.46
	Bole	0.53	0.06	0.19	1.13	0.20
13	Branches	0.75	0.07	0.36	0.30	0.28
	Leaves	1.50	0.15	0.65	1.18	0.40
	Bole	0.50	0.06	0.20	1.17	0.22
15	Branches	0.71	0.07	0.32	0.74	0.25
	Leaves	1.57	0.16	0.60	1.50	0.42
	Bole	0.46	0.07	0.21	1.20	0.24
17	Branches	0.69	0.08	0.30	0.79	0.26
	Leaves	1.60	0.18	0.57	1.53	0.44
	Bole	0.41	0.07	0.21	1.20	0.25
19	Branches	0.66	0.09	0.26	0.81	0.27
	Leaves	1.68	0.54	1.60	0.56	1.60

Table 10-7. Amount of nutrient elements (kg/ha) in standing crop biomass of *S. robusta* plantations.

Nutrient elements	Stand age (year)					
	9	11	13	15	17	19
Nitrogen	16.98	84.29	175.04	186.37	223.84	303.95
Phosphorus	1.34	8.52	18.84	21.25	31.72	47.02
Potassium	7.55	33.75	68.40	74.74	97.16	139.46
Calcium	19.39	109.60	284.27	356.92	473.73	712.56
Magnesium	5.09	26.17	61.39	73.47	95.29	156.92

Table 10-8. Nutrient content within the living biomass of trees in different forest communities.

Forest communities	Nutrients (kg/ha)					Authority
	N	P	K	Ca	Mg	
Pinus sylvestris (55 yrs.)	453	41	-	272	-	Ovington (1959)
Quercus robur (47 yrs.)	464	40	-	292	-	- do -(1958)
Betula verrucosa (55 yrs.)	543	34	-	651	-	- do -(1959)
Second Douglas fir stand	320	66	-	333	-	Cole *et al* (1967)
Tropical forest (Ghana)	2050	150	-	2700	-	Greenland and Kowal (1960)
Tropical dry deciduous (India)	1708	436.3	-	3707	-	Desh Bandhu (1970)
Shorea robusta (India)	7909	650	-	9960	-	Faraqi (1972)
Shorea robusta plantation (19 yrs)	303.9	47.0	139.5	712.0	156.9	Present study.

Litter production and its nutrients :

The monthly fluctuations in litter production in a 19-year old stand of S. robusta (Fig. 10-11) showed that the production of leaf litter was lowest in May, gradually increasing in subsequent months, reaching a peak in March. In April, the production of leaf litter decreased sharply, though remained at a high level. 50% of the total annual litter fall occured in February-March and almost 90% occured between December-April. A similar pattern of leaf litter fall was observed for other species too. Abscission zone may be formed more vigorously during the drier part of the year after November with leaf fall occuring during the time of moisture stress in the forest (Nye, 1961). However, the wood litter production was greater during May-July and remained at a low but a somewhat constant level during the rest of the year. Again this pattern may be due to the formation of abscission zone during the dry winter period, so that wood litter fall reaches its maximum during the following rainy season in May-July (Edwards, 1977).

Bray and Gorham (1964) suggested that leaf litter constitutes roughly 70% of the total litter and there is an inverse relationship between annual litter production and

Fig. 10-11. Monthly litter production in a 19-year old *S. robusta* plantation at Umtesor (1976-77).

Leaf litter : *S. robusta*, ● ; other species, ○ ; wood litter, ▲ .

Fig. 10-12. Comparison of expected and observed values of leaf litter production for a 19-year old *S. robusta* plantation (after Bray and Gorham, 1964).

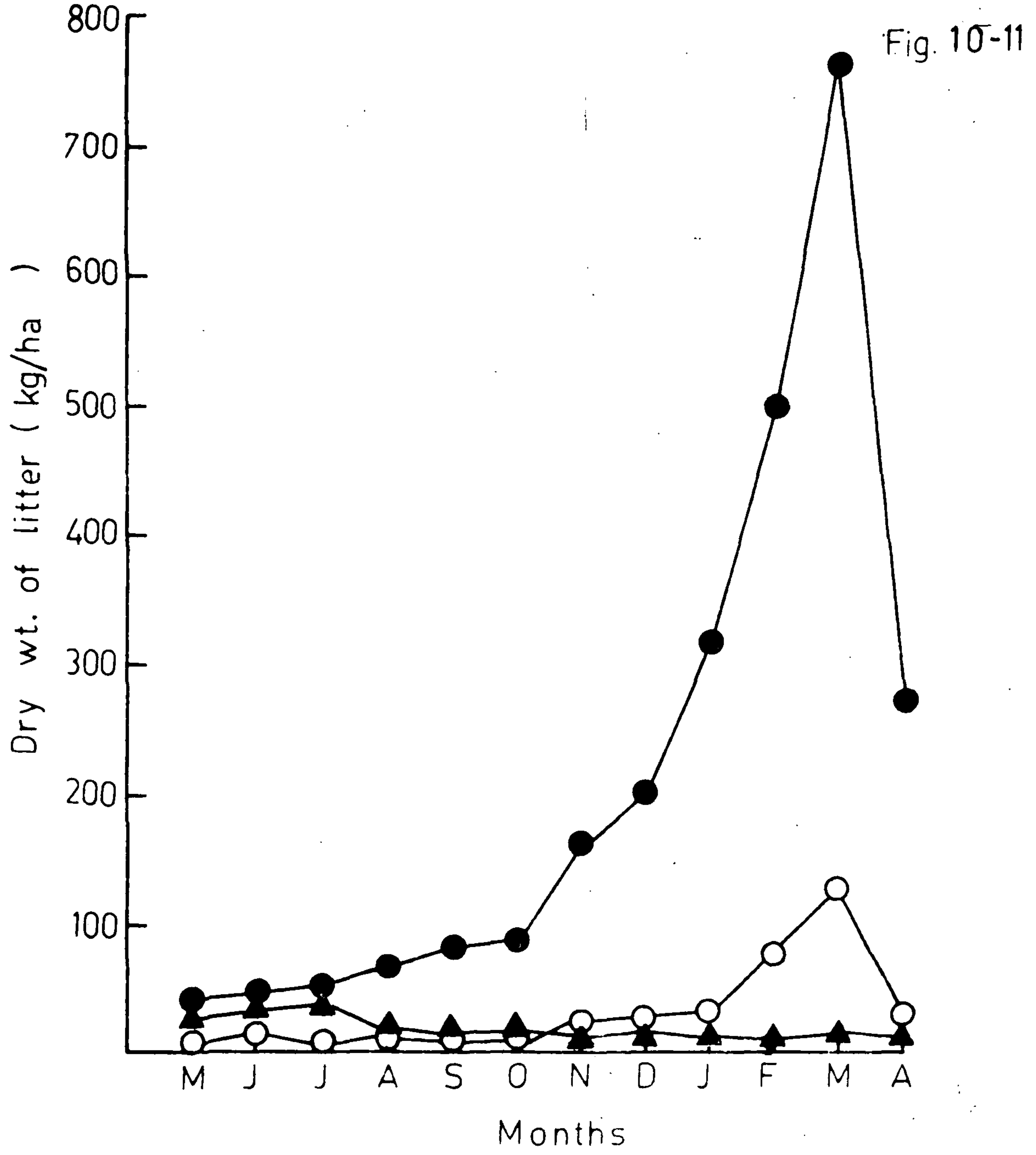


Fig. 10-11

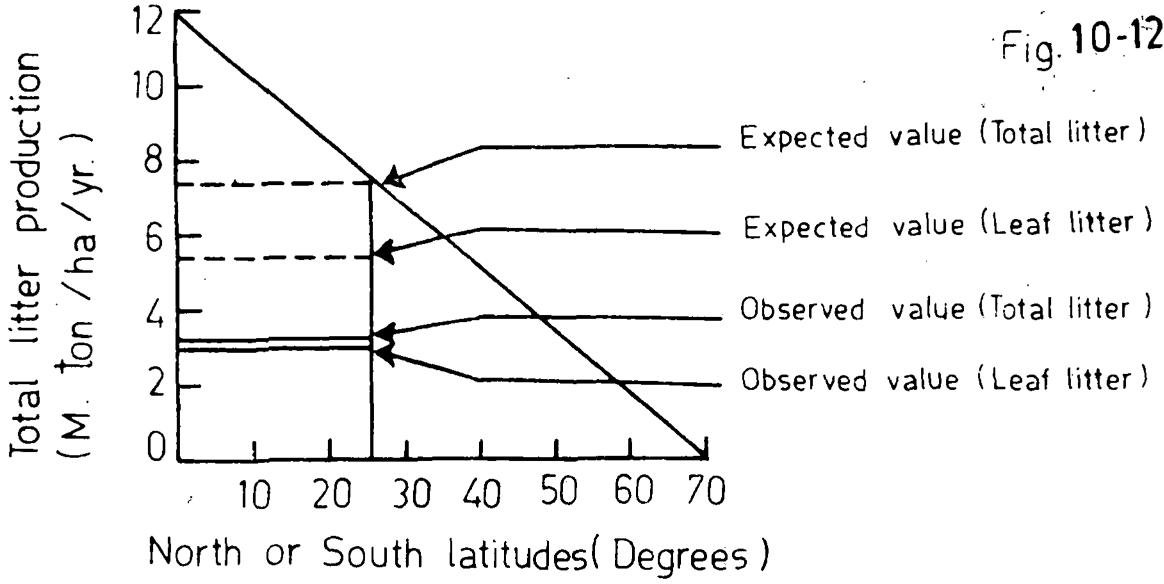


Fig. 10-12

the latitude of the locality. Accordingly, the expected value for the total annual litter production in the present area works out to be 8.2 t/ha with 5.74 t/ha of leaf litter (Fig. 10-12). The total amount of litter production in the present case was 3.12 t/ha/year which was too low than the expected value which may be due to younger age of the stand as well as poor site quality.

Litter production increased markedly with increase in age of the stands reaching a peak in a 13 year plantation but remained more or less at a steady level in the subsequent age groups studied (Fig. 10-13). Maximum litter production of 3.41 t/ha/yr was recorded in the 13 year plantation, although litter per tree and dry weight per leaf was low in this stand in comparison to older stands. This may be related to higher density of individuals in this case (Table 10-9).

Table 10-10 represents the average annual leaf litter production in different S. robusta plantations in India and for different climatic zones of the world. However, the low values obtained in the present case may be due to the comparatively younger age groups of plantations studied.

The monthly concentration (percentage) of different nutrient elements like nitrogen, phosphorus, potassium,

Table 10-9. Some characteristics of *S. robusta* plantations with standard errors.

Stand age (year)	Density/ha	Leaf litter/tree (kg/tree)	Individual leaf weight (gm.)
9	8440 ± 6.39	0.853	0.941 ± 0.111
11	7920 ± 1.40	0.269	0.951 ± 0.152
13	6630 ± 9.75	0.515	1.076 ± 0.315
15	4280 ±10.90	0.615	1.100 ± 0.367
17	4310 ±14.33	0.704	1.280 ± 0.381
19	4620 ±11.33	0.676	1.364 ± 0.390

Table 10-10. Annual leaf litter production in major climatic zones of the world and in *S. robusta* from different parts of India.

Vegetation	Location	Leaf litter mt/ha / yr	Authority
Climatic zones of the world -			
Alpine	67°N Lat.	0.7	Bray and Gorham (1964)
Cool temperate	37°-62°N. Lat.	2.5	Bray and Gorham (1964)
Warm temperate	30°-40°N & S Lat.	3.6	Bray and Gorham (1964)
Equatorial	Within 10°N & S of equator	6.8	Bray and Gorham (1964)
Indian sub-continent -			
Shorea robusta (Plantation)	30.19 N Lat.	5.9	Puri (1953)
Shorea robusta (Plantation)	30.19 N Lat.	5.0	Seth *et al* (1963)
Shorea robusta (Deciduous forest (Sagar)	23.50 N Lat.	2.6-9.3	Upadhaya (1955)
Shorea robusta (Plantation)	25°45"-20°0"N Lat	0.7-3.0	Present study

Fig. 10-13. Litter production in different stands of S. *robusta* at Umtesor.

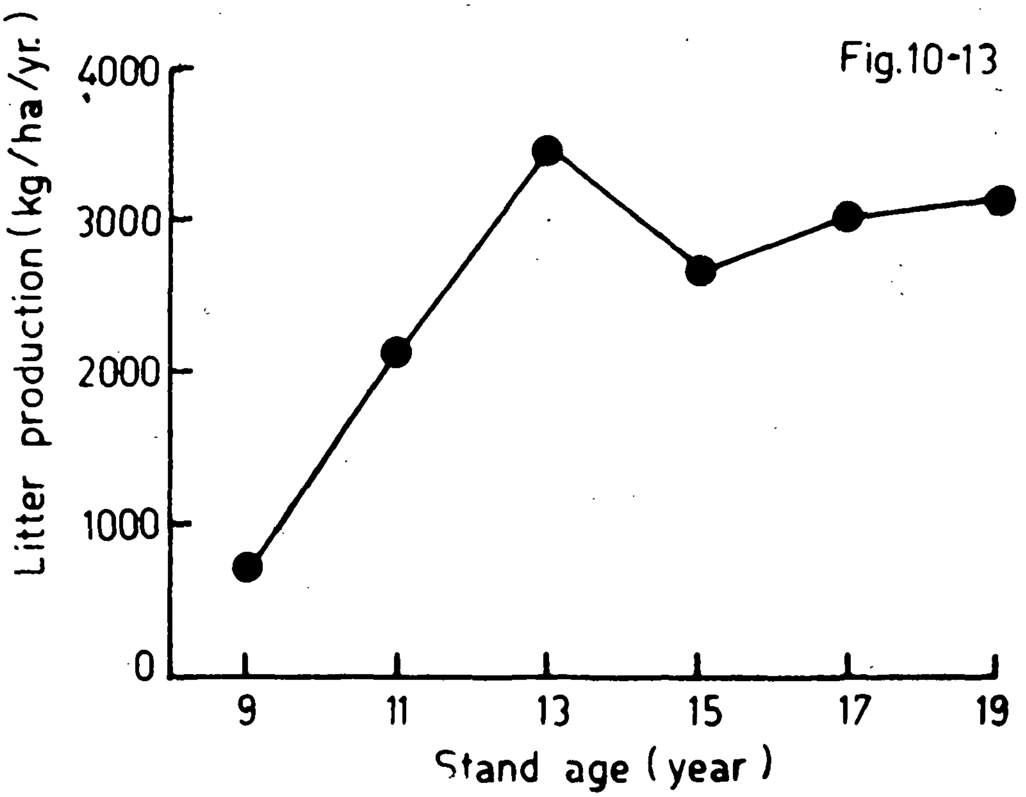
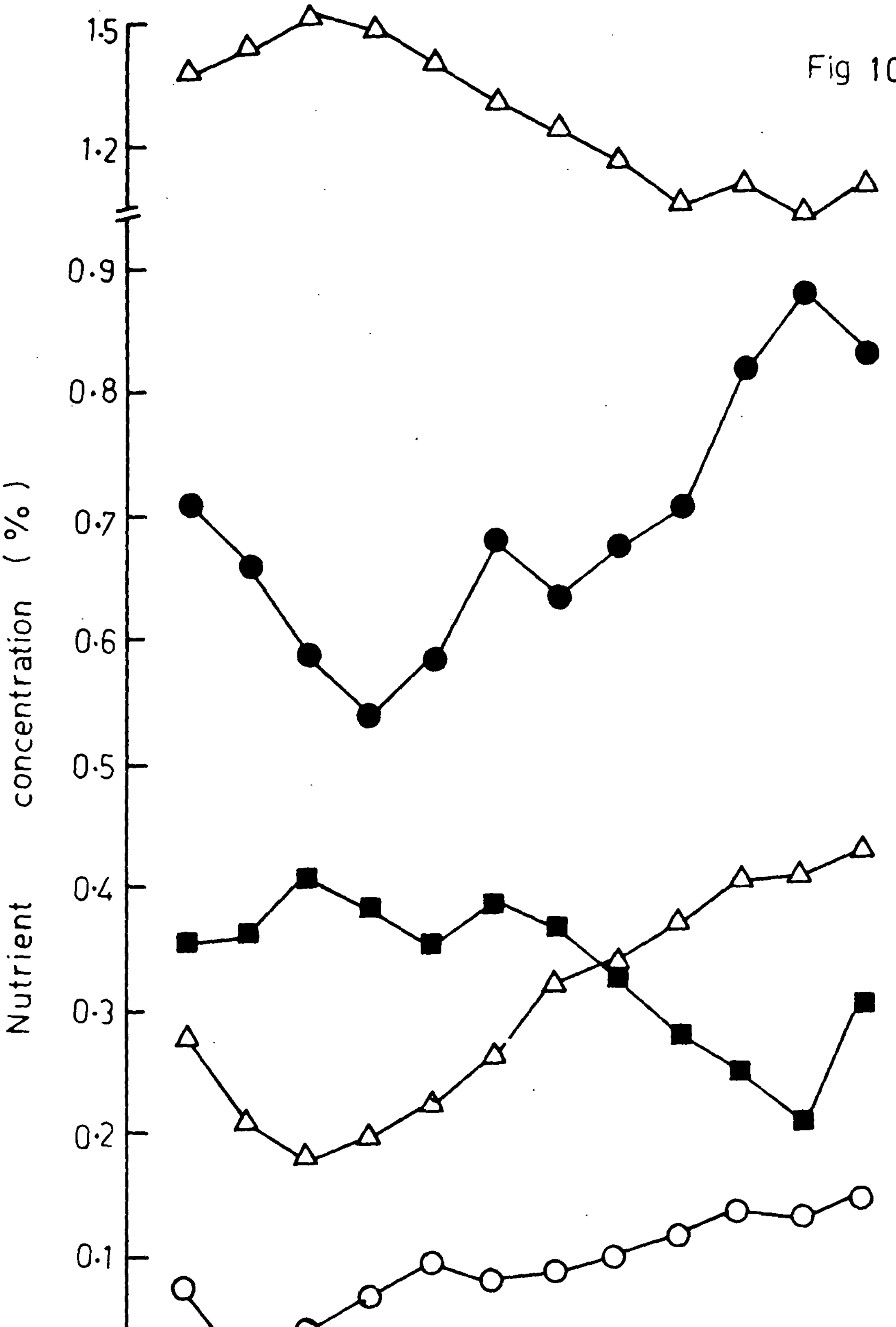


Fig.10-13
Litter production (kg/ha/yr.)
4000
3000
2000
1000
0
9
11
13
15
17
19
Stand age (year)

calcium and magnesium in leaf litter of a 19-year old stand of *S. robusta* and wood litter of this stand showed considerable variations. While Ca and Mg followed a more or less similar trend whereby the concentration was at its maximum during the rainy season (May-September) declining gradually during the dry period reaching the lowest level in March, the pattern for K followed an opposite trend. Nitrogen and phosphorus concentrations followed a similar trend between themselves so that the lowest level was attained during June-July and a maximum level was attained during March-April (Fig. 10-14). The low level of K in litter during monsoon may be related to leaching of larger quantities of K compared to Ca and Mg as has been shown by other workers (Tukey *et al*, 1958; Madgwick and Ovington, 1959; Carlisle *et al*, 1966b). Apart from this, the fluctuation in concentration may also be related to leaching of organic nutrients from the leaves, translocation of elements from leaves before senescence and decomposition of leaves before fall (Gosz *et al*, 1972; Van Cleve and Noonan, 1975). It is also seen that the more mobile elements like N,K and P showed higher concentration towards the senescent period of January-April when maximum litter fall occurs. However, lower concentrations of less mobile elements like Ca and Mg

Fig. 10-14. Monthly variation in concentration of different nutrients in leaf litter of a 19 year old <u>S.</u> <u>robusta</u> plantation. N, ● ; P, ○ ; K, ▲ ; Ca, △ ; Mg, ■ .



1·5
1·2
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
Nutrient concentration (%)
M
J
J
A
S
O
N
D
J
F
M
A
Months

Fig 10-~~14~~

was noted during this period.

A great variation in concentration of N, P, K, Ca and Mg was recorded in wood litter also (Fig.10-15). The concentration of N, K and P was lower during the rainy season as was also recorded for leaf litter though the pattern is less marked. The concentration of Mg was more during the peak period of leaf fall and may be due to the withdrawal of these elements into the wood during this period. This argument is supported due to a reverse pattern wherein the leaf concentration of this nutrient is more during the peak leaf fall period of February-April. The pattern for Ca is however, not very clear though the level of this is generally higher during March-April when maximum leaf fall occured.

Total amount of N, P, K, Ca and Mg in leaf litter (kg/ha/yr) in different stands increased with the age of the stand which is obviously related to litter production (Fig. 10-16). A comparative study of the total quantity of nutrients (kg/ha/yr) with other tropical and temperate forest types of the world showed that the values are much lower compared to others (Table 10-11). However, this may be partly due to the low age of the stand of S. robusta under

Table 10-11. Amount of mineral nutrients returned through litter fall in some tropical and temperate forest types of the world.

Vegetation	Locations	Nutrients (kg/ha/yr)					Authority
		N	P	K	Ca	Mg	
Birch forest	U.S.S.R.	66	5	13	54	19	Russian authors cited by Ovington (1965)
Scot pine forest	England	125	10	57	49	9	Ovington (1959)
Sessile Oak forest	England	27	9	4	15	2.8	Carlisle et al (1966)
Pinus Caribae	Nigeria	7.3	0.4	6.9	11.4	2.7	Egunjobi and Fasehum (1972)
Tectona grandis plantations	Dehradun (India)	52	11	19	131	5	Seth et al (1963
Shorea robusta plantations	Dehradun (India)	46	9	19	77	10	Seth et al (1963
Shorea robusta plantations	Meghalaya (India)	20	2	9	35	9	Present study

Fig. 10-15. Monthly variation in concentration of different nutrients in wood litter of a 19 year old S. robusta plantation. N, ● ; P, ○ ; K, ▲ ; Ca, △ ; Mg, ■ .

Fig. 10-15

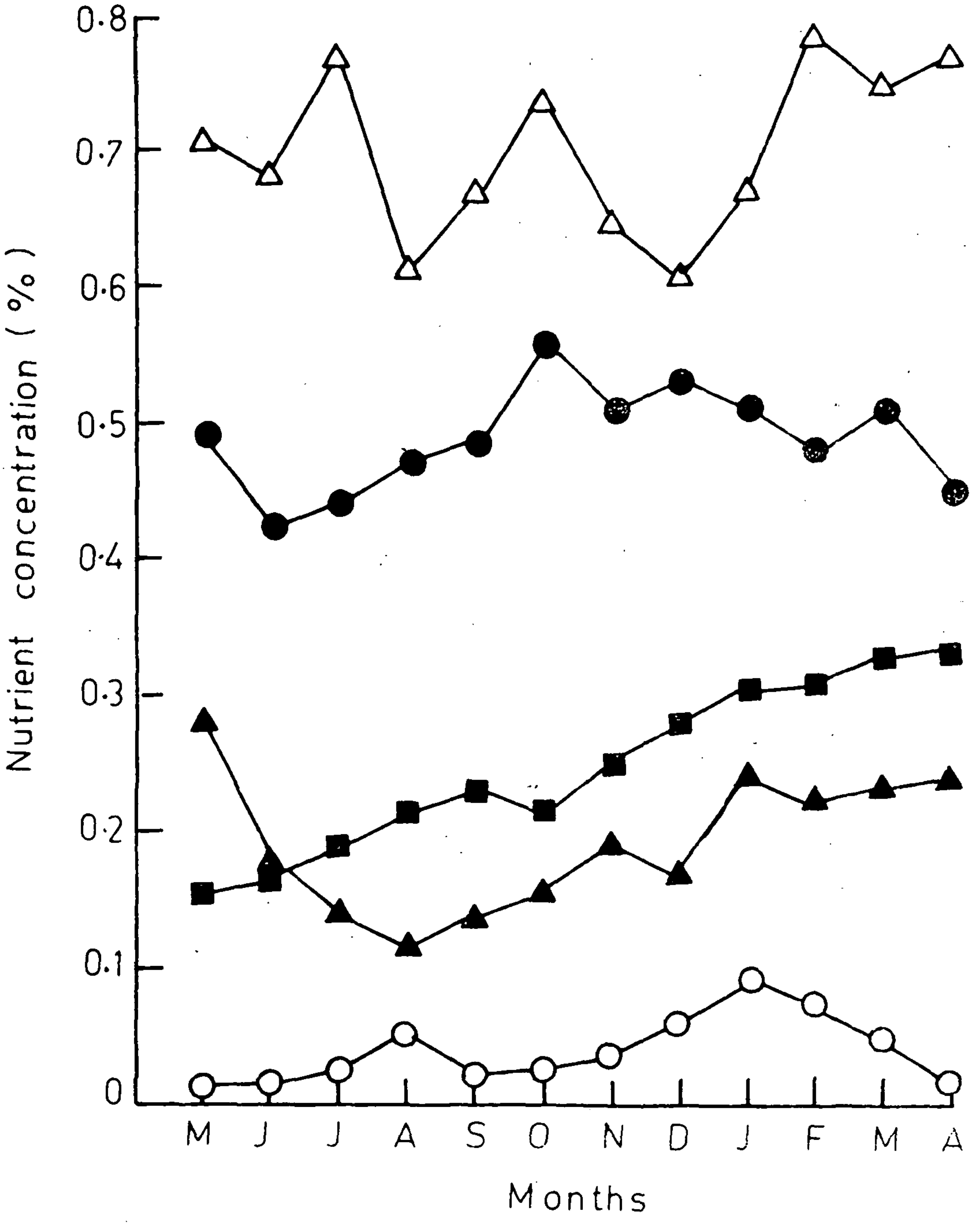
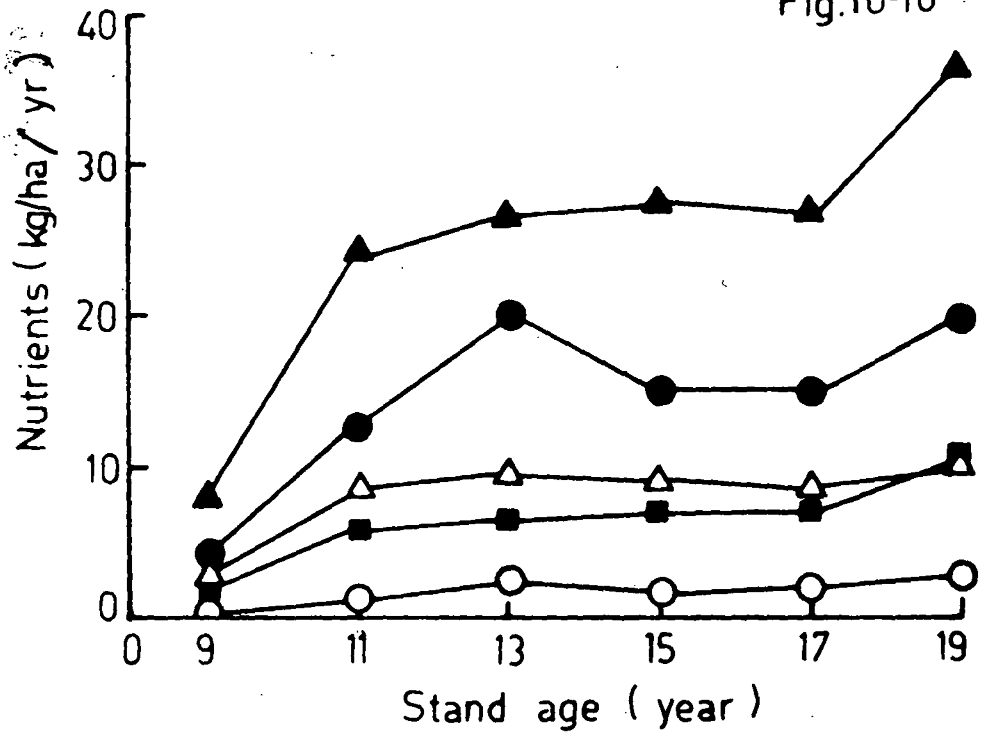

0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
Nutrient concentration (%)
M
J
J
A
S
O
N
D
J
F
M
A
Months

Fig. 10-16. Total amount of nutrient elements in different stands of S. robusta at Umtesor.

N, ● ; P, ○ ; K, ▲ ;
Ca, △ ; Mg, ■ ;

Fig.10-16



study and may also be related to poorer site quality as discussed elsewhere.

The uptake, retention and release pattern of different nutrients in a 19 year old plantation (Table 10-12) showed that all these three are maximum for Ca and N. However, uptake was very low for other nutrients but retention was comparatively much higher, more particularly for an element like P.

SUMMARY

The physical and chemical properties of the soil, biomass and litter production and the nutrient content within their compartments were studied in 9,10,19 year old plantations of *Shorea robusta*. Soil was lateritic sandy loam with a pH ranging 5.9 to 6.5. Concentration of soil nutrients was high during the rainy season due to their release from the decomposing litter. The fluctuation in concentration of nutrients was well marked in the upper layers of the soil only. Soil nutrient pool within a depth of 100 cm had: N, 10709; P, 340; K, 2285; Ca, 945 and Mg, 614 kg/ha.

Table 10-12. Annual uptake, retention and release of different nutrient elements in a 19-year old plantation of *S. robusta*.

Pathway	Nutrients (kg/ha/yr)				
	N	P	K	Ca	Mg
Uptake	84.09	29.25	31.08	109.68	30.16
Retention	64.09	27.25	22.08	74.68	21.16
Release	20.00	2.00	9.00	35.00	9.00

The number of trees/ha decreased with age of the plantations while basal area, height and dbh increased with age. Leaf area/ha was maximum (70172.58mm^2/ha) in a 13-year old stand which was directly related to greater individual leaf area and density. The dry weight of individual tree and standing crop biomass increased with the age and maximum amount of dry matter production 12.744 kg/tree and 58.88 t/ha respectively was recorded in oldest stand of 19-years old. The gree biomass and non-green/green ratio was found to be increased with the age of the stand. The concentration of N, P, K, Ca and Mg in different organs like bole, branches and leaves varied and it also varied with the age of the plantation. Total amount of N, P, K, Ca and Mg was directly related to the organic matter production of each stand.

Litter production was maximum during February-March when about 50% of the total leaf litter was recorded while maximum wood litter production (50%) occurred in the month of May-July. Maximum litter production of 3.41 t/ha/yr was recorded in a 13-year old stand. A great monthly variation in concentration of N, P, K, Ca and Mg was noted in leaf and wood litter which might be due to leaching of nutrients from leaf, translocation or withdrawal of material from leaf and wood litter during different months. Total amount of nutrients was directly related to the annual litter production by the stands and maximum values (N, 20; P, 2: 4, 9; Ca, 35 and Mg, 9 kg/ha) were recorded in a 19-year old stand. Annual uptake, release and retention of nutrients in a 19-year old stand is discussed.

CHAPTER 11

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