DYNAMICS OF FINE ROOTS IN PINE FOREST ECOSYSTEM

By

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THESIS SUBMITTED
IN FULFILMENT OF THE DEGREE OF
DOCTOR OF PHILOSOPHY IN BOTANY
OF
NORTH-EASTERN HILL UNIVERSITY
SHILLONG, INDIA

1998

NORTH-EASTERN HILL UNIVERSITY
SHILLONG

CERTIFICATE

I, Babu John, hereby, declare that the subject matter of the thesis entitled "Dynamics of fine roots in pine forest ecosystem" is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the North-Eastern Hill University for the degree of Doctor of Philosophy in Botany.

17/8/98 | 17/8/98 | 17/8/98 |
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ACKNOWLEDGEMENTS

I take this opportunity to express my deepest sense of gratitude and heartfelt thanks to my revered teachers Prof. R.S. Tripathi and Prof. H.N. Pandey, Department of Botany, North-Eastern Hill University, Shillong for their able guidance, constructive suggestions and constant encouragement throughout the course of present investigation. The words fail me to express my sincere thanks and gratefulness to them.

I am grateful to Prof. H.N. Pandey (Head) and Prof. P. Tandon and Prof. R.R. Mishra (Ex-Heads), Department of Botany North-Eastern Hill University, Shillong for providing necessary laboratory facilities.

I am thankful to Dr. Y.Kumar (Lecturer) and Dr. P.B. Gurung (Herbarium Curator), Department of Botany, NEHU for their help in identification of plant species.

I would like to express my sincere thanks to all the teaching and non-teaching staff of the Department of Botany, NEHU, Shillong for their cooperation and help at various levels of the work. I am extremely thankful to the Library staff of the School of Life Sciences for their help and cooperation.

Mr. B.K. Das took photography of the study site and H.R. Choudhury helped in drawing the graphs. I am thankful to both of them. Help extended to me by Rameshwar Rai in the field as well as in the laboratory is tankfully acknowledged.

I am thankful to Mr. S.C. Sahoo, System Analyst, Centre Seismological Laboratory, Upper Shillong for providing the meterological data.

The completion of the work was mainly possible due to the help and cooperation received in ample measure from my lab mates Dr. (Mrs.) P. Rao, Dr. S.K. Barik, Dr. D. Datta, Dr. (Ms) T. Lyngdoh, Dr. (Mrs.) K. Maithani, Dr. S.K. Dhyani, Mr. Alemmeren Jamir, Mr. Nripemo Odyuo, Mr. Rupam Kataki, and Mrs. Ublari Shilla. I am thankful to all of them. My special thanks are to Dr. A. Arunachalam and Mr. Subhasish DasGupta for their valuable help at various stages of the work.

I am thankful to my friends in the Department, Ms. Easter Meena Blah, Mr. Hiranjit Choudhury, Ms. Mary Hmar, Ms. Darisuk N Dkhar, Mr. Johns Augustine, Mr. P.J. Bora, Ms. Virginia Kalita, Mrs. Rajani Jacob, Ms. Susamma Varghese, Mr. Chitta Ranjan Dev Ms. Gopa Sarma, Ms. Luckily Ranee, Ms. Limasenla, Mr. Atanu Bhattacharjee, Ms. Amary Salam, Mr. Sanjiban Goswami and Ms. Talijungla for their help and cooperation.

I extend my deep sense of gratitude and thanks to my mother, brothers and sisters for their wonderful encouragement and support throughout my studies. I would like to express my sincere thanks to Mr. Joseph Mathew, Mrs. Merline Joseph, Sr. Sisily Cherian and Dr. V.J. Zacharias for their constant encouragement and help.

Financial support received from the University Grants Commission, New Delhi through a research project (Sanction No.F.3-38 (SR-II), dated January, 1994) is gratefully acknowledged.

Last, but not the least, I thank Almighty for giving me the will, courage and strength to accomplish this present investigation.

(Babu John)

Shillong
Dated 21st August, 1998

CHAPTER I

GENERAL INTRODUCTION

The role of fine roots and associated mycorrhizae in forest-biomass dynamics was not much emphasized in the past (Caldwell 1979, Hermann 1977, Persson 1980, Santantonio 1979). Earlier, the studies on root and root growth were paid relatively little attention in the analysis of ecosystem structure and function (Shaver and Billings 1975). However, during the last decade, considerable amount of work has been done in different ecosystems all over the world to understand the importance of roots in tree productivity and overall functioning of the forest ecosystem.

Fine roots are of paramount importance in the functioning of forest ecosystems. They are essential for water and nutrient uptake (Lyr and Hoffman 1967, Lidell and Persson 1995). The thick root mat found on the soil surface in the humid tropical forest plays crucial role in circulation of nutrients within the system and reduces runoff and prevents nutrient and soil sediment losses from the ecosystem. Fine roots together with the associated mycorrhizae play a significant role in rapid and efficient cycling of nutrient elements in those environments where the chances of leaching of nutrients are high and nutrient availability is low (Went and Stark 1968, Stark and Jordan 1978, Cuevas and Medina 1988). Stratified distribution of roots in the forest communities helps in maximum utilization and absorption of water and nutrients.

The fine roots are restricted mainly to the top soil layer. This is particularly true where fertility of soil is low (Greenland and Kowal 1960, Hopkins 1969, Klinge 1973, Stark and Jordan 1978, Yada 1978). Stone and Kalisz (1991) reported that the roots of many tree species may grow to a depth of 5-10 m or more. In deep, well-aerated soils, roots penetrate to great depths and spread widely, but in heavy and poorly aerated soil and in sandy soils, majority of the roots confine themselves to the top soil layer (Woods 1957). In forest, majority of tree fine roots are present in the upper 50 cm of the soil profile, with most of the absorbing fine roots confined to the top 20 cm (Karizumi 1968, Meyer and Gottsche 1971, Hermann 1977). Safford and Bell (1972) reported that 87% of the fine roots were located in the top 15 cm soil in a 39-year old spruce plantation. Kumerow *et al*. (1982) found more than 90% of fine root growth in the upper 10 cm soil in a Cocoa plantation.

The belowground biomass of trees is an important compartment for the storage of nutrients in forest ecosystems (Ovington 1962, Johnson and Risser 1974, Whittaker *et al*. 1979). Between 60 and 70% of the total net primary productivity is invested in the growth and maintenance of the fine root system and associated mycorrhizal assemblages (Agren *et al*. 1980, *Vogt et al*. 1982, Fogel and Hunt 1979). A better understanding of fine roots in forests, requires information on morphology, growth and physiological activity and control of root distribution in soil and their interaction with other components of the ecosystem.

Harris *et al.* (1977), Persson (1980) and McClugherty *et al.* (1982) have reported that in forested ecosystem the annual production of fine root litter may be similar to the leaf litter production. Both aboveground litter fall and belowground fine-roots are equally important in organic matter and nutrient turnover in forest ecosystem (Vogt *et al.* 1986), sometimes the latter assuming more important role than the former. Decomposition of detrital material, litter on the forest floor and roots in the soil profile, releases nutrients which are readily available for absorption by plants. The rate of litter decomposition is influenced by a large number of abiotic and biotic factors of climate and soil complex and resource quality of detrital material (Meentemeyer 1978). Decomposition studies in the forest ecosystems have been mostly carried out on the above ground litter (Swift *et al.* 1979) and relatively less work has been done on the decomposition of root litter (Swift *et al.* 1979).

Due to technical difficulties in studying the root system, its dynamic aspects such as death, renewal and turnover have been largely neglected (Persson 1980). Studies on the temporal pattern of fine-root growth indicate wide fluctuation in the fine-root biomass during the growing season (Heikurainen 1955, Kalela 1985, Gottsche 1972, Kohman 1972, Harris *et al.* 1973, Roberts 1976).

Vogt *et al.* (1986) reported that deciduous species contribute more above- than belowground litter to the detritus, and evergreen species add twice as much root material to the detritus as deciduous species growing at similar latitudes. These results clearly indicate that roots, compared to the foliage, contribute more to soil organic matter accumulation where the vegetation is dominated by evergreen species. Normally, evergreen species grow on poorer sites compared to the deciduous species (Small 1972, Goldberg 1982). Probably this could be the underlying reason for the greater contribution of root litter to soil organic matter on poorer sites. The capacity of evergreen forests to photosynthesize round the year and their longer retention of foliage appear to allow evergreen trees to fix more carbon than the deciduous trees (Schulze *et al.* 1977, Vogt *et al.* 1986). The greater amount of carbon fixation, in turn, may give evergreen species the surplus carbon needed to support a large root biomass. Vogt *et al.* (1991) reported that fine roots contribute more to the ecosystem carbon accumulation in the evergreen forests than in the deciduous forests. Belowground inputs contribute more to ecosystem level cycles than the aboveground input within the evergreen forests. This probably leads to the establishment of evergreen species on nutrient-poor and degraded sites.

The state of Meghalaya has several "Sacred forests, which represent the relic climax vegetation. Much of the original vegetation of this area has been disturbed and altered due to age-old practice of shifting cultivation. Small pockets of these sacred forests left untouched due to certain local beliefs provide a glimpse of original forest that once must have covered these hills. In many parts of Khasi and adjoining hills repeated shifting cultivation involving felling and burning of trees, has greatly altered the original forest cover, which presumably comprised broadleaved evergreen species with or without pine (Champion and Seth 1968). According to Puri *et al.* (1989) Khasi pine (*Pinus kesiya*) was introduced in these hills in pre-historic times.

P. kesiya requires a seasonally dry climate and a well-drained soil for its successful establishment and development. The seedlings can develop on mineral soil and in open places. They do not tolerate shade. Pine is fairly resistant to fire once over 3 m tall (Kowal 1966). *P. kesiya,* an efficient colonizer of abandoned fields forms the climax community under biotic influences. It is preferred by the local people on account of its high annual timber volume increment and because of the fact that it can be easily handled in plantation forestry (Whitmore 1993).

Pinus kesiya covers large areas of Khasi hills, Jaintia hills, Naga hills, Lushai hills and in Manipur. It also occurs in the Shan states of Upper Burma between 800-1900 m. It is found in continental south-east Asia and its distribution extends into the Malay archipelago. *P. kesiya* occurs in Luzon in the Philippines between 450 and 2450 m elevation in the Cordilera Central and Caraballo mountains with small southern outlaying population in the Zambales mountains (Kowal 1966).

The objective of the present research was to study the dynamics of fine roots in a pine forest ecosystem and to evaluate their role in organic matter and nutrient accumulation and turnover in soil supporting *Pinus kesiya* stands of different ages. The study covers the following major aspects :

(i) Vertical distribution and seasonal dynamics of fine (<2 mm diameter) and coarse roots (>2 mm diameter) in terms of biomass and necromass.

(ii) Production of fine and coarse roots of tree and ground vegetation in pine stands.

(iii) Resource quality of tree fine roots and their decomposition .

(iv) Role of fine roots in N and P storage and turnover in soil.

The data generated from the field and laboratory experiments during 1995 and 1996 on the above aspects have been presented and discussed in the thesis in different chapters (IV to VI), which are followed by general discussion and summary (Chapters VII and VIII). The chapters containing experimental results are preceded by general introduction, review of literature, methodologies and description of the study site.

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

Root system of trees plays an important role in the functioning of forest ecosystem (Safford 1974).Growth of root system is decisive both for the development of above-ground vegetation and for the soil formation (Persson 1983). Roots are the connecting link between plant and soil and influence soil profile development (Sutton 1969,Persson 1983).Upon dying, they contribute significantly to the soil organic matter pool (Coleman 1976, Head 1973, McClaugherty 1982, Persson 1979, 1982). Distribution of roots in the soil varies according to species, soil and forest type. Tap roots and sinker roots of many temperate forest tree species reach to a depth of 3-5 m in latosols (Mensah and Jenik 1968, Klinge 1973, Huttel 1975). In hydromorphic soils with permanently water logged subsoil, trees develop a large plate of superficial terrestrial roots (Jenik 1971a). In majority of cases layering of tree roots is strongly influenced by competition offered by the ground vegetation and by the source of soil water. Van Donsclaur-Ten Bokkel Huinink (1966) reported that habitats receiving only rain water have high concentration of roots in the surface soil layer, while in those habitats where ground water is readily available to roots, the roots may grow 10 m deep

(Maxwell 1972). In savanna vegetation grass roots occupy the surface layer while the tree roots spread underneath the grass roots at a depth of 20-30 cm (Lawson *et al.* 1968). The tropical rain forests are shallow-rooted ecosystems (Richards 1952, Whitmore 1975, Jordan 1985).

FINE ROOT DYNAMICS

Tree roots are generally divided into three categories according to their size and morphology viz. (i) structural or supportive coarse roots with slow turnover rate, (ii) smaller diameter roots with intermediate turnover rate, and (iii) fine mycorrhizal roots (<2mm diameter) with fast turnover rate (Vogt *et al.* 1989).

According to Ares and Peilemann (1992), fine roots include nonwoody roots (<2 mm in diameter) and their root tips.The fine feeder roots are not only important for water and nutrient absorption (Lyer and Hoffman 1967, Harris *et al.* 1980), but they also play a crucial role in conservation of nutrients in the ecosystem (Harris *et al.*1977, Khiewtam and Ramakrishnan 1993, Berish 1982, Arunachalam *et al.* 1996a). Fine roots constitute a dynamic component in most forest ecosystems and play important role in carbon cycling (Agren *et al* 1980, Axelsson 1981, Caldwell 1979, Ericsson and Persson 1980). Herrera *et al.* (1978) emphasised the importance of surface feeding fine roots in capturing free ions from the soil. These roots represent functionally important part of the biomass in the forest ecosystems (Buttner and Leuschner 1994). Fine roots and the associated mycorrhizae contribute to the rapid and efficient cycling of nutrient elements on those sites where possibility of leaching of nutrients is high and their availability is low (Went and Stark 1968, Stark 1971, Stark and Spratt 1977, Stark and Jordan 1978, Cuevas and Medina 1988). The density of roots in a particular environment relates to their absorption capacity and indicates their potential for conserving nutrients (Jordan 1985).

Generally, roots having >2 mm diameter are categorised as coarse roots. But so far as fine roots are concerned there is no unanimity among different workers in this regard. Different researchers have considered different diameters for describing fine roots e.g., <6.4 mm (Kimmins and Hawkes 1978), <5 mm (Meier *et al.* 1985), <3 mm (Aber *et al.* 1985), <2 mm (Vogt *et al.* 1983, Persson 1983, Vance and Nadkarni 1992) <1 mm (Santantonio and Herman 1985), <0.5 mm (very fine root) and 0.5-3 mm (fine root) (McClaugherty *et al.* 1982).

DISTRIBUTION OF TREE ROOTS

A lot of work has been done all over the world on the vertical and horizontal distribution of root system in different ecosystems (Vogt *et al.* 1986, 1991). In majority of the cases roots occur relatively close to the soil surface, and most studies have focussed on roots growing in top 0-40 cm soil layer (Hendrick and Pregitzer 1996).

Data on root biomass of individual forest trees are limited mainly on account of difficulties involved in their study in the field situation (Woodwell and Whittaker 1968, Kira and Ogawa 1968). Nonetheless, data are available from a number of plant communities, for instance, from the forest fallows in Congo (Bartholowmew *et al.* 1953), secondary forest in Wigecia (Greenland and Kowal 1960), oil palms in Nigerian plantations (Rees and Tinker 1963), Ivory Coast (Huttel 1969), Mimbo forests in Zaire (Malaissee *et al.* 1972), south-east Asian forests (Ogawa *et al.* 1965, Kira and Shidei 1967), and central Amazonia forests, Brazil (Klinge 1973, Fittakau and Klinge 1973, Klinge *et al.* 1975). Distribution of fine roots and dynamics of roots of different diameter classes in successional communities was studied by Ovington (1962), Coleman (1976), Hermann (1977), Lyer and Hoffman (1967), Santantonio *et al.* (1977) and Berish (1982). Data generated by these studies clearly indicate that root biomass varies widely between different forest types.

Dynamics of fine roots in relation to site factors was studied in pine plantation by Ares and Peinemann (1992). Distribution and activity of fine roots in *Pinus radiata* plantations of Australia was studied by Moir and Bachelard (1969) and Nambiar (1987). Similar studies were conducted by Roberts (1976) in *Pinus sylvestris* forests of Anglia.

Arunachalam *et al.* (1996a) studied seasonal dynamics of fine roots in three regrowing forest stands of a subtropical humid forest in north-east India. Silver and

Vogt (1993) studied the fine root dynamics in a subtropical wet forest ecosystem following single and multiple disturbances and reported that high mortality occurring in fine roots after disturbance may result in significant decline in nutrient availability in soil. Effect of hurricane disturbance on fine root dynamics in a subtropical wet forest has been reported by Parrotta and Lodge (1991).

Proliferation of fine roots and distribution of fine root biomass in soil have been studied by many workers (Heikurainen 1955, Gottsche 1972, Kohman 1972, Harris *et al.* 1973, Roberts 1976, Ford and Deans 1977, Kummerow *et al.* 1978, Singh and Singh 1981, Vogt *et al.* 1981, Buttner and Leuschner 1994) both in the plantations and in the natural forest communities of the tropical and temperate regions. Findings of all these studies indicate that the amount of fine roots varies according to season and soil depth.

Few reports are available to show that fine root biomass changes with age of the tree species (Scholtes 1953, Ovington 1957, Karizumi 1968, McQueen 1968, Moir and Bachelard 1969 and Vogt *et al.* 1981).

Studies have been conducted to evaluate the effect of nutrients (N & P) fertilization (Safford 1974, Lindell and Persson 1995), irrigation (Katterer *et al.* 1995) and soil acidification and aluminium toxicity (Majdi and Persson 1993) on fine root biomass. Safford (1974) reported that surface application of lime and NPK fertilizer had a beneficial effect on the root density. Based on their studies in different forest ecosystems, Lyr and Hoffman (1967), Ford and Deans (1977) concluded that root biomass increases in the nutrient-rich zones of the soil. On the contrary, Gower (1987) reported significantly greater fine root biomass on a site having low soil phosphorus and calcium contents. In temperate coniferous forest Vogt *et al.* (1985) observed an inverse relationship between fine root biomass and soil nitrogen level.

The effect of herbicide application on the growth of roots and uptake of nutrients in a grazed orchard was studied by Atkinson (1980). Deans (1979), Katterer *et al.* (1995) have examined the influence of soil temperature, soil moisture and other environmental factors on root growth and root biomass in different forest types. Pritchett (1986) concluded that soil moisture probably has a greater influence on root development and distribution than most other factors of the soil complex.

Many workers have come to the conclusion that growth of fine roots occurs relatively independently of the shoot growth and the temporal variation in fine root growth is largely determined by the changes in the environmental conditions. The coarse roots generally do not show temporal changes or annual cycle (Harris *et al.* 1977, Santantonio *et al.* 1977, Persson 1978), whereas fine roots are always in a state of constant flux (Persson 1980). In temperate forests, fine roots undergo large seasonal variation in growth and activity (Santantonio and

Hermann 1985) and show two or more peaks (Ford and Deans 1977, Harris *et al.* 1977, Persson 1978) during a year.

In India, Singh and Singh (1981) and Srivastava *et al.* (1986) studied the fine root growth dynamics in teak (*Tectona grandis*) plantations in a dry tropical region of the country and Beena and Garkoti (1994) estimated root biomass in a *Quercus floribunda* forest in the central Himalaya. Similar studies have been conducted in the mixed forests of south India (Parthasarathy 1987, Visalakshi 1994, Sundarapandian and Swamy 1996). In north-east India, Ramakrishnan and Singh (1983), Khiewtam and Ramakrishnan (1993) have estimated root biomass in a mature subtropical humid forest and Arunachalam *et al.* (1996a) have studied seasonal dynamics of fine roots in secondary forest communities after cultural disturbance in a climax subtropical humid forest of Meghalaya. Dhyani (1997) studied the seasonal dynamics of fine roots in agroforestry systems of Meghalaya.

PRODUCTION AND TURNOVER OF FINE ROOTS

Production and turnover of fine roots play an important role in carbon and nutrient dynamics of the forest ecosystems (Edwards and Harris 1977, Persson 1978, Keyes and Grier 1981, McCalugherty *et al.* 1982, Vogt *et al.* 1982). By rapid turnover rate tree fine roots contribute significantly to the carbon and nutrient pool of the soil (Agren *et al.* 1980, Harris *et al.* 1980, Fogel 1983, Persson 1983, Hanssen and Steen 1984, Santantonio and Herman 1985). Fine root production in the forests has been studied by several workers (Karizumi 1968, Marks *et al.* 1968, Moir and Buchelard 1969, Meyer and Gottsche 1971, Safford and Bell 1972, Kockenderter 1973, Harris *et al.* 1977). According to Agren *et al.* (1980), Grier *et al.* (1981) and Vogt *et al.* (1982), fine root production may account up to 75% of the total net primary production in the forest ecosystems. Thornby (1972b), Wareing and Patrick (1975), Keyes and Grier (1981) reported that on poor sites a greater proportion of net primary production is allocated to the roots. Root production is significantly higher in the upper soil layer than at the lower depths (Hendrick and Pregitzer 1966).

The determination of fine root production and turnover in field is a difficult job (Jarvis and Levernz 1983, Linder and Rook 1984, Aber *et al.* 1985, Bower 1985, Connell 1978) due to problems associated with its sampling in the field, wide seasonal fluctuation in biomass and continuous transformation of the fine root biomass into necromass (Reynolds 1970, Santantonio 1979, Persson 1979 & 1980, McCalughtery 1982).

Fine root production in forest ecosystems has been measured by summing positive changes in the fine root biomass during successive time intervals. Some workers have based their calculations only on the live mass of fine roots (Harris *et al.* 1977, Deans 1981, McClaugherty *et al.* 1982), while others (Persson 1978 & 1979, Santantonio *et al.* 1977, Keyes and Grier 1981, Fairley and Alexander

1985, Gholz *et al* 1986) have considered both live as well as dead mass of fine roots in computing fine root production.

Root production may be influenced by a large number of factors. Studies conducted by Lyr and Hoffman (1967), Sutton (1969), Russel (1977), Caldewell 1979) and Persson (1980) reveal that concentration of growth regulating substances, carbohydrates, respiration rate, and availability of nutrients in soil influence root production. Findings of Lyr and Hoffman (1967), Herman (1977), Russel (1977) and Pritchett (1986) indicate that soil moisture stress and low temperature during winter may limit root growth of trees. Turnover of fine roots is usually greater than the leaf litter (Swift *et al*. 1979, Van Praag *et al*. 1988) and it varies according to site conditions and species (Ovington *et al* 1962, Harris *et al* 1977, Persson 1980, Grier *et al*. 1981, Joslin 1983). Kolesinkow (1971) compared the death and replacement of fine roots to leaf shedding in the evergreen plant species.

An increase in the turnover rate of fine roots with increasing nutrient availability in soil has been reported by several workers (Grime 1977, Orians and Solbrig 1977, Chapin 1980, Chapin and Van Cleve 1981). Effect of quantity and form of available nitrogen in soil on fine root turnover in forest ecosystems has been discussed by Aber *et al*. (1985) and Nadelhoffer *et al*. (1985). In cold temperate forest, Axelsson (1981), Alexander and Fairley (1983), Vogt *et al*.

(1983) and Aber *et al.* (1982) reported that the increase in soil nitrogen availability causes a decreases root biomass and production. Shaver and Billing (1975) reported that root turnover rate in tundra ecosystem varied according to species. Santantonio and Santantonio (1987) studied the effect of thinning on production and mortality of fine roots in *Pinus radiata* stand and reported that thinning reduced the live fine roots, whereas the dead roots remained unchanged.

The turnover rate of fine roots varies widely from few weeks (Vogt and Bloomfield 1990) to several years (Lyr and Hoffman 1967, Kolesnikov 1971) in different ecosystems. Literature on fine root production and belowground carbon allocation in forest ecosystems has been reviewed by Nadelhoffer and Raich (1992). They concluded that the role of fine roots in net primary production and nitrogen budgets of forest ecosystems is poorly understood.

NUTRIENT DYNAMICS OF FINE ROOT

Fine roots represent a large and dynamic portion of the belowground biomass and nutrient capital in the tropical and temperate forests (Santantonio *et al.* 1977, Persson 1978, Harris *et al.* 1977). They add large amount of organic matter and nutrients to the soil through extremely rapid turnover (Harris *et al.* 1977, Axelsson 1981, Coleman 1976, Shugart *et al.* 1977, and Srivastava 1985). The importance of fine roots in soil organic matter dynamics and cycling of nutrients in the temperate deciduous forest ecosystem is well documented

(McCalugherty *et al.* 1982, Fogel 1983, Nadelhoffer *et al* 1985, Joslin and Henderson 1987, Hendrick and Pregitzer 1996). In the tropical forest ecosystems, Went and Stark (1968), Redhead (1968 & 1980) reported that the mycorrhizal hyphae and the fine root mats are responsible for the efficient and direct recycling of nutrients.

Vogt *et al.* (1986) established a strong negative correlation between actual estimates of root production and rate of nitrogen cycling in the temperate needle-leaved and broad-leaved forests, and concluded that increase in nitrogen availability in soil due to fertilizer application generally causes decrease in root biomass and production in cold temperate forests. They further concluded that in the tropical forests, poorer the nutrient availability of the site, the greater will be the proportion of belowground input to the total detrital production. Contrary to the above finding of Vogt *et al.* (1986), Arunachalam *et al.* (1996a) reported an increase in fine root biomass with the increase in soil fertility level during regrowth of disturbed humid subtropical forest in north-east India.

FINE ROOT CHEMISTRY

The chemistry of fine roots differs markedly from the foliage (Vogt *et al.* 1991). The lignin content and concentration of nutrients in fine roots is often higher than the current foliage (Meier *et al.* 1985, Arunachalam *et al.* 1996a). In *Pinus sylvestris* lignin content decreased dramatically from very fine to the next larger root diameter class (Berg 1984). This trend, however, was not observed in the case of *Abies amabilis* (Vogt *et al.* 1983). A sharp decrease in N, P and Ca concentrations with the increase in root diameter has been reported by Nambiar (1987) and Arunachalam *et al.*(1996b).

FINE ROOT DECOMPOSITION

Decomposition of dead organic matter is a continuous process beginning with the breakdown of fresh organic materials to the release of soil nutrients (Melillo *et al.* 1989). In general, litter tissues having low carbon, low lignin and high nitrogen content tend to decay at a very fast rate under conditions of high temperature and high moisture (Bloomfield *et al.* 1993).

Various methods have been employed to study root decay, e.g., litter bag technique (Fogel and Hunt 1979, Berg 1981, McClaugherty *et al.* 1982, Gholz *et al.* 1986), trench-plot design (McClaugherty *et al.* 1984, Gholz *et al.* 1986), budget approach (Santantonio and Herman 1985), laboratory incubation method (Hermann *et al.* 1977) and changes in the specific gravity of coarse roots (Yavitt and Fahey 1982). But the litter bag technique has been widely used for decomposition studies in the forest ecosystems.

The decomposition of root litter is one of the important processes in the overall biogeochemical cycling of nutrients in the forest ecosystems. During decay, microorganisms colonise the dead root materials in successive phases and are responsible for the chemical transformations and degradation of organic molecules into simpler forms. This involves three main processes *viz.* leaching, accumulation and net release of inorganic nutrients or mineralization (Swift *et al.* 1979). A large number of factors such as resource quality (Fogel and Cromack 1977, Berg and Staaf 1980 and 1881, Aber and Melillo 1982), physical characteristics of the site (Edmonds 1987), climate (Meentemeyer 1978, Swift *et al.* 1979, Singh and Shekhar 1989a), soil type and plant cover (Christensen 1985), microbial population and their activity (Witkamp 1966, Swift *et al.* 1979) and an array of complex interactions between soil organisms and microclimatic factors (Meentemeyer 1978, Heal *et al.* 1981) are known to influence different steps of decomposition process in the terrestrial ecosystems.

Most of the decomposition studies in the forest ecosystems deal with the leaf/needle and woody litter (Swift *et al.* 1979) and relatively less work has been done to understand the process of root litter decomposition (Waid 1974). Fogel and Cromack (1977), Fogel and Hunt (1979), Berg and Staaf (1981), Persson (1982) Yavitt and Fahey (1982), Vogt *et al.* (1983), Berg 1984), McClaugherty *et al.* (1984) and Bloomfield *et al.* (1993) have studied root decomposition in different forest ecosystems.

According to Findlay (1934), Merrill and Cowling (1966), , Cisternas and Yates (1982), Peterson and Roffe (1982), Miller (1983) and Arunachalam *et* *al.*(1996b), the rate of root decomposition is largely controlled by the initial nitrogen concentration. On the other hand, Fogel and Cromack (1977), Meentemeyer (1978) and Melillo *et al.* (1982) emphasised that the lignin content plays more important role than the nitrogen content in influencing decomposition rate. According to Vogt *et al.* (1991) lignin content does not significantly affect the decomposition of fine roots. Lignin is reported as an interfering factor in the enzymatic degradation of proteins and cellulose and other carbohydrates. (Alexander 1977). The concentration of lignin in the litter has been found to be inversely related to its decomposition rate (Meentemeyer 1978, Sinsubaugh *et al.* 1992). Crawford and Crawford (1980) reported that an external source of carbon is necessary for the microorganisms to degrade lignin.

Nitrogen concentration and C:N ratio have been considered as key factors in the decomposition of root litter (Berg and Staaf 1980, Berg and Ekbohm 1991, McClaugherty and Berg 1987, Taylor *et al.* 1989). Phosphorus concentration and C:P ratio also influence root decay (Schlesinger and Hasey 1981, Staaf and Berg 1982, Berg and Ekbohm 1991). An increase in the decomposition and N-mineralization rates has been reported in the event of death or absence of mycorrhizae (Gadgil and Gadgil 1971 & 1975, Babel, 1977, Fisher and Ghosz 1986a). On the contrary, Fisher and Stone (1969), Dignton *et al.* (1987), Haussling Marschner (1989) and Faber and Verhoef (1991) reported that the presence of conifer roots and mycorrhizae brings about an increase in the decomposition rate.

In terrestrial communities nitrogen is mostly absorbed from the soil in simple inorganic forms such as nitrate and ammonium. They are released from the complex organic compounds by the action of decomposer organisms by a process known as mineralization. Nitrogen mineralization has been reported to have a profound influence in many forest ecosystems, especially where nitrogen availability limits the tree growth (Kraske and Fernandez 1990).

Studies dealing with production, accumulation and decomposition of Pine roots are limited. Nevertheless, some data are available for other species of pine such as *Pinus radiata* from Australia (Moir and Bachelard 1969) and New Zealand (Santantonio and Santantonio 1987) *Pinus sylvestris* from Anglia (Roberts 1976), and Sweden (Persson 1978), and *Pinus halepensis* from Argentina (Ares and Peinemann 1992). Nutrient retranslocation in the fine roots of *Pinus radiata* has been studied by Nambiar (1987).

Das (1980) has studied the growth pattern, primary productivity and litter dynamics in *Pinus kesiya* stands of different ages. Sharma (1981) has examined the mycorrhizal association of *Pinus kesiya* and Jha (1990) has studied the effect of climatic factors on the development of ectomycorrhizae in the same species.

The foregoing review of literature reveals that as such, no study has been carried out on the dynamics of fine roots in *Pinus kesiya* which grows almost in the form of pure stand on the hills between 800-2000 m asl altitude in the entire north-eastern region of this country. The study on the role of fine roots in soil organic matter and nutrient dynamics in this species is of special significance, since *P. kesiya* grows on abandoned jhum fallows and degraded sites having a relatively shallow soil layer which is poor in organic matter and nutrient elements.

CHAPTER III

STUDY SITE AND METHODOLOGY

STUDY SITE

The study was conducted in the subtropical Khasi pine (*Pinus kesiya* Royle Ex. Gordon) forest located in the North-Eastern Hill University campus, Shillong (latitude 25°34'N, longitude 91°54'E, altitude 1500 m asl), the capital of Meghalaya, India (Fig. 3.1). The university campus having an area of about 500 ha is covered by pure pine stands of different ages. Three stands of different ages viz. 6-, 15- and 23-years, each with an area of about 10 ha, were selected for the study (Plate 1). These have been designated as stand I, II & III, respectively in the text. All the three stands located within a radius of 1 km were present on gentle hill slope (11-17°) facing towards west to south west.

GEOLOGY AND SOIL

The Shillong plateau is situated at an average elevation of 1500 m above the Brahmaputra valley (Gansser 1964). The plateau forms the watershed between the Surma valley in the south and the Brahmaputra valley in the north. Geological and chrono-stratigraphic studies have revealed that rock formations ranging in age from the Pre-Cambrian to the Quaternary have gone into the making of the geological sub-strata of the plateau.

The soils are derived from underlying gneisses, schists and granite rocks and

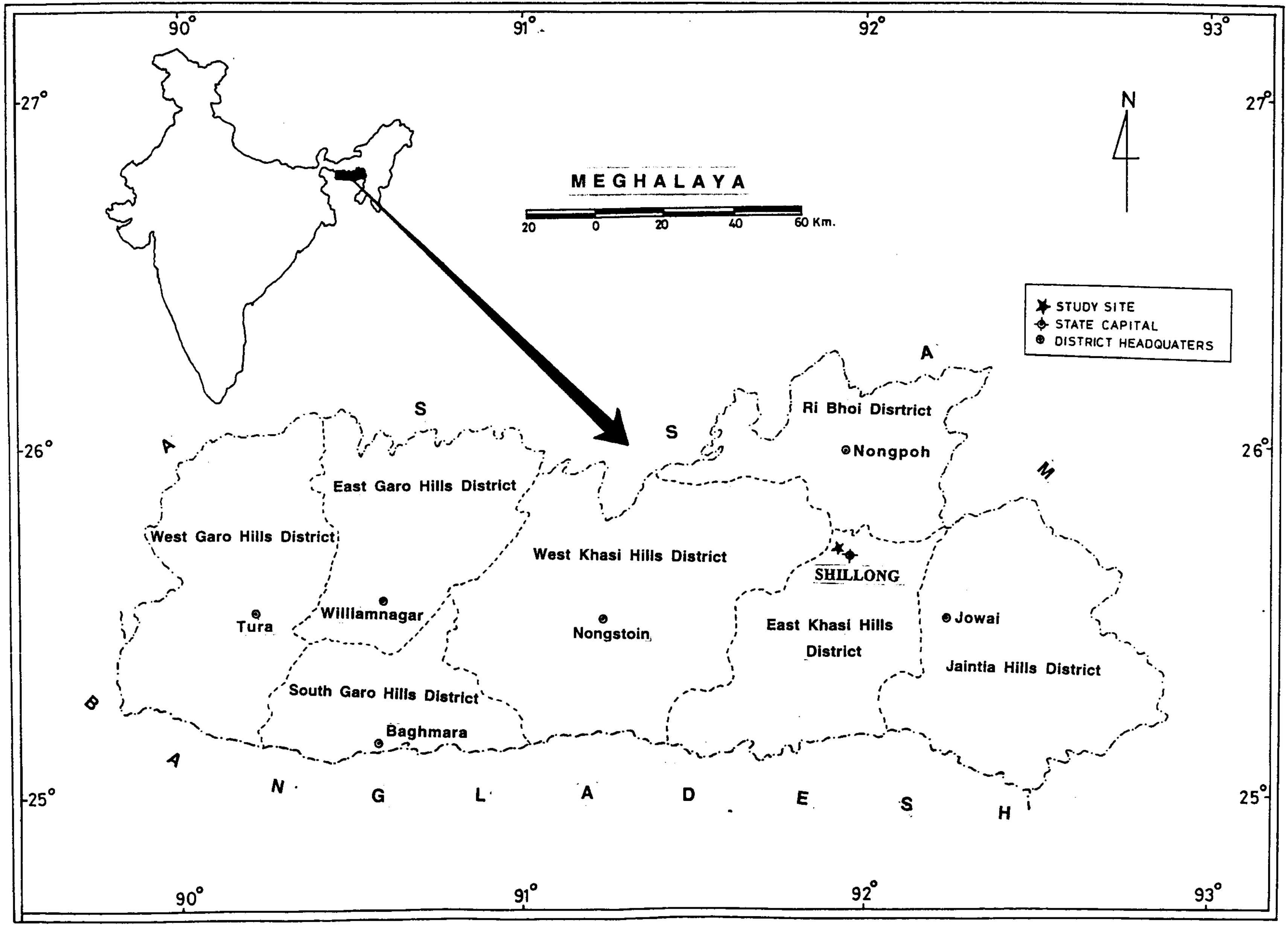

Fig. 3.1. Map showing geographical location of the study site.

Plate 1. An overview of the three forest stands

(A) 6-year old stand (B) 15-year old stand and (C) 23-year old stand they are grouped under latosol (oxisol type) (Pascoe 1950).The soils of Meghalaya have been broadly grouped into four categories viz. (1) red loamy soil (2) lateritic soil (3) red and yellow and (4) alluvial soil. The soils are acidic in nature. The pH ranges between 4.5 and 6.5 except in coal mine areas where pH as low as 3 has been reported by Lyngdoh (1995). Leaching of soluble salts from the soil profile due to excessive rainfall and undulating topography are the main causes of acidic reaction and low organic matter and nutrient content of the soil which varies from place to place depending on the nature of plant cover and topography.

CLIMATE

The climate of Meghalaya is monsoonic with an average annual rainfall of 2500 mm distributed over seven months of the year. Based on the atmospheric conditions, the year can be divided into four distinct seasons viz. spring/mild summer (March-mid-May), rainy (mid-May-September), autumn (October-November) and winter (December-February). The spring season with an average temperature 24.2^{0}C is characterised by occasional showers associated with high wind velocity. The rainy season commences with the onset of south-west monsoon in mid-May and lasts till September. About 85% of the annual rainfall is received during this season and temperature ranges between 23.6^{0}C and 17.6^{0}C. This is followed by a short autumn (October-November). During this period rainfall is considerably low (ca. 133 mm) and atmospheric temperature drops to ca.12.8^{0}C. The winter season extends from December to February. During this period, rainfall is scanty, the days are sunny and nights are frosty. The monthly values of rainfall and mean temperature during the study period (1995-1996) are shown in fig. 3.2 and mean monthly maximum and mean minimum relative humidity is presented in fig. 3.3. The annual rainfall was 2292.2 and 1796.4 mm during 1995 and 1996, respectively. The mean maximum and mean minimum temperatures during the study period were 24.9^0 C and 5.3^{0}C, respectively. The relative humidity was maximum (92%) during September (rainy season) and minimum (49%) during February (winter) (Fig. 3.3).

VEGETATION

The vegetation of Meghalaya has been broadly divided into three types of forests viz. tropical forests, subtropical forests and temperate forests (Chauhan and Singh 1992). According to Forest Survey of India Report (1995), Meghalaya has 4045 sq.km of dense forest cover and 11669 sq.km of open forest cover, the total forest cover being 15714 sq.km., which is 70.06% of the total geographical area of the state. The dense forests are represented by sacred groves, wild-life sanctuaries and/or national parks.

Age-old shifting agriculture, locally called jhum cultivation, and other developmental activities during the last few decades have destroyed natural forests giving rise to secondary successional communities with varied species composition

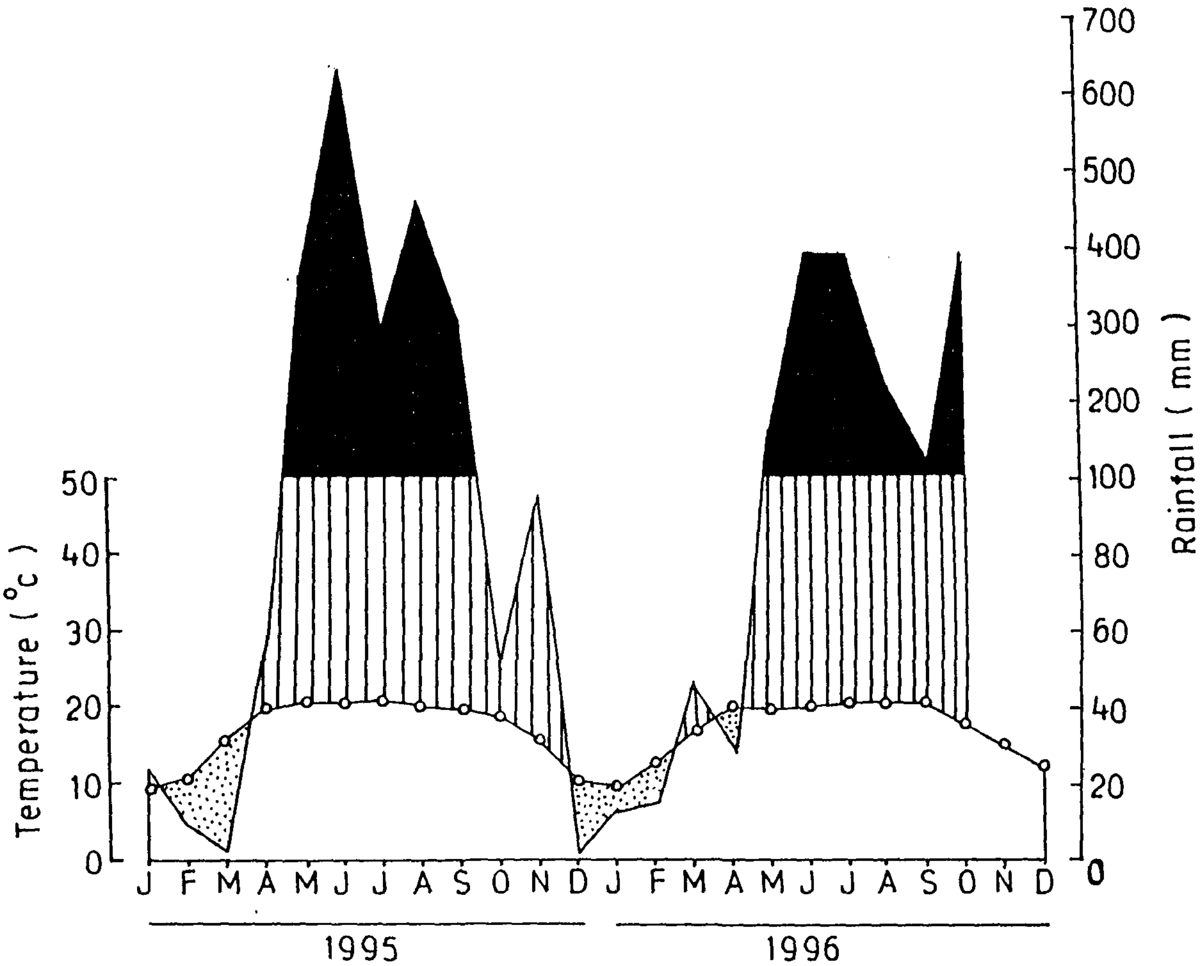

Fig. 3.2. The monthly mean temperature (o—o) and precipitation are shown as curves. Precipitation up to 100 mm has been scaled such that 10°C of temperature correspond to a precipitation of 20 mm. The dotted area reveals the period when precipitation goes below the temperature curve. Precipitation above 100 mm is printed in the scale of 1:10 (black area).

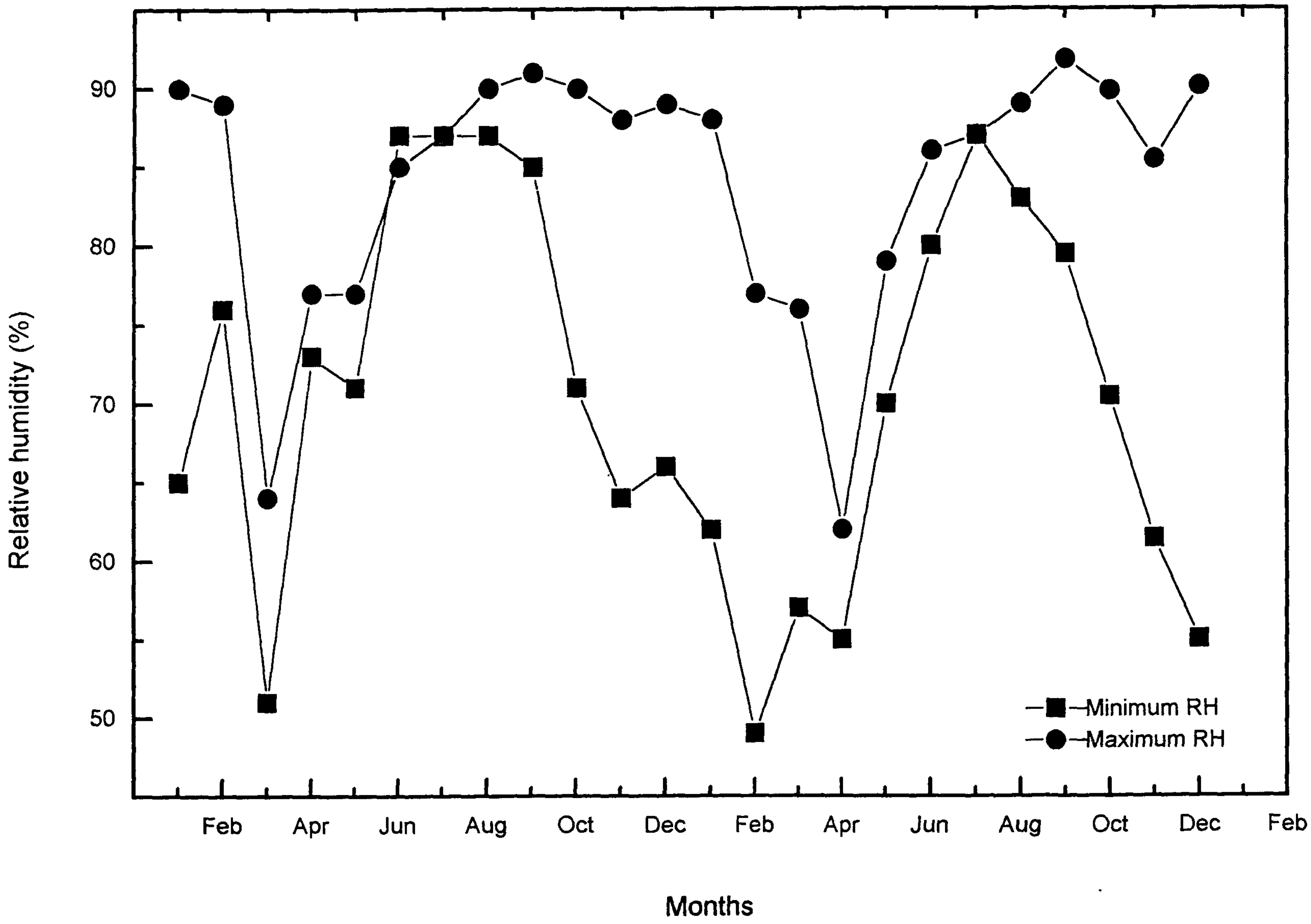

Fig. 3.3. Mean monthly variation in the atmospheric relative humidity at the study site.

ranging from weed-dominated unstable communities on jhum fallows to fairly stable *Pinus kesiya* forests on degraded sites between 800 and 2000 m asl. *Pinus kesiya* grows extremely well in the open habitats and can survive adverse site conditions. This has led the species to occupy vast tracts of land in the Khasi and Jaintia Hills of the state.

METHODOLOGY

Stand age

The age of the forest stand was determined by using regression equation worked out by Das (1980) based on dbh and age data of *Pinus kesiya* plantations in Shillong. The average dbh of trees was 4.85, 12.42 and 19.12 cm in 6, 15-, and 23-year old stands, respectively; the corresponding average tree height was 5.42, 10.91 and 14.37 m.

Community Analysis

In each of the three stands, an area of 5 ha was demarcated for detailed community analysis. Ten 10 m x 10 m quadrats were laid randomly to study the tree component while twenty 1 m x 1 m quadrats were laid for analysing ground vegetation including tree seedlings. Vegetation analysis was carried out during July-August 1995 and 1996 when plants in the ground vegetation were at peak vegetative growth.

Tree population structure in each stand was studied by measuring density of trees in eight arbitrarily divided DBH classes viz. 0-5, 10-15, 16-20, 21-25, 26-30, 31-35, 36-40 and 41-45. Density, frequency, abundance, basal cover and importance value index (IVI) of all species in the ground vegetation were determined according to Misra (1968) and Ellenberg and Muller Dombois (1974). Nomenclature of the plant species follows Hooker (1872-1897). Some important community indices computed for the ground vegetation are as follows :

$$\text{Sorensen's similarity index (Sorensen 1948)} = \frac{2C}{A + B} \times 100$$

Where A = Number of species in stand A

B = Number of species in stand B

C = Number of species common in both A and B stands

$$\text{Shannon's diversity index (Shannon-Wiener 1963)} = - E \frac{(n_1)}{N} \log_e \frac{(n_1)}{N}$$

Where n = Importance value of each species

N = Total importance value

Fine root studies

Root Sampling and Separation

Monthly sampling of root biomass was done from May, 1995 to April, 1997 in each of the three forest stands. On each sampling, 40 cm long soil cores were taken from ten randomly located points in each stand using a 45 cm long tubiform steel corer (6.3 cm inner diameter). Each soil core was subsequently divided into four equal sections (each having 10 cm thickness) starting from the soil surface, which were properly labelled and kept separately. The samples were transferred to the laboratory and stored in a deep freeze at -20°C till the roots were separated. The roots were retrieved carefully from the soil cores by wet-sieving method (Bhom 1979). All the retrieved roots were further washed to remove the adherent soil particles. Loss of roots through the sieve was negligible.

The roots were categorised into four diameter classes (<1, 1-2, 2-5 and 5-10 mm) using a Vernier calliper. Roots of herbaceous species and rhizomes of grasses were grouped separately. Separation of roots of ground vegetation from those of the tree did not pose much problem, since *P. kesiya* roots were light yellow in colour while those of other species were white coloured. Although the pine root tips were white in colour, they could easily be differentiated from the roots of other species. Tree and herbaceous roots were further categorized into live (biomass) and dead (necromass) fractions on the basis of cohesion between cortex and periderm, colour, resistance and presence of live apices (Persson 1979).

Sampling of roots and their subsequent separation into different categories is laborious and time consuming therefore there is always scope of some error in determining the dry mass of different fractions in spite of best effort and care.

Root Biomass and Production

Root samples were dried at 80°C for 48 hours and weighed in an electronic balance to determine the dry mass. The dry mass values for different diameter classes of tree and herbaceous species were recorded separately. Monthly as well as depth-wise variations in biomass and necromass were also determined. The monthly biomass data of different categories of roots were pooled to obtain mean standing biomass during different seasons viz., spring (March-May), rainy (June-September), autumn (October-November) and winter (December-February).

Annual root production of different diameter classes was determined by summing up the significant positive increments in the root biomass and concurrent increment, if any, in the necromass during successive sampling in a given diameter class (Sims and Singh 1978, Harris *et al.* 1977, Persson 1978, McClaugherty *et al.* 1982,Gholz *et al.* 1986, Uma Shanker *et al.* 1993).

Decomposition of Fine roots

For this study fine roots were collected separately in bulk from the top soil layer in all the three stands during June, 1995. They were carefully washed under a gentle flow of tap water to remove the adhering soil particles and organic debris and separated into live and dead portions according to Persson (1983). The roots were further divided into pine roots and roots of the ground vegetation. Only *Pinus kesiya* roots were used for the decomposition study. Due to difficulty in collecting large amount of newly senesced fine roots, live roots measuring <2 mm diameter were separated, air-dried and used for the decomposition experiments. The rate of weight loss and release of nutrients were studied by litter bag method as outlined by McClaugherty *et al.* (1984).

Two grams of air-dried root material was placed in a nylon litter bag (2 mm mesh, size 15 cm x 15 cm) and sixty such bags were prepared. Subsamples of air-dried root materials were used for dry weight determination. The bags were buried in surface soil layer (0-10 cm) at four places in each of the three forest stands during July, 1995. Four bags were retrieved from each stand at 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420 and 450 days. The samples from each bag were washed gently to remove the adhering plant and soil particles, cleaned and dried at 80^{0}C for 48 hours and weighed in an electronic balance. The dried samples were powdered in a grinding mill (Cyclotec-Tecator) and used for chemical analysis. Loss in weight and rate of release of nitrogen and phosphorous during decomposition was determined by remaining weight and element concentration data of the samples obtained from the litter bags.

Soil analysis

Soil samples were collected randomly from all the three stands at ten places on a monthly interval between May 1995 and April 1996 by using a steel corer (6.3 cm diameter and 45cm long). The soil cores thus obtained were divided into four layers corresponding to 0-10, 10-20, 20-30 and 30-40 cm soil depths. The soil samples of each depth were mixed thoroughly, air-dried and passed through a 2 mm mesh sieve to remove the stone pieces and larger root particles. The composite sample was used for detailed analysis.

Soil Bulk density (BD) was determined gravimetrically and the texture was determined by Bouyoucos hydrometer method (Allen *et al.* 1974). Water holding capacity (WHC) was determined by Keen's box method by using copper cups having 7 cm internal diameter and 1.2 cm height (Piper 1942). Cation exchange capacity (CEC) was determined by extracting the soil with 1 M ammonium acetate solution (pH. 7.00) followed by displacement of NH_4^+-N with KCl and distillation with MgO (Allen *et al.* 1974).

Soil pH was determined electronically by a digital pH meter in 1:2.5 suspension of soil and distilled water (Anderson and Ingram 1993). Soil moisture content (SMC) was determined gravimetrically by drying 10 g of fresh sieved soil at 105^{0}C for 24 hours in a hot air oven (Allen *et al.* 1974).

Air-dried soil samples seived through 0.5 mm mesh screen were used for TKN, available-P and soil organic carbon determination.

Total Kjeldahl nitrogen (TKN) was determined by digesting soil samples with concentrated sulphuric acid using Kjeltab as catalyst in a block digestor. Distillation was carried out in a semi-microdistillation set and the distillate was collected in boric acid indicator and titrated with N/140 HCl (Allen *et al.* 1974).

Soil organic carbon (SOC) was determined by rapid titration method (Walkley and Black 1934) and soil organic matter (SOM) was estimated by multiplying the organic carbon content by 1.724 assuming that soil organic matter contains 58% carbon (Allen *et al.* 1974). Available-P was determined by molybdenum blue method after extracting the soil P in 0.5 M sodium bicarbonate solution (Anderson and Ingram 1993).

Root analysis

All the root samples were ground in a grinding mill (Cyclotec-Tecator) and used for chemical analysis.

Root samples were analysed for ash content, total phosphorus, total Kjeldahl nitrogen (TKN), lignin and cellulose. Ash content was determined by igniting the oven-dried root material at 500^{0}C for 6 hours in a muffle furnace. Carbon content was calculated as 50% of the ash free weight (Upadhyay 1993). Total phosphorous was determined by digesting the oven-dried samples with triacid (1 ml $HClO_4$ + 5 ml HNO_3 + 0.5 ml H_2SO_4) in a block digestor and subsequently analysing the digested material by molybdenum blue method (Anderson and Ingram 1993). Total Kjeldahl nitrogen (TKN) was determined by digesting the oven-dried, powdered plant samples with the concentrated H_2SO_4 in a block digestor using Kjeltab as catalyst. Distillation was carried in a semi-microdistillation set and the distillate was collected in boric acid indicator and titrated with N/140 HCl (Allen *et al.* 1974). Lignin and cellulose contents were determined following the method outlined by Peach and Tracey (1956). Total Kjeldahl nitrogen (TKN) and total phosphorus analysis were separately carried out for live and dead fractions, different diameter classes and tree and herbaceous components. Nitrogen and phosphorous contents in the biomass and necromass fractions of the fine and coarse roots were calculated by multiplying dry mass with their respective element concentration.

All analyses were carried out in triplicate and the values were expressed on oven-dry weight basis.

Root Turnover and mineralization

Turnover rate (k) of fine roots was calculated using the mathematical model of Reiners and Reiners (1970) : $k = P/x_m + P$, where P = annual fine root production and x_m = mean annual dry weight. N and P turnover rates were calculated by substituting the dry mass with the values of mineral elements. Turnover time (T) was calculated as reciprocal of turnover rate ie. $T = 1/k$, where T = time in years.

Annual decay constant (k) was calculated with the data obtained from the litter bag experiment using the negative exponential decay model of Olson (1963): $k = \ln (x/x_0)\ t$, where x_0 is the initial dry weight, x is the dry weight remaining at the end of the investigation and t is the time in years. Similarly N and P mineralization constants, k_N and k_P respectively, were calculated using nitrogen and phosphorus stocks in the beginning and at the end of the experiment (Singh and Shekhar 1989b). The time (years) required for 50% (t_{50}) and 99% (t_{99}) nutrient mineralization was calculated as $t_{50} = 0.93/k$ and $t_{99} = 5/k$.

Statistical Analysis

Data were statistically analysed using one-, two- and three-way ANOVA (fixed effects model) to test the effect of sampling dates, soil depth, stand age and root diameter classes on biomass, production and nutrient content of roots. The data on soil were analysed using ANOVA (fixed effects model) to study the effect of stand age, sampling period and soil depth on physicochemical properties of soil. The effect of initial root litter chemistry on its decomposition rate was assessed using simple linear regression function.

Abbreviations used in the text : The following abbreviations have been used to denote different categories of roots.

Biomass = Live roots, Necromass = Dead roots, Total root mass (TRM) = biomass + necromass, TFRB = Tree fine root biomass, TFRN = Tree fine root necromass, TFRM = Tree fine root mass (TFRB+TFRN), CRB = Coarse root biomass, CRN = Coarse root necromass, CRM = Coarse root mass (CRB+CRN), HFRB = Herbaceous fine root biomass, HFRN = Herbaceous fine root necromass, HFRB = Herbaceous fine root mass, TFRB=Total fine root biomass (TFRB+HFRB), TFRN = Total fine root necromass (TFRN+HFRN).

CHAPTER IV

VEGETATION AND SOIL CHARACTERISTICS

INTRODUCTION

Vegetation plays a major role in the development of soil and strongly affects its physico-chemical and biological characteristics (Tatoni *et al.* 1994, Arunachalam *et al.* 1997). Composition of plant community regulates organic matter turnover and nutrient availability in soil by bringing about quantitative and qualitative changes in soil organic matter as well as by controlling losses of mobile nutrients (Woods *et al.* 1992). A close relationship between tree density and soil organic matter content has been reported by Ramakrishnan and Toky (1981) and Aweto (1981). Disturbance in forest ecosystem alters the community composition and thereby influences physical and chemical properties of the soil(Mou *et al.* 1993, Rab 1994).

Degradation of primary broad-leaved forests at higher altitude between 800 & 2000 m in north-east India due to various human activities including shifting agriculture, clear felling or selective cutting of trees for timber and fuelwood purposes have changed the structure and composition of original forest communities and have paved the way for invasion and successful growth of *Pinus kesiya*. It grows extremely well on the degraded and seasonally dry sites where it forms almost a pure stand.

Pine appears in the early successional phase after fire (Nakagoshi *et al.* 1987). It forms the most important tree component of secondary forests in many parts of the world including the Far-East. Being an early successional species, it is shade-intolerant and requires open situation for successful regeneration and growth. Pine is preferred in most of the managed forests because of its low nutrient requirements, fast growth, simple silvicultural requirements and valuable multipurpose wood (Anderziczyk and Brazaziecki 1995).

The three pine stands which were selected for the study of fine root dynamics, were characterised on the basis of floristic composition, tree population structure, phytosociological attributes of the ground vegetation and soil properties. The data on these aspects are presented in this chapter.

RESULTS

Floristic composition and structure of plant community

In all the three stands plant species were distributed into two distinct layers. The upper tree layer was composed of *Pinus kesiya* only. The lower layer underneath the tree canopy was dominated by weeds, grasses, ferns and a large number of other annual and perennial species. The average tree height was 5.42, 10.91 and 14.37 m in 6-, 15- and 23-year old stands, respectively (Fig. 4.1). The tree density decreased significantly ($P<0.01$) from 11020 ha^{-1} in the 6-year old stand to 730 ha^{-1} in the 23-year old stand, but seedling density was maximum (32

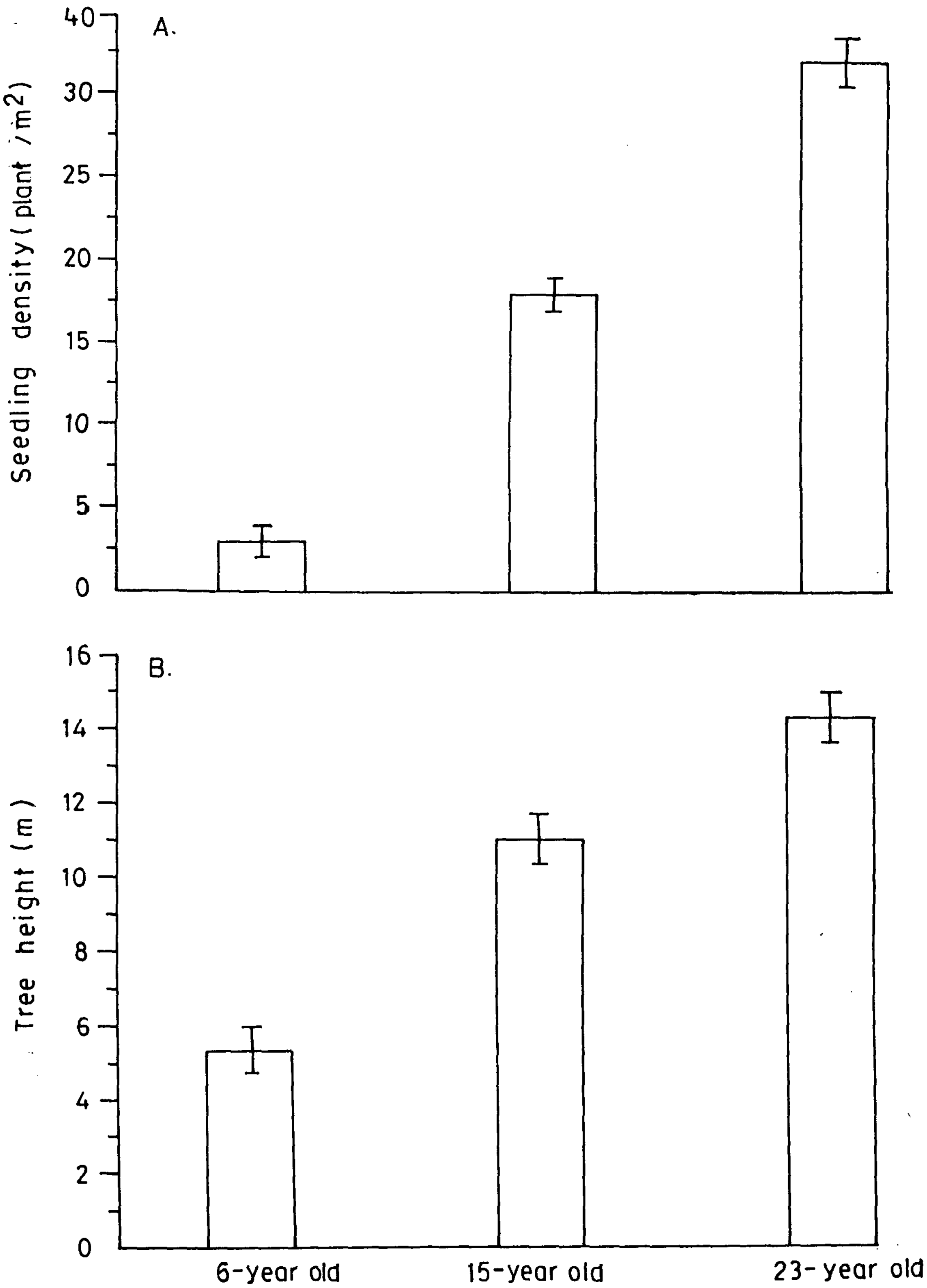

Fig. 4.1. Tree seedling density (A) and average tree height (B) in the three pine star

individuals/m^2) in the 23-year old stand and minimum (3 individuals/m^2) in the 6-year old stand. Trees of lower DBH class were more frequent in the 6-year old stand, while older trees (25-30 cm DBH) were more frequent in the 23-year old stand (Fig. 4.2).

Altogether 40 species were present in the ground flora of the three stands; 32 in the 6-year old stand, 28 in the 15-year old stand, and 29 in the 23-year old stand (Table 4.1). Out of these,19 species were common to all the three stands.

The total density of herbaceous species was 116 individuals/ m^2 in the 6-year old stand, 75 individuals/m^2 in 15-year old stand, and 107 individuals/m^2 in the 23-year old stand (Table 4.2). There was a high degree of similarity (Similarity index 77.09) in species composition of the ground vegetation among all the three stands (Table 4.3). *Axonopus compressus*, *Anotis wightiana*, *Arundinella bengalensis*, *Hydrocotyle javanica* were abundant in all stands, but their importance varied from one stand to another (Fig. 4.3). Species diversity expressed in terms of Shannon's index of diversity varied between 2.75 and 3.02.

Seasonal growth cycle of Pine and ground vegetation

Pinus kesiya showed three distinct growth phases during a year. Flushing occurred during February, June and October. The needles of the first flush, occurring during February, were shed between October and March. The second flushing occurred during June and these needles fell during next January-April.

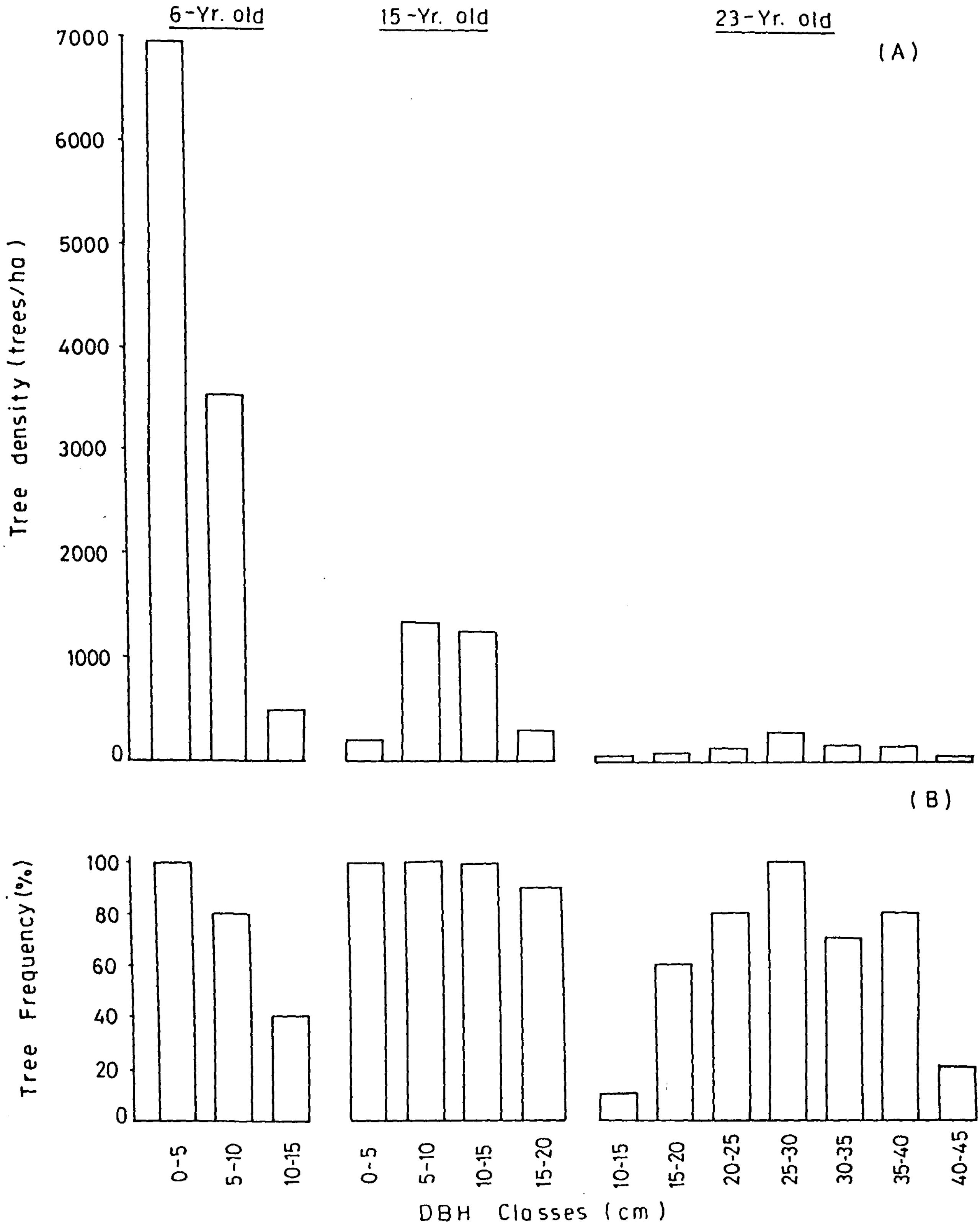

Fig. 4.2. Density (A) and frequency (B) of trees of different DBH classes in the three pine stands.

Table 4.1. Density (Individuals/m^2) of plant species during peak vegetative growth (August-September) in the ground vegetation of the pine stands. The values are mean of 1995 and 1996.

Name of the species	6-year old stand	15-year old stand	23-year old stand
Anemone rivularis (Clarke) Pump.	-	0.44 (24)	-
Anotis wightiana Hk.f.	16.88 (4)	5.70 (10)	2.69 (12)
Arisaema tortuosum (wall.) Schott.	0.22 (32)	-	-
Artemisia parviflora Roxb.	0.68 (5)	0.96 (13)	4.74 (5)
Arundinella benghalensis Druce	14.48 (2)	13.56 (1)	18.16 (1)
Arundinella khaseana Nees.	9.98 (3)	13.89 (2)	13.25 (3)
Axonopus compressus (Sw). Beauv.	27.41 (1)	4.50 (3)	5.90 (4)
Commelina benghalensis Linn.	1.20 (19)	3.78 (5)	3.00 (15)
Commelina longifolia Lamk.	1.02 (23)	0.88 (8)	1.30 (19)
Desmodium microphyllum Miq.	0.58 (20)	0.19 (26)	-
Desmodium sinensis Blume.	-	-	0.38 (26)
Dicranostigma divericulata Hk.f.	0.75 (17)	-	-
Drymaria cordata Willd.	2.82 (10)	3.30 (15)	2.24 (27)
Eriocaulon cinerum R.Br.	1.20 (28)	0.48 (19)	-
Eupatorium adenophorum DC.	3.52 (9)	1.92 (17)	0.93 (14)
Eupatorium riparium Linn.	0.32 (29)	-	0.49 (24)
Fragaria nilgerrensis Schldl.ex.J.Gay.	0.47 (24)	-	0.78 (18)
Gnaphalium leutoalbum Roxb.	3.23 (14)	-	
Gnaphalium hypoleucum DC.	1.50 (18)	-	-
Hemiphragma heterophyllum Dc.	-	1.82 (18)	-
Hydrocotyle javanica Thunb.	4.42 (8)	5.24 (4)	19.07 (2)

Table 4.1 continued

Name of the species	6-year old stand	15-year old stand	23-year old stand
Hypocheris glabra Linn.	0.70 (21)	-	0.58 (23)
Impatiens balsamina Linn.	0.72 (31)	-	-
Kyllinga triceps Linn.f.	1.68 (15)	0.82 (22)	1.50 (25)
Lantana camara Linn.	1.55 (30)	1.29 (12)	1.65 (17)
Melastoma normale Don.	6.35 (7)	1.87 (6)	2.15 (6)
Osbeckia stellata DC.	3.95 (6)	2.89 (9)	1.23 (8)
Ocimum basilicum Linn.	-	-	0.87 (16)
Oxalis corniculata Linn.	3.15 (16)	0.77 (14)	0.85 (22)
Paspalum conjugatum Berg.	-	1.25 (20)	10.90 (10)
Phyllanthus glaucus Wall.	1.83 (11)	1.86 (24)	5.90 (9)
Plantago major Linn.	1.82 (27)	-	1.15 (21)
Plectranthus striatus. Benth.	-	-	3.59 (11)
Pogonatherum crinitum (Thunb.) Kunth.	1.77 (25)	2.54 (11)	1.25 (20)
Polygonum capitatum Hum	-	0.72 (16)	0.83 (7)
Rubus moluccanus Linn.	0.68 (13)	0.49 (7)	0.79 (13)
Scutellaria discolor Linn.	1.53 (12)	0.67 (25)	0.38 (28)
Sonchus oleraceus Linn.	0.48 (22)	0.62 (28)	-
Urena lobata Linn.	0.48 (26)	0.96 (23)	-
Viola serpens Wall.	-	0.39 (27)	0.77 (29)

- = Absent

Values in the parentheses are the IVI ranking

Table 4.2. Species content, average density (individuals/m^2) and IVI of grasses and other species in the ground vegetation of the three pine stands.

Parameters	6-year old stand	15-year old stand	23-year old stand
Number of species			
Grasses	8	8	8
Other species	24	20	21
Density			
Grasses	57	42	55
Other species	59	32	52
Total	116	75	107
IVI			
Grasses	142.36	171.73	148.57
Other species	157.62	128.68	151.36

Table 4.3. Index of similarity (%) between ground vegetation of the three forest stands.

6-year old stnad *vs* 15-year old stand	: 76.66
6-year old stand *vs* 23-year old stand	: 78.68
15-year old stand *vs* 23-year old stand	: 80.70

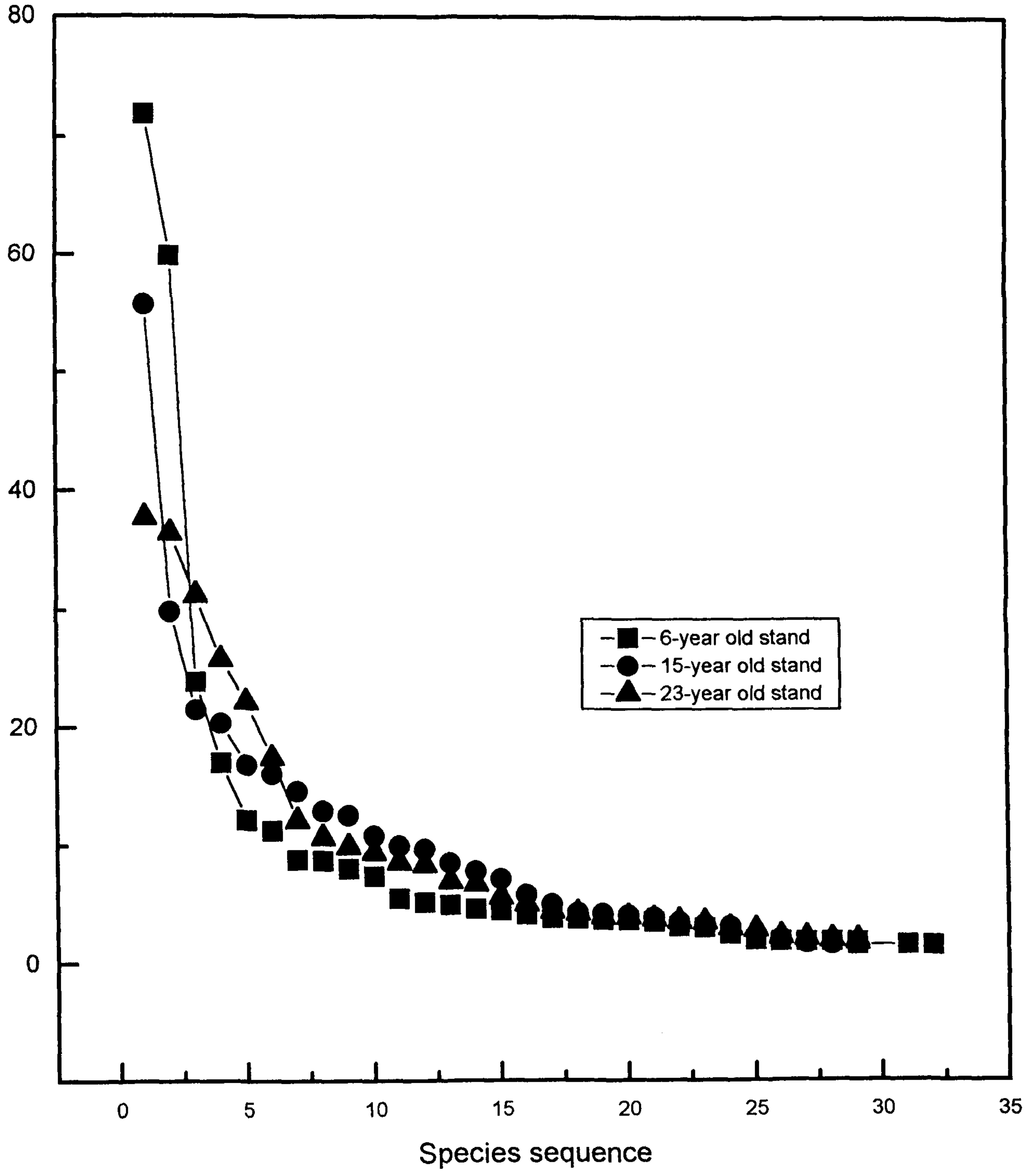

Fig. 4.3. Dominance curve for the ground vegetation in the three forest stands.

The needles that appeared in the third flush during October were shed between March and October. Thus the needle fall occurred throughout the year but peak period of needle fall was during February-March. Both male and female cones appeared during February and the life span of male cone was about two months.

The ground vegetation showed a marked seasonality. During rainy season the forest floor was covered with dense growth of perennial grasses and weeds and annual herbaceous species. Majority of the annual species completed their life-cycle by the end of autumn (November). During winter shoots of almost all species were dry and dead due to low temperature and occasional frost. The dried plant debris accumulated on the forest floor is usually burnt during January-February to minimise serious damage to the forest stand from accidental fire in the event of heavy accumulation of litter over the years.

SOIL

Physical properties of soil

Soil texture varied from sandy to sandy clay loam in the three stands. The proportion of clay increased with soil depth in all stands (Table 4. 4).

Bulk density varied from 0.96 g cm^{-3} to 1.08 g cm^{-3} without showing significant difference between the stands (Table 4.4). Water holding capacity (WHC) of the soil increased significantly ($P<0.0.05$) from 6-year old (69.34%) stand to 23-year old stand (73.82%) (Fig. 4.4). Both bulk density and WHC

Table 4.4. Proportion of sand, silt and clay and bulk density (g cm^{-3}) of soil in the three pine stands.

Stand age	Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural Class	Bulk density (g cm^{-3})
6-year old stand	0-10	88.49 ± 1.20	8.33 ± 1.20	3.17 ± 0.00	S	0.73 ± 0.01
	10-20	81.15 ± 0.71	9.22 ± 0.71	9.64 ± 0.00	S	0.91 ± 0.01
	20-30	72.44 ± 0.69	15.32 ± 0.71	12.23 ± 0.69	SL	1.05 ± 0.01
	30-40	68.08 ± 0.65	15.74 ± 0.53	16.17 ± 0.00	SL	1.15 ± 0.01
Mean		77.54	12.15	10.30	SCL	0.96
15-year old stand	0-10	91.29 ± 0.36	7.62 ± 0.36	1.08 ± 0.00	S	0.97 ± 0.01
	10-20	88.46 ± 0.00	8.36 ± 0.00	3.18 ± 0.00	S	1.01 ± 0.01
	20-30	67.63 ± 1.20	14.59 ± 1.20	17.76 ± 1.20	SL	1.10 ± 0.02
	30-40	49.23 ± 0.71	19.85 ± 1.87	30.91 ± 1.22	SCL	1.22 ± 0.01
Mean		74.15	12.61	13.23	SCL	1.08
23-Year	0-10	77.64 ± 0.00	10.62 ± 0.00	11.73 ± 0.00	SL	0.95 ± 0.01
	10-20	78.98 ± 0.71	11.37 ± 0.71	9.65 ± 0.00	SL	1.02 ± 0.01
	20-30	52.86 ± 1.35	16.68 ± 0.00	30.28 ± 1.20	SCL	1.07 ± 0.01
	30-40	38.63 ± 1.24	22.22 ± 0.72	39.14 ± 0.72	CL	1.15 ± 0.01
Mean		62.03	15.22	22.70	CL	1.05

S = Sandy, SL = Sandy loam, SCL = Sandy clay loam, ± = SEM (n=3)

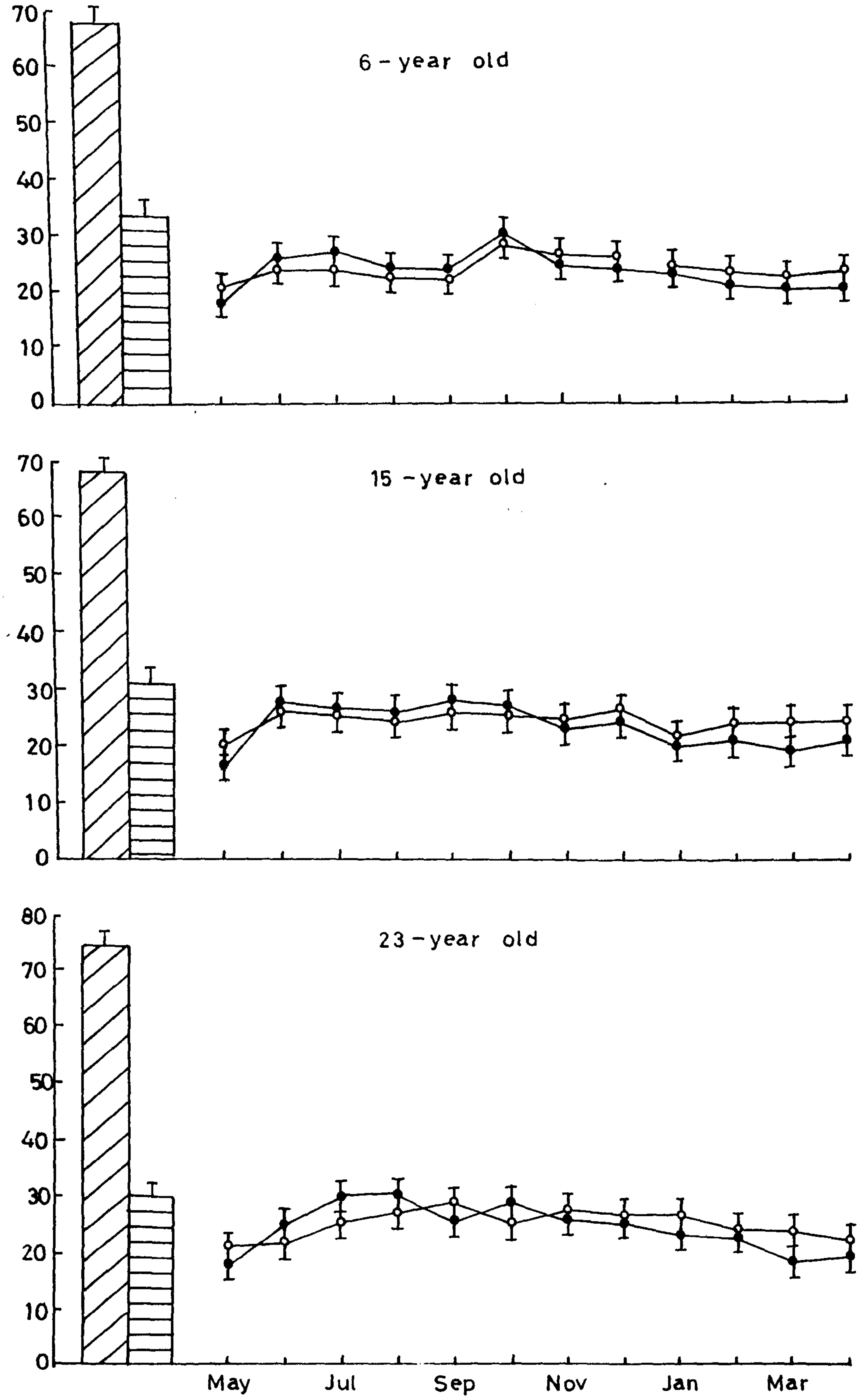

Fig. 4.4. Monthly variation in soil moisture content in 0-20 cm (●–●) and 20-40 cm (○–○) soil layers; water holding capacity (▨) and field capacity (▤) in 0-20 cm soil layer in the three pine stands.

declined with the increase in soil depth in all the three stands.

The soil moisture content fluctuated widely between months. During June to October the average moisture content in the upper layers (0-10 and 10-20 cm) was higher than the sub-soil layers (20-30, 30-40 cm). After October moisture content in the lower layers gradually increased while in the upper layer it decreased due to scanty rainfall and high evaporation (Fig.4.4). As a result, the difference between upper and lower soil layers was maximum during winter.

Chemical properties of soil

The cation exchange capacity (CEC) decreased with increase in soil depth in all stands (Fig. 4.5). However, it significantly (ANOVA $P < 0.05$) increased from 9.07 meq. 100 g^{-1} in the 6-year old stand to 11.56 meq 100 g^{-1} in 15-year old stand and then it declined to 9.88 meq 100 q^{-1} in the 23-year old stand.

The soil reaction was acidic (pH 4.8 to 5.5) in all stands and pH significantly (ANOVA $P<0.01$) increased with increase in soil depth. In all stands wide variation in pH was recorded between January and June during which period two peaks, (January and May) and one trough (March-April) were observed. After July, pH slowly increased to attain peak during winter (Fig. 4.6).

Soil organic carbon

Soil organic carbon (SOC) fluctuated between months (Fig.4.7). Organic carbon showed maximum value during winter and minimum during rainy season

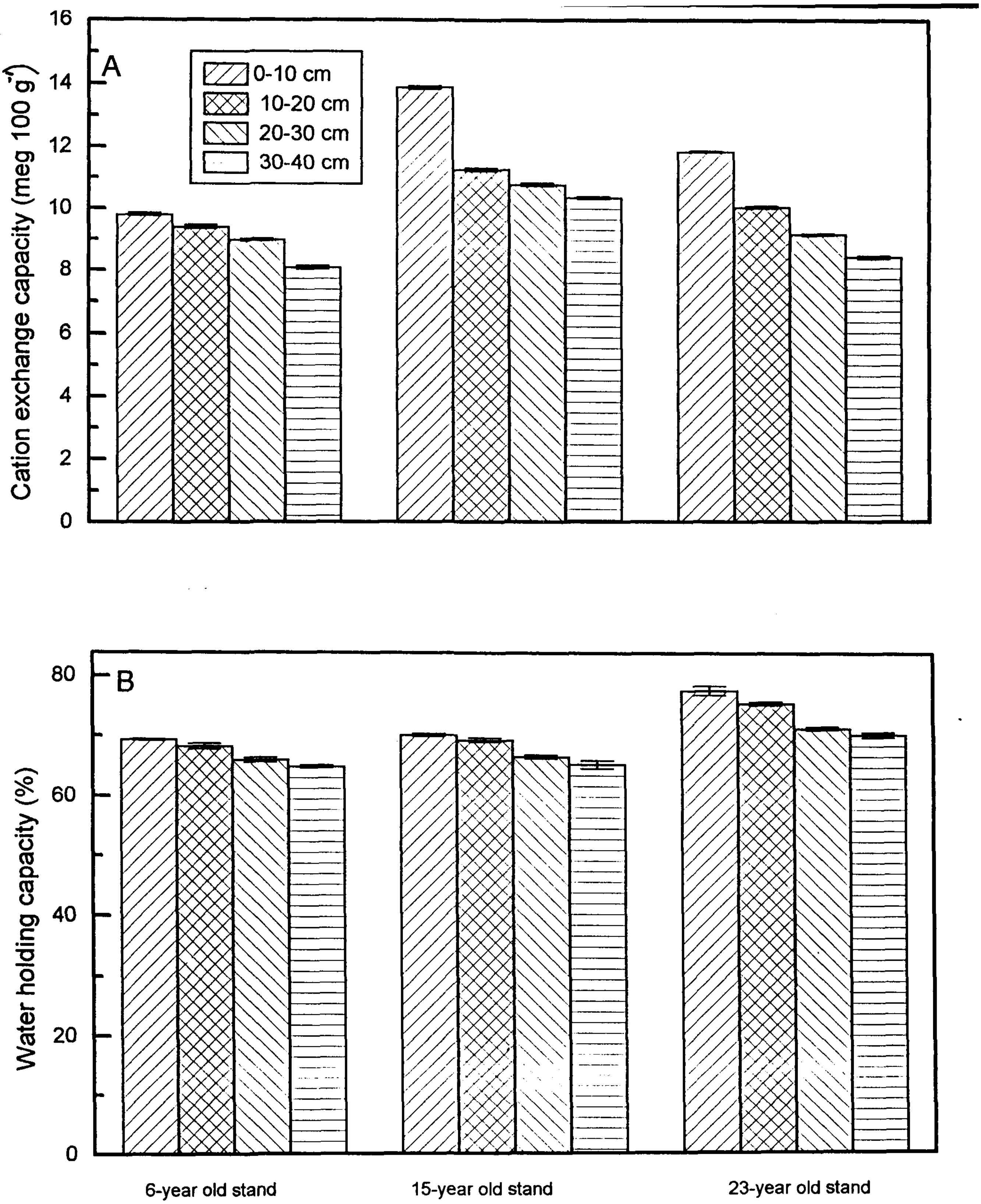

Fig. 4.5. Cation exchange capacity (A) and water holding capacity (B) in different soil layers in pine stands of different ages. Vertical lines represent SEM.

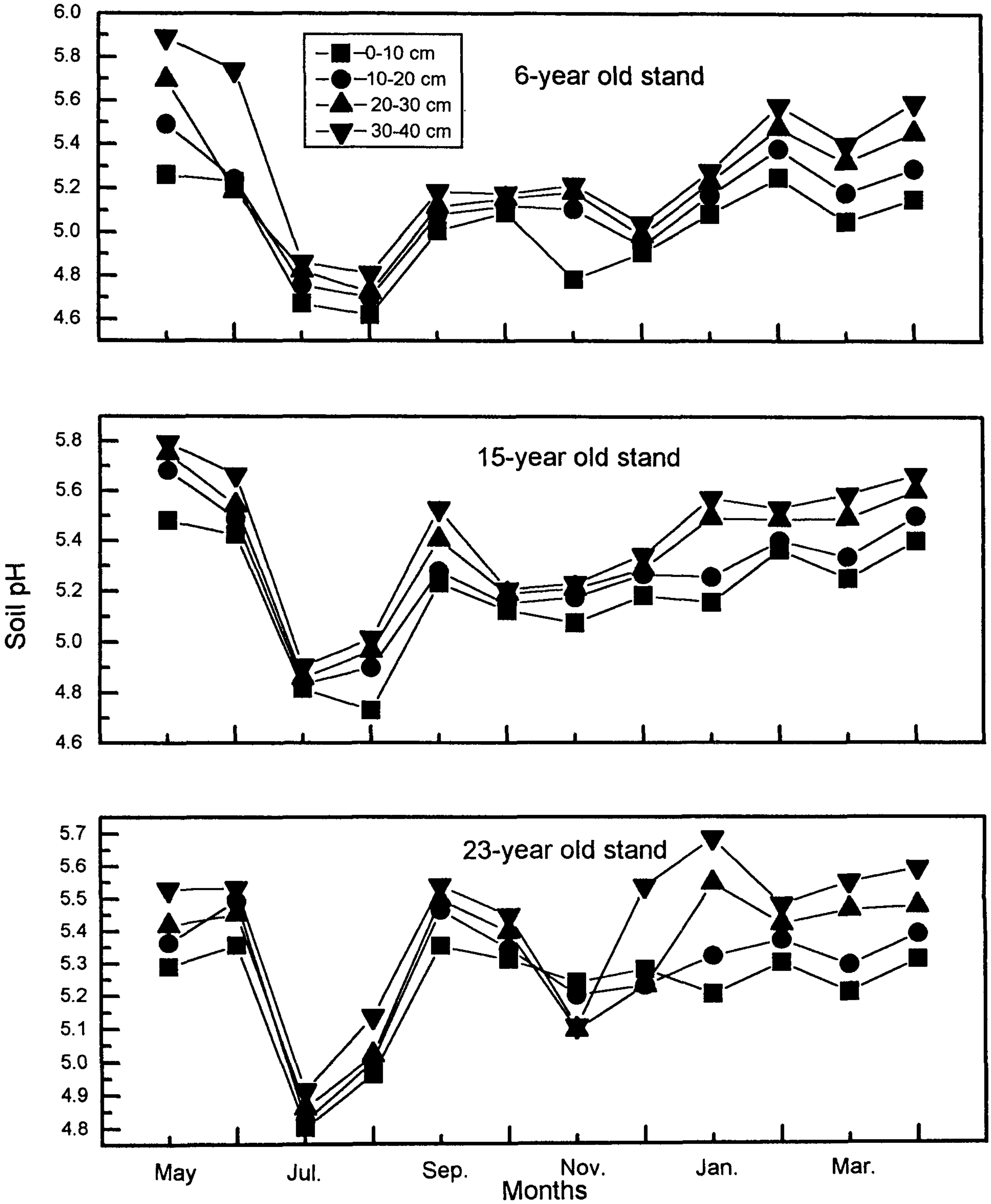

Fig. 4.6. Monthly variation in soil pH in different pine forest stands.

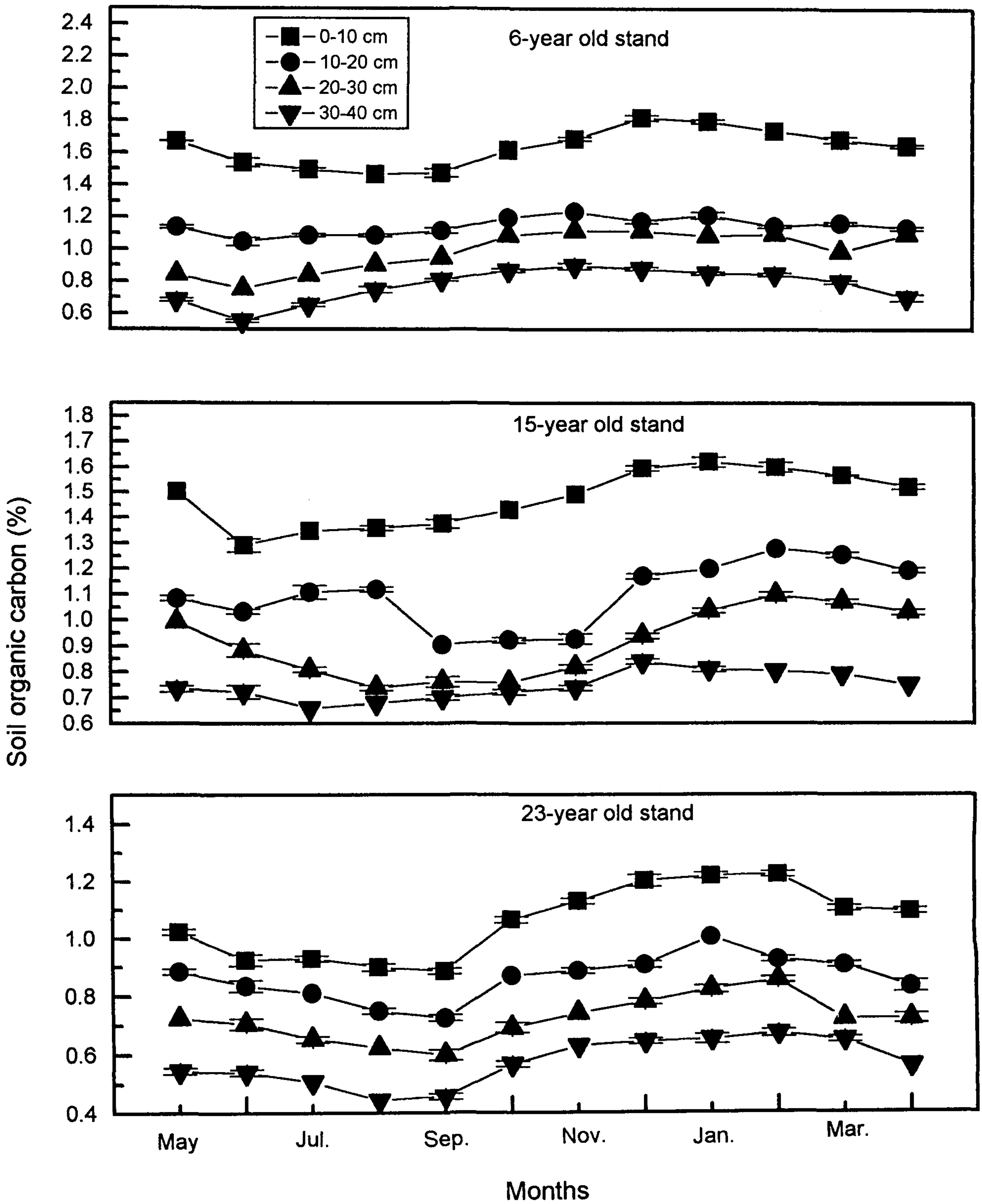

Fig. 4.7. Monthly variation of soil organic carbon in different soil layers in pine stands of different ages. Vertical lines represnt SEM.

in all stands. It significantly (ANOVA $P<0.01$) declined from upper to lower soil layers and from young to old stand. Seasonal variation in soil organic matter (SOM) content was similar to SOC. It decreased significantly (ANOVA $P<0.01$) with the increase in soil depth in all stands.

Total Kjeldahl nitrogen

Total kjeldahl nitrogen (TKN) concentration significantly (ANOVA $P<0.01$) varied between months but did not show a distinct seasonal trend (Fig. 4.8). TKN declined significantly ($P<0.01$) with the increase in soil depth. The average values of TKN were more or less the same in all the three stands.

Available-P

Concentration of available-P was very low in all stands and it varied between the months, but the variations were not significant (Fig. 4.9). Although it declined significantly (ANOVA $P<0.01$) with increase in soil depth, the difference between top layer (0-20 cm) and sub-soil layer (20-40 cm) was more prominent in case of 6- and 23-year old stands.

DISCUSSION

Community dynamics

Community characteristics like species composition, density, dominance and species diversity showed marked differences during stand development. Pine enteres the abandoned `jhum' fallows in the early years after disturbance and

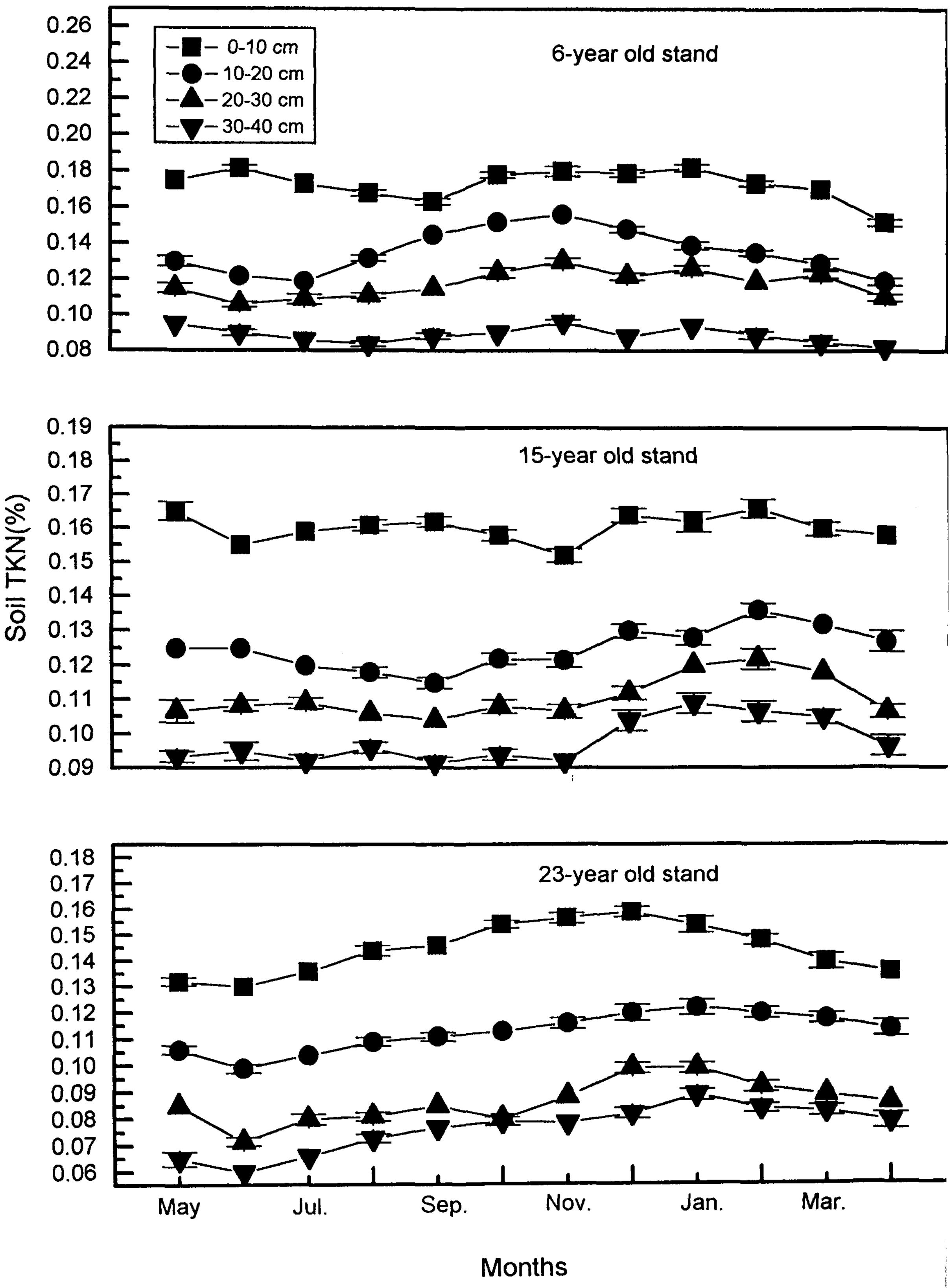

Fig. 4.8. Monthly variation of total kjeldahl nitrogen (TKN) in different soil layers in pine stands of different ages. Vertical lines represent SEM.

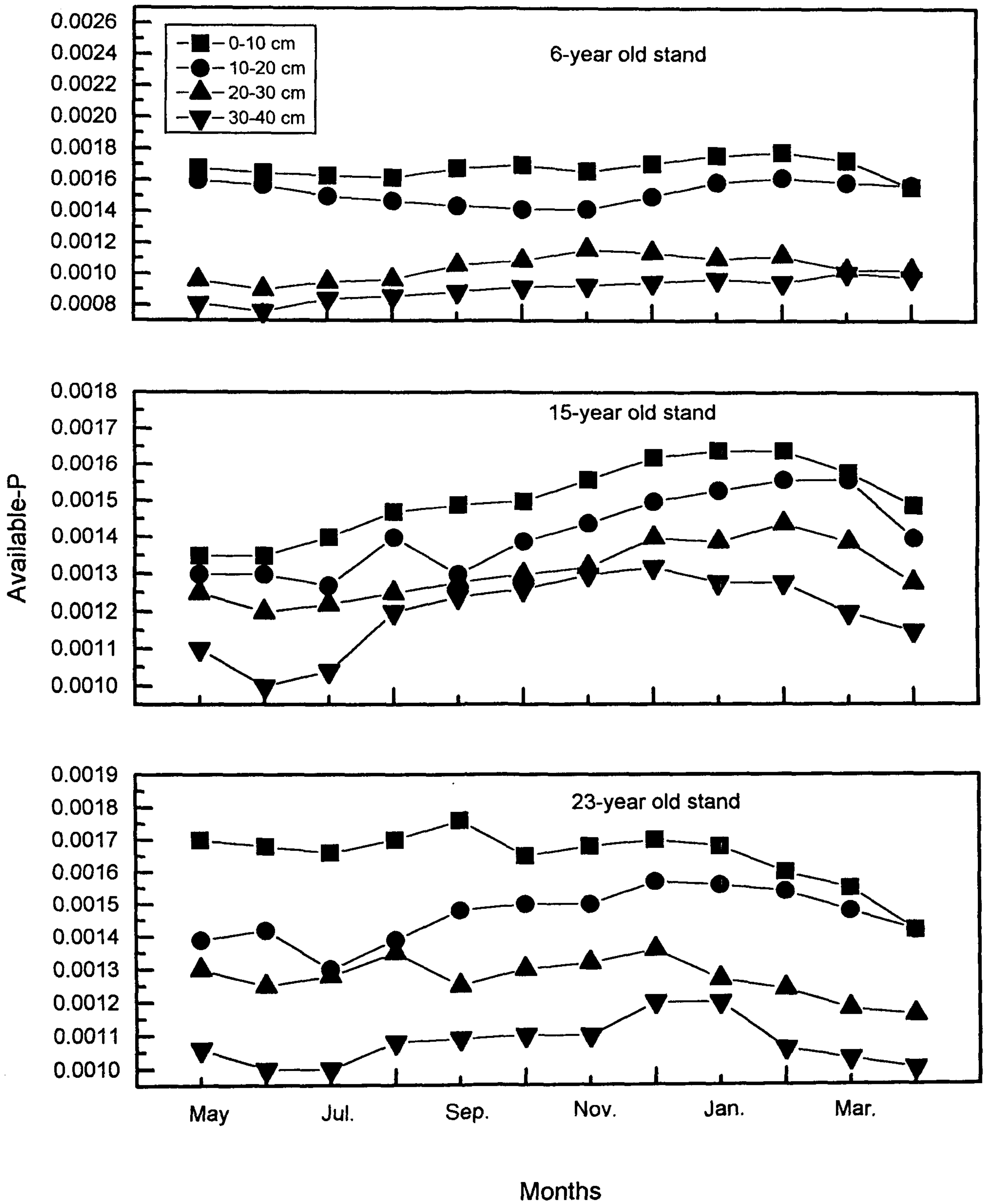

Fig. 4.9. Monthly variation of available-P in different soil layers in pine stands of different ages.

remains there for years during the stand development, indicating its greater dominance over other species owing to faster growth rate, shade-intolerance and low nutrient requirement (Das and Ramakrishnan 1987, Arunachalam *et al.* 1997).

In the initial stage of stand development, the tree seedlings and saplings were distributed in close spacing which in turn favoured natural thinning/pruning, and ultimately, the density of *P. kesiya* declined sharply from 6-year old stand to 23-year old stand. The decline in tree density with increasing stand age was mainly due to natural thinning, selective cutting of trees and annual burning that caused sapling mortality. In addition to these factors, competition by mature trees and herbaceous flora for light, space and nutrients might have also caused mortality of pine saplings (Harmer, 1995). As a result, the trees of lower DBH classes were more frequent in the youngest stand and those of higher DBH were common in the older stands. However, the tree seedling density sharply increased with stand age. With the progression of stand development the gaps created in the canopy due to various factors might have favoured seed germination and seedling establishment of the light demanding pine. Low seedling density in the youngest stand could be attributed to the low seed production and unfavourable light condition on forest floor due to dense growth of saplings. A dense herbaceous layer has been reported offers keen competition to seedlings and saplings of the overstorey dominants (Tripathi and Khan 1990). High mortality of seedlings in all stands, therefore could be atrtributed to the competition from the herbaceous weeds and human disturbances.

During the establishment phase of plantation, the higher rooting density of herbaceous weeds compared with that of the trees confers a competitive advantage on weeds in terms of uptake of water and nutrients from the surface soil (Nambiar 1990). But after few years, trees dominate the site since growth of herbaceous species is checked on account of reduced light on the forest floor due to tree canopy development, and decreased water and nutrient availability to the herbaceous species (Smethurst and Nambiar 1995). A closed canopy resulted in the decline of the herbaceous density from 116 individuals m^{-2} in the 6-year old stand to 75 individuals m^{-2} in the 15-year old stand due to mainly the decrease in the amount of light reaching the forest floor (Papanastasis *et al.* 1995). However, an increase in density of herbs to 107 individuals m^{-2} in the 23-year old stand could be attributed to the broken canopy in this stand due to natural/man-made pruning.

The species richness of ground vegetation in a community characteristically increases during the course of secondary succession (Nicholson and Monk 1974, Peet and Christensen 1980). However, in the present study, the number of herbaceous species did not show much variation among the stands. It showed high degree of similarity in species composition between the stands.The dominant nature of perennial grasses in all stands, particularly in the youngest stand, could be attributed to their fibrous root system and their ability to establish in a wide range of microsite conditions. The number of herbaceous species in the 15-year old stand (28) was higher than the number (12) reported by Arunachalam (1996) for a 16-year old Oak forest located about 20 km away from the present study site.

Soil properties

Eyre (1968) reported that during early stages of stand development, loss of finer soil particles is the dominant process and therefore there is an increase in the proportion of sand. Such a trend was not observed in the present case. Scholes *et al*. (1994), Congdon and Herbohn (1993) established a positive correlation between clay content and water holding capacity of the soil. In this study, although the clay content gradully increased with stand and soil depth, water holding capacity was maximum in the surface layer which had lower proportion of clay particles but higher amount of organic matter content.

Gradual increase in bulk density observed with soil depth and stand age, could be due to the compaction of soil with stand development. The low bulk density of soil in the surface layer can be attributed to high concentration of roots which loosen the soil (Aweto 1981) and also due to detrital accumulation and high organic matter content in the surface soil. Soil organic matter (SOM) has been reported to improve available water and minimise compaction in the sandy soils (Sands 1983, Squire 1983).

The wide fluctuation of soil moisture content between months and between soil depths may be attributed to the marked seasonality in rainfall and temperature conditions. During rainy and autumn seasons the surface soils had higher moisture content than the lower soil layers. Decline in the soil moisture content in the surface layer during dry winter and spring seasons could be the result of higher evapotranspiration loses from the soil and vegetation and percolation and infiltration of water to the lower depths (Tiwari *et al.* 1992).

Slightly acidic nature (4.8-5.5) of soil with a gradual increase in pH with soil depth could be the result of plant uptake and leaching and runoff losses of cations such as Ca, Mg, and K from the surface soil due to high rain fall and hilly terrain of the study sites.

Cation exchange capacity (CEC) of soils is known to be dependent on the clay and organic matter contents. In the present study CEC was positively correlated with the clay content. Gholz and Fisher (1982) have reported that during the establishment phase in *Pinus elliottii* a major portion of the SOM content of the top soil (0-10 cm) is lost through burning and decomposition. However, in the present case a reverse trend was observed. Total Kjeldahl nitrogen (TKN) decreased with stand age as well as with soil depth. Gholz *et al.*

(1986), however, have reported an increase in total N content in soil with increasing stand age. Accumulation of litter and fine roots in the surface soil might have contributed to the higher percentage of N in the top soil. Available-P did not vary much between months and stands. Maximum TKN and Available-P during autumn and winter in all stands may be attributed to the reduction in leaching of nutrients due to cesation of summer rain and input of nutreints after mild ground fire during winter season.

Vegetation plays an important role in determining the nutrient status of a particular site. Emmer (1994) reported that the plant species potentially influence the composition of soil according to the elemental composition of their aboveground litter and their subsequent contribution to litter fall. It has been found out that pine forest stands are nutritionally poor. A comparison of certain important physico-chemical properties of the soil of pine stands under study on one hand and a broad-leaved forest and grassland community on the other hand, shows a marked difference in nutrient levels of the soil. The soils of Oak forest and grassland communities developed under similar edapho-climatic conditions in greater Shillong area have higher organic carbon, TKN and available-P than the pine stands, but the soil texture, WHC, pH and bulk density did not vary much among these communities (Table. 4.5). A low nutrient level of the soil in the pine forest may be attributed to low concentration of carbon, nitrogen, phosphorus and

Table 4.5. Physio-chemical properties of soil in pine and oak forests and grassland communities developed under similar climatic condition at higher elevation (1500-1900 m) of Meghalaya.

Parameters	15-year old pinestand	16-year old oak forest regrowth [1]	Arundinella Grassland [2]
Bulk density (g/cm^3)	1.08±0.05	1.46 ± 0.04	1.13 ± 0.07
WHC (%)	67.31 ±1.31	69.30±1.54	81.42±1.69
SMC (%)	24.08±0.47	39.32±0.61	55.50±1.20
pH	5.29±0.04	5.28±0.03	5.76±0.06
CEC (Meq 100^{-1})	11.56±0.13	17.20±0.51	12.23±0.20
TKN (%)	0.13±0.01	0.51±0.02	0.20±0.01
Available-P (%)	0.01±0.001	0.58±0.02	0.25±0.009
Organic-C (%)	1.09±0.14	3.33±0.32	2.03±0.025

WHC = Water holding capacity

SMC = Soil moisture content

CEC = Cation exchange capacity

TKN = Total kjeldahl nitrogen

± = SEM

1 = after Arunachalam (1996), and 2 = after Uma Shanker (1991).

other nutrients in the pine needle (Das 1980) and their slow release during decomposition (Rout and Gupta 1990).

CHAPTER V

BIOMASS AND PRODUCTION OF FINE AND COARSE ROOTS

INTRODUCTION

Root systems of trees play a vital role in the functioning of forest ecosystem as do the leaves (Safford 1974). Its functions include anchorage, absorption of water and mineral nutrients, and synthesis of various essential compounds like growth regulators (Kramer and Boyer 1995). Surface root mat takes up dissolved nutrients before they leach down to mineral soil, thereby preventing their loss (Stark and Jordan 1978). Density of roots in a particular environment indicates their absorption capacity and potential for conserving nutrients (Jordan 1985).

The amount of water and mineral nutrients available to plants depends on the volume of soil occupied by their roots and it is a well established fact that the plants with deep root systems are more tolerant of drought than the shallow rooted plants (Kramer and Boyer 1995).

The depth and lateral spread of root system depends on both heredity and environment. Environmental factors which generally affect root growth are soil texture and structure, aeration, moisture, temperature, and competition with other plants (Kramer and Boyer 1995).

The presence of mycorrhizal roots increases absorption of water and enhances drought tolerance in plants . MacFall (1994) reported that mycorrhizae increase the rate of mineralization, and increase the supply of minerals, especially phosphorus, to the roots.

Fine roots represent functionally important biomass of forest ecosystem. They are mainly concentrated in the top 10 cm soil layer and act as the main absorbing organ (Vogt *et al.* 1986). They also prevent run-off-cum leaching losses (Lyr and Hoffman 1967, Harris *et al.* 1980, Berish 1982).

The importance of fine roots in functioning of the forest ecosystem has been emphasised by Harris *et al.* (1977), Persson (1983), Singh and Singh (1981), Vogt *et al.* (1982, 1983, 1991). And a large number of studies have been conducted on the fine roots both in the tropical (Jordan and Escalante 1980, Ramakrishnan and Singh 1983, Srivastava *et al.* 1986, Nambiar 1987, Parrotta and Lodge 1991, Silver and Vogt 1993, Visalakshi 1994, Sundarapandian and Swamy 1996, Arunachalam *et al.* 1996a) and the temperate (Persson 1979, Keyes and Grier 1981, Vogt *et al.*1983, Gale and Grigal 1987, Fahey and Hughes 1994) forest ecosystems.

Fine roots are in constant flux with death and replacement taking place simultaneously (Persson 1983). They enrich soil with nutrients and organic matter by rapid turnover and sometimes play more important role than the leaf litter on the forest floor (Arunachalam 1996). In forests fine roots show considerable temporal variation in growth (Deans 1979, Ford and Deans 1977, Gottsche 1972, Roberts 1976, Persson 1978).

The longevity of fine roots in trees varies widely between species ; from one week or two in apple and other fruit trees to ca. 60 days in *Actinidia deliciosa* (Kinman 1932). Longevity of roots in herbaceous plants also varies considerably (Kramer and Boyer 1995).

Study of aboveground productivity in the forest ecosystem all over the world has received far greater attention of the researchers than the belowground productivity. As a result, relatively less data is available on belowground productivity. Earlier works estimated belowground productivity to be about 40% of the aboveground productivity (Newbould 1967). Recent studies, however, show that belowground productivity may be as high as 50 % to 80% of the net primary productivity (Agren *et al.* 1980, Caldwell 1979, Persson 1980).

Baver *et al.* (1980), Cavelier (1992), Gregory *et al.* (1990) Gross *et al.* (1993) pointed out that both physical and chemical characteristics of the soil affect belowground productivity in the forest. The effect of climatic factors on root productivity has been discussed by Cuenca *et al.* (1993), Gergory *et al.* (1990).

Data presented in this chapter aims to analyse some of the major aspects of fine root dynamics such as growth periodicity, spatial and temporal distribution pattern, production and turnover in three pure pine stands of different ages. An attempt has been made to find out the contribution of ground vegetation to the total fine root mass in these forests.

RESULTS

VERTICAL DISTRIBUTION OF ROOT MASS

In the 6-year old pine stand 51% of tree fine roots (<2 mm diameter) was present in the top 10 cm soil layer while in the case of 15- and 23-year old stands, the corresponding values were 32% and 33%, respectively. In the 6-year old stand 27.5% of the fine roots were present in 10-20 cm layer, and only 6.4 % was recorded in the 30-40 cm soil layer. In the 15- and 23-year old stands 10-20 cm soil layer had ca. 29% and 35% fine root mass, respectively. These values further declined to ca. 12 and 9 % in the 30-40 cm soil depth. Thus, in all the three forest stands, fine root mass declined significantly ($P<0.01$) with increasing soil depth (Fig. 5.1).

In all stands, major portion (65-66%) of herbaceous fine roots was concentrated in the 0-10 cm soil layer; it sharply declined to ca.20-27% in the 10-20 cm soil layer and to 4-6% in the 30-40 cm soil layer. This decrease in herbaceous fine roots with increasing soil depth was significant ($P<0.05$) in all the three forest stands (Fig. 5.2).

In contrast, majority of the coarse roots were confined to the 10-20 cm soil layer in the 6-year old stand and to the 10-30 cm depth in the 15- and 23- year old stands. The coarse root mass increased significantly down to 30 cm soil depth,

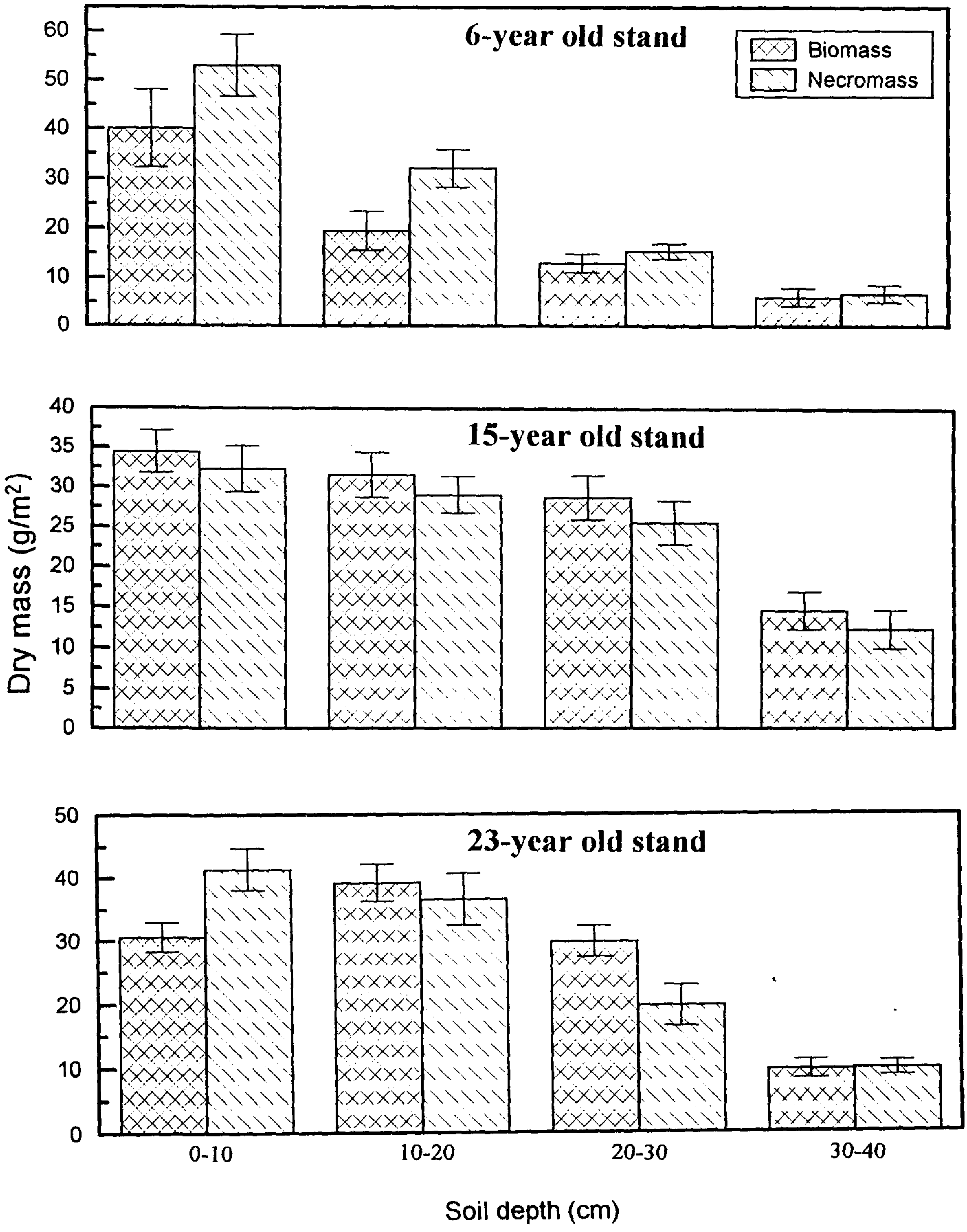

Fig. 5.1. Mean accumulation of dry mass (g/m2) of tree fine roots in different soil layers in pine stands of different ages. Vertical lines represent SEM.

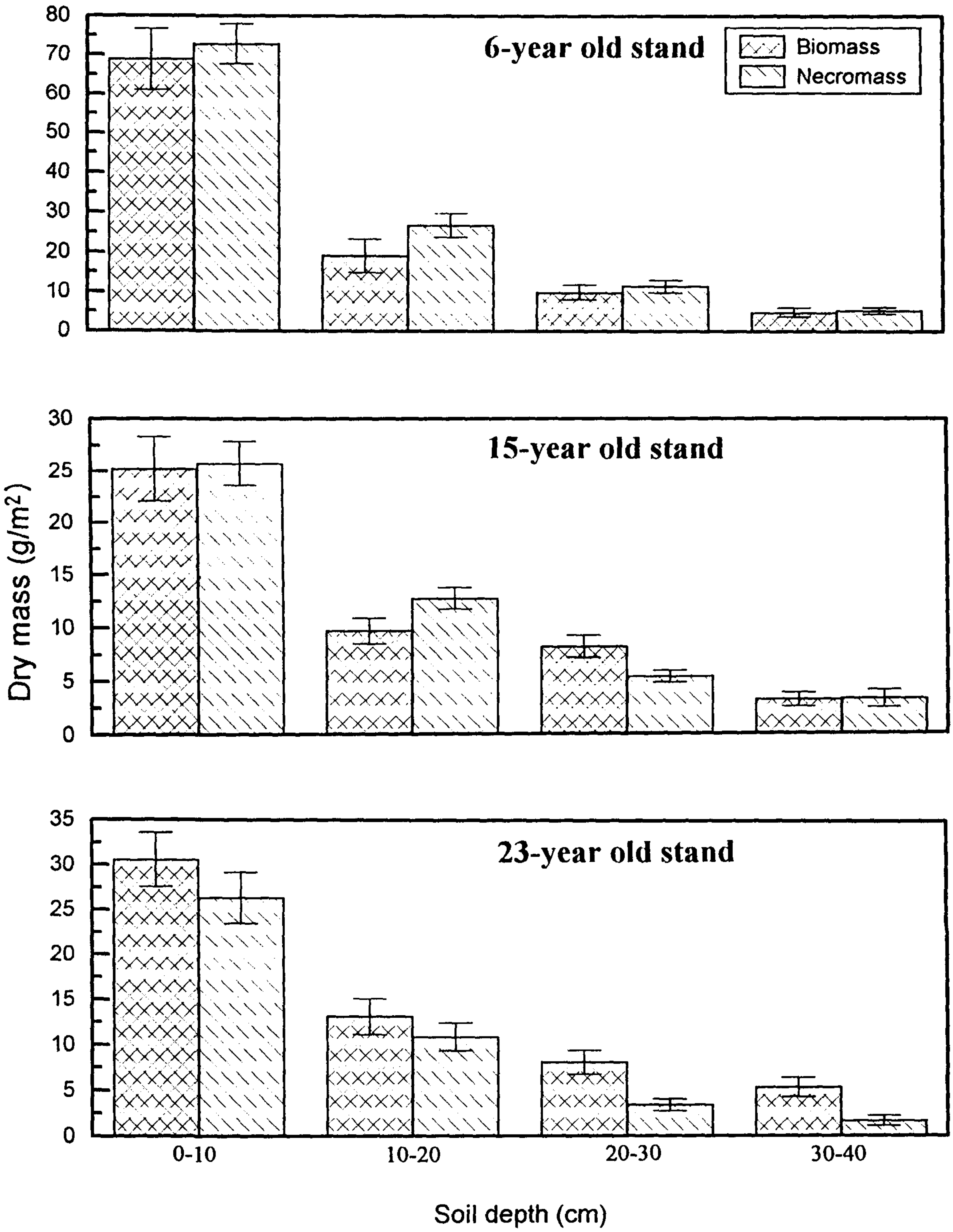

Fig. 5.2. Distribution of herbaceous fine roots (mean dry wt. g/m^2) in the soil profile of the three pine stands. Vertical lines represent SEM.

below which it declined in all the three stands (Fig. 5.3).

About 73-79% of rhizome biomass was present in the upper 10 cm soil layer; it declined sharply to 2-4% in the 20-30 cm soil layer and was absent below 30 cm soil depth (Fig. 5.4).

TEMPORAL VARIATION IN ROOT MASS

The monthly variation in the biomass and necromass of tree fine roots, herbaceous fine roots and rhizomes in stands I, II and III are shown in Tables 5.1 to 5.12. Both pine and herbaceous roots showed wide monthly fluctuations in all the stands. Dry mass of pine roots peaked during June-July in all the stands and the minimum values were recorded during April in stand I and II and during June in stand III (Table. 5.13). Herbaceous roots showed a trend similar to the pine roots, with peaks during June-July and trough during April in all the three forest stands (Table 5.14).

Seasonal mean of fine root mass of pine was maximum during rainy season and minimum during spring season in all the stands (Fig. 5.5. The seasonal variation in fine root mass of ground vegetation was similar to pine (Fig. 5.6). Both pine and herbaceous fine roots varied significantly ($P < 0.01$) between the seasons.

Coarse root biomass and rhizome biomass also varied widely between months (Tables 5.15 & 5.16). Coarse root (2-10 mm diameter) biomass peaked

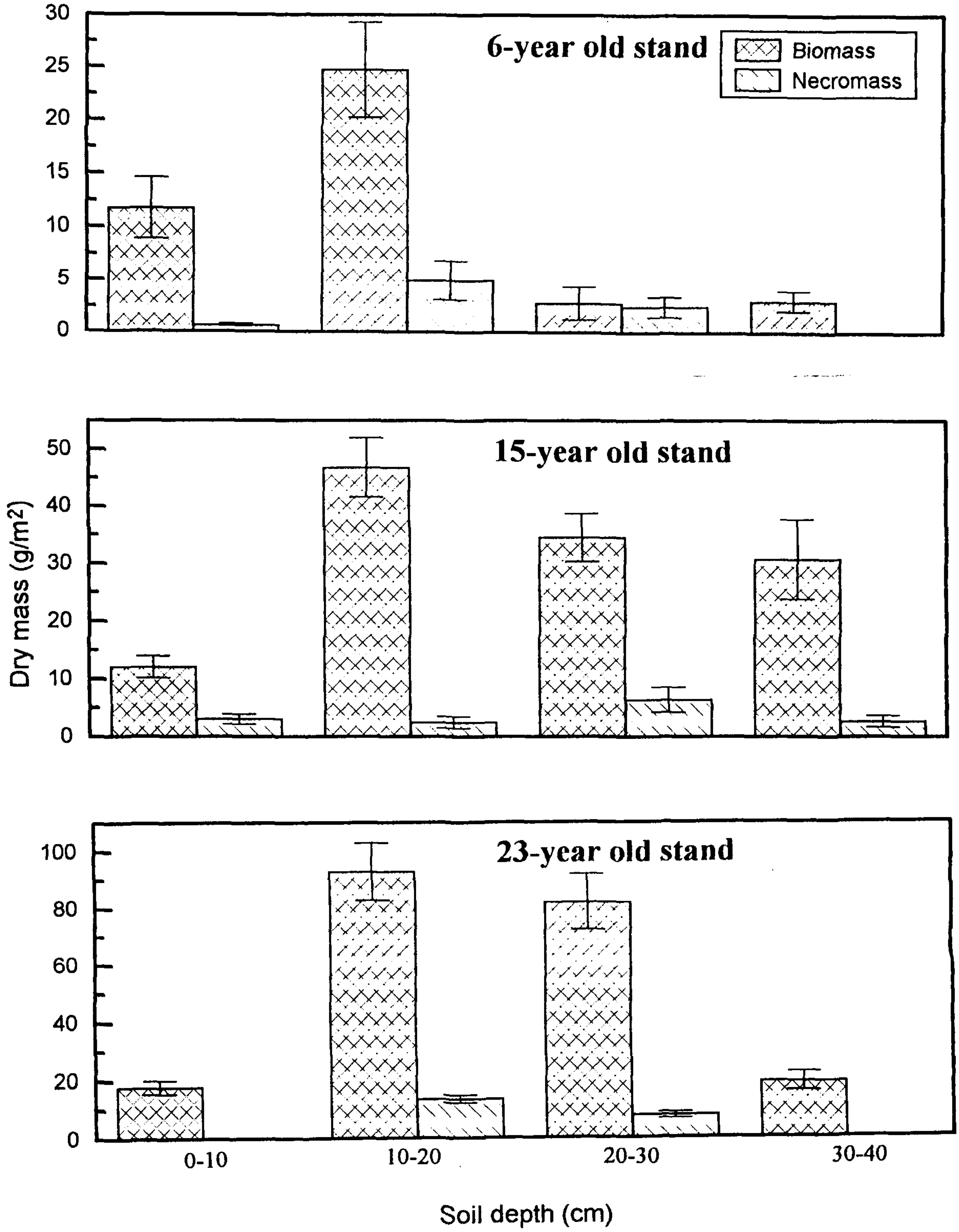

Fig. 5.3. Mean accumulation of drymass (g/m2) of tree coarse roots in different soil layers in pine stands of different ages. Vertical lines represent SEM.

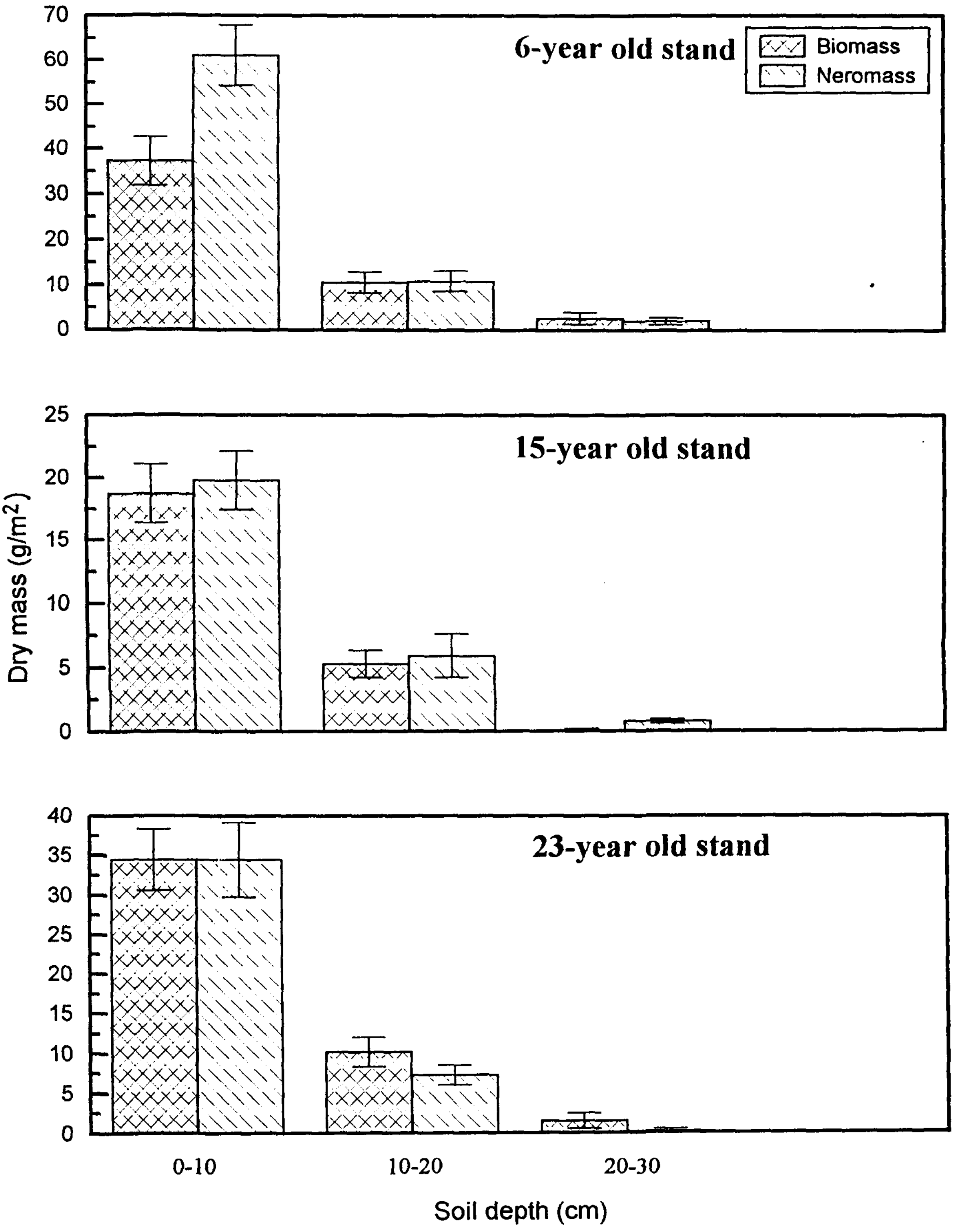

Fig. 5.4. Mean accumulation of drymass (g/m^2) of rhizome in different soil layers in pine stands of different ages. Vertical lines represent SEM.

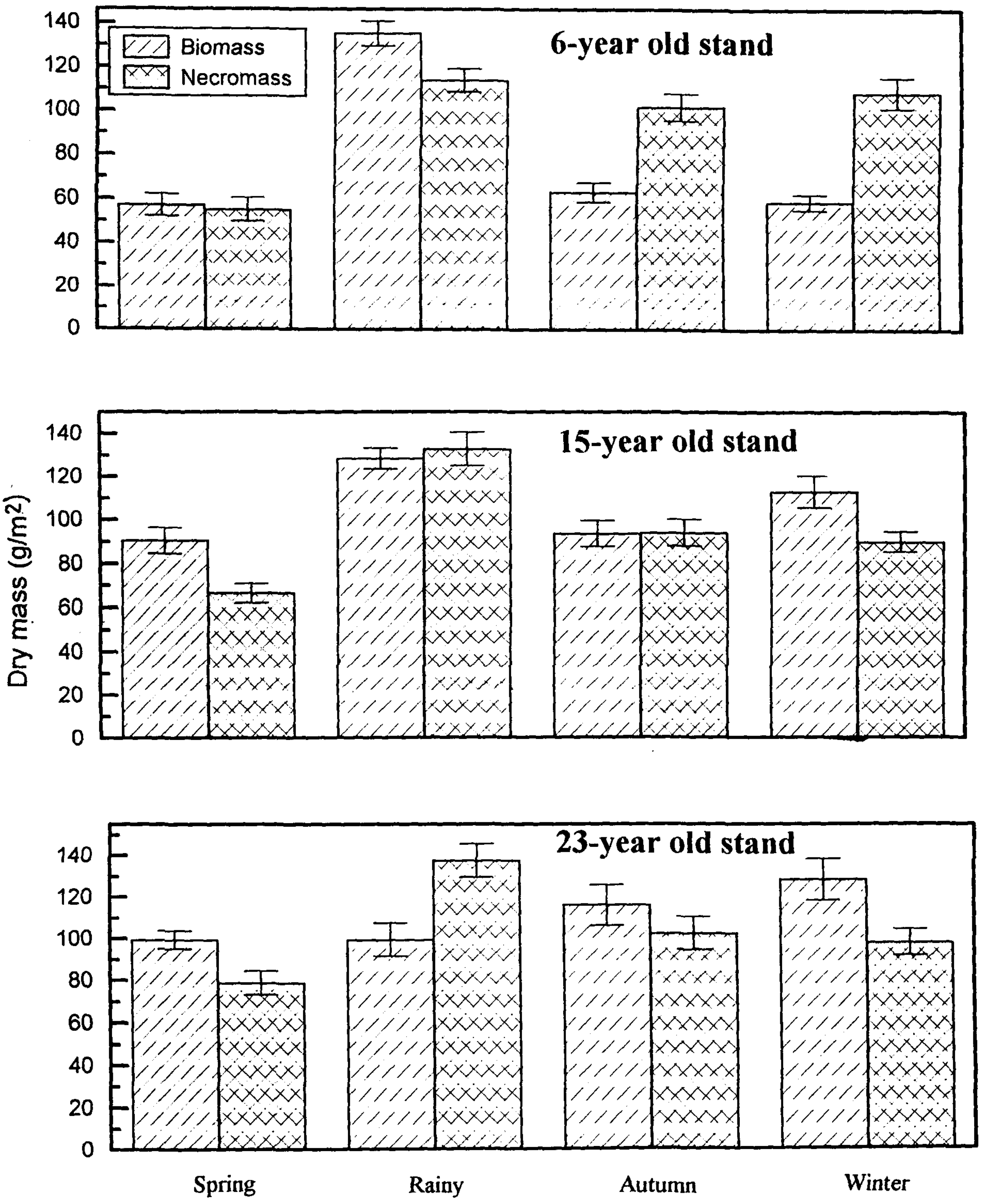

Fig. 5.5. Seasonal variation in biomass and necromass of tree fine roots in the three pine stands. Vertical lines represent SEM.

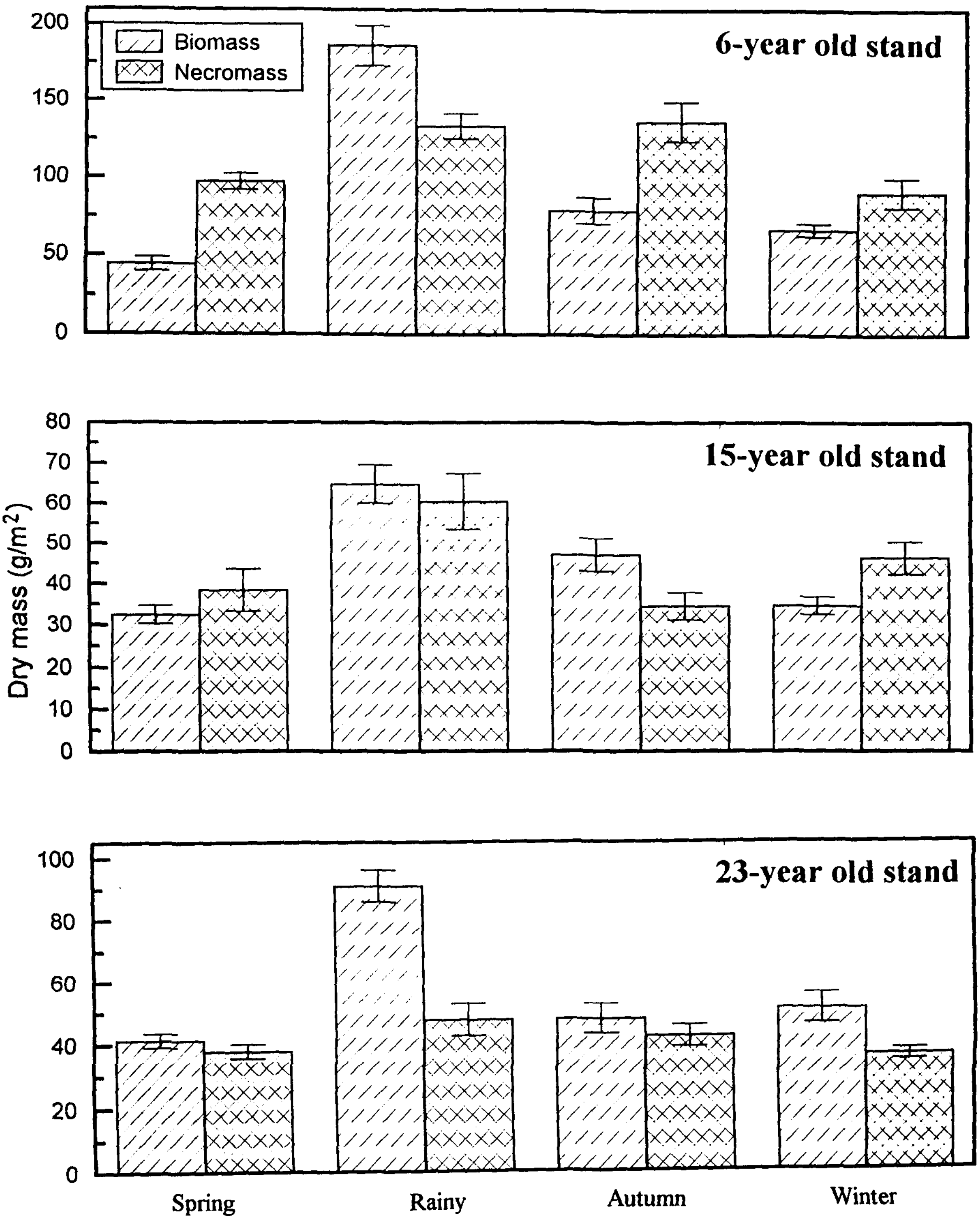

Fig. 5.6. Seasonal variation in herbaceous biomass and necromass in the three pine stands. Vertical lines represent SEM.

Table 5.1. Dry mass (g m^{-2}) of tree fine roots (<2 mm diameter) in 6-year old pine stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	31.68	31.94	11.15	11.21	16.92	7.77	2.24	3.55
	±6.56	±7.82	±3.49	±2.72	±4.44	±2.14	±1.20	±0.56
Jun.	113.34	50.01	51.63	45.54	26.36	23.94	23.61	18.24
	±17.91	±10.34	±13.78	±13.88	± 6.67	±6.97	±7.62	±4.97
Jul.	77.14	73.24	45.05	52.24	22.99	14.82	12.15	16.85
	±21.52	±16.65	±16.59	±12.52	±8.69	±4.99	±5.39	±5.49
Aug.	47.76	94.81	15.55	33.52	13.98	24.79	8.78	10.18
	±9.69	±15.96	±5.83	±8.89	±6.67	±6.48	±4.92	±3.69
Sep.	53.77	63.06	11.40	27.20	8.16	16.76	10.62	11.43
	±13.78	±16.86	±5.48	±7.42	±3.37	±5.48	±5.48	±5.74
Oct.	31.03	45.83	20.65	30.94	6.38	9.16	4.23	-
	±6.95	±8.48	±4.73	±7.75	±3.49	±3.55	±2.89	-
Nov.	31.41	71.44	12.64	25.92	16.35	15.63	4.81	5.48
	±8.26	±15.17	±5.74	±7.14	±8.60	±6.14	±1.96	±2.02
Dec.	29.69	49.82	14.61	38.75	6.42	12.15	1.77	4.11
	±6.96	±8.54	±5.67	±8.20	±1.93	±4.43	±0.71	±0.59
Jan.	42.77	70.93	9.43	47.70	10.53	11.06	2.02	1.18
	±8.82	±14.39	±3.67	±10.53	±3.58	±3.02	±0.97	±0.46
Feb.	25.49	30.84	24.21	37.11	6.94	18.07	4.14	4.48
	±4.49	±7.46	±6.79	±9.91	±1.52	±2.99	±1.86	±1.68
Mar.	24.18	35.58	20.01	11.64	13.71	15.20	-	2.36
	±5.99	±9.34	±8.72	±1.86	±3.93	±2.80	-	±1.55
April	15.54	20.15	13.39	24.42	14.83	16.41	9.37	2.18
	±4.05	±2.18	± 3.96	±5.89	± 3.42	± 3.58	± 4.98	± 0.93

L= Live, D = Dead, - = Absent, ± = S.E.M.

Table 5.2. Dry mass (g m^{-2}) of coarse roots (2-10 mm diameter) in 6-year old stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	-	-	40.72	14.64	12.58	-	2.58	-
	-	-	± 9.32	±3.54	± 4.56	-	±1.49	-
Jun.	13.97	-	38.04	12.17	14.52	-	5.96	-
	± 8.95	-	± 12.21	± 6.66	± 3.97	-	± 2.16	-
Jul.	22.99	-	49.88	24.58	7.57	30.68	29.12	-
	± 8.32	-	±10.54	± 4.86	± 2.32	± 12.03	± 9.95	-
Aug.	6.73	8.26	31.68	9.28	-	-	-	-
	± 2.34	± 4.73	±12.32	± 3.12	-	-	-	-
Sep.	-	-	28.54	-	-	-	-	-
	-	-	±10.55	-	-	-	-	-
Oct.	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
Nov.	6.32	-	25.92	-	-	-	-	-
Dec.	11.28	-	23.71	-	-	-	-	-
	± 7.25	-	± 8.12	-	-	-	-	-
Jan.	43.84	-	13.65	-	-	-	-	-
	± 8.12	-	± 3.58	-	-	-	-	-
Feb.	-	-	33.74	-	-	-	-	-
	-	-	± 7.18	-	-	-	-	-
Mar.	25.57	-	-	-	-	-	-	-
	± 8.16	-	-	-	-	-	-	-
April	10.68	-	11.81	-	-	-	-	-
	± 7.16	-	± 9.34	-	-	-	-	-

L = Live, D = Dead, - = Absent, ± = S.E.M.

Table 5.3. Dry mass (g m^{-2}) of herbaceous fine roots in 6-year old pine stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	42.58	89.54	13.44	12.99	3.08	-	-	
	±4.15	±24.24	±3.29	±4.09	±0.36	-	-	-
Jun.	175.68	52.82	47.38	42.38	22.47	9.72	12.36	8.43
	±45.28	±14.17	±4.53	±7.32	±8.06	±1.40	±5.12	±0.93
Jul.	133.04	94.89	48.88	38.83	18.35	13.30	8.66	8.28
	±12.89	±14.17	±3.07	±1.30	±2.78	±4.47	±1.23	±1.09
Aug.	129.20	80.49	18.32	21.55	8.38	14.95	6.17	7.76
	±14.27	±4.11	±1.27	±2.23	±1.32	±2.74	±0.12	±1.91
Sep.	84.81	85.71	15.82	35.21	8.28	18.85	8.32	8.51
	±4.73	±12.14	±1.46	±7.82	±0.28	±6.21	±0.71	±0.28
Oct.	36.07	88.76	22.86	28.91	9.25	10.31	5.98	5.73
	±3.80	±2.54	±3.36	±6.54	±2.64	±2.78	±1.43	±0.92
Nov.	41.99	84.83	19.28	34.84	16.32	14.73	7.97	6.48
	±15.92	±29.02	±3.78	±5.78	±7.07	±2.88	±0.12	±0.74
Dec.	49.64	58.04	16.32	13.92	9.37	4.23	2.93	3.55
	±8.15	±3.15	±2.32	±1.88	±2.25	±1.02	±0.99	±0.52
Jan.	46.39	84.70	13.67	34.24	4.08	13.27	1.06	2.55
	±3.01	±8.76	±4.00	±12.13	±0.66	±4.42	±0.15	±0.81
Feb.	43.21	46.98	8.03	19.82	7.41	7.51	1.40	2.52
	±10.98	±3.93	±1.05	±7.25	±0.12	±2.51	±0.14	±0.19
Mar.	28.07	56.27	-	13.49	3.36	13.35	-	6.85
	±6.35	13.15	-	±5.69	±0.54	±1.64	-	±0.57
April	16.72	52.62	6.85	26.14	9.73	17.88	4.52	3.65
	±3.54	±15.40	±0.96	±8.11	±2.12	±6.21	±0.68	±0.45

L = Live, D = Dead, - = Absent, ± = S.E.M.

Table 5.4.Rhizome biomass (g m^{-2}) in 6-year old pine stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	21.34	32.46	7.97	16.98	-	-	-	-
	±8.10	±12.97	±3.33	±8.05		-	-	-
Jun.	84.77	54.92	25.85	18.61	8.01	3.76	-	-
	±26.12	±15.25	±9.65	±9.76	±3.67	±0.96	-	-
Jul.	22.68	71.35	9.04	9.25	10.03	3.95	-	-
	±6.95	±29.59	±6.09	±4.45	±7.19	±2.67	-	-
Aug.	50.25	77.70	5.02	5.42	-	3.42	-	-
	±20.43	±23.30	±3.33	±3.05	-	±1.55	-	-
Sep.	43.15	62.28	17.32	-	-	6.26	-	-
	±19.28	±31.37	±9.52	-	-	±4.26	-	-
Oct.	34.73	24.14	2.93	2.96	-	-	-	-
	±14.64	±11.83	±1.96	±1.49	-	-	-	-
Nov.	24.58	55.15	15.04	12.64	-	-	-	-
	±11.81	±21.03	±8.91	±6.72	-	-	-	-
Dec.	20.78	80.91	9.03	13.42	-	-	-	-
	±5.79	±28.32	±4.52	±5.48	-	-	-	-
Jan.	41.00	60.59	11.90	6.92	-	-	-	-
	±13.39	±23.67	±8.59	±3.92	-	-	-	-
Feb.	38.42	70.19	-	2.46	-	-	-	-
	±21.49	±3.24	-	±1.74	-	-	-	-
Mar.	31.59	38.42	2.55	18.35	12.93	1.06	-	-
	±16.20	±18.07	±1.83	±12.15	±7.49	±0.71	-	-
April	13.14	53.43	22.31	25.70	2.49	7.60	-	-
	±4.67	±16.43	±8.72	±12.22	±1.55	±3.17	-	-

L = Live, D = Dead, - = Absent, ± = S.E.M.

Table 5.5. Dry mass (g m^{-2}) of tree fine roots (<2 mm diameter) in 15-year old pine stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	34.57	29.65	36.14	19.44	13.49	9.59	8.47	4.71
	±6.32	±2.23	±5.70	±4.70	±3.95	±4.79	±2.92	±1.87
Jun.	57.27	29.82	52.33	20.69	38.57	34.92	30.74	26.49
	±10.10	±8.95	±6.06	±6.78	±6.57	±9.84	±8.77	±8.78
Jul.	43.81	52.43	26.01	53.06	33.11	50.37	14.61	26.79
	±7.20	±14.96	±6.29	±12.56	±8.10	±12.21	±5.42	±9.48
Aug.	30.13	51.06	35.67	57.92	30.91	27.14	16.61	18.47
	±8.28	±14.14	±6.82	±9.28	±8.53	±9.29	±7.96	±7.85
Sep.	28.35	33.12	23.71	22.12	30.50	11.43	22.46	16.45
	±8.66	±5.54	±3.83	±5.76	±7.07	±5.01	±8.43	±5.29
Oct.	21.87	25.92	25.26	29.91	39.94	40.59	9.41	6.32
	±7.07	±5.58	±8.53	±9.95	±8.66	±9.09	±5.26	±3.68
Nov.	36.85	24.67	29.94	34.99	22.01	22.12	2.31	3.96
	±8.61	±5.42	±6.56	±11.52	±6.88	±7.63	±0.93	±2.11
Dec.	30.09	23.93	28.82	23.39	30.31	32.34	19.72	12.62
	±4.83	±1.63	±5.41	±6.14	±7.20	±7.88	±5.68	±3.08
Jan.	33.99	35.95	50.25	27.97	21.15	17.66	4.76	7.47
	±7.32	±7.42	±11.98	±7.38	±6.89	±6.66	±1.53	±1.74
Feb.	29.54	34.52	31.15	18.25	44.39	28.94	15.88	9.68
	±7.91	±5.73	±6.88	±1.37	±9.85	±6.38	±4.92	±2.77
Mar.	39.91	22.22	23.24	20.34	15.23	7.51	20.56	10.25
	±6.98	±4.89	±7.10	±6.64	±5.77	±2.77	±6.32	±2.49
April	27.32	24.71	17.01	21.96	25.39	24.30	10.09	5.25
	±7.16	±4.67	±5.60	±5.29	±9.09	±7.29	±4.28	±1.86

L = Live, D = Dead, ± = S.E.M.

Table 5.6. Dry mass (g m^{-2}) of coarse roots (2-10 mm diametr) in 15-year old stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	-	-	53.74	-	-	1.84	35.23	-
	-	-	±25.59	-	-	±0.56	±13.08	-
Jun.	8.26	-	53.29	-	37.02	-	92.85	-
	±4.61	-	±32.89	-	±14.81	-	±46.53	-
Jul.	31.78	-	31.91	8.51	95.74	42.12	52.05	32.71
	±12.87	-	±12.18	±4.23	±48.97	±23.97	±23.99	±2.18
Aug.	20.37	-	35.36	22.15	21.21	22.05	56.36	-
	±12.11	-	±20.17	10.43	±11.49	8.63	±23.88	-
Sep.	-	-	131.79	-	22.84	-	15.57	-
	-	-	±84.15	-	±13.02	-	±9.52	-
Oct.	15.61	-	166.42	-	98.70	-	46.67	-
	±8.32	-	±45.79	-	±37.98	-	±24.76	-
Nov.	-	37.29	-	-	53.48	-	-	-
	-	±15.94	-	-	±23.36	-	-	-
Dec.	-	-	-	-	36.23	11.46	30.94	-
	-	-	-	-	±15.08	±5.42	±12.12	-
Jan.	-	-	45.89	-	18.47	-	-	-
	-	-	±12.40	-	±9.17	-	-	-
Feb.	-	-	-	-	17.75	-	40.03	-
	-	-	-	-	±12.92	-	±27.11	-
Mar.	70.07	-	43.43	-	-	-	-	-
	±31.71	-	±18.88	-	-	-	-	-
April	-	-	-		13.62	-	-	-
	-	-	-	-	±8.97	-	-	-

L = Live, D = Dead, - = Absent, ± = S. E.M.

Table 5.7. Dry mass (g m^{-2}) of herbaceous fine roots in 15-year old pine stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	22.53	28.26	10.53	6.33	2.03	0.38	1.18	3.65
	± 0.42	± 0.42	± 0.54	± 0.33	± 0.06	± 0.00	± 0.00	± 1.23
Jun.	48.74	26.05	25.69	11.03	19.88	6.71	4.56	2.51
	± 18.15	± 0.55	± 7.92	± 1.84	± 7.19	± 1.42	± 1.46	± 0.04
Jul.	28.67	31.09	10.52	44.87	15.67	6.35	4.89	11.62
	± 0.63	± 2.88	± 1.90	± 12.52	± 2.91	± 1.74	± 0.71	± 1.68
Aug.	25.24	23.62	9.82	15.71	14.49	5.99	3.80	6.29
	± 3.30	± 4.85	± 0.77	± 0.83	± 0.77	± 0.43	± 0.07	± 0.00
Sep.	25.05	29.89	15.23	12.87	5.61	6.61	1.97	0.99
	± 3.30	± 4.85	± 0.77	± 0.83	± 0.77	± 0.43	± 0.07	± 0.00
Oct.	31.53	16.31	7.57	7.01	7.29	4.32	2.82	-
	± 3.65	± 4.47	± 0.91	± 0.76	± 0.20	± 0.07	± 0.03	-
Nov.	28.14	30.37	6.42	4.89	6.76	6.07	4.21	0.78
	± 3.45	± 4.68	± 1.46	± 1.05	± 0.88	± 0.35	± 1.39	± 0.00
Dec.	22.03	24.62	6.89	16.94	7.58	5.49	6.20	2.93
	± 0.83	± 0.53	± 0.02	± 1.05	± 0.35	± 0.78	± 0.79	± 0.06
Jan.	24.98	28.92	8.23	6.42	3.05	3.17	0.94	1.75
	± 0.53	± 2.46	± 1.96	± 1.09	± 0.32	± 0.45	± 0.00	± 0.15
Feb.	14.43	31.19	5.02	14.39	4.06	7.05	1.56	3.43
	± 2.33	± 0.43	± 1.33	± 5.29	± 0.60	± 0.73	± 0.00	± 0.85
Mar.	22.97	24.09	6.67	9.68	7.26	7.45	6.67	5.24
	± 1.60	± 5.88	± 0.68	± 2.33	± 0.52	± 1.22	± 2.39	± 1.63
April	8.53	14.74	3.96	9.17	5.39	5.88	-	0.81
	± 0.78	± 5.38	± 0.42	± 1.07	± 0.79	± 0.91	-	± 0.00

L = Live, D = Dead, - = Absent, ± = S.E.M.

Table 5.8.Rhizome dry mass (g m^{-2}) in 15-year old pine stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	12.40	12.89	6.64	10.47	-	-	-	-
	±4.05	±2.89	±2.50	±4.05	-	-	-	-
Jun.	27.38	34.86	7.20	7.92	-	-	-	
	±12.07	±12.49	±3.74	±3.43	-	-	-	-
Jul.	18.07	25.67	4.70	4.70	-	-	-	-
	±12.24	±11.84	±2.12	±1.38	-	-	-	-
Aug.	14.89	43.03	4.98	-	-	4.41	-	-
	±11.62	±18.19	±2.13	-	-	±1.39	-	-
Sep.	15.83	19.78	6.86	5.61	2.03	2.87	-	-
	±7.86	±9.35	±2.58	±2.36	±1.13	±1.12	-	-
Oct.	10.95	21.69	-	-	-	-	-	-
	±9.59	±12.69	-	-	-	-	-	-
Nov.	24.84	14.87	7.10	-	-	2.43	-	-
	±10.19	±10.13	±3.93	-	-	±1.63	-	-
Dec.	23.78	15.05	-	-	-	-	-	-
	±10.59	±5.32	-	-	-	-	-	-
Jan.	10.66	14.77	11.56	10.22	-	-	-	-
	±4.45	±7.17	±3.65	±3.55	-	-	-	-
Feb.	15.27	10.38	6.21	2.31	-	-	-	-
	±7.42	±5.89	±2.41	±1.52	-	-	-	-
Mar.	27.61	11.31	8.72	16.32	-	-	-	-
	±8.42	±4.37	±3.74	±8.42	-	-	-	-
April	23.56	14.59	-	14.09	-	-	-	-
	±13.09	±4.99	-	±8.32	-	-	-	-

L = Live, D = Dead, - = Absent, ± = S.E.M.

Table 5.9. Dry mass (g m^{-2}) of tree fine roots (<2 mm diameter) in 23-year old stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	28.77	33.06	29.23	26.58	25.84	6.53	7.45	14.96
	±7.04	±4.36	±6.73	±6.48	±5.75	±2.87	±2.55	±4.95
Jun.	21.82	22.65	32.23	19.36	24.29	15.66	11.04	13.63
	±4.07	±4.61	±7.25	±6.53	±6.75	±6.80	±2.51	±5.96
Jul.	43.58	90.54	35.13	79.66	37.48	49.85	10.53	9.97
	±6.23	±17.14	±6.88	±12.46	±11.01	±14.39	±3.73	±3.95
Aug.	24.70	66.30	37.10	67.01	26.88	24.71	20.22	12.71
	±5.61	±13.02	±7.94	±13.05	±8.72	±5.34	±6.23	±3.33
Sep.	21.09	30.22	26.44	30.50	18.91	12.64	7.19	8.94
	±5.07	±13.89	±7.32	±8.94	±5.99	±4.85	±3.18	±3.37
Oct.	27.54	47.54	34.67	25.08	22.65	14.39	11.65	7.69
	±6.31	±7.64	±10.59	±12.62	±7.44	±4.45	±5.89	±3.77
Nov.	39.01	43.18	47.14	35.17	40.06	23.67	9.81	8.56
	±11.22	±11.52	±13.24	±8.47	±11.27	±7.63	±2.62	±2.43
Dec.	25.67	35.83	46.11	39.25	32.21	15.21	1.65	2.80
	±5.39	±5.51	±12.15	±13.58	±11.93	±4.95	±0.45	±0.93
Jan.	45.17	38.25	40.94	27.16	42.59	24.21	9.22	6.26
	±18.69	±3.27	±8.84	±7.51	±15.70	±6.44	±3.53	±1.84
Feb.	32.68	33.12	42.58	35.26	27.66	22.83	15.83	14.71
	±13.12	±7.66	±12.39	±7.51	±9.00	±7.72	±5.48	±4.52
Mar.	33.52	26.48	44.21	26.32	39.97	14.23	8.10	5.79
	±15.82	±3.61	±14.80	±9.92	±9.84	±6.12	±3.21	±2.49
April	25.15	29.63	32.84	27.48	19.53	12.83	4.23	12.96
	±5.91	±4.74	±7.17	±5.92	±5.33	±3.73	±2.18	±3.42

L = Live, D = Dead, ± = S.E.M.

Table 5.10. Dry mass (g m^{-2}) of coarse roots (2-10 mm diameter) in 23-year old pine stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	8.61	-	128.08	-	82.03	-	-	-
	±4.28	-	±25.79	-	±36.41	-	-	-
Jun.	36.78	-	157.80	-	94.95	-	93.79	-
	±12.57	-	±65.42	-	±45.21	-	±29.31	-
Jul.	27.73	-	114.01	60.72	148.40	15.21	123.64	-
	±10.47	-	±45.69	±23.12	±64.25	±5.65	±65.97	-
Aug.	-	-	192.89	29.91	134.75	-	-	-
	-	-	±56.37	±19.72	±55.72	-	-	-
Sep.	-	-	64.99	10.90	28.07	3.80	-	-
	-	-	±22.47	±4.61	±6.76	±1.45	-	-
Oct.	15.98	-	71.01	30.72	13.08	25.70	15.23	-
	±9.23	-	±32.17	±12.52	±8.30	±9.19	±6.79	-
Nov.	42.72	-	145.43	18.69	217.66	15.83	-	-
	±12.58	-	±39.26	±12.33	±99.84	±7.96	-	-
Dec.	-	-	64.12	12.27	60.10	15.26	-	-
	-	-	±22.71	±3.76	±21.99	±8.23	-	-
Jan.	42.90	-	13.86	-	40.47	-	-	-
	±10.61	-	±6.91	-	±21.90	-	-	-
Feb.	-	-	51.75	-	110.01	18.60	-	-
	-	-	±18.25	-	±58.10	±8.16	-	-
Mar.	39.41	-	40.53	-	31.09	-	-	-
	±13.85	-	±13.59	-	±12.81	-	-	-
April	-	-	72.43	-	25.28	-	-	-
	-	-	±22.41	-	±13.94	-	-	-

L = Live, D = Dead, - = Absent, ± = S.E.M.

Table 5.11. Dry mass (g m^{-2}) of herbaceous fine roots in 23-year old pine stand.

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	30.35	39.73	10.22	2.99	4.74	0.44	-	-
	±0.84	±3.42	±2.34	±0.97	±1.31	±0.00	-	-
Jun.	38.85	26.95	20.90	9.97	11.22	6.73	8.05	3.86
	±7.62	±3.69	±3.87	±0.93	±4.36	±0.07	±2.15	±0.17
Jul.	53.09	41.09	23.92	17.04	5.55	2.27	3.43	1.25
	±8.79	±1.58	±7.13	±0.64	±0.35	±0.09	±0.94	±0.00
Aug.	39.16	33.15	14.89	6.64	7.60	1.31	3.24	2.93
	±1.83	±6.61	±3.86	±1.45	±2.74	±0.00	±0.75	±0.37
Sep.	30.69	23.24	12.56	7.98	6.14	6.14	4.42	0.99
	±7.56	±0.25	±0.51	±0.35	±0.30	±1.89	±1.12	±0.03
Oct.	24.30	31.78	9.94	10.47	4.74	0.53	1.93	-
	±2.78	±1.44	±1.14	±0.49	±1.75	±0.00	±0.16	-
Nov.	27.39	27.20	12.99	10.22	11.59	4.05	3.18	0.97
	±0.11	±0.99	±0.79	±1.99	±3.18	±0.19	±0.25	±0.05
Dec.	28.94	29.66	13.05	9.28	6.73	2.80	1.99	1.15
	±2.04	±1.23	±0.34	±0.30	±0.12	±0.16	±0.25	±0.00
Jan.	34.24	21.62	13.09	10.59	6.76	2.77	1.50	0.72
	±5.00	±2.80	±3.68	±1.21	±2.42	±0.00	±0.00	±0.00
Feb.	30.28	19.25	7.79	8.94	8.97	2.87	0.62	-
	±1.81	±4.30	±0.75	±0.39	±0.97	±0.00	±0.00	-
Mar.	15.78	5.29	8.82	23.71	20.16	6.82	0.90	6.73
	±0.88	±1.40	±0.51	±7.70	±3.51	±1.23	±0.00	±1.43
April	14.11	17.70	9.41	12.81	3.14	4.74	7.13	1.87
	±0.39	±5.64	±0.47	±4.56	±0.70	±0.00	±2.04	±0.00

L=Live, D=Dead, - =Absent, ± = S.E.M.

Table 5.12.Rhizome dry mass (g m^{-2}) in 23-year old pine stand

Months	Soil depth (cm)							
	0-10		10-20		20-30		30-40	
	L	D	L	D	L	D	L	D
May	19.41	26.38	12.09	13.05	-	-	-	-
	±7.16	±4.98	±3.43	±4.36	-	-	-	-
Jun.	46.70	45.64	20.06	19.57	3.21	-	-	-
	±12.49	±10.90	±8.72	±8.41	±2.18	-	-	-
Jul.	56.64	64.26	14.15	8.88	1.53	2.43	-	-
	±14.02	±19.63	±8.11	±3.58	±0.99	±1.65	-	-
Aug.	48.82	14.33	4.33	5.39	-	-	-	-
	±25.24	±3.93	±1.80	±1.84	-	-	-	-
Sep.	41.34	27.85	17.01	4.99	-	1.56	-	-
	±11.81	±9.60	±8.26	±1.81	-	±0.54	-	-
Oct.	23.02	28.24	21.12	2.27	-	-	-	-
	±5.61	±9.40	±7.79	±1.53	-	-	-	-
Nov.	48.07	38.54	3.80	3.02	-	-	-	-
	±16.61	±11.68	±1.58	±1.59	-	-	-	-
Dec.	33.03	25.80	-	3.02	-	-	-	-
	±13.12	±10.03	-	±1.23	-	-	-	-
Jan.	26.27	39.63	10.25	7.63	-	-	-	-
	±7.30	±9.97	±3.21	±2.09	-	-	-	-
Feb.	18.32	24.46	12.96	6.61	-	-	-	-
	±5.10	±6.26	±3.80	±3.18	-	-	-	-
Mar.	32.62	35.61	2.71	7.29	11.81	-	-	-
	±10.00	±11.49	±1.87	±3.99	±6.64	-	-	-
April	20.03	28.60	4.05	5.92	2.40	-	-	-
	±4.55	±7.48	±1.56	±2.80	±1.25	-	-	-

L = Live, D = Dead, - = Absent, ± = S.E.M.

Table 5.13. Tree fine root mass (g m^{-2}; 0-40 cm) in the three pine stands.

	6-year old stand			15-year old stand			23-year old stand		
Months	L	D	T	L	D	T	L	D	T
May	62.01	54.49	116.49	49.68	63.40	156.08	91.31	81.12	172.44
	±12.05	±9.37	±23.91	±5.32	±3.05	±16.12	±8.26	±5.10	
Jun.	214.94	137.74	352.68	178.93	111.93	290.86	89.39	71.31	160.71
	±30.14	±19.12	±31.30	±12.94	±12.10	±9.90	±7.81	±3.17	
Jul.	157.34	157.18	314.52	117.54	182.65	300.19	126.72	230.02	356.74
	±12.60	±18.39	±38.35	±12.38	±16.17	±30.81	±9.95	±15.91	
Aug.	86.09	163.32	249.41	113.31	154.59	267.91	108.92	170.74	279.65
	±5.70	±12.93	±16.12	±23.91	±13.63	±8.90	±10.96	±17.82	
Sep.	83.96	118.46	202.42	105.03	83.12	188.15	73.64	82.32	155.96
	±7.15	±10.19	±21.63	±9.16	±7.30	±16.93	±7.28	±5.23	
Oct.	62.31	85.93	148.24	96.49	102.75	199.24	96.52	94.71	191.23
	±7.10	±6.17	±12.19	±8.73	±18.15	±20.36	±8.94	±9.13	
Nov.	65.22	118.48	183.71	91.11	85.74	176.85	136.03	110.60	246.63
	±7.30	±24.18	±12.68	±6.37	±9.10	±13.17	±13.94	±26.12	
Dec.	52.50	104.84	157.34	108.95	92.28	201.23	105.65	93.09	198.74
	±8.12	±20.18	±13.73	±7.19	±5.36	±28.30	±14.91	±4.18	
Jan.	64.77	130.88	195.65	110.17	88.17	198.34	137.93	95.89	233.83
	±8.20	±9.15	±19.45	±9.12	±4.91	±18.06	±12.35	±9.02	
Feb.	61.25	90.51	151.76	120.98	91.41	212.39	118.75	105.93	224.68
	±5.03	±7.24	±23.01	±17.38	±10.19	±35.02	±11.39	±16.01	
Mar.	57.89	64.79	122.69	98.95	60.32	159.26	125.81	72.84	198.65
	±4.58	±8.17	±19.12	±6.09	±5.17	±16.18	±13.03	±9.17	
April	53.15	63.18	116.34	79.82	76.22	156.04	81.76	82.91	164.67
	±6.09	±8.16	±15.10	±6.02	±8.95	±23.16	±5.09	±12.47	

L = Live, D = Dead, T = Total, ± = S.E.M.

Table 5.14. Herbaceous fine root mass (g m^{-2}); 0-40 cm) in the three pine stands.

Months	6-year old stand			15-year old stand			23-year old stand		
	L	D	T	L	D	T	L	D	T
May	59.12	102.53	161.65	36.26	38.61	74.86	45.29	43.15	88.45
	±4.10	±12.49	±17.27	±4.12	±3.09	±8.16	±7.12	±5.38	
Jun.	257.91	113.33	371.27	98.56	46.29	145.15	79.02	47.51	126.53
	±32.18	±14.10	±37.28	±6.02	±3.12	±13.80	±6.18	±4.17	
Jul.	208.93	155.30	364.23	59.75	93.93	153.68	85.99	61.65	147.64
	±28.88	±17.31	±33.50	±4.71	±5.54	±12.01	±4.93	±6.30	
Aug.	162.07	124.75	286.82	53.34	51.59	104.93	64.89	44.02	108.92
	±18.10	±12.93	±21.80	±3.96	±7.02	±9.15	±7.12	±4.71	
Sep.	117.22	148.28	265.50	47.88	50.35	98.23	53.81	38.45	92.15
	±19.81	±13.80	±23.06	±7.92	±8.04	±5.84	±6.03	±8.09	
Oct.	74.21	133.72	207.92	49.21	27.45	76.65	40.91	42.77	83.68
	±8.04	±15.93	±24.02	±2.89	±2.28	±12.31	±6.70	±9.16	
Nov.	85.56	148.90	226.46	45.52	42.12	87.63	55.15	42.43	97.57
	±6.80	±16.85	±23.05	±4.30	±7.35	±8.16	±9.30	±12.30	
Dec.	78.25	79.74	157.99	42.68	43.95	86.64	50.72	42.90	93.62
	±9.17	±10.05	±13.01	±5.07	±8.29	±10.05	±5.38	±3.97	
Jan.	65.21	134.76	199.97	37.19	40.25	77.45	55.58	35.70	91.28
	±4.92	±17.38	±14.07	±6.10	±3.91	±6.04	±8.03	±3.97	
Feb.	60.09	134.77	194.83	25.05	56.04	81.09	47.66	31.06	78.73
	±10.16	±15.05	±18.17	±4.03	±7.01	±9.17	±5.09	±3.45	
Mar.	31.43	89.96	121.39	43.55	46.45	90.01	45.66	42.56	88.22
	±4.05	±9.13	±14.46	±9.01	±5.08	±7.12	±10.10	±4.07	
April	37.80	100.29	138.09	17.87	30.59	48.47	33.80	37.10	70.91
	±7.01	±15.90	±17.12	±1.39	±4.07	±7.17	±2.30	±7.05	

L = Live, D = Dead, ± = S.E.M.

Table 5.15. Coarse root mass (g m^{-2}; 0-40 cm) in the three pine stands.

	6-year old stand			15-year old stand			23-year old stand		
Months	L	D	T	L	D	T	L	D	T
May	55.89	14.64	70.53	88.98	1.84	90.82	218.73	-	218.73
	±5.03	±2.17	±5.90	±9.31	±0.09	±12.10	±23.85	-	
Jun.	72.50	12.17	84.68	191.43	-	191.43	383.34	-	383.34
	±7.30	±3.01	±6.73	±13.94	-	±20.73	±37.91	-	
Jul.	109.56	55.26	164.83	211.48	83.33	294.83	413.77	-	413.77
	±26.04	±6.70	±18.91	±27.27	±10.93	±36.33	±45.71	-	
Aug.	38.41	17.53	55.94	133.32	44.21	177.52	327.64	29.91	357.55
	±4.08	±3.10	±7.17	±15.79	±9.01	±18.28	±23.08	±2.63	
Sep.	28.53	-	28.53	170.21	-	170.21	93.06	14.71	107.76
	±6.90	-	±2.10	±12.03	-	±19.27	±3.90	±3.01	
Oct.	-	-	-	327.41	-	327.41	115.31	56.62	171.73
	-	-	-	±39.07	-	±41.91	±13.20	±5.04	
Nov.	49.78	-	49.78	53.48	37.29	90.77	405.81	34.52	440.33
	±7.30	-	±12.63	±10.12	±7.90	±15.62	41.96	±5.75	
Dec.	34.98	-	34.98	67.17	11.46	78.63	124.22	27.54	151.76
	±4.03	-	±8.31	±5.05	±2.93	±7.71	±12.45	±3.16	
Jan.	57.48	-	57.48	64.37	-	64.37	97.24	-	97.24
	±5.05	-	±12.39	±8.91	-	±5.04	±19.49	-	
Feb.	33.74	-	33.74	57.79	-	57.79	161.76	18.60	180.36
	±12.01	-	±6.92	±7.57	-	±16.82	±25.40	±3.05	
Mar.	25.57	-	25.57	113.50	-	113.50	111.04	-	111.04
	±9.03	-	±5.01	±13.84	-	±14.94	±16.92	-	
April	22.49	-	22.49	13.62	-	13.62	97.70	-	97.70
	±9.04	-	±3.86	±3.04	-	±5.03	±12.48	-	

L= Live, D = Dead, - = Absent, T = Total, ± = S.E.M.

Table 5.16. Dry mass of rhizome (g m^{-2}; 0-40 cm) in the three pine stands.

	6-year old stand			15-year old stand			23-year old stand		
Months	L	D	T	L	D	T	L	D	T
May	29.32	49.45	78.63	19.04	23.36	42.40	31.49	39.44	70.94
	±4.02	±8.91	±12.09	±6.06	±7.14	±8.29	±7.01	±4.30	
Jun.	140.63	97.02	237.65	34.58	42.77	77.36	69.97	65.21	135.18
	±18.59	±10.65	±26.93	±4.92	±5.03	±11.12	±9.03	±8.03	
Jul.	41.75	84.55	126.31	22.77	30.37	53.14	72.32	75.57	147.89
	±7.01	±13.54	±23.06	±2.59	±7.06	±9.15	±18.02	±9.07	
Aug.	55.27	86.54	141.82	19.87	47.43	67.32	53.15	19.72	72.87
	±12.08	±16.17	±20.83	±7.01	±9.16	±10.03	±6.75	±9.06	
Sep.	60.47	68.54	129.02	25.61	29.25	54.86	58.35	34.39	92.75
	±8.06	±9.15	±16.05	±3.94	±6.61	±8.08	±10.40	±9.50	
Oct.	37.66	27.12	64.77	10.95	21.68	32.63	44.15	30.51	74.66
	±6.70	±4.06	±5.12	±0.97	±4.01	±8.03	±7.38	±7.61	
Nov.	39.63	67.79	107.42	31.93	17.29	49.22	51.87	41.56	93.43
	±5.09	±12.36	±32.19	±7.07	±4.51	±3.15	±5.02	±9.01	
Dec.	29.82	127.34	157.15	23.77	15.04	38.82	33.02	28.82	61.84
	±5.04	±27.74	±21.90	±2.30	±2.09	±7.48	±3.46	±6.05	
Jan.	52.90	67.52	120.42	22.21	24.39	46.61	36.52	47.26	83.78
	±7.01	±9.07	±22.91	±2.92	±5.02	±3.94	±4.06	±3.01	
Feb.	38.42	72.65	111.07	21.46	12.68	34.14	31.28	31.06	62.34
	±5.06	±12.51	±28.43	±3.07	±2.83	±7.47	±8.03	±4.98	
Mar.	47.07	57.83	104.90	36.33	27.63	63.96	47.14	42.90	90.04
	±9.03	± 8.59	±16.94	±4.51	±6.03	±4.01	±9.26	±5.06	
April	37.95	86.74	124.68	23.55	28.66	52.23	26.48	34.52	61.01
	±8.92	±5.94	±12.68	±4.95	±5.90	±9.95	±5.25	±8.09	

L = Live, D = Dead, T = Total, ± = S.E.M.

during rainy season in all the three stands, while the lowest values were recorded during winter in the 15- and 23-year old stands and during autumn in the 6-year old stand (Fig. 5.7). Difference in coarse root biomass between months in the three stands was not significant.

Rhizomes showed peak during rainy season in all the three stands. Its minimum value was recorded during autumn in stand I and II and during winter in stand III (Fig. 5.8).

Total fine root mass (pine roots + herbaceous roots) in the three forest stands is shown in Fig. 5.9. It varied significantly ($P<0.01$) between months and showed maximum value during rainy season and minimum during spring in all the three stands.

The mean fine root mass declined from 338.42 g m^{-2} in the 6-year old stand to 321.22 g m^{-2} in 23-year old stand. In stand I, fine roots contributed about 87% of the total roots while in stand II and III their proportion declined to 68 and 56% respectively.

The contribution of herbaceous fine roots to the total fine root mass declined from 65% in the 6-year old stand to 30-32% in the 15- and 23 year old stands. The CFRM/CRM ratio was much higher in stand I as compared to the other two stands. The contribution of tree fine roots to the total belowground dry mass increased from 32.57% in the 6-year old stand to 42.38% in the 15-year old

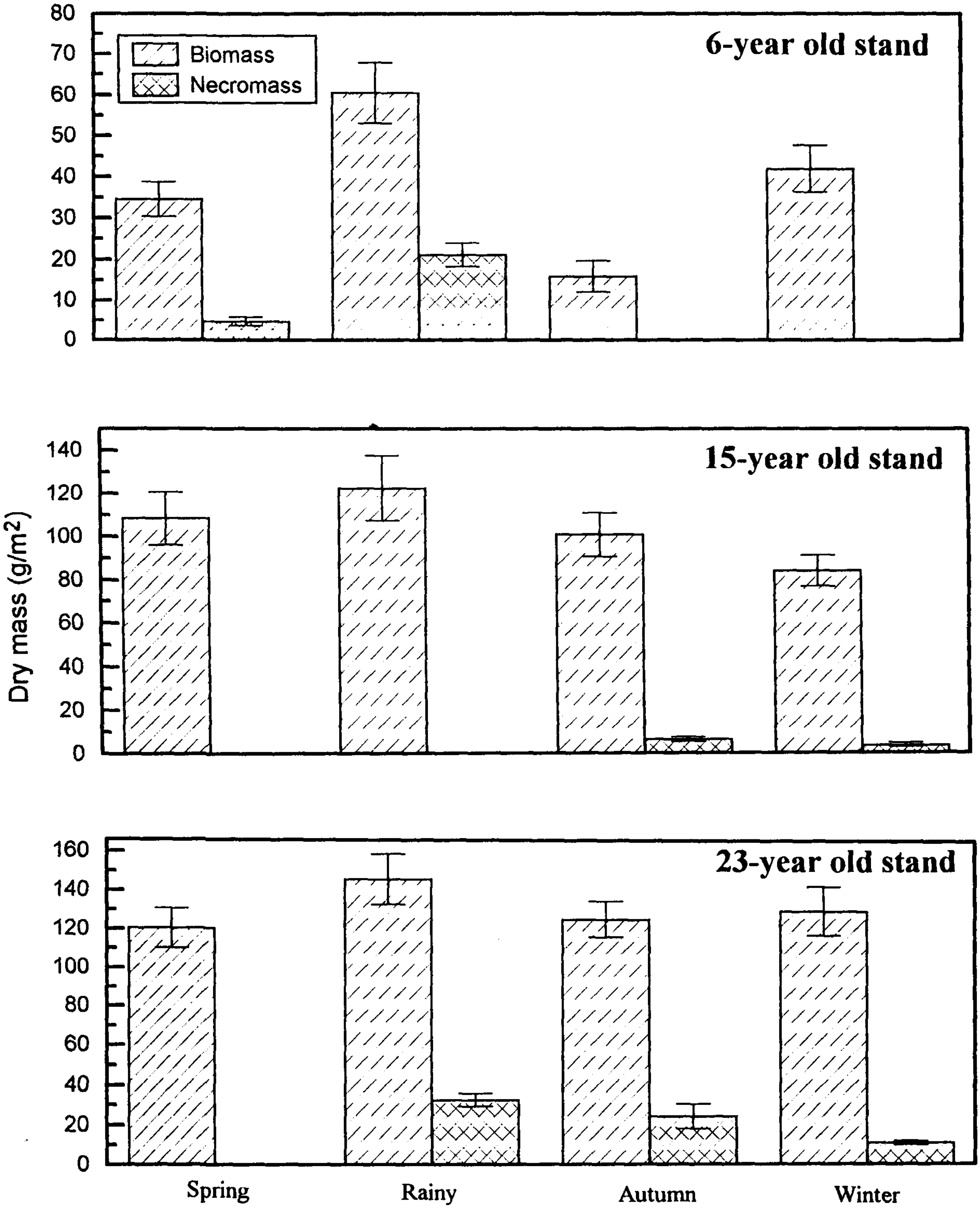

Fig.5.7. Seasonal variation in biomass and necromass of tree coarse roots in the three pine stands. Vertical lines represent SEM.

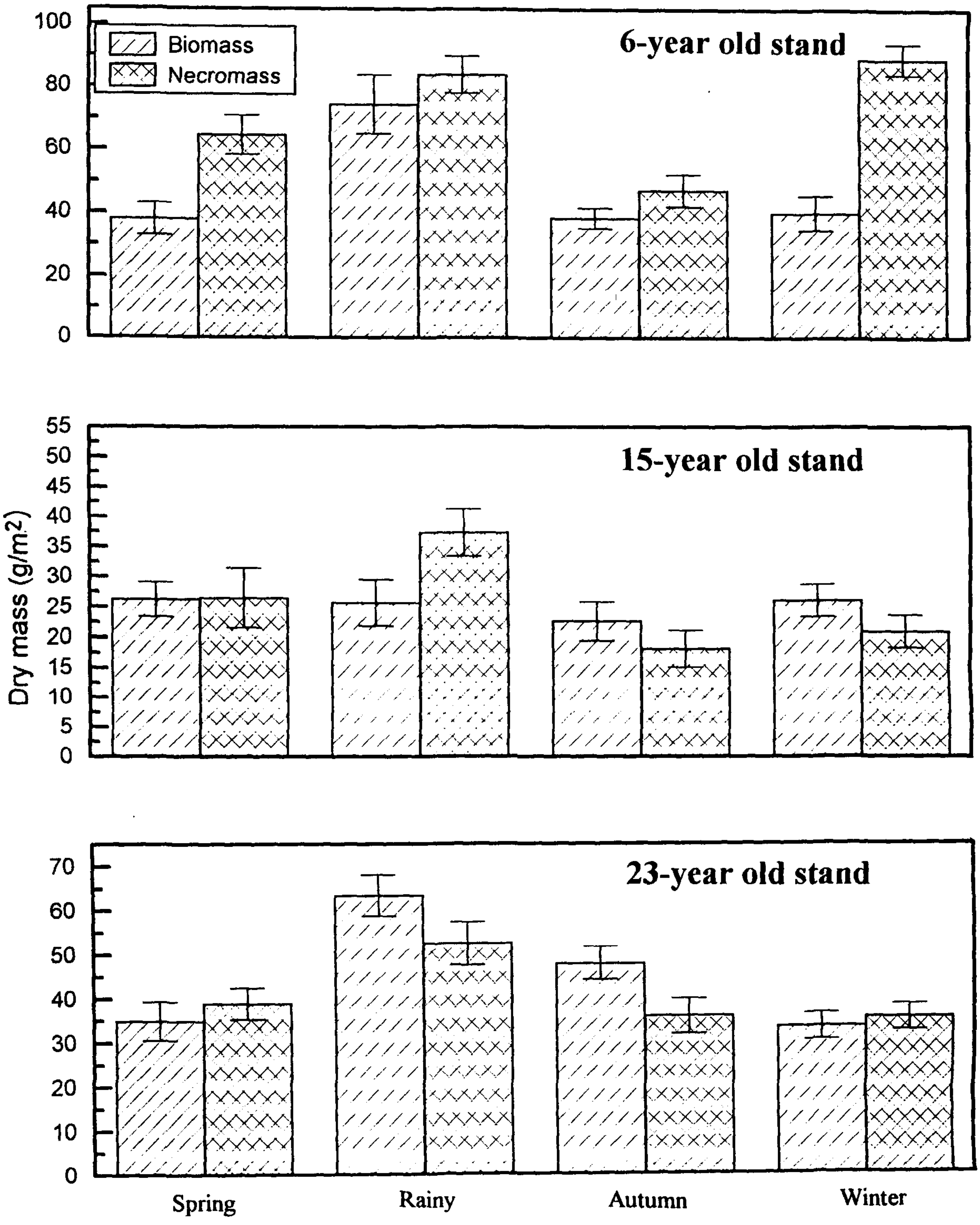

Fig.5.8. Seasonal variation in rhizome biomass and necromass in the three pine stands. Vertical lines represent SEM.

stand and it marginally declined in the 23-year old stand. Coarse root contribution increased significantly with stand age. However, roots of ground vegetation and rhizomes declined with stand age (Table 5.17).

The biomass/necromass ratio was highest (1.03-1.26) during spring and lowest (0.54) during winter in stand I and during rainy season (0.72-1.00) in stands II and III. HFRB/HFRN ratio was 1.39-1.90 during rainy season in stand I and III and 1.36 during autumn in stand II. TFRM/HFR ratio was higher during winter and lower during rainy season in stand II and III and during autumn in stand I (Table 5. 18).

Total root mass (TRM) : The monthly and seasonal variations in TRM (total fine roots + total coarse roots) were similar to CFRM (Fig 5. 9). It varied significantly ($P<0.01$) between months.

ROOT PRODUCTION AND TURNOVER

Monthly as well as depth-wise productivity data of various root fractions are given in Tables 5.19- 5.22. Productivity declined significantly ($P<0.01$) with increasing soil depth. Monthly fine root production of pine did not vary significantly with stand age, while production of herbaceous fine roots declined significantly ($P<0.01$) with increasing stand age. The annual total fine root production (pine + herbs) was maximum (1054.69 g m^{-2}) in the youngest stand and minimum (731.81 g m^{-2}) in the 15-year old stand. Pine contributed 44% to total

Table 5.17. Mean percent contribution of fine and coarse roots and rhizomes to total dry mass in top 40 cm soil layer in the three pine stands.

Category	6-year old stand	15-year old stand	23-year old stand
Tree roots			
Fine roots (<2 mm)	32.57	42.38	32.64
Coarse roots (2-10 mm)	8.85	28.24	33.92
Ground vegetation			
Roots (<2 mm)	37.36	19.02	12.63
Rhizome	21.19	10.36	13.29

Table 5.18. Seasonal variation in relative distribution of dry mass in different fractions of underground parts in the three pine stands.

	Spring (March-May)	Rainy (Jun-Aug.)	Autumn (Oct.-Nov.)	Winter (Dec.-Feb.)
6-year old stand				
TFRB/TFRN	1.03	1.19	0.62	0.54
HFRB/HFRN	0.46	1.39	0.58	0.73
TFRN/HFRM	0.79	0.87	0.76	1.05
CRB/CRN	7.10	2.85	-	-
CFRM/CRM	6.54	7.33	23.82	7.79
15-year old stand				
TFRB/TFRN	1.16	1.00	1.03	1.08
HFRB/HFRN	0.84	1.07	1.36	0.75
TFRM/HFRM	2.21	2.08	2.29	2.49
CRB/CRN	-	-	14.73	22.24
CFRM/CRM	2.09	3.16	2.58	3.24
23-year old stand				
TFRB/TFRN	1.26	0.72	1.13	1.31
HFRB/HFRN	1.09	1.90	1.12	1.40
TFRM/HFRM	2.24	1.70	2.41	2.58
CRB/CRN	-	4.45	5.07	11.50
CFRM/CRM	2.16	2.12	2.06	2.22

TFRB = Tree fine root biomass, TFRN = Tree fine root necromass, HRB = Herbacous fine root biomass, HRN = Herbaceous fine root necromass, CRB = Coarse root biomass, CRN = Coarse root necromass, TFRM = Total tree fine root mass, HRM = Total herbaceous root mass, CRM = Total coarse root mass, CFRM = Composite fine root mass (Tree + herbs)

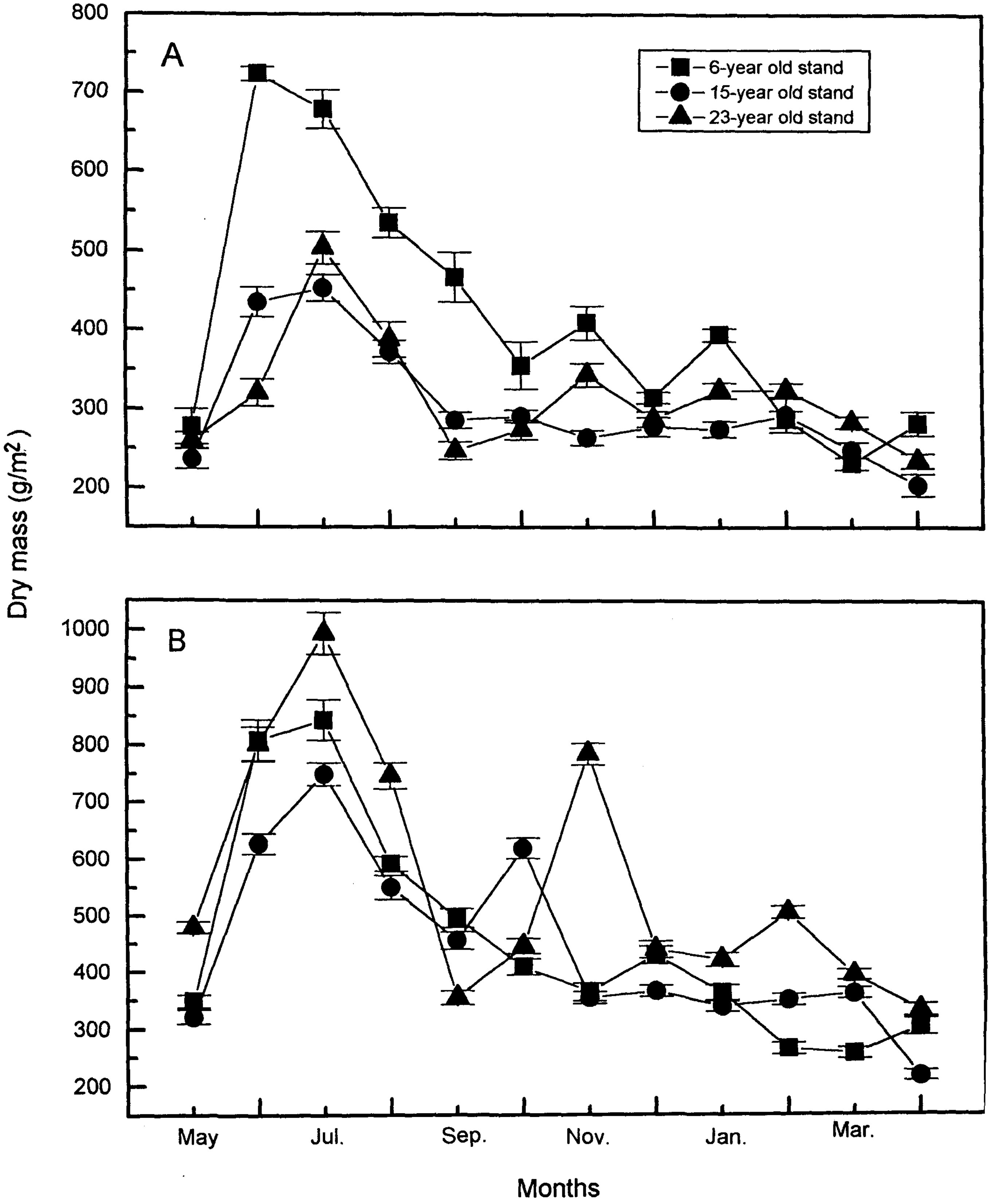

Fig. 5.9. Monthly variation in total (tree + herbs) fine root mass (A) and total (fine + coarse root mass (B) in top 40 cm soil layer of the pine stands of different ages. Vertical lines represnt SEM.

Table 5.19. Monthly production of fine roots of tree and herbaceous vegetation (dry mass g m^{-2}) in 6-year old pine stand.

	Soil depth (cm)				
Months	0-10	10-20	20-30	30-40	Total
Tree roots (<1 mm diameter)					
May	75.69	24.65	24.01	21.24	145.59
Jun.	-	13.08	-	-	13.08
Jul.	-	-	-	-	-
Aug.	8.46	0.13	-	-	8.57
Sep.	-	-	-	-	-
Oct.	25.79	1.12	-	3.94	30.86
Nov.	-	-	3.80	-	3.80
Dec.	22.15	-	6.88	0.25	29.28
Jan.	-	10.25	-	5.42	15.67
Feb.	-	-	-	-	-
Mar.	0.49	7.84	11.25	1.77	21.37
April	10.65	-	-	-	10.65
Tree roots (1-2 mm diameter)					
May	24.03	50.15	-	17.81	91.99
Jun.	-	-	1.03	-	1.03
Jul.	-	-	-	-	-
Aug.	-	-	-	7.01	7.01
Sep.	1.15	16.48	0.72	-	18.34
Oct.	-	-	17.19	-	17.19
Nov.	-	7.17	-	-	7.17
Dec.	12.07	-	-	-	12.07
Jan.	-	4.52	-	-	4.52
Feb.	-	2.15	8.91	-	11.06
Mar.	-	-	-	7.60	7.60
April	5.6	3.4	-	-	9.00
Herbaceous roots (< 2 mm diameter)					
May	132.79	63.33	29.12	20.79	246.04
Jun.	31.94	15.21	8.78	5.76	61.68
Jul.	-	-	-	-	-
Aug.	-	16.36	12.46	4.70	33.53
Sep.	-	7.04	2.86	-	9.90
Oct.	19.43	-	10.25	3.52	33.19
Nov.	24.92	0.06	0.34	-	25.32
Dec.	29.03	21.84	-	0.59	51.45
Jan.	6.38	1.96	3.34	1.27	12.96
Feb.	25.95	-	-	-	25.95
Mar.	-	29.31	16.89	4.52	50.72
April	26.89	10.91	-	-	37.80

- = No production

Table 5.20. Monthly production of fine roots of tree and herbaceous vegetation (dry mass g m^{-2}) in 15-year old pine stand.

	Soil depth (cm)				
Months	0-10	10-20	20-30	30-40	Total
Tree roots (< 1 mm diameter)					
May	23.38	20.85	24.69	24.94	93.88
Jun.	-	-	-	-	-
Jul.	-	2.96	-	-	2.96
Aug.	-	-	2.49	6.38	8.88
Sep.	4.51	-	-	-	4.51
Oct.	7.42	6.82	-	-	14.24
Nov.	-	0.34	3.55	9.94	13.83
Dec.	9.44	9.84	5.49	-	24.78
Jan.	-	0.12	10.46	5.79	16.38
Feb.	-	-	-	3.74	3.74
Mar.	-	-	12.18	-	12.18
April	3.06	1.66	-	3.23	7.95
Tree roots (1-2 mm diameter)					
May	-	1.69	25.72	19.14	46.55
Jun.	-	-	-	-	-
Jul	2.56	20.78	-	6.42	29.76
Aug.	2.52	-	-	0.49	3.02
Sep.	-	3.98	23.71	-	27.69
Oct.	11.55	2.93	-	-	14.48
Nov.	-	-	15.98	16.13	32.11
Dec.	-	16.79	-	-	16.79
Jan..	-	-	24.05	5.54	29.59
Feb.	12.81	9.03	-	3.49	25.32
Mar.	-	-	14.76	-	14.76
April	16.29	3.36	-	-	19.65
Herbaceous roots (<2 mm diameter)					
May	31.67	19.85	19.41	5.04	75.98
Jun.	15.86	33.74	2.18	7.19	58.98
Jul.	0.46	0.13	1.58	0.004	2.19
Aug.	12.43	-	-	-	12.43
Sep.	20.87	-	1.95	1.92	24.74
Oct.	13.43	-	1.08	2.16	16.68
Nov.	-	4.71	1.65	4.14	10.50
Dec.	9.09	2.64	-	-	11.74
Jan.	-	9.98	6.07	2.31	18.26
Feb.	10.43	2.27	5.48	6.92	25.11
Mar.	-	-	-	-	-
April	11.88	0.27	-	-	12.15

- = No production

Table 5.21 Monthly production of fine roots of tree and herbaceous vegetation (dry mass g m^{-2}) in 15- year old pine stand.

	Soil depth (cm)				
Months	0-10	10-20	20-30	30-40	Total
Tree roots (< 1 mm diameter)					
May	2.18	-	-	0.18	2.36
Jun.	44.95	47.60	-	0.78	93.34
Jul.	-	4.65	2.34	8.48	15.46
Aug.	-	-	-	-	-
Sep.	14.52	-	-	1.62	16.14
Oct.	3.30	15.95	16.61	7.10	42.96
Nov.	-	-	-	-	-
Dec.	3.74	-	22.15	8.72	34.61
Jan.	-	30.72	-	8.91	39.63
Feb.	-	-	-	-	-
Mar.	-	-	-	-	-
April	-	-	-	-	-
Tree roots (1-2 mm diameter)					
May	-	6.07	-	8.61	14.69
Jun.	44.70	15.58	25.65	-	85.94
Jul.	-	-	-	3.95	3.95
Aug.	-	-	-	-	-
Sep.	9.25	8.47	7.88	3.52	29.13
Oct.	8.16	8.56	10.09	-	26.82
Nov.	-	-	1.22	-	1.22
Dec.	18.19	1.22	-	2.31	21.72
Jan.	-	1.03	-	-	1.03
Feb.	1.99	2.68	17.04	-	21.72
Mar.	-	-	-	-	-
April	5.00	5.50	-	-	10.50
Herbaceous roots (<2 mm diameter)					
May	11.03	70.66	12.77	39.91	134.37
Jun.	28.37	2.05	1.18	0.77	32.39
Jul.	0.99	-	3.42	1.22	5.63
Aug.	2.49	4.54	2.89	1.18	11.12
Sep.	4.61	0.34	0.74	0.03	5.73
Oct.	4.42	5.42	10.37	1.55	21.77
Nov.	5.17	1.62	0.87	-	7.66
Dec.	5.60	10.37	3.83	0.96	20.78
Jan.	1.53	5.85	4.48	-	11.87
Feb.	-	16.57	15.14	7.01	38.73
Mar.	-	2.55	-	6.23	8.78
April	2.43	4.63	15.98	-	23.10

- = No production

Table 5.22. Monthly coarse root production (dry mass g m^{-2}; 0-40 cm) in three pine stands.

Months	6-year old stand	15-year old stand	23-year old stand
May	16.62	102.45	261.61
Jun.	80.16	32.41	-
Jul.	-	-	-
Aug.	-	36.89	-
Sep.	-	157.20	22.25
Oct.	49.78	-	290.50
Nov.	-	13.69	-
Dec.	22.50	-	-
Jan.	-	-	77.36
Feb.	-	55.71	-
Mar.	-	-	-
April	-	-	-
Total	169.06	398.35	651.72

- = No Production

fine root production in stand I, but in stand II and III its contribution was 63% and 58% respectively. Annual production of coarse roots increased significantly ($P<0.01$) with increasing stand age (Table 5.22). The contribution of coarse roots to the total root production was 14, 35 and 45% in stand I, II and III, respectively. The total root production declined from 1223.75 g $m^{-1}yr^{-1}$ in the 7-year old stand to 1130.16 g $m^{-1}yr^{-1}$ in 15-year old stand. However, it was significantly ($P<0.05$) higher (1434.87 g m^{-1} $yr^{-1)}$ in the 23-year old stand. The difference between stand I and II was not significant. The contribution of different root fractions to the total root production varied greatly.

The turnover rate of tree fine roots, herbaceous fine roots and coarse roots are given in Table 5.23. The turnover rate of both tree fine roots and coarse roots declined with increase in stand age, whereas a reverse trend was observed in case of herbaceous fine roots.

DISCUSSION

Studies on the vertical distribution of fine roots show that majority of them are concentrated in the top 20 cm soil layer (Hermann 1977, Kummerow *et al.* 1982, Persson 1983, Arunachalam *et al.* 1996a). In the present study, the youngest stand ca. 51% of tree fine roots was obtained in the top 10 cm soil layer, whereas in the 15- and 23-year old stands, the relative proportion declined to 32-33%. In stand I, the proportion of fine roots declined sharply to about 27% in the

Table 5.23. Turnover rate(yr^{-1}) of tree fine and coarse roots and herbaceous fine roots in the three pine stands.

Category	6-year old stand	15-year old stand	23-year old stand
Tree fine roots	0.79	0.69	0.68
Tree coarse roots	0.76	0.74	0.71
Herbaceous fine roots	0.73	0.74	0.76

subsurface layer (10-20 cm) as compared to the older stands where the value ranged between 29% and 35%. With increasing age of the tree more fine roots were produced and distributed in the subsurface soil layer. Persson (1983) in Scot pine and Srivastava *et al.* (1986) in teak plantations have also reported a similar production pattern.

The bulk of herbaceous fine roots and rhizomes was present in the top 10 cm soil layer in all the three forest stands. Meyer and Gottsche (1971) ascribed the decrease in root biomass in lower soil layers to the deterioration in nutrient status and biological condition. Ford and Deans (1977) have attributed greater fine root concentration in the surface soil layer to high nutrient concentration and more moisture retention in the surface soil layer. In the present study ca. 67-82% total fine root mass (pine + herbs) was confined to the top 20 cm soil layer confirming the findings of earlier workers such as Safford and Bell (1972) who reported 87% of the fine roots in the top 15 cm of soil of a 39-year old spruce plantation and Harris *et al.* (1977) estimated up to 71% of *Pinus taeda* fine roots in the top 20 cm soil profile. Vogt *et al.* (1980) have reported similar distribution pattern in *Abies amabilis* stands where >80% of fine roots was present in the upper 15 cm soil profile. Klinge (1973), Klinge and Herrera (1978) and Stark and Spratt (1977) have also shown that majority of roots are distributed in the top soil layer in the tropical forests. Comparatively higher (82%) fine roots in the upper 20 cm soil profile in the youngest stand under investigation was the result of higher density of young trees and of herbaceous species especially grasses in the stand. The coarse root whose main function is to provide mechanical support to tree (Stone and Kalisz 1991) were concentrated in the 10-30 cm soil layer in all the three pine stands.

The root biomass in forest is always in a state of flux with death and replacement taking place simultaneously (Persson 1983); its rate however, varies monthly, seasonally and annually. In the present study, a wide monthly fluctuation in root biomass was observed throughout the year. When monthly data were pooled on seasonal basis there emerged a seasonal pattern with a high mean biomass during the rainy season and low value during the spring season in all the three forest stands. High tree root biomass occurred during rainy season when shoot growth was at its peak on account of relatively higher temperature and better availability of water and nutrients in the soil. Seasonal trend in tree coarse root biomass was similar to tree fine roots. A marked seasonality in root biomass of the ground vegetation observed in all stands was related to their seasonal growth pattern. Rainy season being the period of active vegetative growth of herbaceous species, showed maximum biomass, while the minimum value was recorded during spring which marks the regrowth of ground vegetation after a dormant phase during severe winter, which caused the death of majority of annual species.

Parthasarathy (1988), Vishalaksi (1994), Sundarapandian and Swamy (1996) from deciduous and evergreen forests of south India and Khiewtam and Ramakrishnan (1993) from subtropical humid forest of north-east India have also reported a similar seasonal trend in root mass. The seasonal periodicity of roots is known both from the temperate and tropical forest ecosystems of the world (Harris *et al.* 1977, Srivastava *et al.* 1986, Sundrapandian and Swamy 1996, Arunachalam *et al.* 1996a). This has been attributed to several factors such as changes brought about in soil moisture, soil temperature, root production and root decomposition (Hook *et al.* 1984).

Decline in mean annual fine root biomass from 338.42 g m^{-2} in the 6-year old stand to 321.22 g m^{-2} in the 23-year old stand was mainly related to the high density of young trees as well as herbaceous vegetation in the youngest stand. Conversion of tree fine roots into coarse roots during ageing of the stand was responsible for greater coarse root biomass in the older stands. Vishalakshi (1994) has also suggested that plant density and basal cover could influence root mass. A sharp decline in the contribution of ground vegetation to the mean fine root mass from 6-year old stand to 23-year old stand was due to decrease in the density of herbs.

Decline in fine root production with soil depth observed in the present study is in agreement with the findings of Hendrick and Pregitzer (1966). Greater production of fine roots in the top soil layer obtained by Ford and Deans (1977), Srivastava *et al.* (1986), Khiewtam and Ramakrishnan (1993), Arunachalam *et al* (1996a) in different forest ecosystems have been attributed to favourable soil condition for root growth. The declining trend of herbaceous fine root production with stand age could be due to the reduction in plant density.

It has been suggested that a large flux of belowground organic matter takes place through the fine roots. Fine root production which accounted for 55-86% of the total root production in three forest stands was higher than the values reported by Arunachalam *et al.* (1996a) from 7- to 16-year old regrowth of subtropical humid forest in the same area. These values are also higher than those reported by Harris *et al.* (1977) and Persson (1978) from temperate deciduous forest and Scot pine stands respectively. In the present investigation fine root production was maximum in the 6-year old stand. Relatively high proportion of fine root production in the youngest stand may be attributed to the high density of young trees and dominance of perennial grasses. The total root production was maximum in the 23-year old stand. This was mainly due to the greater contribution of coarse roots to the total root production in the oldest stand. With age, more fine roots were converted into coarse roots to provide better structural support to the plant as well as to tap water and mineral nutrients from deeper soil layer. This explains the increase in coarse root production in the older stands.

Literature available on fine root production shows wide variation with respect to species the world over. The fine root production value obtained in the present investigation is in agreement with McClaugherty *et al.* (1982) from a Red pine forest (Massachusetts, U.S.A). Vitousek and Sanford (1986) and Cuves and Medina (1988) reported a higher fine root production from Terra firme forest of Venezuela. However, lower values have been recorded from majority of the pine stands (Persson 1983, Nadelhoffer *et al.* 1985, Aber *et al.* 1985).

The turnover rates obtained in the present investigation are comparable to the values reported by Aerts *et al.* (1992) from a wet heathland ecosystem and by Arunachalam (1996) from a subtropical forest ecosystem. However, the above values are found to be lower than the values obtained by Srivastava *et al.* (1986) from a teak plantation.

The high proportion of fine roots in the top layer of soil profile might help *Pinus kesiya* in successfully colonising the abandoned jhum fallows and degraded sites having a relatively thin and highly leached nutrient-poor soils of this region.

CHAPTER VI

ROLE OF FINE AND COARSE ROOTS IN NITROGEN AND PHOSPHORUS DYNAMICS

INTRODUCTION

Fine roots play an important role in the overall nutrient dynamics of the forest ecosystem by making significant contribution to the soil organic matter and inorganic nutrient stocks. Studies indicate that in many forest ecosystems annual fine root litter production reaches very close to the foliar litter production (Harris *et al.* 1977, Persson 1980 and McClaugherty *et al.* 1982). Decomposition studies in the forest ecosystems have been carried out mostly on leaf and needle litter (Swift *et al.* 1979), while relatively less work has been done on root litter decomposition. Root decomposition and mineralization patterns may differ from the aboveground litter because of the differences in resource quality of the two types of litter and microlevel changes in soil condition under which they undergo decomposition, since root litter is decomposed in the soil profile while leaf litter is decomposed on the soil-air interface.

The rates of litter decomposition and nutrient mineralization are influenced by a large number of factors such as climate, soil moisture content, activities of soil microbes, soil fauna etc. (Singh and Gupta 1977, Meentemeyer 1978). Resource quality or chemical composition of the decomposing material also determine the rate of decay (Hermann *et al.* 1977, Singh and Gupta 1977, Meentemeyer 1978, Christernsen 1986). Nitrogen content of litter has been reported to have an important effect on the rate of decomposition (Petersson and Rafe 1982). Meentemeyer (1978) and Melillo *et al.* (1982), however, have reported that the lignin content in the litter exerts stronger influence than nitrogen on the rate of decomposition by interfering with the enzymatic degradation of cellulose and other carbohydrates and proteins (Alexander 1977). Initial C/N ratio and lignin/N ratio are determining factors in root decomposition (Melillo *et al.* 1982). Vallis and Jones (1973) reported that polyphenolic content also affects N release pattern.The rate of decomposition of the foliage and roots differs considerably due to high lignin content (Vogt *et al* . 1991) and high concentration of trace elements (Dahlgren *et al.* 1991) in the latter. Meier *et al.* (1985) reported that fine roots have higher concentration of nutrients than the foliage. Presence of mycorrhizal fungi on fine roots may change their chemistry and offer resistance to decay (Harley and Smith 1983, Kabata-Pendias and Pendias 1984).The chemical composition of roots varies with diameter, both within the species as well as between the species (Berg 1984).

Roots contribute to the soil carbon pool through biomass input, exudation (Smith 1976) and production of volatile compounds (Rovira *et al.* 1979). Generally, fine roots contribute more to the soil organic matter content than litter because of their higher annual input and faster decay rate (Vogt *et al.* 1991). Thus, root production and turnover are important processes in the overall cycling of nutrients in the forest ecosystems (Caldwell 1979, Vogt *et al.* 1983, Aber *et al.* 1985).

In this chapter, data on N and P concentration and their accumulation in tree fine roots and coarse roots and herbaceous fine roots and rhizomes have been presented. Decomposition pattern and N and P mineralization and turnover rates have also been discussed in order to understand the role of fine roots in N and P dynamics in the three pine stands under investigation.

RESULTS

N and P Concentration in fine and coarse roots

N Concentration

Data on monthly variation in N concentration of tree fine and coarse roots and herbaceous roots and rhizomes are given in Tables 6.1 to 6.3. N concentration in tree fine roots varied significantly ($P < 0.01$) between months in all the stands. However, differences between the stands were not significant. The live fraction had significantly higher ($P < 0.01$) concentration than the dead roots. The mean concentration of N declined from 0.59% in the live roots to 0.52% in the dead roots.

N concentration in coarse roots also varied widely between months. Mean N concentration in coarse roots (0.23%) was much lower than the fine roots

Table 6.1. Monthly variation in N concentration (%) in tree roots and belowground parts of the ground vegetation in the 6-year old pine stand.

Months	Tree roots				Ground vegetation			
	Fine *		Coarse **		Roots		Rhizome	
	BM	NM	BM	NM	BM	NM	BM	NM
May	0.533	0.500	0.258	-	0.563	0.554	0.400	0.358
	±0.008	±0.000	±0.008	-	±0.001	±0.008	±0.008	±0.000
Jun.	0.575	0.542	0.216	-	0.558	0.500	0.466	0.425
	±0.004	±0.008	±0.003	-	±0.014	±0.000	±0.001	±0.008
Jul.	0.666	0.625	0.358	-	0.542	0.525	0.442	0.392
	±0.008	±0.004	±0.000	-	±0.008	±0.001	±0.008	±0.008
Aug.	0.675	0.658	0.175	-	0.533	0.416	0.33	0.283
	±0.008	±0.000	±0.000	-	±0.008	±0.000	±0.001	±0.001
Sep.	0.600	0.550	0.175	-	0.592	0.508	0.292	0.242
	±0.008	±0.000	±0.000	-	±0.008	±0.000	±0.001	±0.001
Oct.	0.500	0.475	0.175	-	0.508	0.408	0.300	0.208
	±0.003	±0.008	±0.003	-	±0.008	±0.001	±0.001	±0.008
Nov.	0.550	0.475	0.200	-	0.525	0.436	0.300	0.250
	±0.008	±0.005	±0.006	-	±0.000	±0.001	±0.004	±0.008
Dec.	0.592	0.533	0.192	-	0.442	0.383	0.225	0.183
	±0.000	±0.008	±0.000	-	±0.008	±0.008	±0.001	±0.001
Jan.	0.508	0.492	0.283	-	0.566	0.550	0.350	0.300
	±0.007	±0.000	±0.008	-	±0.000	±0.001	±0.008	±0.014
Feb.	0.575	0.492	0.233	-	0.508	0.475	0.450	0.433
	±0.003	±0.008	±0.008	-	±0.001	±0.014	±0.008	±0.008
Mar.	0.558	0.542	0.266	-	0.542	0.426	0.358	0.308
	±0.000	±0.005	±0.008	-	±0.008	±0.008	±0.014	±0.006
April	0.516	0.475	0.300	-	0.583	0.558	0.325	0.316
	±0.004	±0.008	±0.014	-	±0.008	±0.008	±0.014	±0.001

* = < 2 mm in diameter, ** = 2-10 mm in diameter, BM = Biomass, NM = Necromass,
- = Absent, ± S.E.M.

Table 6.2. Monthly variation in N concentration (%) in tree roots and belowground parts of the ground vegetation in the 15-year old pine stand.

Months	Tree roots				Ground vegetation			
	Fine *		Coarse **		Roots		Rhizome	
	BM	NM	BM	NM	BM	NM	BM	NM
May	0.575	0.525	0.216	-	0.566	0.500	0.425	0.400
	±0.014	±0.008	±0.008	-	±0.00	±0.008	±0.014	±0.00
Jun.	0.600	0.566	0.192	-	0.500	0.458	0.358	0.300
	±0.008	±0.008	±0.008	-	±0.008	±0.014	±0.008	±0.015
Jul.	0.650	0.583	0.275	-	0.608	0.483	0.325	0.300
	±0.014	±0.008	±0.000	-	±0.014	±0.008	±0.008	±0.008
Aug.	0.566	0.550	0.200	-	0.533	0.492	0.308	0.283
	±0.008	±0.014	±0.008	-	±0.008	±0.008	±0.014	±0.008
Sep.	0.575	0.525	0.208	-	0.592	0.500	0.350	0.266
	±0.008	±0.000	±0.014	-	±0.008	±0.014	±0.014	±0.014
Oct.	0.625	0.575	0.292	-	0.608	0.575	0.442	0.375
	±0.014	±0.008	±0.008	-	±0.008	±0.008	±0.000	±0.000
Nov.	0.542	0.466	0.175	-	0.383	0.350	0.308	0.242
	±0.008	±0.008	±0.000	-	±0.000	±0.000	±0.008	±0.014
Dec.	0.508	0.483	0.216	-	0.350	0.316	0.225	0.208
	±0.008	±0.008	±0.014	-	±0.014	±0.004	±0.014	±0.014
Jan.	0.591	0.491	0.208	-	0.516	0.492	0.392	0.350
	±0.014	±0.008	±0.008	-	±0.008	±0.008	±0.000	±0.000
Feb.	0.608	0.475	0.233	-	0.525	0.425	0.442	0.383
	±0.008	±0.000	±0.008	-	±0.008	±0.014	±0.008	±0.008
Mar.	0.642	0.492	0.283	-	0.566	0.550	0.283	0.250
	±0.008	±0.008	±0.014	-	±0.008	±0.008	±0.008	±0.014
April	0.633	0.475	0.275	-	0.533	0.492	0.475	0.425
	±0.014	±0.008	±0.008	-	±0.000	±0.014	±0.008	±0.008

* = < 2 mm in diameter, ** = 2-10 mm in diameter, BM = Biomass, NM = Necromass,
- = Absent, ± S.E.M.

Table 6.3. Monthly variation in N concentration (%) in tree roots and belowground parts of the ground vegetation in the 23-year old pine stand.

	Tree roots				Ground vegetation			
Months	Fine *		Coarse **		Roots		Rhizome	
	BM	NM	BM	NM	BM	NM	BM	NM
May	0.550	0.525	0.243	-	0.566	0.633	0.425	0.325
	±0.014	±0.000	±0.008	-	±0.014	±0.008	±0.014	±0.000
Jun.	0.583	0.575	0.225	-	0.533	0.491	0.375	0.333
	±0.008	±0.008	±0.000	-	±0.014	±0.014	±0.008	±0.014
Jul	0.583	0.550	0.300	-	0642	0.600	0.400	0.333
	±0.014	±0.008	±0.014	-	±0.008	±0.000	±0.014	±0.008
Aug.	0.600	0.542	0.150	-	0.608	0.500	0.308	0.250
	±0.008	±0.014	±0.008	-	±0.014	±0.008	±0.008	±0.008
Sep.	0.600	0.542	0.175	-	0.600	0.500	0.275	0.216
	±0.014	±0.014	±0.014	-	±0.000	±0.014	±0.014	±0.014
Oct.	0.608	0.533	0.266	-	0.616	0.425	0.433	0.358
	±0.008	±0.008	±0.008	-	±0.014	±0.008	±0.008	±0.014
Nov.	0.500	0.458	0.158	-	0.392	0.375	0.275	0.250
	±0.000	±0.000	±0.014	-	±0.008	±0.008	±0.008	±0.014
Dec.	0.508	0.466	0.200	-	0.400	0.366	0.208	0.200
	±0.000	±0.008	±0.008	-	±0.008	±0.008	±0.014	±0.008
Jan.	0.575	0.500	0.200	-	0.642	0.592	0.466	0.425
	±0.014	±0.014	±0.014	-	±0.014	±0.014	±0.008	±0.014
Feb.	0.583	0.525	0.192	-	0.588	0.442	0.466	0.308
	±0.000	±0.014	±0.008	-	±0.008	±0.008	±0.008	±0.008
Mar.	0.492	0.425	0.183	-	0.550	0.500	0.433	0.316
	±0.000	±0.000	±0.000	-	±0.014	±0.014	±0.014	±0.014
April	0.642	0.616	0.300	-	0.550	0.533	0.375	0.325
	±0.014	±0.008	±0.008	-	±0.014	±0.008	±0.014	±0.008

* = < 2 mm in diameter, ** = 2-10 mm in diameter, BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M.

(0.59%) (Table 6.7). In none of the three stands, N concentration in both fine as well as coarse roots, showed any definite seasonal trend.

N concentration in herbaceous fine roots and rhizomes also varied significantly ($P<0.05$) between months. In both fine roots and rhizomes, biomass had significantly ($P<0.05$) higher concentration than the necromass. Average N concentration in roots was (0.51%) higher than the rhizomes (0.33%). However, herbaceous roots had lower N concentration than the tree fine roots.

P Concentration

Monthly values of P are given in Tables 6.4 to 6.6. The overall pattern was similar to N. Fine roots had significantly ($P<0.05$) higher concentration than the coarse roots. The average P concentration (0.13%) in fine roots was higher than the coarse roots (0.085%). It varied significantly ($P<0.01$) between months in all stands. Average P concentration in the biomass (0.13%) and necromass (0.12%) was almost the same.

P concentration in herbaceous fine roots and rhizomes varied significantly ($P<0.05$) between months and mean concentration (0.14%) in biomass was higher than the necromass (0.12%) in all stands (Table 6.7). P concentration in biomass and necromass did not show any definite seasonal trend.

N and P accumulation in fine and coarse roots

N Stock

Figs 6.1 to 6.4 show monthly variation in N accumulation (Kg ha^{-1}) in fine

Table 6.4. Monthly variation in P concentration (%) in tree roots and belowground parts of the ground vegetation in the 6-year old pine stand.

Months	Tree roots				Ground vegetation			
	Fine*		Coarse**		Roots		Rhizome	
	BM	NM	BM	NM	BM	NM	BM	NM
May	0.142	0.125	0.071	-	0.134	0.121	0.128	0.117
	±0.005	±0.002	±0.003	-	±0.002	±0.001	±0.001	0.0003
Jun.	0.126	0.123	0.060	-	0.111	0.110	0.139	0.119
	±0.003	±0.002	±0.001	-	±0.002	±0.002	±0.002	0.0005
Jul.	0.111	0.103	0.065	-	0.120	0.107	0.110	0.105
	±0.001	±0.002	±0.001	-	±0.002	±0.002	±0.001	0.0003
Aug.	0.128	0.126	0.062	-	0.127	0.112	0.140	0.106
	±0.000	±0.001	±0.002	-	±0.002	±0.002	±0.000	0.0005
Sep.	0.132	0.124	0.074	-	0.125	0.112	0.139	0.105
	±0.002	±0.000	±0.001	-	±0.001	±0.000	±0.001	0.0008
Oct.	0.118	0.110	0.063	-	0.118	0.112	0.143	0.115
	±0.003	±0.002	±0.004	-	±0.001	±0.002	±0.001	0.0008
Nov.	0.143	0.115	0.067	-	0.143	0.123	0.140	0.105
	±0.002	±0.003	±0.003	-	±0.002	±0.000	±0.001	0.0006
Dec.	0.142	0.128	0.065	-	0.105	0.116	0.141	0.120
	±0.002	±0.001	±0.003	-	±0.002	±0.003	±0.000	0.0008
Jan.	0.121	0.116	0.085	-	0.122	0.114	0.111	0.111
	±0.002	±0.001	±0.000	-	±0.001	±0.002	±0.002	0.0006
Feb.	0.112	0.107	0.045	-	0.142	0.128	0.184	0.124
	±0.003	±0.005	±0.002	-	±0.002	±0.001	±0.002	0.0008
Mar.	0.138	0.128	0.078	-	0.150	0.131	0.110	0.078
	±0.001	±0.001	±0.001	-	±0.001	±0.002	±0.001	0.0006
April	0.151	0.124	0.074	-	0.142	0.101	0.123	0.109
	±0.001	±0.002	±0.002		±0.001	±0.002	±0.003	0.0006

* = < 2 mm in diameter, ** = 2-10 mm in diameter, BM = Biomass, NM = Necromass,
- = Absent, ± =S.E.M. (n= 3)

Table 6.5. Monthly variation in P concentration (%) in tree roots and belowground parts of the ground vegetation in the 15-year old pine stand.

Months	Tree roots				Ground vegetation			
	Fine *		Coarse **		Roots		Rhizome	
	BM	NM	BM	NM	BM	NM	BM	NM
May	0.124	0.119	0.069	-	0.124	0.119	0.148	0.119
	±0.001	±0.0003	±0.0003	-	±0.0003	±0.0006	0.0003	±0.0006
Jun.	0.126	0.113	0.065	-	0.120	0.116	0.131	0.114
	±0.0003	±0.0003	±0.0003	-	±0.0003	±0.0003	±0.0006	±0.0008
Jul.	0.125	0.131	0.059	-	0.111	0.100	0.141	0.118
	±0.0006	±0.0008	±0.0005	-	±0 0008	±0.0003	±0.0003	±0.0006
Aug.	0.120	0.114	0.058	-	).135	0.127	0.129	0.121
	±0.0003	±0.0006	±0.0005	-	±0.0003	±0.0005	±0.0008	±0.0003
Sep.	0.139	0.125	0.059	-	0.127	0.120	0.160	0.133
	±0.0003	±0.0003	±0.0006	-	±0.0003	±0.0006	±0.0008	±0.0003
Oct.	0.123	0.118	0.059	-	0.114	0.110	0.142	0.119
	±0.0003	±0.0005	±0.0008	-	±0.0003	±0.0003	±0.0006	±0.0008
Nov.	0.125	0.112	0.065	-	0.136	0.129	0.160	0.113
	±0.0005	±0.0006	±0.0003	-	±0.0006	±0.0006	±0.0003	±0.0008
Dec.	0.131	0.120	0.064	-	0.119	0.110	0.142	0.118
	±0.0005	±0.0006	±0.0003	-	±0.0003	±0.0003	±0.0003	±0.0003
Jan.	0.147	0.121	0.048	-	0.162	0.132	0.120	0.107
	±0.0003	±0.0008	±0.0006	-	±0.0008	±0.0003	±0.0006	±0.0005
Feb.	0.124	0.120	0.073	-	0.122	0.114	0.127	0.120
	±0.0003	±0.0008	±0.0006	-	±0.0003	±0.0005	±0.0008	±0.0003
Mar.	0.149	0.176	0.072	-	0.070	0.158	0.198	0.104
	±0.0008	±0.0003	±0.0006	-	±0.0003	±0.0008	±0.0006	±0.0005
April	0.147	0.161	0.048	-	0.134	0.125	0.158	0.124
	±0.0003	±0.005	±0.0003	-	±0.0005	±0.0003	±0.0006	±0.0003

* = < 2 mm in diameter, ** = 2-10 mm in diameter, BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M.

Table 6.6. Monthly variation in P concentration (%) in tree roots and belowground parts of the ground vegetation in the 23-year old pine stand.

	Tree roots				Ground vegetation			
Months	Fine *		Coarse **		Roots		Rhizome	
	BM	NM	BM	NM	BM	NM	BM	NM
May	0.142	0.121	0.084	-	0.129	0.121	0.147	0.128
	±0.0003	±0.0005	±0.0006	-	±0.0003	±0.0005	±0.0006	±0.0008
Jun.	0.132	0.119	0.076	-	0.136	0.120	0.142	0.117
	±0.0003	±0.0005	±0.0003	-	±0.0008	±0.0003	±0.0005	±0.0008
Jul.	0.137	0.128	0.069	-	0.139	0.125	0.146	0.120
	±0.0003	±0.0006	±0.0008	-	±0.0003	±0.0003	±0.0005	±0.0008
Aug.	0.134	0.120	0.069	-	0.137	0.120	0.141	0.069
	±0.0005	±0.0003	±0.0005	-	±0.0006	±0.0008	±0.0006	±0.0003
Sep.	0.133	0.126	0.064	-	0.143	0.126	0.152	0.122
	±0.0003	±0.0003	±0.0005	-	±0.0005	±0.0005	±0.0003	±0.0003
Oct.	0.129	0.142	0.060	-	0.140	0.124	0.153	0.125
	±0.0003	±0.0005	±0.0008	-	±0.0003	±0.0006	±0.0003	±0.0003
Nov.	0.109	0.129	0.056	-	0.132	0.121	0.151	0.129
	±0.0003	±0.0005	±0.0006	-	±0.0003	±0.0008	±0.0006	±0.0003
Dec.	0.125	0.116	0.050	-	0.128	0.116	0.137	0.123
	±0.0003	±0.0005	±0.0008	-	±0.0006	±0.0003	±0.0006	±0.0008
Jan.	0.158	0.127	0.076	-	0.118	0.113	0.149	0.129
	±0.0003	±0.0003	±0.0005	-	±0.0003	±0.0008	±0.0006	±0.0006
Feb.	0.141	0.132	0.068	-	0.131	0.124	0.140	0.138
	±0.0003	±0.0006	±0.0006	-	±0.0005	±0.0006	±0.0003	±0.0008
Mar.	0.158	0.142	0.076	-	0.132	0.122	0.190	0.114
	±0.0006	±0.0005	±0.0003	-	±0.0003	±0.0008	±0.0008	±0.0003
April	0.120	0.119	0.097	-	0.127	0.119	0.158	0.124
	±0.0008	±0.0005	±0.0006	-	±0.0008	±0.0003	±0.0003	±0.0005

* = < 2 mm in diameter, ** = 2-10 mm in diameter, BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M.

Table 6.7.Mean N and P concentrations (n=12) in the belowground components of vegetation in the three pine stands.

	6-year old stand		15-year old stand		23-year old stand	
	BM	NM	BM	NM	BM	NM
N concentration						
			Tree roots			
Fine	0.57	0.52	0.59	0.52	0.57	0.52
	±0.02	±0.02	±0.03	±0.03	±0.03	±0.02
Coarse	0.24	-	0.23	-	0.22	-
	±0.02	-	±0.03	-	±0.02	-
			Ground vegetation			
Roots	0.54	0.48	0.52	0.47	0.55	0.49
	±0.02	±0.03	±0.03	±0.02	±0.02	±0.02
Rhizome	0.35	0.31	0.36	0.31	0.37	0.30
	±0.02	±0.02	±0.03	±0.02	±0.03	±0.04
P concentration						
			Tree roots			
Fine	0.13	0.12	0.13	0.12	0.13	0.12
	±0.03	±0.02	±0.01	±0.01	±0.03	±0.02
Coarse	0.06	-	0.061	-	0.12	-
	±0.03	-	±0.02	-	±0.02	-
			Ground vegetation			
Roots	0.12	0.12	0.13	0.12	0.13	0.12
	±0.03	±0.03	±0.02	±0.02	±0.02	±0.02
Rhizome	0.13	0.11	0.14	0.12	0±.15	0.12
	±0.02	±0.03	±0.04	±0.02	±0.03	±0.02

BM = Biomass, NM = Necromass, - Absent, ± = S.E.M.

and coarse roots of tree and fine roots and rhizomes of the ground vegetation in the three forest stands. N accumulation in tree fine roots varied significantly ($P<0.01$) between months but difference between the stands was not significant. In 6-, 15- and 23-year old stands, maximum N accumulation in fine roots 33.93, 21.63 & 21.33 kg ha^{-1} respectively, was observed during rainy season. Corresponding minimum values 13.05, 12.68 & 15.66 kg ha^{-1} were recorded during the spring season (Tables 6.8 - 6.10).

N accumulation in biomass and necromass fractions of the fine roots varied widely between different months. In the 6-year old stand accumulation of N in fine root biomass was higher than the necromass only during May-July; in all other months necromass accumulated more N than the biomass. In 15- and 23-year old stands live roots accumulated more N than dead roots in all months except July and August.

N accumulation in coarse roots also showed wide monthly variation (Fig. 6.2), but it increased significantly ($P<0.01$) with increasing stand age. It declined sharply with increasing soil depth in all the three stands.

The trends exhibited by the herbaceous roots and rhizomes were similar to the tree fine roots. It varied significantly ($P<0.01$) between months in all stands. During rainy season (June-September), N accumulation in live roots and rhizomes was higher than the dead roots and a reverse trend was observed during winter

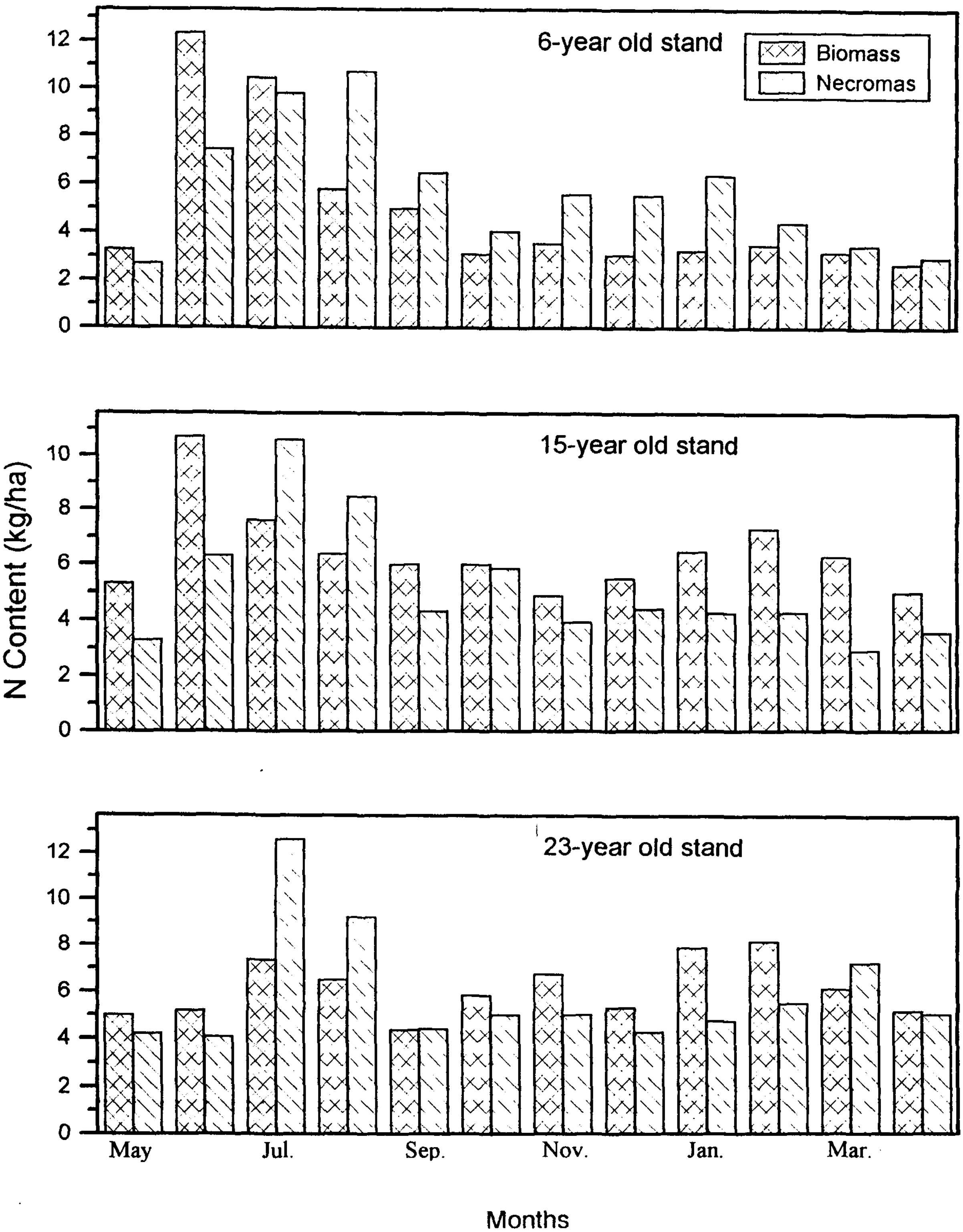

Fig. 6.1. N accumulation pattern in biomass and necromass fractions of tree fine roots in top 40 cm soil layer in the three pine stands.

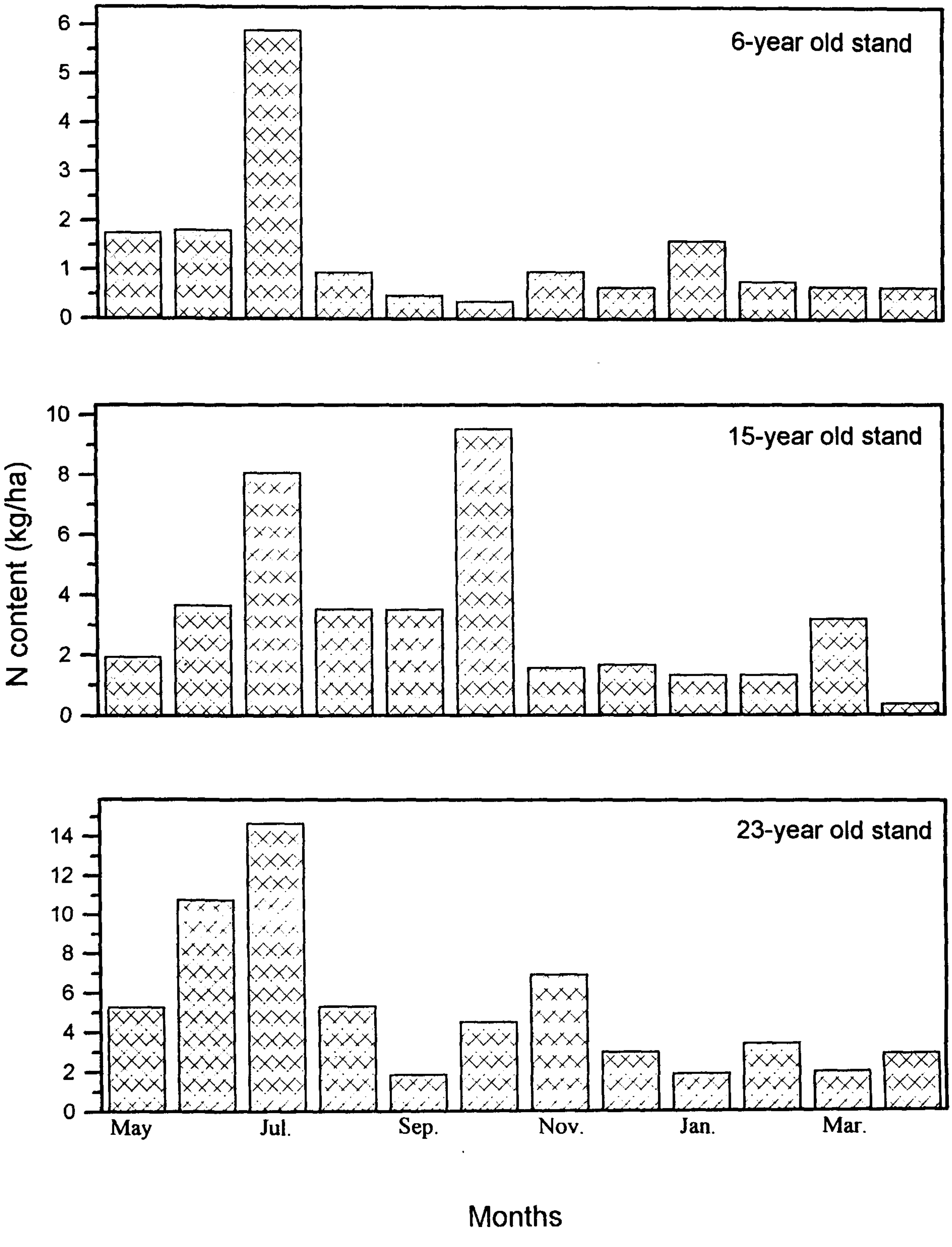

Fig. 6.2. N accumulation in tree coarse roots in top 40 cm soil layer in the three pine stands

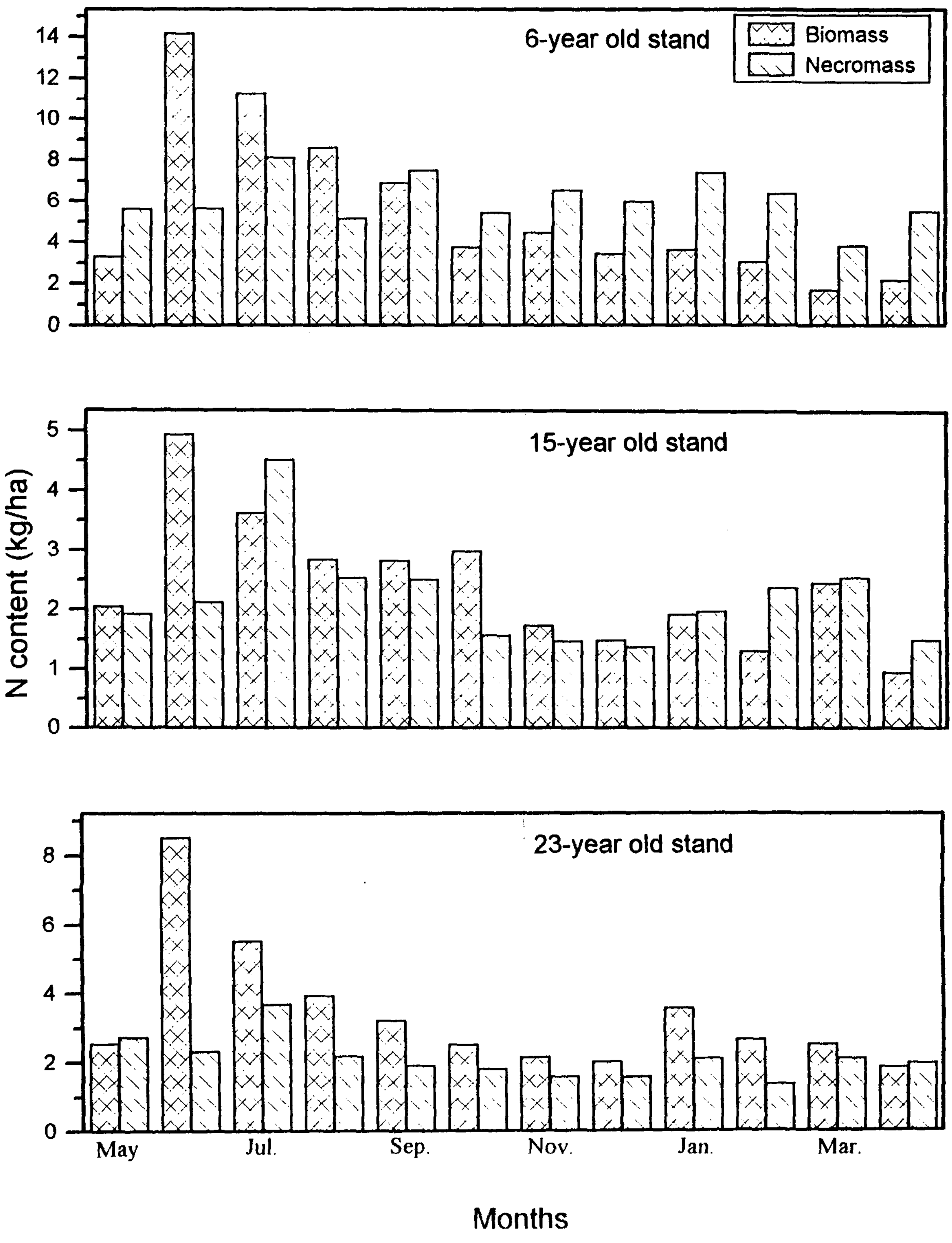

Fig.6.3. N accumulation pattern in biomass and necreomass fractions of herbaceous fine roots in top 40 cm soil layer in the three pine stands.

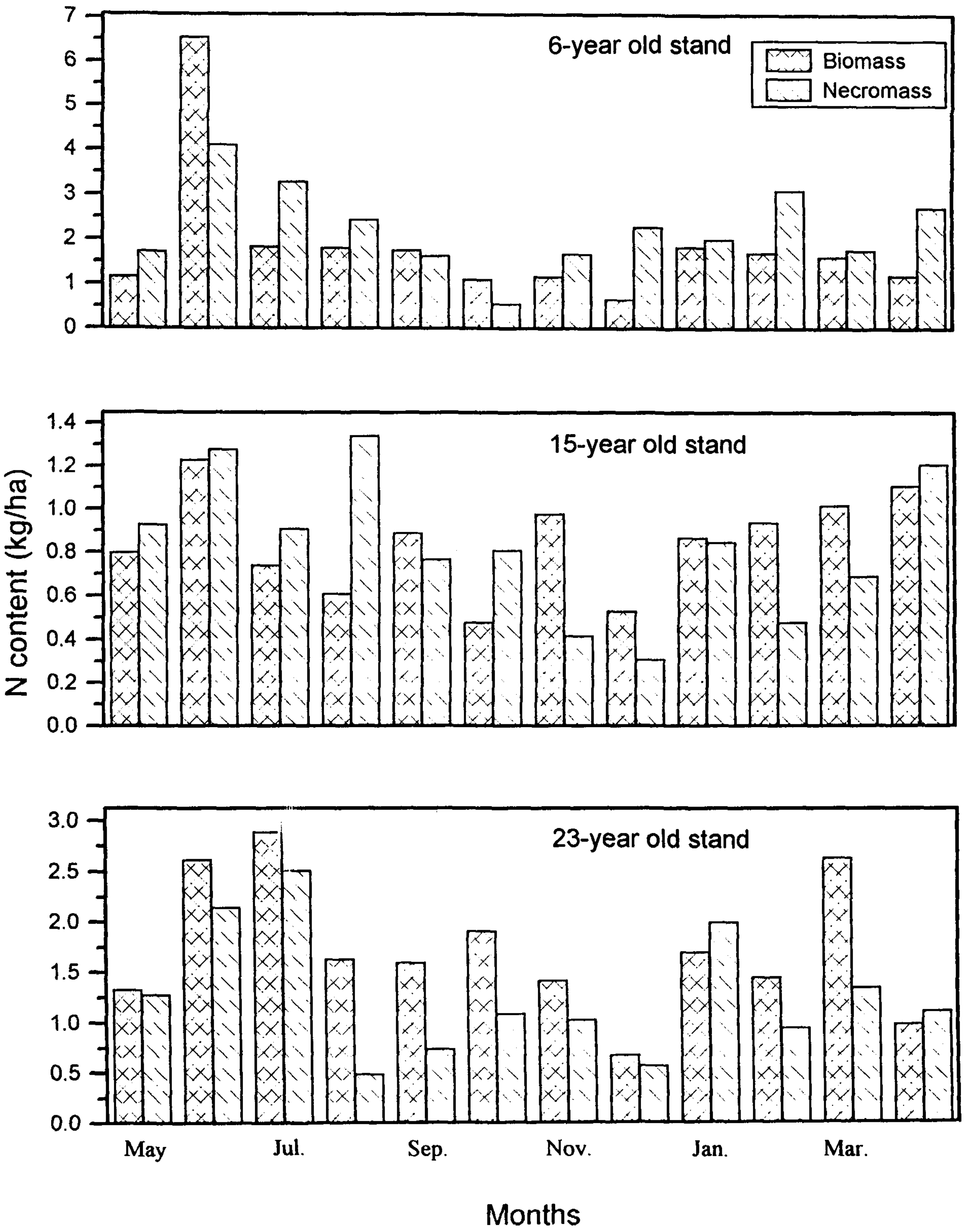

Fig. 6.4. N accumulation pattern in biomass and necromass fractions of rhizome in top 40 cm soil layer in the three pine stands.

Table 6.8. Mean N accumulation (kg ha^{-1}) in tree and herbaceous roots in the 6- the year old pine stand during four seasons of the year.

Season	0-10 BM	0-10 NM	10-20 BM	10-20 NM	20-30 BM	20-30 NM	30-40 BM	30-40 NM
Tree roots	**<1 mm diameter**							
Spring	0.93	1.33	0.44	0.56	0.46	0.56	0.07	0.10
	±0.15	±0.12	±0.23	±0.07	±0.02	±0.05	±0.03	±0.005
Rainy	2.82	3.17	0.93	1.23	0.67	0.77	0.41	0.50
	±0.54	±0.41	±0.07	±0.11	±0.04	±0.09	±0.03	±0.03
Autumn	0.76	2.67	0.32	0.92	0.13	0.48	0.15	0.13
	±0.06	±0.16	±0.03	±0.06	±0.005	±0.01	±0.009	±0.003
Winter	1.04	1.93	0.42	1.66	0.41	0.67	0.13	0.12
	±0.11	±0.08	±0.13	±0.70	±0.81	±0.11	±0.007	±0.002
	1-2 mm diameter							
Spring	0.28	0.18	0.28	0.08	0.27	0.02	0.10	-
	±0.00	±0.001	±0.001	±0.003	±0.002	±0.001	±0.009	-
Rainy	0.86	0.62	0.54	0.73	0.22	0.27	0.27	0.18
	±0.02	±0.03	±0.04	±0.07	±0.01	±0.01	±0.02	±0.009
Autumn	0.59	0.38	0.38	0.46	0.33	0.14	0.06	-
	±0.03	±0.01	±0.01	±0.03	±0.003	±0.002	±0.001	-
Winter	0.44	0.64	0.28	0.45	-	-	0.05	-
	±0.02	±0.03	±0.01	±0.01	-	-	±0.05	-
Herbaceous roots								
Spring	1.63	3.63	0.38	0.96	0.41	0.57	0.08	0.19
	±0.27	±0.33	±0.01	±0.03	±0.02	±0.02	±0.001	±0.001
Rainy	7.32	4.16	1.98	1.68	0.87	0.75	0.54	0.42
	±0.62	±0.44	±0.20	±0.29	±0.06	±0.08	±0.03	±0.001
Autumn	2.00	4.63	1.08	1.70	0.06	0.68	0.04	0.33
	±0.17	±0.23	±0.08	±0.12	±0.01	±0.01	±0.01	±0.02
Winter	2.67	3.19	0.73	0.87	0.40	0.42	0.06	0.14
	±0.54	±0.16	±0.12	±0.12	±0.04	±0.03	±0.01	±0.003

Soil depth (cm)

BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M, Spring (March - May), Rainy (June - September), Autumn (October - November), Winter (December - February)

Table 6.9. Mean N accumulation (kg ha^{-1}) in tree and herbaceous roots in the 15-year old pine stand during four seasons of the year.

Season	Soil depth (cm) 0-10		10-20		20-30		30-40	
	BM	NM	BM	NM	BM	NM	BM	NM
Tree roots	**<1 mm diameter**							
Spring	0.92	1.20	0.58	0.81	0.51	0.59	0.42	0.42
	±0.13	±0.15	±0.03	±0.23	±0.21	±0.03	±0.12	±0.17
Rainy	1.47	1.97	1.09	1.67	1.22	0.91	0.63	0.83
	±0.69	±0.56	±0.43	±0.73	±0.009	±0.24	±0.07	±0.12
Autumn	1.11	1.22	0.75	1.57	0.67	1.18	0.13	0.22
	±0.37	±0.26	±0.16	±0.17	±0.05	±0.32	±0.02	±0.001
Winter	1.09	1.31	0.96	1.05	0.79	0.96	0.41	0.40
	±0.14	±0.25	±0.25	±0.15	±0.29	±0.16	±0.06	±0.03
	1-2 mm diameter							
Spring	0.61	0.22	0.54	0.32	0.31	0.18	0.18	0.13
	±0.09	±0.02	±0.02	±0.01	±0.03	±0.02	±0.02	±0.001
Rainy	0.46	0.31	0.51	0.36	0.45	0.55	0.34	0.20
	±0.08	±0.04	±0.09	±0.04	±0.06	±0.12	±0.04	±0.03
Autumn	0.28	0.18	0.46	0.23	0.62	0.45	0.11	0.002
	±0.04	±0.02	±0.06	±0.007	±0.09	±0.03	±0.02	±0.001
Winter	0.29	0.27	0.56	0.15	0.52	0.32	0.18	0.04
	±0.09	±0.04	±0.06	±0.02	±0.04	±0.05	±0.03	±0.003
Herbaceous roots								
Spring	1.03	1.19	0.40	0.45	0.28	0.24	0.14	0.12
	±0.47	±0.39	±0.09	±0.10	±0.05	±0.02	±0.02	±0.01
Rainy	1.54	1.54	0.74	1.17	0.67	0.35	0.18	0.25
	±0.56	±0.17	±0.36	±0.79	±0.13	±0.02	±0.06	±0.001
Autumn	1.43	1.12	0.33	0.28	0.34	0.24	0.17	0.13
	±0.16	±0.12	±0.05	±0.01	±0.03	±0.06	±0.04	±0.001
Winter	1.16	0.13	0.38	0.47	0.28	0.23	0.16	0.13
	±0.31	±0.19	±0.09	±0.12	±0.05	±0.03	±0.02	±0.01

BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M, Spring (March - May), Rainy (June - September), Autumn (October - November), Winter (December - February)

Table 6.10. Mean N accumulation (kg ha^{-1})in tree and herbaceous roots in the 23-year old pine stand during four seasons of the year.

Season	Soil depth (cm) 0-10		10-20		20-30		30-40	
	BM	NM	BM	NM	BM	NM	BM	NM
Tree roots	**<1 mm diameter**							
Spring	0.83	1.35	0.87	1.12	0.58	0.46	0.34	0.59
	±0.09	±0.08	±0.08	±0.17	±0.03	±0.02	±0.01	±0.01
Rainy	1.11	2.38	1.01	2.07	0.70	1.11	0.41	0.48
	±0.21	±0.32	±0.13	±0.43	±0.05	±0.17	±0.09	±0.10
Autumn	0.96	2.12	0.99	1.27	0.61	0.78	0.35	0.39
	±0.16	±0.26	±0.19	±0.16	±0.12	±0.08	±0.06	±0.02
Winter	0.88	1.63	0.92	1.41	0.75	0.85	0.42	0.42
	±0.06	±0.29	±0.06	±0.24	±0.08	±0.12	±0.04	±0.05
	1-2 mm diameter							
Spring	0.58	0.19	0.81	0.25	0.74	0.11	0.02	-
	±0.06	±0.02	±0.15	±0.048	±0.05	±0.01	±0.009	-
Rainy	0.31	0.46	0.55	0.81	0.27	0.75	0.13	0.14
	±0.01	±0.17	±0.09	±0.11	±0.05	±0.02	±0.01	±0.01
Autumn	0.54	0.27	0.81	0.28	0.74	0.19	0.14	0.04
	±0.10	±0.07	±0.32	±0.09	±0.11	±0.02	±0.002	±0.009
Winter	0.64	0.25	0.93	0.34	0.72	0.26	0.04	-
	±0.16	±0.03	±0.18	±0.06	±0.14	±0.07	±0.009	-
Herbaceous roots								
Spring	1.14	1.14	0.54	0.72	0.53	0.22	0.15	-
	±0.51	±0.63	±0.04	±0.05	±0.05	±0.02	±0.01	-
Rainy	2.26	1.74	1.75	0.58	0.43	0.23	0.66	0.13
	±0.46	±0.39	±0.45	±0.05	±0.02	±0.03	±0.17	±0.02
Autumn	1.32	1.57	0.59	0.55	0.42	0.12	0.13	0.02
	±0.15	±0.22	±0.15	±0.11	±0.07	±0.01	±0.006	±0.001
Winter	1.79	1.18	0.65	0.48	0.43	0.14	0.08	0.02
	±0.15	±0.33	±0.17	±0.05	±0.07	±0.007	±0.004	±0.001

BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M, Spring (March - May), Rainy (June - September), Autumn (October - November), Winter (December - February)

(December-February) and spring (March-May). Accumulation of N in the top 10 cm soil layer was significantly ($P < 0.01$) higher than the subsurface layer (10-20 cm) in all the three stands. It declined from 50-60% in the upper 10 cm soil layer to 25-30% in 10-20 cm soil layer.

Total N accumulation in the tree roots as well as in the belowground parts of herbaceous vegetation was maximum (26.21 kg ha^{-1}) in the 23-year old stand while minimum accumulation (18.73 kg ha^{-1}) was recorded in the 6-year old stand. In the 6-year old stand major portion (60%) of the total N (tree + herb) was stored in the belowground biomass of the ground vegetation, whereas in the 15-and 23-year old stands the share of tree roots was 74 and 77% respectively (Table 6.14).

P Stock

Monthly values are shown in Figs.6.5 to 6.8. P accumulation in tree fine roots varied significantly ($P<0.01$) between months in all the three stands but differences between the stands was not significant. Accumulation of P in coarse roots also varied between months and it significantly ($P<0.01$) increased with stand age. Accumulation of P in roots and rhizomes of the ground vegetation was similar to that of the tree fine roots. It varied significantly ($P<0.01$) between months in all cases. P accumulation in tree fine roots and herbaceous roots was maximum during rainy season and minimum during spring season in all the stands

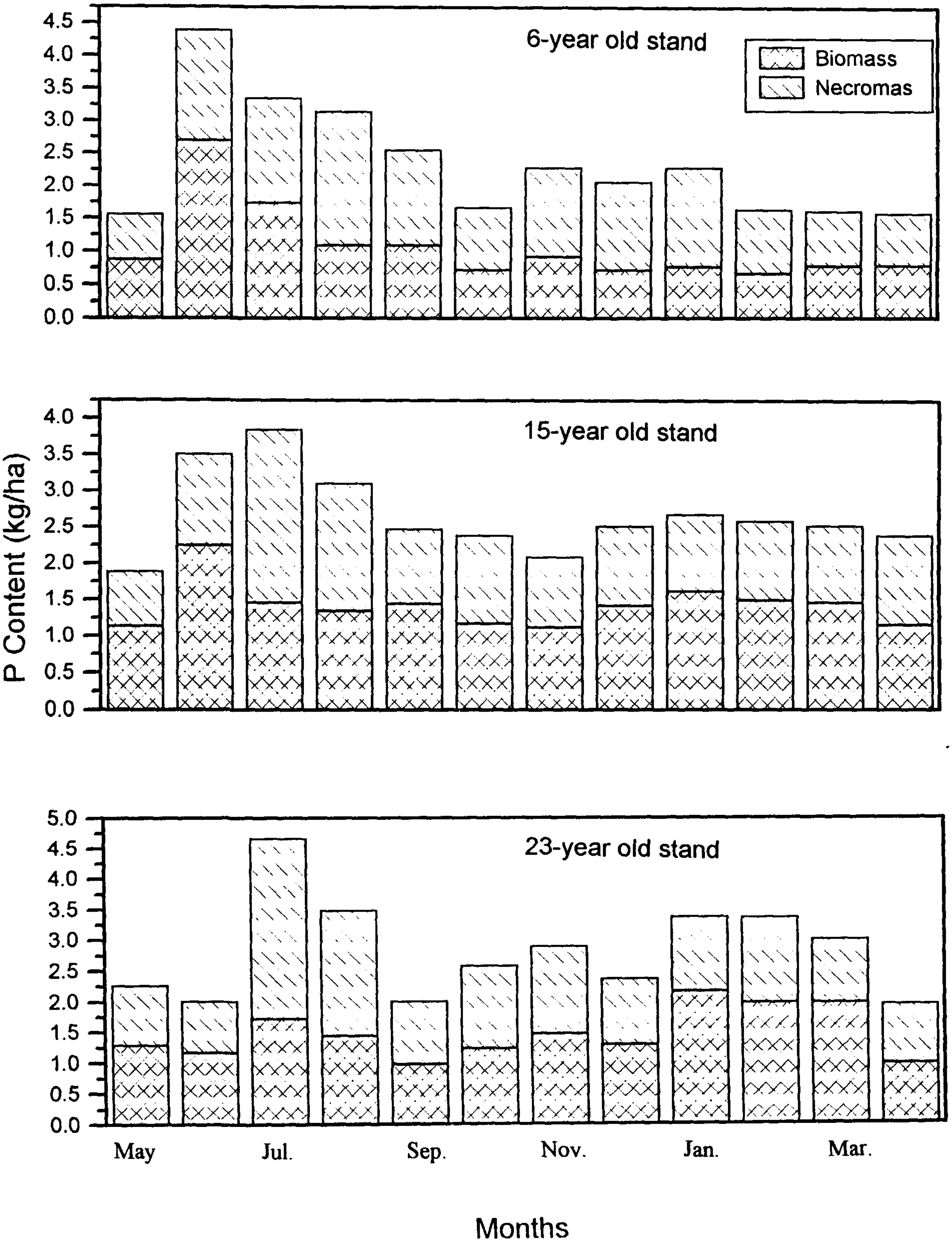

Fig. 6.5. P accumulation pattern in biomass and necromass fractions of tree fine roots in top 40 cm soil layer in the three pine stands.

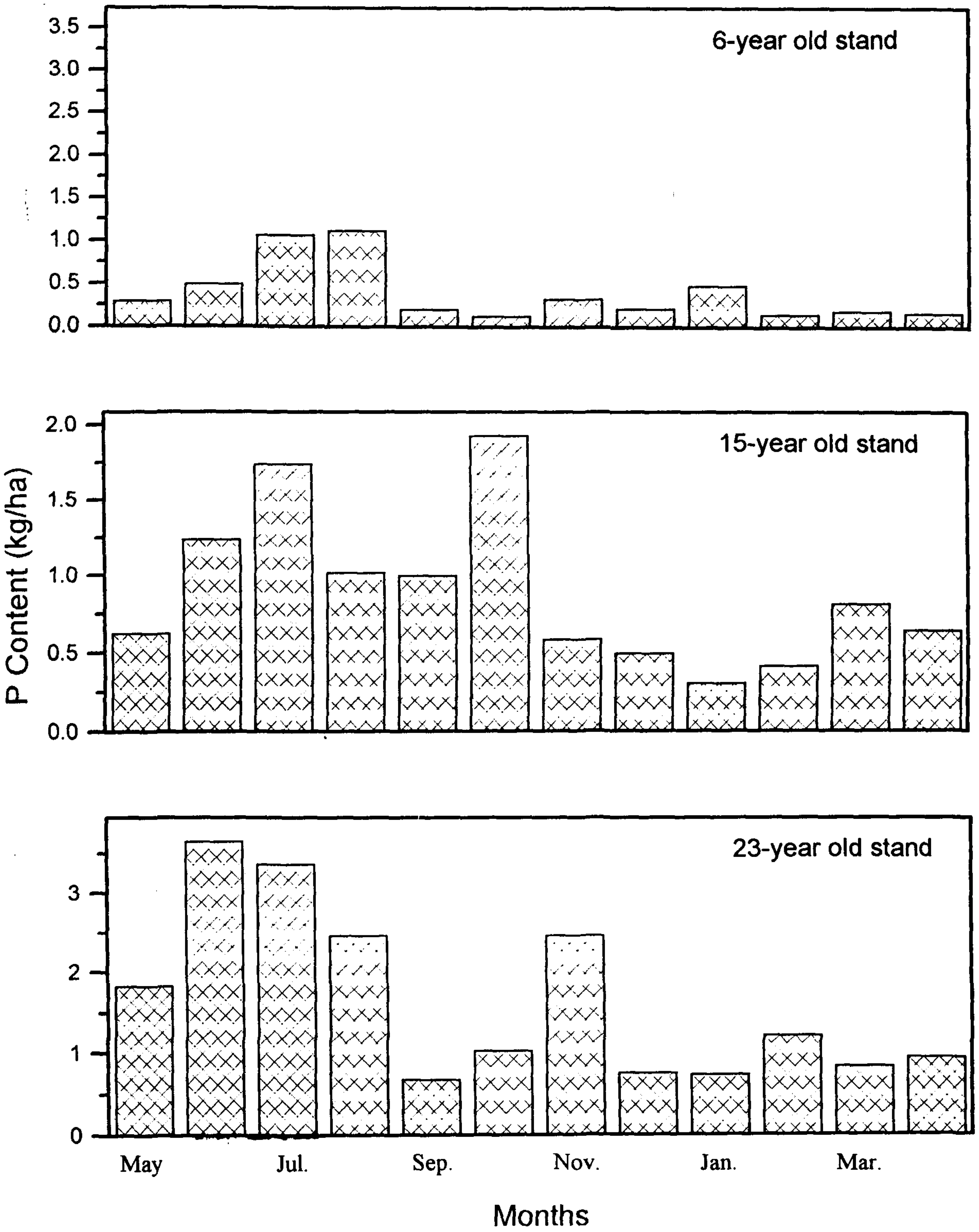

Fig. 6.6. P accumulation in tree coarse roots in top 40 cm soil layer in the three pine stands.

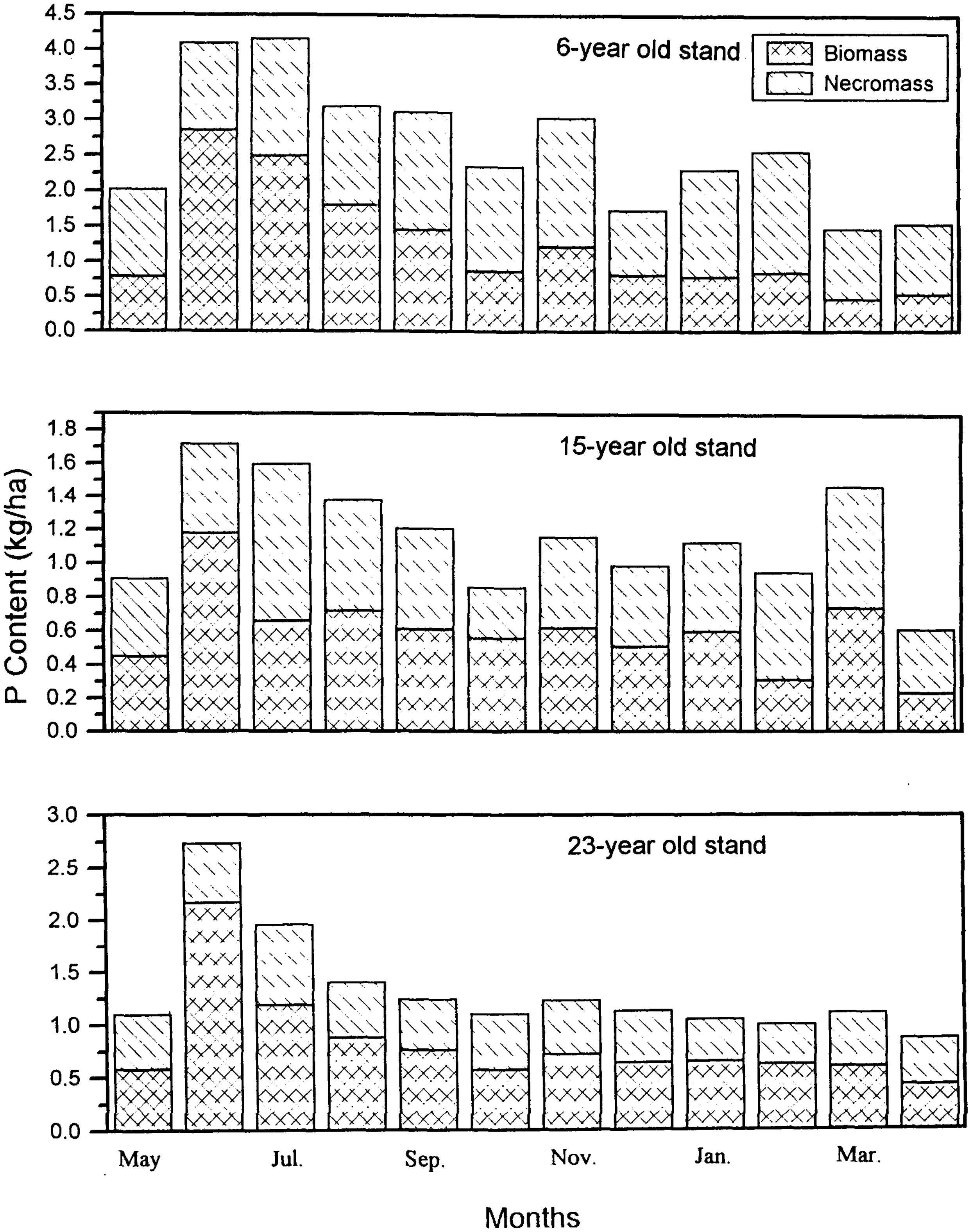

Fig. 6.7. P accumulation pattern in biomass and necromass fractions of herbaceous fine roots in top 40 cm soil layer in the three pine stands.

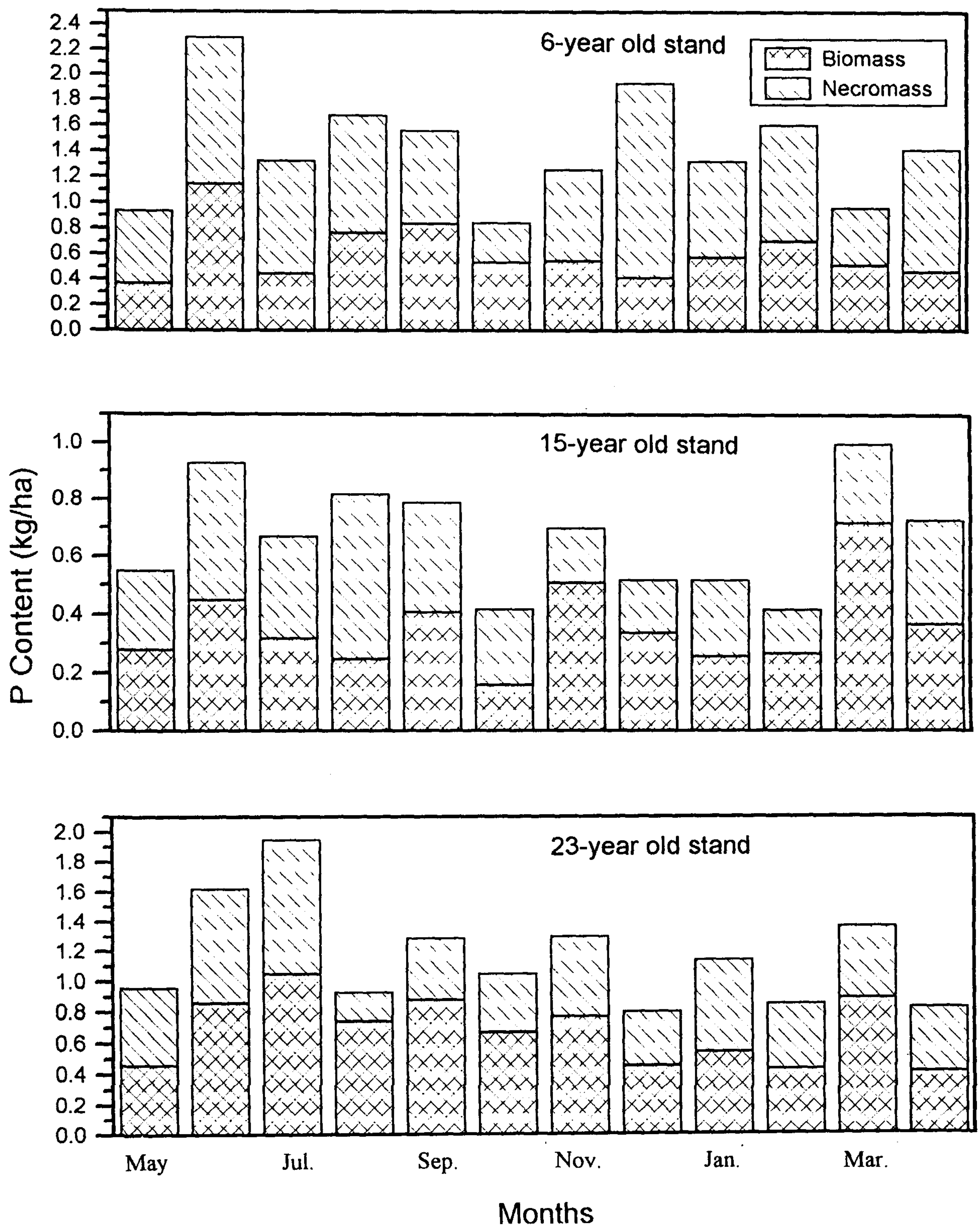

Fig. 6.8. P accumulation pattern in biomass and necromass fractions of rhizome in top 40 cm soil layer in the three pine stands.

(Tables 6.11 to 6.13). P accumulation declined significantly ($P<0.01$) from 50-63% in the upper 10 cm soil layer to 4-12% in 30-40 cm soil layer.

Total P accumulation (tree + herbaceous roots) was maximum (7.02 kg ha^{-1}) in the 23-year old stand and minimum (4.56 kg ha^{-1}) in the 6-year old stand. In the 15- and 23-year old stands, 77-80% of total P was accumulated by tree roots while in the 6-year old stand their share was only 37% (Table 6.14)

N AND P INPUT IN SOIL THROUGH ROOTS

Total annual N and P input to soil by the tree roots (fine + coarse) and belowground parts (roots + rhizome) of ground vegetation are given in Table 6. 14. N and P input by tree roots increased significantly ($P<0.01$) with increase in the stand age. But in the case of herbaceous vegetation, it significantly declined ($P<0.01$) from the 6-year old stand to 15-year old stand followed by a marginal increase in the 23-year old stand. Total nutrient input was maximum (65.70 kg N ha^{-1}; 17.21 kg P ha^{-1}) in the 23-year old stand and minimum (51.92 kg N ha^{-1}; 11.63 kg P ha^{-1}) in the 15-year old stand (Table 6.14).

N AND P TURNOVER RATE

N and P turnover rates are given in Table 6.14. In the case of tree roots the turnover rate decreased from 6-year old stand to 15-year old stand and then remained more or less unchanged until 23-year old stand. In the case of herbaceous roots also a similar trend was observed. In the 6-year old stand N and P turnover

Table 6.11. Mean P accumulation (kg ha^{-1})in tree and herbaceous roots in the 6-year old pine stand during four seasons of the year.

Season	Soil depth (cm) 0-10		10-20		20-30		30-40	
	BM	NM	BM	NM	BM	NM	BM	NM
Tree roots	**<1 mm diameter**							
Spring	0.21	0.36	0.11	0.16	0.11	0.15	0.02	0.29
	±0.03	±0.12	±0.02	±0.05	±0.01	±0.04	±0.003	±0.003
Rainy	0.60	0.67	0.19	0.26	0.14	0.16	0.88	0.11
	±0.14	±0.17	±0.03	±0.06	±0.05	±0.02	±0.007	±0.002
Autumn	0.17	0.64	0.07	0.22	0.03	0.01	0.03	0.04
	±0.11	±0.009	±0.05	±0.006	±0.002	±0.004	±0.002	±0.001
Winter	0.24	0.44	0.09	0.38	0.09	0.16	0.31	0.04
	±0.05	±0.10	±0.001	±0.09	±0.009	±0.01	±0.004	±0.001
	1-2 mm diameter							
Spring	0.07	0.04	0.09	0.02	0.09	0.005	0.04	-
	±0.004	±0.001	±0.01	±0.001	±0.002	±0.000	±0.000	-
Rainy	0.20	0.13	0.12	0.16	0.05	0.06	0.05	0.04
	±0.07	±0.05	±0.05	±0.01	±0.02	±0.01	±0.01	±0.001
Autumn	0.14	0.08	0.09	0.09	0.08	0.03	0.02	-
	±0.06	±0.009	±0.007	±0.07	±0.01	±0.01	±0.002	-
Winter	0.11	0.12	0.07	0.08	-	0.01	-	-
	±0.01	±0.03	±0.007	±0.01	-	±0.00	-	-
Herbaceous roots								
Spring	0.41	0.84	0.09	0.22	0.10	0.13	0.02	0.04
	±0.09	±0.12	±0.01	±0.03	±0.01	±0.02	±0.001	±0.001
Rainy	1.56	0.88	0.39	0.37	0.17	0.16	0.11	0.09
	±0.47	±0.20	±0.08	±0.09	±0.05	±0.009	±0.02	±0.001
Autumn	0.47	0.97	0.27	0.36	0.16	0.14	0.08	0.07
	±0.08	±0.15	±0.09	±0.06	±0.03	±0.04	±0.01	±0.001
Winter	0.57	0.74	0.16	0.20	0.08	0.09	0.02	0.03
	±0.10	±0.12	±0.07	±0.06	±0.008	±0.01	±0.001	±0.003

BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M, Spring (March - May), Rainy (June - September), Autumn (October - November), Winter (December - February)

Table 6.12. Mean P accumulation (kg ha^{-1})in tree and herbaceous roots in the 15-year old pine stand during four seasons of the year.

Season	Soil depth (cm) 0-10		10-20		20-30		30-40	
	BM	NM	BM	NM	BM	NM	BM	NM
Tree roots	**<1 mm diameter**							
Spring	0.27	0.29	0.17	0.29	0.14	0.19	0.12	0.14
	±0.06	±0.03	±0.07	±0.07	±0.03	±0.05	±0.02	±0.04
Rainy	0.33	0.41	0.24	0.35	0.25	0.19	0.14	0.18
	±0.12	±0.10	±0.09	±0.09	±0.08	±0.05	±0.02	±0.02
Autumn	0.25	0.26	0.17	0.34	0.15	0.25	0.03	0.05
	±0.09	±0.08	±0.05	±0.11	±0.09	±0.10	±0.00	±0.01
Winter	0.28	0.31	0.24	0.24	0.21	0.22	0.09	0.11
	±0.06	±0.10	±0.05	±0.06	±0.09	±0.07	±0.02	±0.03
	1-2 mm diameter							
Spring	0.17	0.05	0.15	0.08	0.09	0.04	0.05	0.004
	±0.03	±0.009	±0.02	±0.00	±0.01	±0.008	±0.00	±0.00
Rainy	0.15	0.05	0.16	0.07	0.14	0.04	0.11	0.004
	±0.01	±0.01	±0.06	±0.01	±0.06	±0.001	±0.02	±0.001
Autumn	0.09	0.06	0.15	0.07	0.21	0.14	0.02	0.07
	±0.01	±0.009	±0.008	±0.00	±0.05	±0.01	±0.00	±0.008
Winter	0.11	0.11	0.21	0.06	0.19	0.12	0.07	0.02
	±0.00	±0.007	±0.01	±0.00	±0.03	±0.009	±0.00	±0.001
Herbaceous roots								
Spring	0.26	0.30	0.10	0.11	0.07	0.06	0.04	0.04
	±0.10	±0.10	±0.02	±0.01	±0.00	±0.00	±0.00	±0.004
Rainy	0.39	0.30	0.10	0.11	0.07	0.06	0.04	0.04
	±0.14	±0.09	±0.04	±0.08	±0.00	±0.00	±0.001	±0.006
Autumn	0.37	0.28	0.09	0.07	0.09	0.06	0.04	0.05
	±0.07	±0.08	±0.01	±0.00	±0.01	±0.009	±0.00	±0.00
Winter	0.28	0.33	0.09	0.16	0.07	0.06	0.04	0.03
	±0.08	±0.13	±0.01	±0.06	±0.00	±0.009	±0.00	±0.001

BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M, Spring (March - May), Rainy (June - September), Autumn (October - November), Winter (December - February)

Table 6.13. Mean P accumulation (kg ha^{-1}) in tree and herbaceous roots in the 23-year old pine stand during four seasons of the year.

Season	Soil depth (cm) 0-10		10-20		20-30		30-40	
	BM	NM	BM	NM	BM	NM	BM	NM
Tree roots	**<1 mm diameter**							
Spring	0.24	0.33	0.25	0.27	0.16	0.11	0.09	0.14
	±0.07	±0.12	±0.09	±0.09	±0.06	±0.03	±0.01	±0.07
Rainy	0.25	0.53	0.22	0.46	0.15	0.25	0.09	0.10
	±0.11	±0.16	±0.07	±0.17	±0.02	±0.05	±0.009	±0.01
Autumn	0.23	0.52	0.23	0.31	0.14	0.19	0.08	0.09
	±0.05	±0.11	±0.08	±0.06	±0.04	±0.01	±0.01	±0.02
Winter	0.22	0.42	0.23	0.36	0.18	0.21	0.10	0.11
	±0.05	±0.11	±0.08	±0.08	±0.06	±0.03	±0.01	±0.01
	1-2 mm diameter							
Spring	0.13	0.05	0.18	0.06	0.17	0.03	0.005	-
	±0.03	±0.009	±0.01	±0.004	±0.009	±0.04	±0.00	-
Rainy	0.08	0.13	0.10	0.15	0.14	0.08	0.05	0.04
	±0.00	±0.01	±0.02	±0.03	±0.05	±0.007	±0.009	±0.005
Autumn	0.14	0.07	0.21	0.07	0.20	0.05	0.04	0.008
	±0.02	±0.009	±0.02	±0.006	±0.06	±0.009	±0.007	±0.00
Winter	0.19	0.06	0.28	0.08	0.22	0.06	0.02	-
	±0.04	±0.007	±0.13	±0.01	±0.03	±0.001	±0.001	-
Herbaceous roots								
Spring	0.28	0.28	0.14	0.18	0.13	0.05	0.04	-
	±0.07	±0.09	±0.04	±0.04	±0.01	±0.009	±0.001	-
Rainy	0.56	0.38	0.43	0.13	0.11	0.05	0.03	0.03
	±0.15	±0.12	±0.10	±0.04	±0.08	±0.001	±0.011	±0.000
Autumn	0.35	0.36	0.15	0.12	0.11	0.03	0.03	0.006
	±0.11	±0.09	±0.08	±0.03	±0.03	±0.000	±0.000	±0.00
Winter	0.39	0.28	0.14	0.11	0.09	0.03	0.02	0.007
	±0.09	±0.07	±0.05	±0.03	±0.01	±0.001	±0.000	±0.000

BM = Biomass, NM = Necromass, - = Absent, ± = S.E.M, Spring (March - May), Rainy (June - September), Autumn (October - November), Winter (December - February)

Table 6.14. Annual input of nutrients by tree roots and belowground parts of ground vegetation , their mean accumulation in belowground biomass and turover rates in the three pine stands.

	6-year old		15-year old		23-year old	
	N	P	N	P	N	P
Annual input (kg h^{-1})						
Trees	27.94	6.35	38.76	8.87	48.96	13.35
	(48.21)	(45.35)	(74.65)	(76.26)	(74.52)	(77.57)
Ground vegetation	30.01	7.65	13.16	2.76	16.74	3.86
	(51.78)	(54.64)	(25.34)	(23.73)	(25.47)	(22.42)
Total	57.95	14.00	51.92	11.63	65.70	17.21
Mean accumulation (kg ha$^{-1)}$						
Trees	7.50	1.70	15.66	3.58	20.80	5.67
	(40.04)	(37.28)	(77.33)	(74.73)	(79.35)	(80.76)
Ground vegetation	11.23	2.86	4.59	1.21	5.41	1.35
	(59.95)	(62.72)	(22.66)	(25.26)	(20.64)	(19.23)
Total	18.73	4.56	20.25	4.79	26.21	7.02
Turnover rate (year^{-1})						
Trees	0.79	0.79	0.71	0.71	0.70	0.70
Ground vegetation	0.73	0.73	0.74	0.69	0.76	0.74
Mean	0.76	0.76	0.73	0.70	0.73	0.72

Values in the parentheses are the percent of the total rate was slower in ground vegetation than tree roots but the trend was reversed in the old stand.

DECOMPOSITION OF FINE ROOTS OF PINE.

Weight loss

Pine roots decomposed in a three phased manner in all the three forest stands (Fig. 6.9). The first phase lasting for about 30 days, was characterised by a slow rate of weight loss. During this period the average daily rate of weight loss was 1.3, 1.1 and 1.0 mg day^{-1} in the 6-, 15- and 23-year old stands respectively. This was followed by a phase of rapid weight loss up to 90 days when the average rate was 4.1 mg day^{-1}. During the third phase, the decay process slowed down considerably and it continued at an average rate of 0.7 mg day^{-1} until 450 days. The difference in the rate of weight loss between the stands was not significant.

N and P mineralisation

N concentration in root litter showed a marked decrease and/or increase during decomposition process. Initially, the concentration decreased up to 150 days, followed by a period of gradual increase up to 270 days, and thereafter it again decreased until 450 days (Fig. 6.10 A). N mineralization pattern expressed as percent of the initial N content remaining in the decomposing root mass (Fig. 6.10 A) exhibited marked temporal variation. Initially, up to 150 days the average rate of N mineralization was 4.0, 3.0, and 3.1 mg day^{-1} in the 6-, 15- and 23-year

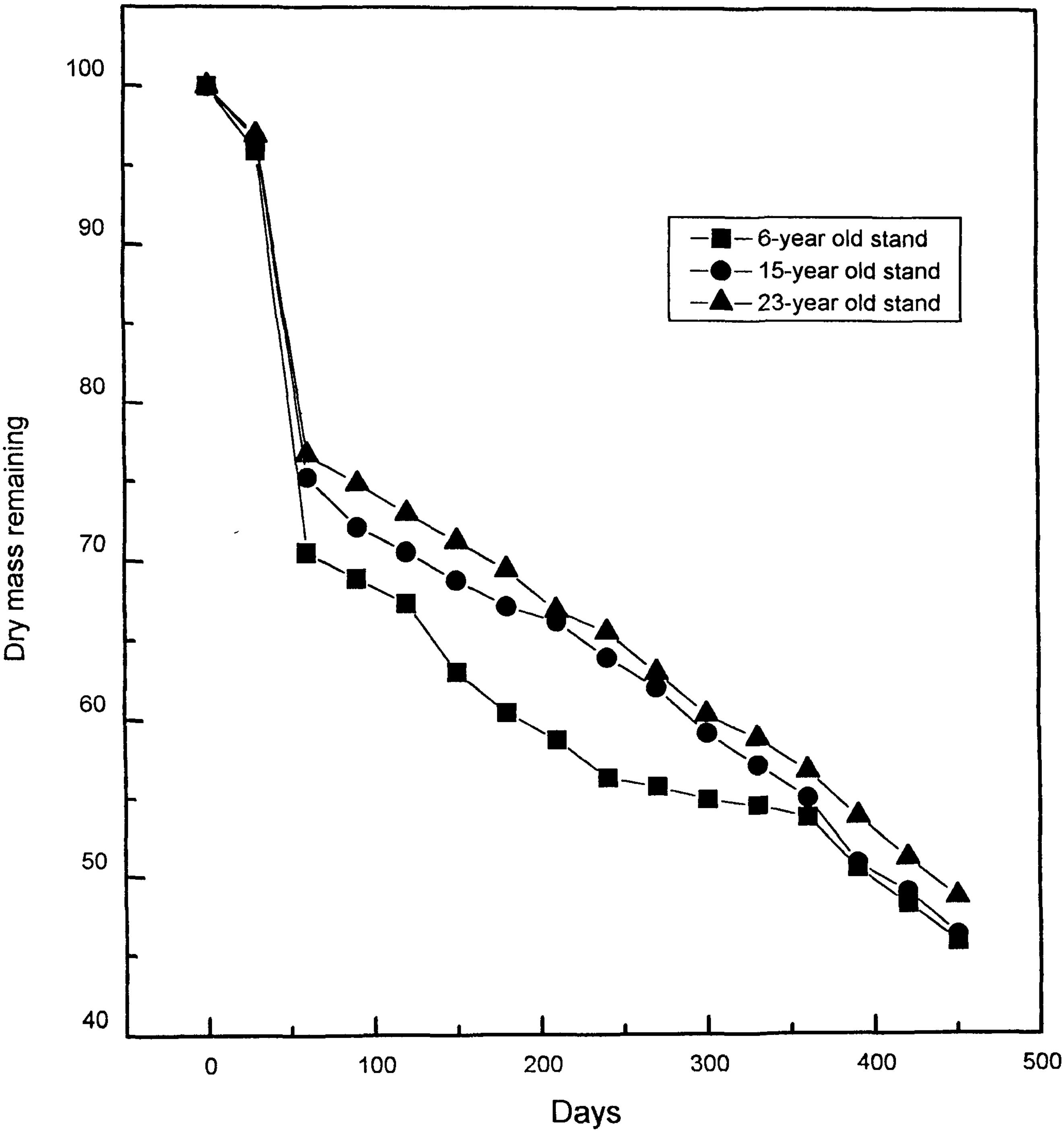

Fig. 6.9. Mean dry weight remaining (% of the initial) in the fine roots during decomposition in the three pine stands.

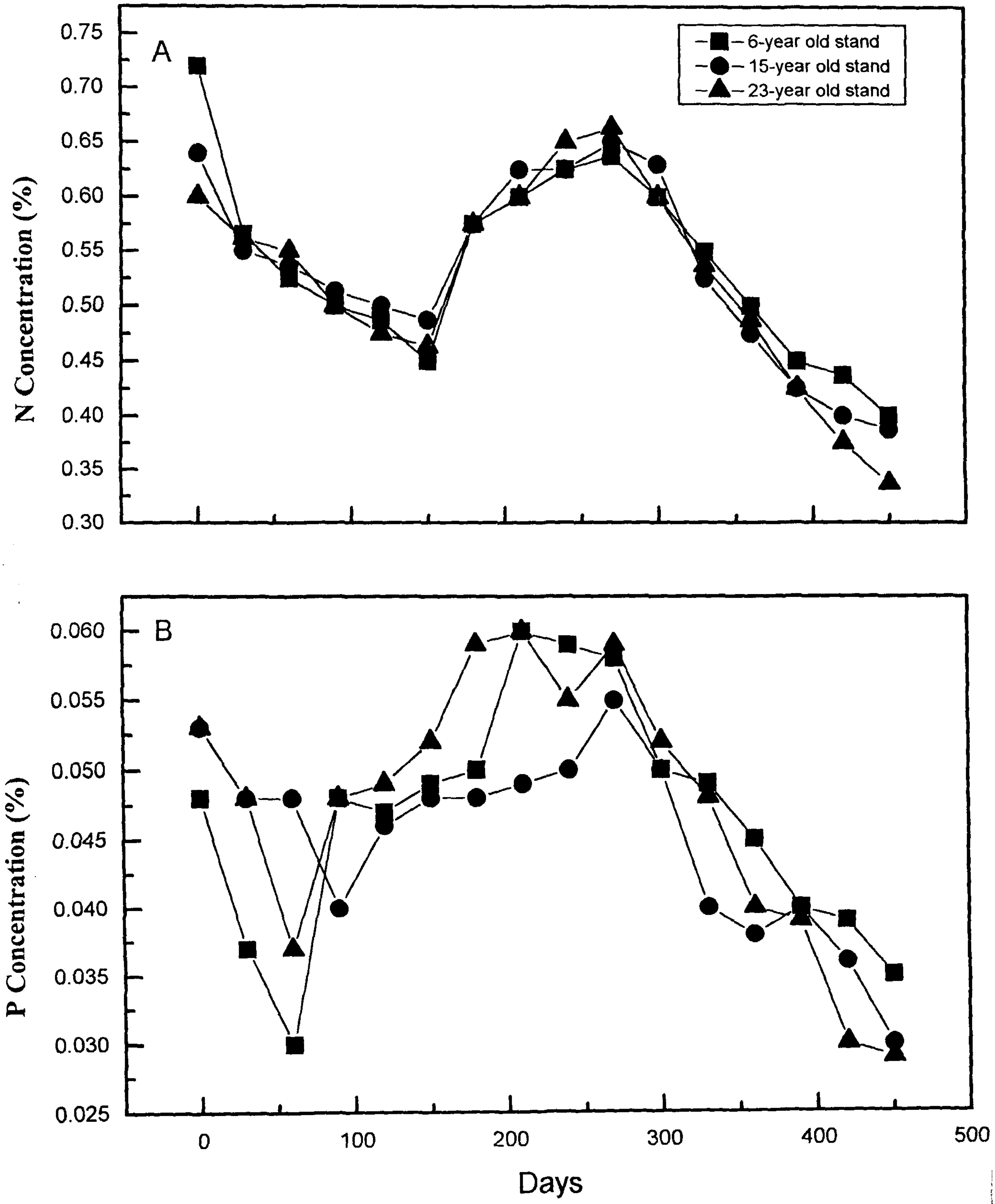

Fig. 6.10. Changes in nitrogen (A) and phosphorus (B) concentrations in the fine roots during decomposition in the three forest stands.

rate of N mineralization was 4.0, 3.0 and 3.1 mg day-^{1} in the 6-, 15- and 23-yeaer old stands respectively. This was followed by a period of nutrient immobilization when N content registered an increase (compared to 150 days). During next phase of decay between 270-450 days, the average rate of N release was 1.2, 1.8 and 2.2 mg day^{-1} in the 6-, 15- and 23-year old stands, respectively. N mineralization constant (k_N) varied between 1.40 and 1.53 (Table 6.15). Annually about 53-59% of initial N content in roots was mineralized in the three stands.

The temporal variation in P concentration in the decomposing roots was more or less similar to that of N, indicating distinct periods of immobilization and mineralization (Fig. 6.10 B). During the initial 60 days of root decay, the rate of P mineralization was 9.4, 5.3 and 7.7 mg day^{-1} in the 6-, 15- and 23-year old stands, respectively (Fig. 6.11 B). The period between 60 and 210 days was characterised by P immobilization when the concentration of P in the decaying litter registered a marked increase. Steady decrease in P concentration after 210 days indicated that the mineralization (Fig. 6.11 B) sets in after this period, when the average rate of P release was 1.5, 1.4 and 1.9 mg day^{-1} in the 6, 15- and 23-year old stands, respectively. Phosphorus mineralization constant (k_P) gradually declined from 1.55 in the 6-year old stand to 1.41 in 15 - and 23-year old stands (Table l6.15). About 51-58% of the initial P content in roots was mineralized annually in the three forest stands.

DISCUSSION

Fine roots play an important role in the nutrient cycling of the forest

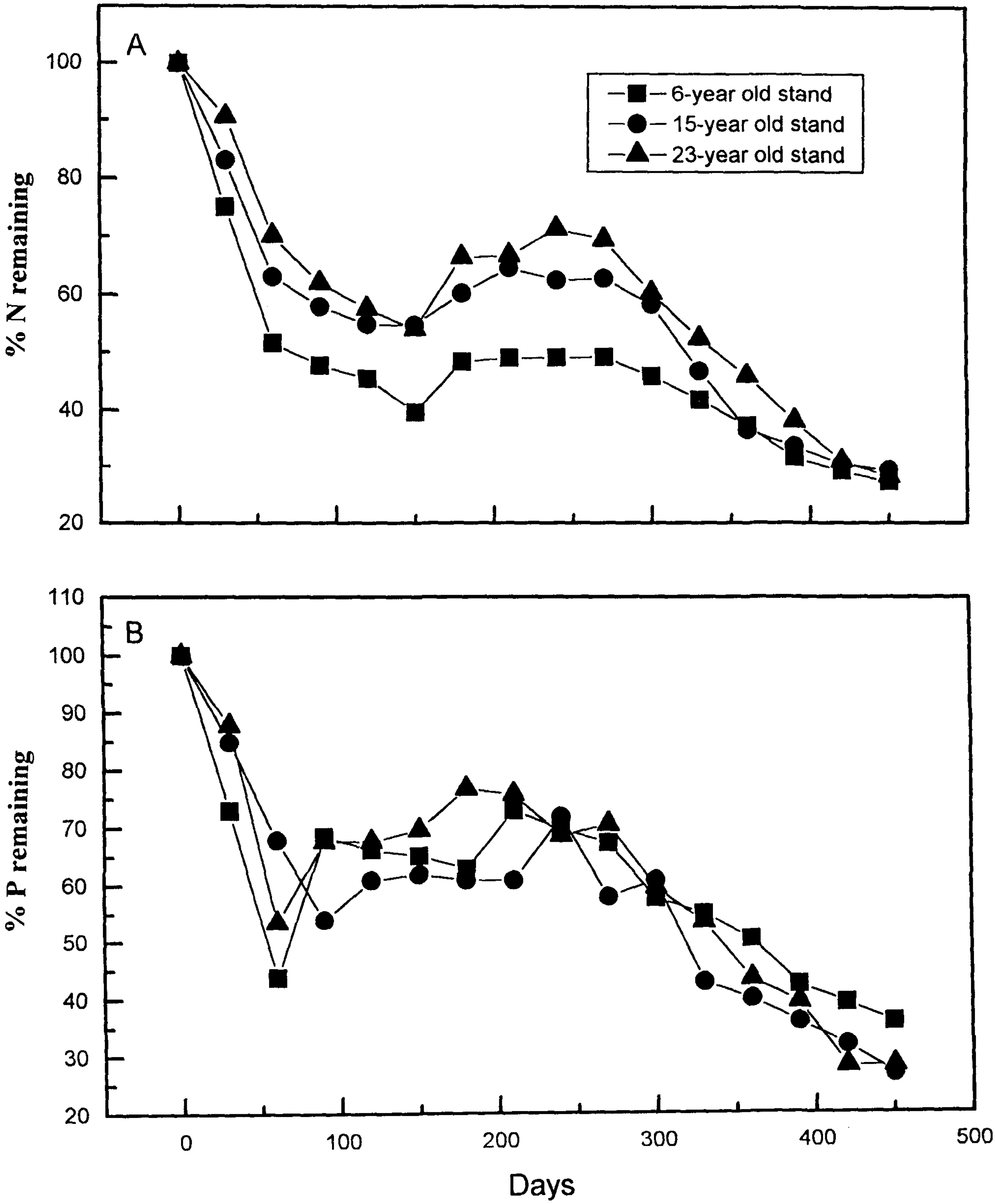

Fig. 6.11. Mineralization of N (A) and P (B) during decomposition of tree fine roots in the three forest stands.

Table 6.15. Annual deacy constant (k yr.$^{-1}$ *) and mineralization constant (k_N & k_P) for tree fine roots in the three forest stands. Values were computed from the data obtained from the litter bag experiment.

Parameters	Stand age		
	6-year	15-year	23-year
Root decay			
% mass loss yr^{-1}	41.37	41.45	39.13
k	1.82	1.77	1.89
t_{50}	0.51	0.52	0.49
t_{99}	2.74	2.82	2.64
N mineralization			
%release yr^{-1}	58.95	53.03	56.08
k_N	1.40	1.53	1.46
t_{50}	0.66	0.60	0.63
t_{99}	3.57	3.26	3.24
P mineralization			
% release yr^{-1}	51.94	58.41	58.17
k_P	1.55	1.41	1.41
t_{50}	0.60	0.65	0.65
t_{99}	3.22	3.54	3.54

* According to Olson (1963)

ecosystem.They quickly absorb nutrients that are released during the decomposition of detrital mass on the forest floor, prevent nutrient loss from the system (Walter 1971) and add significant amount of organic matter and nutrients to the soil by their rapid decay (Vogt *et al.* 1991). Since death and renewal of fine roots take place simultaneously (Persson 1983), they continuously add nutrients to the soil system.The nutrient concentration in roots is strongly influenced by its diameter (Vogt *et al.* 1991). In the present study, N and P concentration decreased sharply with increase in root diameter. Vogt *et al.* (1983) and Nambiar (1987) have reported similar relationship between nutrient concentration and root diameter in *Abies amabilis* and *Pinus radiata.* The resorption of nutrients from young roots during maturation could be one of the possible reasons for lowering the N and P concentration in the older roots. N and P concentration in tree fine and coarse roots and herbaceous fine roots and rhizomes showed minor variation. The higher concentration in the roots than the rhizomes could be attributed to greater metabolic activities in the former (Boral 1993). Higher N and P concentrations in the live roots than the dead roots could be due to their translocation to the live tissues during senescence (Nambiar 1987).

N and P accumulation pattern varied widely between the stands, months and also between different categories of roots. Although their accumulation in roots is a function of concentration and mass, the latter contributed more to the observed nutrient accumulation pattern in the belowground parts. In all stands, maximum nutrient accumulation during rainy season coincided with the peak root mass. Similarly, maximum accumulation in the 23-year old stand can be ascribed to the higher root mass. The decline in N and P accumulation with increase in soil depth was related to depth-wise distribution pattern of root mass in the soil profile. The decline in the contribution of the ground vegetation to the mean N and P accumulation with the increase in the age of the pine stand was mainly due to the decrease in belowground biomass of the ground vegetation in the older stands (Chapter 5). In all three pine stands, the relative abundance of N and P in tree and herbaceous roots was in the order of N>P, agreeing with the findings of Nambiar (1987) and Khiewtam and Ramakrishnan (1993).

Annual N and P input in the soil through tree roots and belowground parts of the ground vegetation was related to the production. The input by the former increased with stand age while that by the latter decreased.

During decomposition, the initial slow rate may be attributed to the time-lag for the colonization and establishment of microbes (Alexander 1977). The rapid rate of decay after an initial lag phase was the net effect of a large number of processes such as utilization of readily available energy sources by microbes, loss of water soluble organic compounds and inorganic salts and non-structural carbohydrates from the decomposing root litter (Bloomfield *et al.* 1993, Arunachalam *et al.* 1996b). The decline in the rate of weight loss during the third phase could be due to the relatively higher percentage of lignin, cellulose and tannin in the left-over decaying root tissues (Fogel and Cromack 1977). These materials are known as interfering factors during enzymatic degradation (Alexander 1977). Lignin has been reported to be most likely constituent which limits weight loss during extended period of decomposition (Fogel and Cromack 1977, Berg and Staff 1980). All the three stands having a three-phased weight loss pattern showed seasonal fluctuations. Warm-humid rainy season was characterised by a faster rate of decay in all the stands, whereas during autumn and winter the decay was slow. Rochow (1974) and Swift *et al.* (1979) attributed seasonal change in root decomposition rate in the tropical forest ecosystems to the soil moisture condition, ambient temperature and microbial activity.

C, N, P, Lignin and cellulose concentrations in fine roots did not vary significantly between the stands. Lignin/N and C/N ratios, however, increased from the 6-year old stand to 23-year old stand (Table 6.16). The relationship between initial root chemistry and decay rate during different phases of decay has been worked out by computing correlation coefficient (r) and the values are furnished in Table 6.17. In the first two phases, carbon and nitrogen concentrations were positively correlated with the decay rate, whilst the lignin, cellulose and C/N were negatively correlated.

Table 6.16. Initial chemical composition of tree fine roots.

Stand age	C (%)	N (%)	P (%)	Lignin (%)	Cellulose (%)	C/N	Lignin/ Nitrogen
6-year old	27.66	0.72	0.048	17.40	34.90	38.63	24.30
	±0.18	±0.01	±0.001	±0.34	±0.21		
15-year old	25.67	0.64	0.053	19.38	38.95	40.01	30.1
	±0.30	±0.01	±0.001	±0.26	±0.96		
23-year old	25.97	0.60	0.053	22.61	39.36	43.29	37.68
	±0.25	±0.01	±0.005	±0.18	±0.28		

Table 6.17. Relationship between decomposition rate of fine roots (% weight loss day^{-1}) and their initital chemical composition.

	Correlation coefficient : r values			
Initial chemical composition	First phase (0-30 days)	Second phase (30-90 days)	Third phase (90-450 days)	Average decay rate
Carbon (%)	0.671*	0.726*	-0.584	0.201
Nitrogen (%)	0.747*	0.869*	-0.646*	0.531
Phosphorous (%)	-0.462	-0.551	0.463	-0.208
Lignin (%)	-0.690*	-0.945	0.675*	-0.396
Cellulose (%)	-0.716*	-0.811*	0.650*	-0.299
C/N	-0.653*	-0.905*	0.602	-0.332

* Significant at P <0.05), n = 9.

The stock of nitrogen and phosphorus in the decomposing fine roots fluctuated with time in all the three forest stands. The rapid decline during initial phase which coincided with the rainy season, was mainly due to leaching. An increase in N and P content during autumn and winter seasons might be the result of microbial immobilization (Anderson 1973), nutrient input in soil by precipitation (Bocock 1963) and atmospheric N_2 fixation (Wood 1974). Thus N and P were mineralized at faster rate during rainy season when conditions were favourable for mineralization, while autumn and winter seasons were characterized by immobilization.

CHAPTER VII

GENERAL DISCUSSION

Hills of north-east India are covered by secondary forest of *P. kesiya* which yields valuable multi-purpose soft wood timber. In Meghalaya, *P. kesiya* grows luxuriantly forming almost pure forest stand at higher elevations of Khasi and Jaintia hills.The objective of the present study was to evaluate the role of fine roots in organic matter and nutrient (N & P) dynamics in soils of pine stand. In order to achieve the above objective data on temporal and spatial variations in biomass and production of fine and coarse roots, their contribution to nutrient input and accumulation in soil as well as on root decay and mineralization patterns were collected from 6-, 15- and 23-year old *P. kesiya* stands developed on gentle sloping hills at an altitude of 1500 m. Since results on each of the above aspects have been discussed separately in the foregoing chapters, an attempt has been made in this chapter to synthesize the important findings to understand the role of roots, particularly fine roots (<2 mm diameter) in organic matter and nutrient dynamics in the soil system of pine stand.

Vegetation and soil characteristics

The 6-year old stand composed of young trees (average tree height 5.42 m and DBH 4.85 cm) had a density of 11020 individuals ha^{-1}. Tree population density declined significantly to 730 individuals ha^{-1} when the stand attained the age of 23-years (average tree height 14.37 m and DHB 19.12 cm). The reduction in tree density with increasing stand age was mainly due to natural thinning, selective cutting of trees and annual burning that caused sapling mortality. In addition to these factors, competition between mature trees and ground vegetation for light, space and nutrients might have also caused mortality of pine saplings (Harmer 1995).

The botanical composition of forest floor was similar in young as well as old stands. Grasses such as *Axonopus compressus, Arundinella bengalensis, Arundinella khasiana, Anotis weightiana* and weeds like *Eupatorium adenophorum* and *Lantana camara* were present in all the three stands. Their density declined sharply from 116 individuals m^{-2} in the 6-year old stand to 75 individuals/m^2 in the 15-year old stand and then again increased in the 23-year old stand.

The soil characteristics showed some marked differences between the stands. Soil organic carbon (SOC) declined in the older stand but soil pH, TKN, Available-P and moisture content did not vary significantly between the stands. Lower input of organic matter to soil due to poor growth of ground vegetation and change in litter production pattern may explain decline in SOC in the older stands. The greater contents of soil organic matter, TKN, and available-P in the surface soil compared to the subsoil layers in all stands can be attributed to the accumulation of litter on the soil surface and concentration of roots in the upper soil layer. A comparative analysis of certain important properties of soils of the pine forest semievergreen oak forest and grassland communities under similar climatic and physiographic conditions showed that the soils in pine stands has low TKN, available-P and organic matter content than the broadleaved forest and grassland (Table 7.1).

The soil of abandoned agricultural fields also have high nutrient and organic matter contents than the mature pine stand (Boral 1993). Low quality of pine litter, annual burning of forest floor during dry winter followed by intermittent heavy rain during spring and continuous rain during monsoon periods causing rapid loss of organic matter and nutrients through overland flow and leaching are the main reasons for low concentrations of SOC, N and P in the soil of pine stands.

Vertical distribution and seasonal variation in fine and coarse root mass

The distribution pattern and density of roots within the soil profile depend on the genetic make-up of the plant and soil environment (Buck 1986, Haissing and Rienschneider 1988, Myers *et al*, 1994). The distribution of fine roots also reflects the availability of nutrients in the soil profile (Jordan 1985, Vitousek and Sanford 1986). Large congregation of tree and herbaceous fine roots in the

Table 7.1. Physio-chemical properties of soil in pine and oak forests and grassland communities developed under similar climatic condition at higher elevation (1500-1900 m) of Meghalaya.

Parameters	15-year old pinestand	16-year old oak forest regrowth [1]	Arundinella Grassland [2]
Bulk density (g/cm^3)	1.08±0.05	1.46 ± 0.04	1.13 ± 0.07
WHC (%)	67.31 ±1.31	69.30±1.54	81.42±1.69
SMC (%)	24.08±0.47	39.32±0.61	55.50±1.20
pH	5.29±0.04	5.28±0.03	5.76±0.06
CEC (Meq 100^{-1})	11.56±0.13	17.20±0.51	12.23±0.20
TKN (%)	0.13±0.01	0.51±0.02	0.20±0.01
Available-P (%)	0.01±0.001	0.58±0.02	0.25±0.009
Organic-C (%)	1.09±0.14	3.33±0.32	2.03±0.025

WHC = Water holding capacity

SMC = Soil moisture content

CEC = Cation exchange capacity

TKN = Total kjeldahl nitrogen

± = SEM

1 = after Arunachalam (1996), and 2 = after Uma Shanker (1991).

uppermost (0-10 cm) soil layer was related to the low bulk density and high percentage of soil organic matter and mineral nutrients in that layer. Meyer and Gottsche (1971), ascribed the decrease in root biomass in the lower layers of the profile to the deterioration in nutrient status and biological condition. Lyr and Hoffman (1967) and Ford and Deans (1977) concluded on the basis of their studies that root biomass increases in the nutrient-rich zone of the soil. On the contrary, Gower (1987) and Vogt *et al.* (1985) reported greater root biomass in the nutrient poor soils and argued that better development of roots in nutrient-poor soil helps in meeting nutrient requirements of plants.

The coarse roots whose main function is to provide mechanical support to tree (Stone and Kalisz 1991) were concentrated in the lower (10-30 cm) soil layer in all the three pine stands. Similar findings have also been reported by Persson (1980) from *Pinus sylvestris* stand in Sweden.

The present investigation revealed that 67-82% of the total fine root mass (tree + herbs) was concentrated in the upper 20 cm soil layer. Safford and Bell (1972) reported 87% fine roots in the top 15 cm soil layer in a 39-year old spruce plantation and Vogt *et al.* (1981) found >80% fine roots in the first 15 cm soil layer in *Abies amabilis* stands. Harris *et al.* (1977) reported that in *Pinus taeda* stands 71% fine roots were confined to the upper 20 cm layer. Studies of Klinge (1973), Klinge and Herrera (1978), Stark and Spratt (1977) in the tropical forests revealed that 60-90% of total root biomass is found in the humus layer. Arunachalam *et al*. (1996a) reported about 82-84% fine root mass in the top 20 cm soil layer in a subtropical humid forest of Meghalaya. Besides the absorption of water and mineral nutrients, fine roots in the upper soil layer play a major role in the conservation of nutrients thereby preventing the loss through leaching.

Rainy season was the favourable period for root growth when both fine as well as coarse root biomass was higher than during the spring season which happened to be the period of minimum biomass accumulation. The period of minimum root biomass coincided with the peak period of flushing and reproductive growth (cone formation), while maximum accumulation occurred during rainy season when shoot elongation ceases and male cones are already shed and conditions are congenial on account of favourable temperature and better availability of water and nutrients in soil. Sutton (1969), however, holds the view that the tree root growth flush is independent of shoot growth in temperate coniferous forest. Seasonal trend in coarse root biomass was similar to the fine roots. A marked seasonality in root biomass of the ground vegetation observed in all stands was related to their seasonal growth pattern. Rainy season being the period of active vegetative growth of herbaceous species, showed maximum biomass, while the minimum value was recorded during spring which marks the beginning of regrowth of ground vegetation after about three months long

(December-February) dormant phase during severe winter. Parthasarathy (1988), Vishalakshi (1994) and Sundarapandian and Swamy (1996) in the mixed deciduous and dry evergreen forest of south India, Srivastava *et al.* (1986) in the tropical deciduous forests and Khiewtam and Ramakrishnan (1993) in subtropical broadleaved forest of north-east India have reported similar seasonal trend in the root mass. A close relation between root growth periodicity and environmental factors has also been reported by Daubenmire (1965), Etherington (1975) and Russel (1977).

The maximum fine root mass in the 6-year old stand could be attributed to the high density of young trees as well as that of the ground vegetation. Conversion of fine roots into coarse roots during ageing of the stand was responsible for greater coarse root biomass in the older stands. A significant decline in the contribution of ground vegetation to the mean fine root mass from the youngest to the oldest stand was due to their decreased density in the latter stand.

Fine and coarse root production

Annual production of fine roots was maximum (1054.69 g m^{-2}) in the 6-year old stand while total root production was maximum (1434.87 g m^{-2}) in the 23-year old stand. The production of fine and coarse root did not show any definite seasonal trend. The literature survey revealed a wide variation in fine root production in different forest ecosystems of the world (Table 7.2). This variation

Table 7.2. Fine root production (FRP) in forest ecosystems of the world.

Forest types	FRP(g m^{-2})	Reference
Terra firme forest, Venezuela	1540	Vitousek and Sanford (1986)
Terra firme forest , Venezuela	117	Cuevas and Medina (1988)
Black oak, USA	591	Nadelhoffer *et al.* (1985)
Red oak, USA	524	Ditto
Sugar maple, USA	650	Aber *et al.* (1982)
Red pine, USA	1090	McClaugherty *et al.* (1982)
Mixed hardhood, USA	1140	Ditto
180-year old fir, USA	1708	Vogt *et al.* (1982)
35-year old picea, Belgium	701	Van Praag *et al.* (1988)
6-year old oak, Meghalaya	590	Arunachalam *et al.* (1996a)
13-year old oak, Meghalaya	720	Ditto
16-year old oak, Meghalaya	780	Ditto
6-year old *Pinus kesiya*	1054	Present study
15-year old *Pinus kesiya*	732	Ditto
23-year old *Pinus kesiya*	783	Ditto

could be due to differences in their stand age, species composition, density and soil characteristics.

The maximal fine root production occurred in the top soil layer which had higher SOM, TKN, available-P and soil moisture contents. Ford and Deans (1977) have also attributed high concentration of fine roots in the surface soil layers in *Picea sitchensis* plantation to its higher nutrient concentrations and greater moisture retention capacity.

Role of fine and coarse roots in N and P dynamics

Nutrient concentration in roots varies from species to species and is also influenced by the root diameter diameter (Vogt *et al.* 1991). The present study clearly showed that the concentration of N and P declined from fine to coarse roots. McClaugherty *et al.* (1984) in *Pinus resinosa* and Fogel and Hunt (1983) in *Doughlas fir* stand observed similar trend in N and P concentration of the roots. Nambiar (1987) also found similar results, but did not cite any possible reason for the same. Withdrawal of nutrients from young roots during maturation could be one of the reasons for the lowering of N and P concentration in the older roots.

A comparison of N and P concentrations in the fine roots of various pinus species as well as broadleaved trees revealed higher concentration of N in broad leaved species than the conifers. Among the different species of pine, *Pinus kesiya* had very low concentration of N and P (Table 7. 3).

Table 7.3. N and P concentrations in tree roots of coniferous and broadleaved species.

Species	N (%)	P(%)	Reference
Coniferous species			
Pinus sylvestris	0.57	0.067	Berg (1984
Pinus radiata	1.21	0.080	Nambiar (1987)
White pine	0.93	-	McClaugherty *et al.* (1984)
Red pine	0.93	-	Ditto
Pinus kesiya	0.65	0.051	Present study
Abies amabilis	0.86	-	Vogt *et al.* (1983)
Sitka spruce	1.55	-	Alexander & Fairley (1993)
Broadleaved species			
Sugar maple	1.67	-	McClaugherty *et al.* (1984)
Oak forest	1.18	0.036	Arunachalam *et al* . (1996b)

- = Data not available

The accumulation of N and P in tree roots as well in the belowground biomass of the ground vegetation showed significant monthly variation and decreased with increasing soil depth. Tree roots contributed more N and P in the oldest stand, whereas ground vegetation contributed more in the youngest stand. Seasonal and depth-wise changes in N and P accumulation were mainly influenced by biomass accumulation pattern and the role of nutrient concentration was relatively less important in this regard (McClaugherty *et al.*1982).Khiewtam and Ramakrishnan (1993) and Arunachalam (1996) have also reported a similar accumulation pattern in the subtropical broadleaved forests of Meghalaya. However, the values reported by these workers are higher than those obtained in the present study.

In order to understand the relative importance of litter and roots (fine + coarse) in soil nutrient dynamics in pine forest ecosystem, data of the present study on roots were examined along with the data on litter from Das (1980) who had studied litter dynamics in 7-, 15-, and 22-year old pine stands in the same area. A comparison of data presented in Table 7.4 reveals that mean accumulation of both litter and root mass increased from 6-year old to 23-year old stand. Roots contributed 86-88% to the total organic mass, while the share of litter varied between 12 & 14 % only. Contribution of roots to annual organic matter input to the soil in these forest stands varied between 58 and 65%. Role of litter was

Table 7.4. Comparative analysis of the role of roots (fine + coarse) and litter in soil nutrients (N & P) dynamics in pine forest ecosystem. Data on litter has been taken from Das (1980).

Paameters	6-year old stand		15-year old stand		23-year old stand	
	Litter *	Roots	Litter	Roots	Litter	Roots
I. Organic matter (kg ha^{-1})						
Mean accumulation	558	3908	727	4419	747	5769
	(13)	(87)	(14)	(86)	(12)	(88)
Annual producion	6663	12237	8090	11301	8984	14348
	(35)	(65)	(42)	(58)	(39)	(61)
II. Nutrients (kg ha^{-1})						
N accumulation	5.80	18.73	7.20	20.25	6.94	26.21
	(24)	(76)	(26)	(74)	(21)	(79)
P accumulation	0.47	4.56	0.58	4.79	0.48	7.02
	(9)	(91)	(11)	(89)	(6)	(94)
N input	69.29	57.95	80.09	51.92	83.55	65.70
	(54)	(46)	(61)	(39)	(56)	(44)
P input	5.66	14.00	6.47	11.63	5.83	17.21
	(29)	(71)	(36)	(64)	(25)	(75)
III. Turnover rate (year^{-1})						
Organic matter	0.92	0.76	0.92	0.72	0.92	0.71
N	0.92	0.76	0.92	0.72	0.92	0.71
P	0.92	0.75	0.92	0.71	0.92	0.71

* Litter data were collected from 7-, 15- and 22-year old pine stands.

Values in parentheses are percent of the total relatively less important, as they contributed only 35-42% to the total input. N and P accumulation both in root and litter mass increased with stand age. Roots contributed 74-79% N and 89-94% P, whereas litter added 21-24% N and 9-11% P only. Nutrient input through both litter as well as roots increased from young to old stand. N input through litter was 54-61% and by roots 39-46%. The reverse trend was observed in case of P i.e., roots contributed 64 and 75% and the litter added 25-36% of P.

Decomposition

Contrary to the three phased decomposition pattern observed in the present study as also reported by Arunachalam *et al.* (1996b), McClaugherty *et al.* (1984), Fogel and Cromack (1977), Berg and Staff (1980) reported a two-phased decomposition pattern - an initial phase of rapid weight loss followed by a period of slow decay rate. Rapid rate of decay in all the stands coincided with the rainy season. Rochow (1974), Swift *et al.* (1979) and Bhatt *et al.* (1985) attributed seasonal change in root decomposition rate in the tropical forest ecosystems to the soil moisture condition, ambient temperature and microbial activity. A significant positive correlation between the rate of weight loss and rainfall, air temperature and soil moisture content has been reported by Arunachalam *et al.* (1996b). Annual fractional weight loss (k) (1.77-1.89) was within the range reported for the tropical forest ecosystem (0.3-3; Anderson and Swift 1983), teak forest (0.4-2.8; Singh and

Shekhar 1989a), and montane forest (0.6-1.9; Singh *et al.* 1984). The values are, however, much higher than those reported from the temperate forest ecosystems (0.16; Fogel and Hunt 1979, 0.09-0.12; McClaugherty *et al.* 1982, 0.6; Persson 1982).

Mineralization

N and P release from the decaying root litter was influenced by the seasonal cycle of mineralization and immobilization processes. The former occurred at a rapid rate during rainy season while the latter was dominant during autumn and winter season. Similar seasonal trend has also been reported by Anderson 1973. Annually ca. 53-59% N and 51-58% P content in the roots were mineralized in the three forest stands. These values are comparable with the findings of Arunachalam *et al.* (1996b) in the semievergreen broadleaved forest of Meghalaya. The average rate of nutrient release (N 1.6 mg day^{-1}, P 1.6 mg day^{-1}) did not vary significantly between the young and old stands but annual turnover rate showed an increasing tendency with the stand age. N and P turnover in root was four times higher than the fine litter on the forest floor.

CHAPTER VIII

SUMMARY

Destruction of primary subtropical humid broadleaved forest at higher elevations of Meghalaya has paved the way for the development of secondary *Pinus kesiya* forests on disturbed sites. In fact, *Pinus kesiya* grows luxuriantly between 800-2000 m altitude in the entire north-eastern region of India. The species is commonly used for afforestation purposes because of its ability to establish and grow quickly on poor and denuded sites. The trees are usually planted at close spacing which favours natural pruning and helps in the production of straight and good quality logs.

The main objective of the present investigation was to study the dynamics of fine roots in pine forest ecosystem with special emphasis on their role in organic matter and nutrient (N & P) accumulation and turnover in soils supporting *Pinus kesiya* stands. The role of fine roots in soil organic matter and nutrient dynamics assumes greater significance in the light of their tremendous ability to grow on degraded sites which are characterised by relatively shallow infertile soil. The study was carried out in 6-, 15- and 23-year old pure pine stands located in and around North-Eastern Hill University Campus, Shillong (latitude $25^0 34'$N, longitude $91^0 54'$E and altitude 1500 m asl.) during 1995-1996.

The following major aspects have been covered under the present study :

1. Vertical distribution and seasonal dynamics of fine roots (<2 mm diameter) and coarse roots (>2 mm diameter) in terms of live and dead biomass.
2. Production of fine and coarse roots of pine tree as well as ground vegetation in the pine stands.
3. Resource quality of fine roots of pine trees, their decay and N and P mineralization patterns.
4. Storage of N and P in fine and coarse roots and their turnover in the soil.

Vegetation and soil characteristics

All the three stands were characterised by the presence of two distinct vegetational layers, the upper tree layer comprising *Pinus kesiya* trees and the lower layer composed of grasses, ferns and a large number of annual and perennial weeds. The tree DBH was maximum (19.12 cm) in the oldest stand, but its density declined from 11020 individuals/ha in the 6-year old stand to 730 individuals/ha in the 23-year old stand. The tree seedling density was maximum (32 individuals/m^2) in the 23-year old stand and minimum (3 individuals/m^2) in the 6-year old stand.

Altogether 40 species were present in the ground flora of all the three forest stands. Their total density declined from 116 individuals/m^2 in the 6-year old stand to 75 individuals/m^2 in the 15-year old stand followed by an increase to 107 individuals/m^2 in the 23-year old stand.

Soil texture varied from sandy to sandy clay loam. Bulk density and water holding capacity of the soil increased from the 6-year old stand to the 23-year old stand. CEC, SOC, TKN and available-P decreased with increasing soil depth. TKN, SOC and available-P showed wide monthly variation, and the values were high during winter, and low during rainy season. A comparison of these parameters with that of the oak forest and grassland soils of the adjoining areas clearly revealed the low fertility level of the soil under pine forest ecosystem.

Vertical distribution and seasonal variation in root mass

The vertical distribution of tree fine roots expressed as percent of the total root mass up to 40 cm soil depth showed 32-51% accumulation in the 0-10 cm soil layer, 28-35% in 10-20 cm soil layer, 15-27% in 20-30 cm soil layer and 6.4-12% in 30-40 cm soil layer. Out of the total herbaceous fine roots, 65-66%, 20-26%, 9-14% and 4-6% were distributed in 0-10, 10-20, 20-30 and 30-40 cm soil depths, respectively. Similarly, a major portion (73-79%) of rhizomes was localised in the top 10 cm soil layer and their proportion declined to 2-4% in the 20-30 cm soil depth. Majority of the coarse roots were confined to the 10-30 cm soil layer.

Wide monthly fluctuations were observed in tree fine roots, herbaceous fine roots, coarse roots and rhizomes in all the three forest stands. When monthly data were pooled on the seasonal basis, a seasonal pattern with a high mean biomass during the rainy season and a low during the spring season was clearly evident. The annual means of the fine root and coarse root biomass were maximum in the 6-year and 23-year old stand, respectively.

The contribution of herbaceous fine roots to the total fine root mass was 56% in the youngest stand and 32% in the other two stands.

Root production

The annual fine root production was maximum (1054.69 $g/m^2/yr$) in the 6-year old and minimum (732.16 $g/m^2/yr$) in the 15-year old stand. The coarse root production increased from 169.06 $g/m^2/yr$ in the 6-year old stand to 651.72 $g/m^2/yr$ in the 23-year old stand. As a result, the maximum root production (1434.87 $g/m^2/yr$) was recorded in the oldest stand. The annual root turnover rate, though low (0.73 yr^{-1}), did not vary between the stands.

N and P concentration

N and P concentration in fine roots was significantly higher than the coarse roots. Similarly, herbaceous fine roots had a higher N and P concentration than the rhizome. Live roots always had higher N and P concentration than the dead roots. They showed minor monthly variation without definite seasonal trend.

N and P accumulation

The accumulation of N and P varied between months and declined sharply with increasing soil depth in all the three stands. Nutrient accumulation was maximum during the rainy season and minimum during the spring season. The annual means of N and P storage were maximum in the 23-year old stand and minimum in the 15-year old stand. Herbaceous vegetation contributed about 71% to the total N and P stock in the youngest stand, while in the older stands the major contribution (ca. 70%) to the total nutrient stock in roots was by pine.

Annual N and P input to the soil by tree roots increased with stand age from 6-year old stand (27.94 N & 6.35 P kg/ha) to 23-year old stand (48.96 N & 13.35 P kg/ha), while the inputs by the herbaceous vegetation decreased. The annual turnover rates of k_N was 0.76, 0.73 and 0.73 and k_P was 0.76, 0.70 and 0.72 in 6-, 15- and 23-year old stands, respectively.

Weight loss

During decay, tree fine roots passed through three distinct phases. The initial phase lasted upto 30 days with a slow rate of weight loss (1.13 mg/day), followed by a phase of rapid weight loss (4.1 mg/day) from 30-90 days and the third phase characterized by a slow weight loss (0.7 mg/day) lasted for 90-450 days.

N and P mineralization

Similar to the weight loss pattern, N and P were mineralized in three distinct phases. An initial decline in N and P concentrations marked a phase of nutrient release. This was followed by a phase of nutrient immobilization when a marginal increase in N and P concentration was recorded in the decaying roots. This was again followed by a phase of mineralization.

Organic matter accumulation increased from 3908 kg/ha in the 6-year old stand to 5769 kg/ha in the 23-year old stand annually. And the same was in evidence with respect to the annual production of roots (12237, 11301 and 14248 kg/ha in 6-,15- and 23-year old stands, respectively). The accumulation of N (18.73-26.21 kg/ha) and P (4.56-7.02 kg/ha) increased from 6-year old stand to 23-year old stand. Annual input of N ranged from 57-65 kg/ha and of P from 14.00-17.21 kg/ha. A comparison between the above values on roots and those obtained by Das (1980) on litter (Table 7.4) clearly shows that roots play more important role than the litter in organic matter and nutrient accumulation in *Pinus kesiya* forests stands of varying ages.

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