ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

SEASONAL AND DEPTH RELATED PATTERNS OF FINE ROOT MASS IN FOUR INDIGENOUS TREE SPECIES OF A TROPICAL DRY AFROMONTANE FOREST IN ETHIOPIA

A THESIS SUMITTED TO THE SCHOOL OF GRAGUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN BIOLOGY

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LIST OF ABBREVIATIONS

DBH Diameter at breast height.

FAO Food and Agriculture Organization of the United Nations

FBM Fine root biomass

FNM Fine root necromass

NMA National Meteorological Agency

TFM Total fine root mass

ABSTRACT

The seasonal pattern and vertical distribution (up to 60 cm) of fine root of four indigenous tree species; *Celtis africana* and *Croton macrostachyus*, (deciduous) *Prunus africana* and *Podocarpus falcatus* (evergreens) were investigated in the dry afromontane forest of Munesa-Shashamane, South Ethiopia, using the sequential coring method.

While seasonal changes were more pronounced in the deciduous species compared with the evergreens, marked seasonal changes in total fine root mass, fine root biomass, and fine root necromass were observed in all the studied species. The highest values of measured fine root parameters were recorded during major rain season followed by small rain and dry seasons. In all species, total fine root mass, fine root biomass, and necromass in the major rain season were significantly higher than other seasons. In the two wet seasons, *Croton macrostachyus* had highest total fine root mass, fine root biomass and necromass followed by *Celtis africana, Prunus africana* and *Podocarpus falcatus* in that order. In contrast, in the dry season, generally, the evergreens had higher total fine root mass, fine root biomass and necromass compared with the deciduous species. In the dry season, the highest total fine root mass record was that of *P. africana* and then decreased, in order, from *Croton macrostachyus* to *Podocarpus falcatus* to *Celtis africana*. Further, fine root biomass of *Prunus africana* > *Podocarpus falcatus* >*Croton macrostachyus* > *Celtis africana* in the dry season. Dry season fine root necromass data analysis showed inconsistent results.

Fine root accumulation was significantly largest in the uppermost 10 cm soil layer. A general decrease in total fine root mass, fine root biomass and fine root necromass with increasing depth was recorded for all the species studied in all seasons. The decline in fine root biomass concentration with increasing depth might be attributed to the decreased organic carbon and nitrogen, increased acidity and clay content downwards in the examined soil profile. The distribution of fine root necromass was similar to that of fine root biomass with the highest concentration on the upper surface. This can be expected compared to the lower depths given greatest amount of live fine root biomass in the upper soil profiles that eventually die at the end leading to higher necromass on the upper layers as compared to the lower depths.

The above results are discussed in light of understanding the forest under investigation and its management.

1. INTRODUCTION

1.1. Background

The belowground part of a tree can be roughly seen as a mirror image of the aboveground system, with its specific morphology and function in the soil environment. The root system of a plant or a tree serves both mechanical and biological functions. A tree root system consists of coarse and fine branches (the coarse roots and the fine root). Fine, small and coarse roots are the major components of belowground biomass (Vogt and Person, 1991), and their vertical distribution defines the extent to which they modify soil physical and biological properties at depth. Coarse or woody roots provide support and anchorage, persist well through time and can absorb small amount of water and nutrient. However, those roots that are the most active in absorption of water, nutrient and mycorrhizal formation are the ephemeral fine root (Brundrett *et a*l., 1990). The fine root are usually the high-order laterals that make up most of the surface area of the root system. A symbiotic association between non-woody fine root and mycorrhizal fungi forms the main nutrient-absorbing organ in most trees (Smith and Read, 1997).

According to De Angelis *et al*. (1991), fine root are small but functionally important fractions of tree biomass. Fine root (with diameter < 2 mm) represent a dynamic portion of belowground biomass, nutrient capital and a significant part of net primary production in native and managed ecosystems (Harris *et al*., 1997). Through continuous development and interaction with the soil environment, the belowground part of trees forms a highly heterogeneous and dynamic network in a forest soil. While young rootlets develop, the older parts senesce and eventually die. The dead roots become part of the soil organic

matter, which undergoes decomposition and further mineralization processes that are influenced by abiotic factors and soil organisms. An appreciable amount of the photosynthetically fixed carbon will be incorporated via roots into the soil carbon pool (Atkinson, 1992).

1.2. Root diameter classes

Researchers are inclined to choose root diameter size classes arbitrarily. The commonly used root diameter classes as summarized by Vogt and Person (1991) are: (1) fines roots, < 0.5 mm; (2) fine roots, 0.5-2 mm; (3) Small roots > 2 to 5 mm; (4) medium roots, > 5 to 20 mm; (5) large roots, > 20 mm.

Traditionally, fine root are also classified based on arbitrary diameter classes. There is no standard size class operational definition of the fine root system. Thus, classification criteria vary from study to study (Hendricks *et al*., 2000), because fine root morphology and size class differ between species and even within species across sites (Fitter, 1991). As a result some authors specify fine root as a diameter class ranging from 0-1 mm (Burton *et al*., 2000; Comas *et al*., 2000; Pregitizer *et al*., 2002) while the majority are in favour of the widely accepted diameter class ≤ 2 mm (Hendrick and Pregitizer, 1993a; Tufekeiogl *et al*., 1999; Puttsepp, 2004; Yang *et al*., 2004).

The rationale behind classifying fine root (≤ 2 mm) as one is based on the idea that all roots in this diameter class are structurally and functionally identical (Kosola *et al*., 1995). However, within a given diameter class, roots with different function and structure

(branching pattern) have been reported in different proportion. A notable source of variation within the so-called homogenous unit is the position of fine root in the branching system (branching order), which is believed to control carbon allocation (Guo *et al*, 2004). Pregitizer *et al* (1997) reported significantly different fine root traits like root diameter, specific root length, and nutrient concentration with branching order in two perennial herbs and two tree species of the temperate region. The same study showed that fine root of lowest order and smallest diameter have higher level of metabolic activity. Furthermore, fine root life span has been reported to vary significantly among different diameter classes of fine root of apple (Wells and Eissensat, 2001). The aforementioned studies revealed that diameter based classification can increase the risk of lumping together roots of different branching order and functional group. Several authors stressed the urgent need for a re-evaluation of the widely held diameter-based definition of the fine root and establishment of functional definition in this regard (Wells and Eissensat, 2001; Pregitizer, 2002). According to King *et al*. (2002), what has been termed fine root in the literature is probably a mix of static and dynamic root fraction.

For most tree species; however, subdividing and separating roots into < 1 and > 1 mm in diameter consists of fine ramification with Mycorrhizal root tips that are morphologically very distinctive from the rest of the root system. Roots > 1 mm in diameter tend to be secondary roots in which the epidermis and cortex have sloughed off and xylem has become enclosed by a cylinder of phloem with an outside layer of suberized tissue (Marshal, 1986). These roots increase in diameter by cambial growth. To this effect,

McClaugherty (2003) suggested that fine root should be defined to include root tips and small-diameter roots without secondary growth.

1.3. Root life span

Like other plant organs roots have a life history in which they pass from birth to death. Birth and death rate of the individual roots determine the size and population structure of the root system (Eissensat and Yanai, 2002). The study of root demography is the interest of many science disciplines: ecology, physiology, crop science and soil science. For instance, a good understanding of root demography could enable agronomist and horticulturalist to increase yield while reducing agrochemical inputs. However, growing too many roots may also be disadvantageous as it consumes large amount of carbohydrate and nutrients that could other wise be used by photosynthetic organs or harvested parts (Eissensat and Yanai, 1997).

Root life span has an important implication for plant growth, productivity, belowground carbon dynamics, nutrient cycling and competition (Anderson *et al.*, 2003). According to Wilson (1998), root competition can be more intense and involves many neighbors than shoot competition. Most of the competition among plants take place underground. In contrast to aboveground competitions that primary involves a single resource, light, plants compete for a broad range of soil resources, including water in the belowground. There may be advantages to long lived roots in the capture of limited soil resources just as perennial structure aboveground can give plants a competitive advantage for light capture (Eissensat and Yanai, 1997). Demography of root also influences ecosystem process associated with material and energy flow. Although the aboveground part form a

substantial proportion of the total biomass, the nutrient and organic matter input to the soil through the roots is important for soil fertility maintenance and carbon sequestration (Lehmann and Zech, 1998) and some times fine roots play more important role than the leaf litter. Tree fine root enrich the soil with nutrients and organic matter by rapid turnover (Person, 1979). Thus production and death of fine root can have a substantial influence on ecosystem carbon and mineral nutrient cycling.

Fine root longevity depends on species, climate and soil condition. It can range from weeks to several years (Hendricks and Pregitzer, 1993b). Furthermore, estimates of root life span vary widely with methods (Eissensat and Yanai, 2002). According to the studies made using transparent windows in the soil by Eissensat and Yanai (1997), the median life span of the finest roots ranged from < 20 days in fast growing trees and deciduous fruits to 1 year in slow growing forest trees. In the data set containing 190 studies in non-agricultural ecosystems, based mainly on changes in biomass from sampling soil monoliths, soil cores or in growth cores, average life span ranged from ≈290 days in tropical ecosystem to ≈3 years in high latitude ecosystem (Gill and Jackson, 2000). Recent studies based on tracer approaches have indicated that fine root may live considerably longer-averaging 4-8 years in some temperate forests (Matamala *et al*., 2000; Gaudinski *et al*., 2000). Eissensat and Yanai (2002) argued that although differences in methods contribute substantially to differences in estimates of life span, undoubtedly much of the variation in reported life span is caused by differences in environmental condition and plant species (genetic and environmental factor).

1.4. The role of fine root in forest ecosystems

Forests play an important role in the global carbon cycle because 80% of the carbon stored in terrestrial vegetation is in forest biomass (Olson *et al*., 1985). Forest soil contains around 70% of the total carbon globally (Post *et al*., 1992). Fine root constitute the most dynamic portion of the belowground component and tend to show high turnover rate. For example, Fogel (1983) estimated that annual loss of fine root in forest ecosystems ranges from 40-72% of the standing crop. Even though fine root constitutes a small fraction (< 5%) of a total standing biomass (Gill and Jackson, 2000), their production represents a large proportion of total net primary production in most forest ecosystems (Fogel, 1983; Nadelhoffer and Raich, 1992). Based on 253 fine root biomass field studies in a wide range of ecosystems, Jackson *et al* (1997) estimated that approximately 33% of global net primary production is used for fine root production. According to Fahay and Hughes (1994), fine root production has been found to be equivalent to, or greater than, aboveground litter fall in a number of forests, and may constitute more than half of the net primary production. Up to 67% of annual net primary production is being allocated to fine root in some forest ecosystem (Grier *et al*., 1981).

Accordingly, the flux of carbon through the production and mortality of fine root in forest ecosystem is considered as a major component of terrestrial carbon and nutrient cycle (Grier *et al*., 1981; Ruess *et al*., 1996; Eissensat *et al*., 2000). Fine root production probably constitutes about 30-50% of the carbon being cycled annually through forest ecosystems (Grier *et al*., 1981). Nutrient inputs to the soil via fine root turnover can be as

much as or more than those returned in the aboveground litter (Hendrick and Pregitzer, 1993b). Fine root (including mantles of mycorrhizal fungi) annually cycle ecologically significant amount of N, P, K, Ca, and Mg. For example, 100 kg ha^{-1} $year^{-1}$ of N was cycled through fine root in a mature *Abies amabilis* stand in Washington (Vogt *et al*., 1983). Similarly, Chen *et al*. (2002) revealed that 20 kg ha^{-1} N could be released annually from the fine root in undisturbed, mature Douglas-fir forests in coniferous forest of pacific North West United States.

Fine root production and turnover may be a sensitive indicator for changing soil environment (Bloomfield *et al*., 1996). For example, fine root are to some extent more sensitive indicators of forest nutritional status than it can be provided by foliar analysis (Vogt *et al*., 1993). Foliar analysis may detect deficiencies for certain elements, but only if these deficiencies are major (Helmisaari, 1997). The element concentrations in the fine root may be better indicators of nutritional conditions (Person *et al*., 1995). It has been demonstrated that fine root N content especially (ratios of N: cations) gives good additional information on nutrient status and mineral nutrient requirements of forest trees (Person *et al*., 1995).

For the purpose of forest productivity and vitality, and their relationship with soil resources, the interface between soil nutrient pool and tree roots, as uptake organs to sustain aboveground growth, is of utmost importance. It is also important to use root parameters as indicators of growth potential and nutrient acquisition since it is difficult to describe growth potential using soil analysis unless proper speciation of chemical forms

is carried out, distinguishing forms free for uptake from those that can bound structurally (Rost-Siebert, 1985 cited in Bakker, 1999).

The spatial distribution of fine root biomass in the soil is well related to the availability of nutrients and water. For example, as an adaptation tactic to drought, fine root can redistribute to deeper soil horizon (Persson *et al*., 1995).

In addition, indices derived from fine root morphology such as length-to-weight ratio or specific root length (SRL) and from fine root chemical composition (e.g. nutrient weight proportions in relation to nitrogen (where N= 100%), Ca/Al molar ratio) can sensitively reflect changes in soil qualities (Puttsepp, 2004). At low pH and low base saturation, the molar ratio of base cations to Al in the fine root becomes a critical parameter. The threshold conditions for potential forest impacts from Al stress have been estimated as Ca/Al molar ratio lower than 0.2 in fine root as a threshold for moderate risk, and ratio lower than 0.1 as a threshold for high risk (Cornal and Grigal, 1995). Hence a good understanding of plant root dynamics and quantifying fine root production is crucial to the understanding of ecosystem structure and function**.**

Despite these facts; however, traditionally, roots have not been included as part of field physiological studies of woody plants. Generally, studies on roots are limited and still at their formative stage**.** This is due to two main reasons: First, the importance of fine root in the ecosystem functioning was underestimated for a long time (Persson, 1990). Second, belowground study is labor intensive and costly and hence discourages many.

Therefore, much of the emphasis was given on examining the growth and development of shoot rather than the root system. The study of the aboveground productivity in the forest ecosystem all over the world engaged far greater attention of researchers than the study of belowground productivity. As a result relatively less data are available on belowground productivity. Root biomass data are much more scarce than shoot and most of the available information originates from managed mono- specific forest stands of temperate North America and Europe (Nadelhoffer and Raich, 1992).

Little is known about the dynamics of tropical forest fine root. However, the few data available indicate that fine root turnover rate is higher in the tropics than it is in temperate and boreal forests (Lauenroth and Gill, 2003). Given the generally high root turnover of fine root in the tropics, their role in carbon and nutrient cycling might be higher compared to their role in the temperate forests.

Tropical montane forests are generally acknowledged for their wide range of environmental services (FAO, 2003). They fulfill important functions with respect to hydrology and slope stability in mountains. They ensure hydrological stability of river basins by balancing discharge at low sediment yield and keeping water quality high. Montane forests typically grow on steep slopes at elevations with moderate to high rainfall where a high potential for soil erosion exists. Size, structure, and dynamics of tree root systems are likely to be key factors for slop stability and nutrient retention (Hertel *et al*, 2003).

A characteristic property of tropical montane forests is the accumulation of considerable amount of carbon on the forest floor and in the mineral soil, which distinguishes them from most lowland forests (Tanner, 1985). A large fraction of the carbon and nutrient pool accumulated in the soil is likely to originate from dying fine root (Bloomfield *et al*., 1993). Thus, production rate and turnover of fine root are key processes in the carbon budget of montane forest.

Montane forests are among the most vulnerable ecosystem on Earth (Monasterio *et al*., 1987). As these forests grow in highly vulnerable environment and are vanishing at an alarming rate (FAO, 2005), they have emerged more recently as a matter of particular interest in scientific research and land use planning. To warranty the benefit from tropical montane for the future, this resource needs to be managed in a sustainable manner integrating all aspects of production, conservation and rehabilitation. This requires among others knowledge of structure and function of the forest. Knowledge of the structure and function of tropical forest is often limited by lack of information on plant root dynamics. In the mean time tropical forests, including the Afromontane forests in Ethiopia, are being destroyed at an alarming rate (Legese Negash, 1995). The dry Afromontane forest of Munesa-Shashamane is not an exception. It has been under major disturbance mainly by shifting cultivation, clear felling or selected cutting of the trees for timber and fuel wood purposes (Asferachew Abate, 2004).

Management practices that ensure sustainable forest ecosystems need basic information on fine root biomass production and turnover. However, this is not the case in the tropics.

While many studies in the tropics have concentrated upon estimates of above ground litter fall (e.g. Proctor, 1984; Vitousek and Sanford, 1986), fewer have focused on the belowground processes. Moreover, Compared to tropical low lands, few studies have focused on root systems of tropical montane forests partly due to the severe logistic and methodological problems (Hertel *et al*., 2003). As a result, published data on the fine root biomass and necromass estimates in tropical montane forests trees are scarce. On the other hand, the seasonal differences in leaf production between deciduous and evergreen species have been well studied (Aerts, 1995). However, seasonal differences in root production and death are poorly documented (Joslin *et al*., 2001).

In Ethiopia, as to our knowledge, tree fine root biomass studies almost did not exist so far, except for a study made on tree fine root of two indigenous and two exotic species at Munesa- shashamane forest by Asferachew Abate (2004). Fine root seasonal patterns of ecologically contrasting deciduous and evergreen species at a time has not been studied. The present study originated in recognition of these deficiencies.

2. OBJECTIVE

2.1. General objective

The general objective of this study is to investigate the seasonal patterns and vertical distribution of fine root of four indigenous tree species of a tropical montane forest in Ethiopia.

2.2. Specific objectives

1) To compare seasonal differences of fine root biomass and necromass among deciduous and evergreen tree species.

2) To assess fine root vertical distribution and seasonal variation in four indigenous tree species.

3) To provide information on fine root phenology of four indigenous tree species.

3. DESCRIPTION OF THE STUDY AREA

This study was conducted at Munesa-Shashamane forest, South East Ethiopia. It is located about 240 km south of Addis Ababa. Munesa Shashamane forest lies within latitudes $7^{o}12'$ and $7^{o}32'$N and longitudes $38^{o}45'$ and $38^{o}56'$E and covers an altitudinal range between 2100 and 2700 meters above sea level. As in other parts of Ethiopia, Precambrian rock forms the basement of the study area (Mesfin Weldemariam, 1972). The soils are derived from weathered parent volcanic rocks, mainly reddish in color, freely draining, and are of medium to heavy texture, and humic ferralsol (Ludgren, 1971).

The clay content increases with depth whereas the proportion of sand showed a marked decline with depth. The soil is acidic and pH varies from 5.4 in the upper (0-15 cm) layer to 4.7 in the lower 30-60 cm (Table 1). Soil organic carbon and total nitrogen showed a declining tendency with soil depth (Table 1). The main rain season extends from mid June to mid October with maximum rainfall occurring between July and August. There is also a small rain season called "Belg Rain" between March and May. The mean monthly temperature ranges between 15.8 and 18.79 ^{0}C. The dry season of the area extends from November to February (Fig. 2). The mean annual rainfall calculated for the area based on ten years data (1996-2005 G.C) collected from Degaga (2000 m.a.s.l) station was about 1067 mm, out of which 68.74 percent occurred during the major rain season while the remaining 24.47 and 6.79 percent was recorded in the small rain and dry seasons, respectively.

The vegetation of the area can be categorized as belonging to the dry afromontane evergreen forest. The upper story of natural forest consists almost entirely of *Podocarpus falactus* (Thumb.) R. Br. ex Mirb. In the intermediate and lower storys, the most common species include. *Maesa lanceolata* Forssk., *Allophylus abysinicus* (Hochst.) Radkl. , *Prunus africana* (Hook. F.) Kalkman, *Apodytes dimidiata* E. Mey. And Arn., *Bersama abyssinica* Fresen., *Buddleja polystachya* Fresen., *Croton macrostachyus* Hochst. Ex Endl., *Dombeya torida* (J. F. Gmel.) P. Bamps., *Dovyalis abyssinica (A.* Rich*)* Warb., *Hagenia abyssinica* (Bruce) J. F. Gmel., *Myrsine melanophloeos* (L.) R.Br., *Teclea nobilis* Del. and *Veronia auriculifera* Hiern (Chaffey, 1979; Gemedo Dalle, 1999).

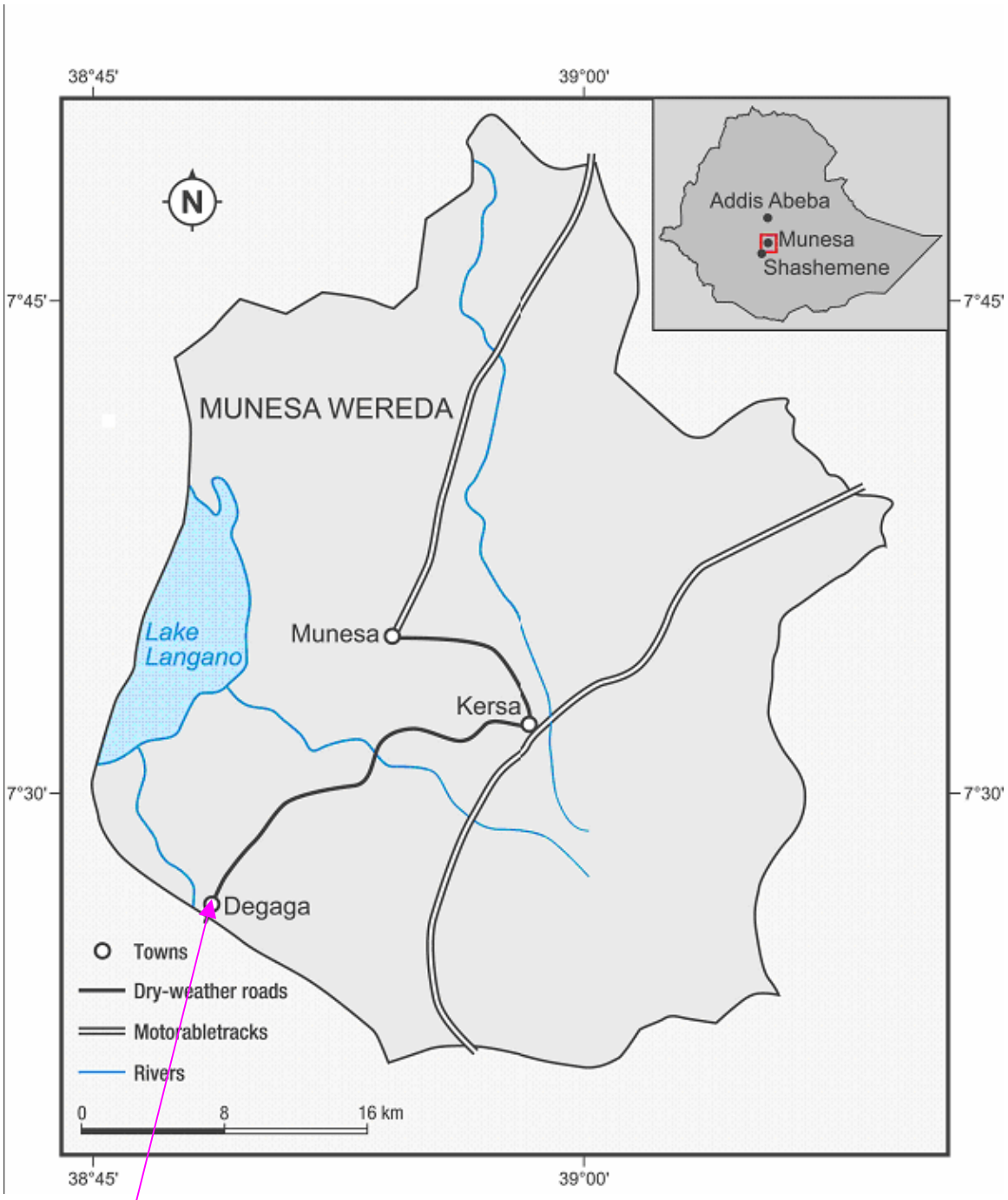

Fig. 1 Location of the study area

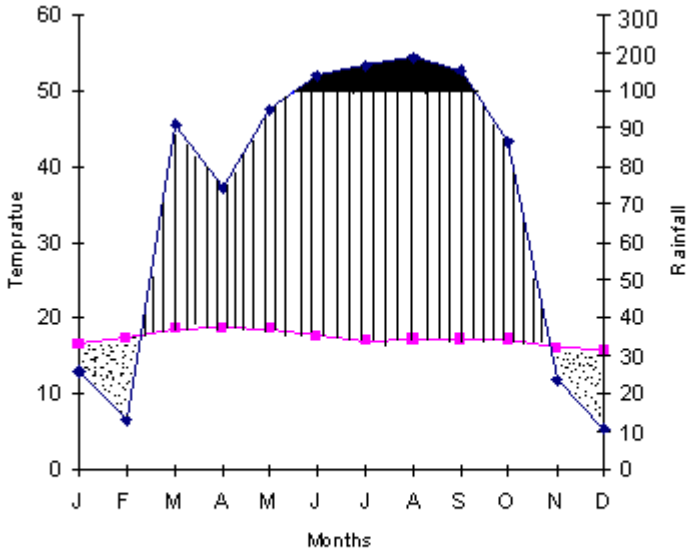

Fig.2 Klimadiagramm of the study area. Dry periods are dotted, wet periods are hatched or blacked (for periciptation above 100 mm).

Table 1. Soil characteristics of the study area in the natural forest

		Soil texture			Soil	
Soil depth	pH	Sand (%)	Silt (%)	Clay (%)	Organic carbon g kg^{-1}	Nitrogen g kg^{-1}
0-15	5.4	20	30	50	61.3	5.2
15-29	5.3	23	23	54	32.3	3
29-68	4.7	8	18	74	28.8	2.4
68-108	4.5	8	18	74	17.4	1.7

Source: Yeshanew Ashagrie 2004

4. MATERIAL AND METHODS

4.1. The study species

Four tree species were selected for the present study. Two are evergreen (*Podocarpus falcatus* (Thunb.) R. Br. ex Mirb., *Podocarpaceae* and, *Prunus africana* (Hook.F.) Kalkman., *Rosaceae*) and the remaining are deciduous (*Croton macrostachyus* (Hochst.) Del., *Euphorbiaceae* and *Celtis africana (*Brum.*)* F., *Ulmaceae)*. *Podocarpus falcatus* is the only representative of the family found in Ethiopia and is a climax and highly demanded timber tree. *Croton macrostachyus* is the most common pioneer species in the study area. *Celtis africana* is a deciduous canopy tree in the study area. *Prunus africana* represents intermediate and lower story species of the area.

4.2. The study approach

The most important factors that affect biomass accumulation in the forest trees are: site quality, standing age, standing density and genetic variation (Satoo and Madwick, 1982). Thus, in order to make useful assessment, biomass estimations mainly focus on assessing the biomass of single species under different site conditions (Helmisaari *et al*., 2002), single species with different age group (Laclaus *et al*., 2000) and different species of a similar age under similar conditions (Wang *et al*., 2000). To make sound fine root biomass estimations and comparisons across seasons between deciduous and evergreen species, the present study investigated different species under similar site condition. Owing to difficulties in determining age in the natural forest of the study area; however, trees of similar diameter at breast height (DBH) class were selected for root biomass

investigation. Three study sites were selected based on co-occurrence of the study tree species and ease of finding trees of similar DBH.

4.3. Sample collections

Samples were collected in the months of May, August, and January 2006 for the small rain, major rain and dry season, respectively. They were taken using systematic random sampling from three individuals of each tree species in three directions at three points around the bole at 1 meter horizontal distance deep into 60 cm (0-10, 10-20, 20-30, 30-60). A corer with 8 cm inner diameter and 25 cm length with a sharpened tip was driven into the ground to the desired sampling depth using a plastic hammer weighing 5 kg. Cores of similar depth of the same tree were mixed giving us four samples per tree per season i.e. 12 samples per species per season. Therefore, a total of 144 (4x4x3x3) samples were collected for the three seasons. A point sampled once was not sampled again to avoid disturbance of rooting environment.

4.4. Sample storage and processing

Processing soon followed sample collections. In case of delay, roots were stored in a refrigerator at about 4 ^{0}C. Fine root were separated from the soil by soaking in water and then gently washing them over a series of sieves with a mesh size of 2.8, 2, 1 and 0.5 mm. All roots that were 2 mm or less in diameter represented fine root class in this study. At sample collection sites live fine root of *Celtis africana* were whitish whereas those of *Croton macrostachyus* were yellowish. *Podocarpus falcatus* and *Prunus african* had similar colors they differed only by the distribution of nodules on the surface, *P. falcatus*

having clustered nodules whereas *P. africana* with scattered ones. No attempt was made to distinguish dead fine root into species because they were all dark in color. However, as long as root sampling is confined within 1 m horizontal distance from the bole of a tree distanced from other trees and shrubs, taking care of the herbaceous roots (without secondary thickenings) one can be sure that almost all of the fine roots are from that particular tree (Hertel D. Pers. Comm.).

Separation into live and dead fractions in the lab was done using a combination of visual and mechanical techniques based on the elasticity of their tissue and the color of the cortex. Live roots are usually pale-colored, elastic, and are free of decay whereas dead roots are black, broken easily, and in various stage of decay. The separated live and dead fine roots were oven dried at 70 ^{0}C to constant weight and dry weight was recorded. Results were calculated in dry mass per volume basis. And the volume calculated as $\pi r^2 h$. Where, r is the radius of the core (4 cm (0.04m)) and h is the height of the required depth.

4.5. Data Analysis

Data on biomass and necromass, vertical distribution of fine root biomass and necromass were generated for each species.

All the data collected were subjected to analysis of variance (ANOVA) test (SPSS/Pc$_+$, statistical package, and version 13). Multiple comparisons of means were carried out using Tukey's Honestly Significant Difference (HSD). Significances level was defined at $\alpha = 0.05$.

Table 2. DBH of the studied tree species.

	DBH (m)			
Species	Site 1	Site 2	Site 3	Mean
Celtis africana	0.36	0.37	0.39	0.37
Croton macrostachyus	0.35	0.36	0.37	0.36
Podocarpus falcatus	0.34	0.35	0.35	0.34
Prunus africana	0.35	0.35	0.34	0.34

Fig. 3 The corer (right) and hammer (left) used for fine root sampling.

5. RESULTS

5.1. Small rain season

5.1.1. Total fine root mass (Sum of Biomass and Necromass)

Total fine root mass (sum of live biomass and necromass) (here after also referred to as TFM) of all the study species in the small rain season is presented in Fig. 4a. There was a large variation in TFM among species during the small rain season. However, these variations were not statistically significant (P>0.05). It ranged from 706.61 to 1061.11 g/m^3 .The highest value was that of *Croton macrostachyus* and the lowest was of *Podocarpus falcatus*. *Celtis africana* and *Prunus africana* had TFM of 893.8 and 883.22 g/m^3, respectively. The two deciduous tree species total is significantly higher as compared to the evergreens.

5.1.2. Fine root biomass

In this season, fine root biomass (live fine root mass) here after also referred to as FBM varied highly among the study species. Similar to the TFM, *C. macrostachyus* was with the highest FBM (725.33 g/m^3) followed by *C. africana* 616.62 g/m^3. The remaining two evergreen species: *P. africana* and *P. falcatus* had FBM of 584.03 and 432.87 g/m^3, respectively (Fig. 4b). The mean differences were not statistically significant (P>0.05).

5.1.3. Fine root necromass

Small rain season fine root necromass (dead fine root mass) here after also referred to as FNM is shown in Fig. 4c. Other than *P. africana*, that had slightly more necromass (299.19 g/m^3) as compared to *C. africana* (277.18 *g*/m^3), similar tendency in FNM like TFM and FBM was observed. *C. macrostachyus* had the highest (335.78) and *P. falcatus* the lowest (273.74 g/m^3) record. The mean differences between species were not statistically significant. Still the two deciduous species together had more necromass compared with the evergreen total.

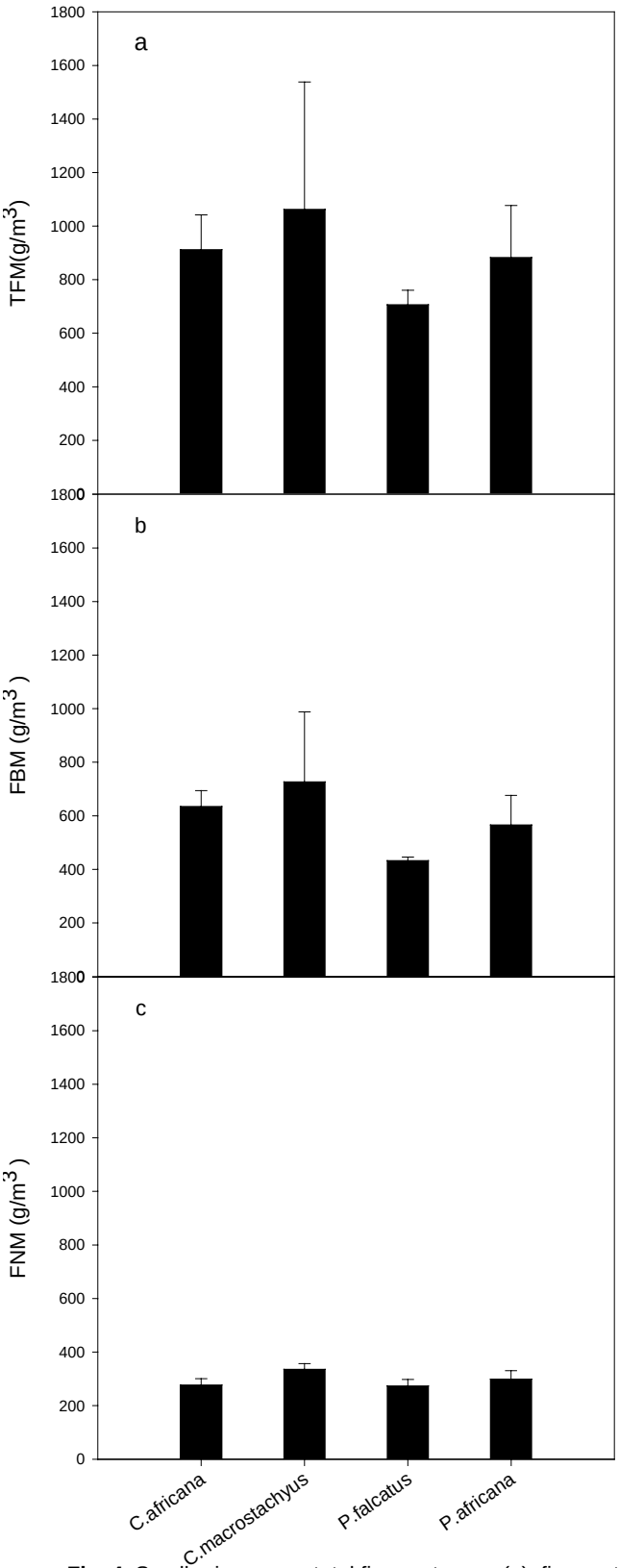

Fig. 4. Small rain season total fine root mass (a), fine root biomass (b), and fine root necromass (c) of all study species

5.1.4. Vertical distribution

All the studied species showed a decreasing pattern of TFM with increasing soil depth (Fig. 5a). Overall in this season, 64.9 % of TFM was present in the top 10 cm soil layer and it declined significantly with increase in soil depth. The lowest depth (30-60 cm) had only 3.7 % of TFM.

FBM of all the studied species showed a decreasing pattern with increasing depth (Fig. 5b). In all species, 62.3 - 67.3 % of FBM was concentrated in the upper 10 cm soil layer. This sharply declined to 17.13 - 19.34 % in the 10-20 cm soil layer, 10 - 12.8 % in the 20-30 cm layer, and 2.1 - 4.1 % in 30-60 cm soil layer.

FNM vertical distribution is shown in Fig. 5c. Except for *C. macrostachyus*, which had slightly more TFM at depth 20-30 cm than depth 10-20 cm, all the studied species had decreased FNM with increased soil depth. The upper 10 cm contributed 71 % of FNM while the lowest 30-60 cm accounted for 3.47 % only.

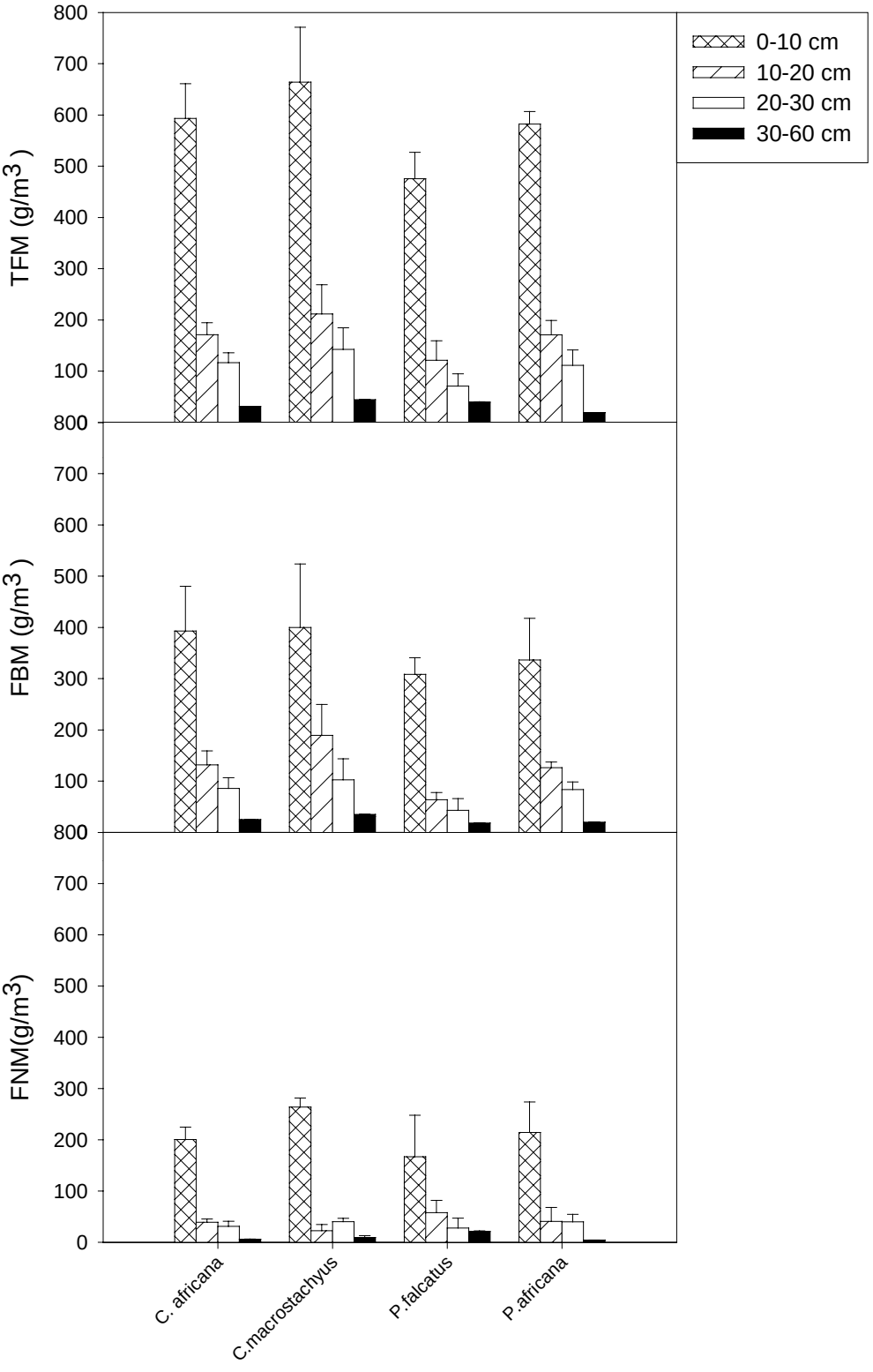

Fig. 5 Small rainy season vertical distribution of total fine root mass (a), fine root biomass (b), and fine root necromass (c).

5.2. Major rain season

5.2.1. Total fine root mass

Like small rain season, in the main rain season too, *C. macrostachyus* had the highest total fine root mass (2512.66 g/m^3), followed by *C. africana* (1960.52 g/m^3). *P. africana* and *P. falcatus* had total fine root mass of 1541.93 and 1011.81 g/m^3, respectively (Fig. 6a). The two deciduous species total is significantly higher when compared with the evergreens total. However, mean differences among species were not statistically significant (P>0.05).

5.2.2. Fine root biomass

Fine root biomass of the study species in the major rain season is shown in Fig. 6b. C. *macrostachyus* had FBM (1729.6 g/m^3) followed by *C. africana* (1630.55), *P. africana* (1058.08*)* and *P. falcatus* (541.16 g/m^3).

5.2.3. Fine root necromass

Fine root necromass ranged between 329.63 and 783.06 g/m^3**.** The highest value was that of *C. macrostachyus* and the lowest was recorded for *C. africana*. *P. africana* and *P. falcatus* had 483.85 and 470.65 g/m^3 FNM, respectively (Fig. 6c). Still the two deciduous tree species together had slightly more fine root necromass as compared to the evergreens.

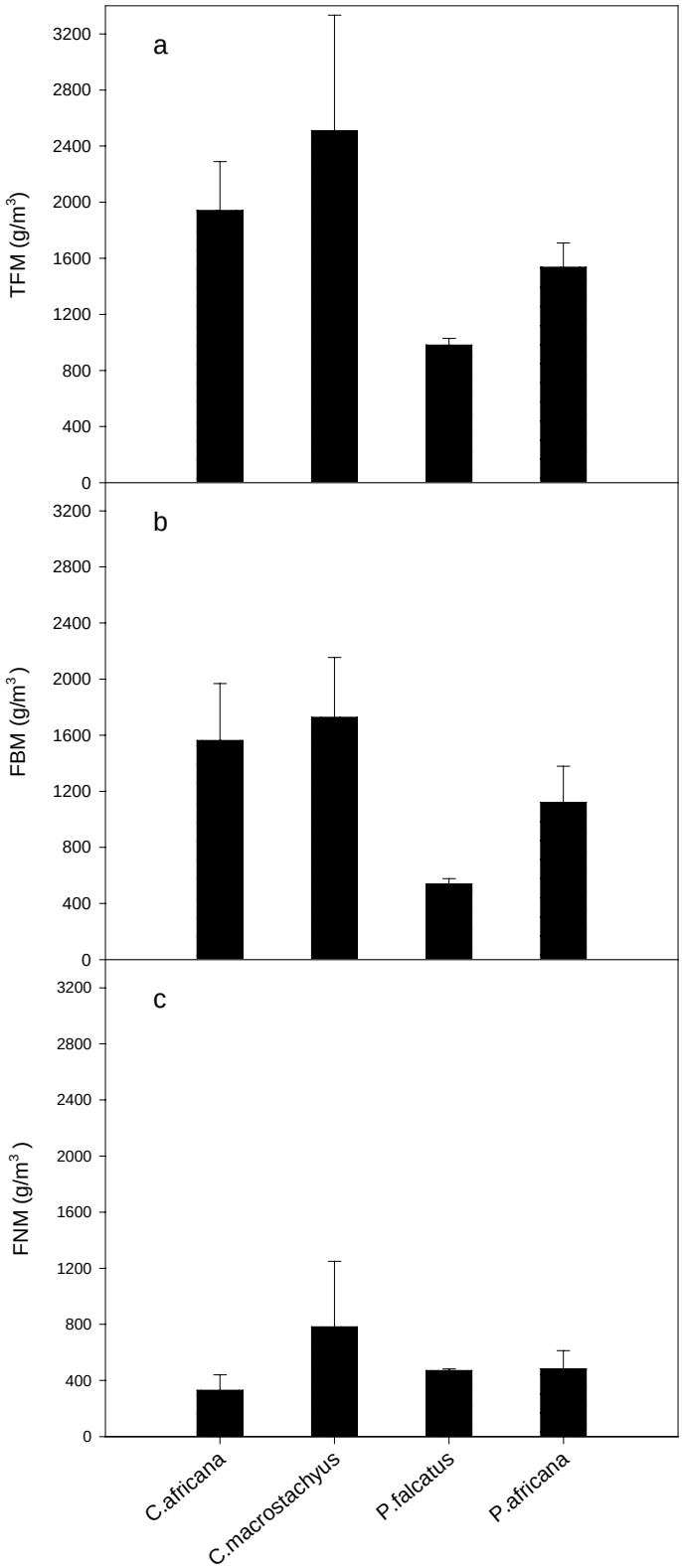

Fig. 6. Major rain season total fine root mass (a), fine root biomass (b), and fine root necromass (c) of all study species.

5.2.4. Vertical distribution

Total fine root mass of all the studied tree species showed a sharp decline with increasing depth (Fig. 7a). Between 47.4 to 61.8 % of TFM was concentrated on the upper 10 cm soil layer. It dropped to, and ranged from 25.7 to 37.18 % in the 10-20 cm soil depth, 8.5 to 14.6 % in the 20-30 cm soil depth. The lowest depth (30-60 cm) accounted for 0.9 to 2.9 % of the total fine root mass in the studied species during the major rain season.

Fine root biomass also decreased from the top downwards (Fig. 7b). Over all, 55 % of FBM was present in the upper 10 cm soil layer, 29 % in the 10-20 cm, and 13.2 % in the 20-30 cm. In the lower soil depth (30-60cm), 2.8 % of FBM was available.

Fine root necromass also declined sharply with increased depth (Fig. 7c). FNM proportion of the upper 10 cm soil layer was 57.8 %. The 10-20 cm depth interval accounted for 27.7 %. The lower depth intervals 20-30 and 30-60 cm accounted for 11 and 3.5 %, respectively.

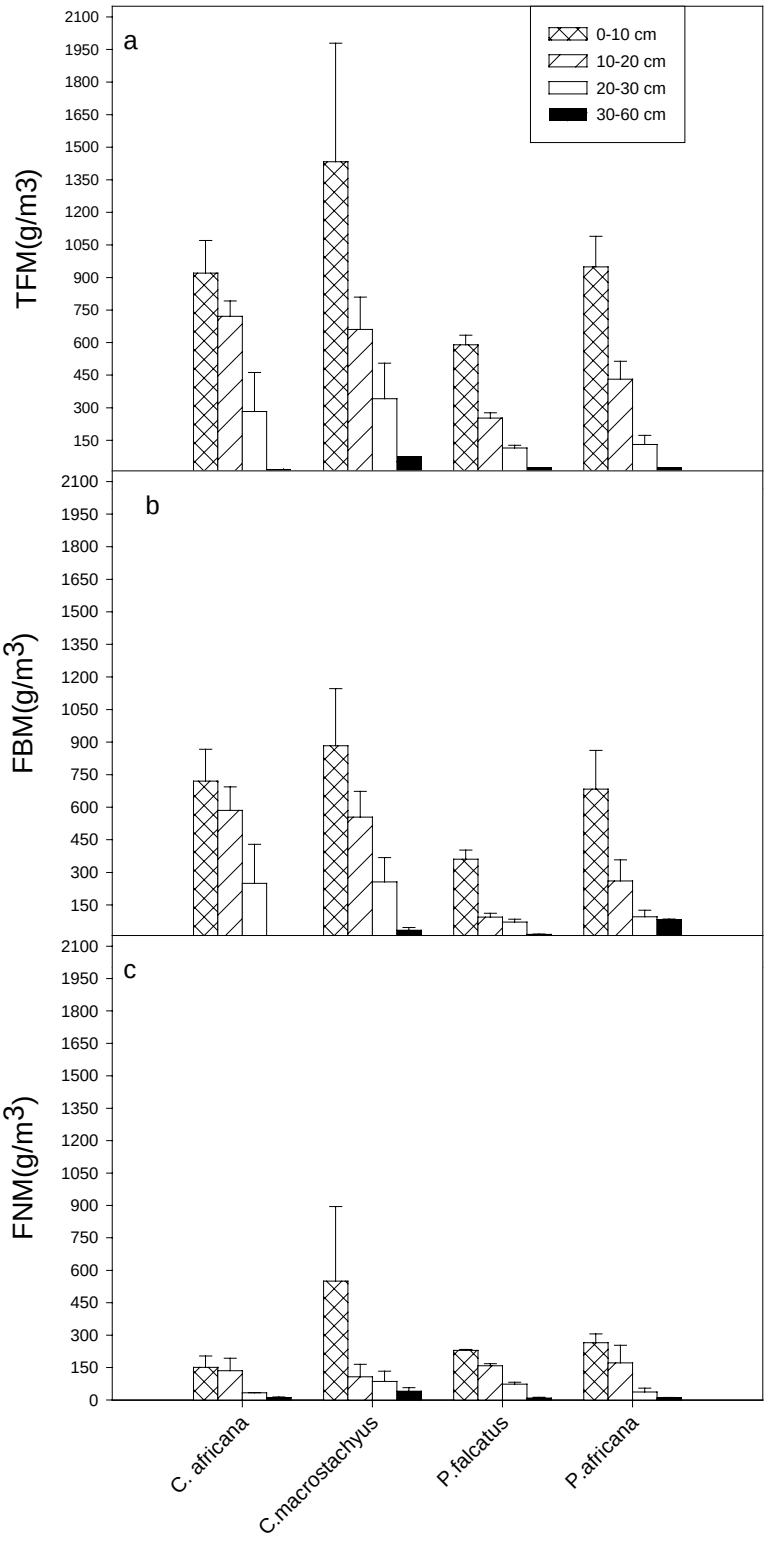

Fig. 7 Major rainy season Vertical distribution of total fine root mass (a), fine root biomass (b), and fine root necromass (c)

5.3. Dry season

5.3.1. Total fine root mass

As indicated in Fig. 8a different features were observed with respect to total fine root mass in relation to the two wet seasons. Contrary to the wet seasons, the highest fine root total mass record was that of *P. africana* (766.59) followed by *C. macrostachyus* (569.11 g/m^3). *P. falcatus* and *C. africana* had TFM of 548.69 and 490.67 g/m^3, respectively. Total fine root mass of the two evergreen species together was higher than the deciduous total.

5.3.2. Fine root biomass

In the dry season, different FBM feature was observed in relation to the wet seasons. The two evergreen tree species had more fine root biomass as compared with their respective deciduous species. *P. africana* produced the highest FBM (584.03 g/m^3) followed by *P. falcatus* (449.16 g/m^3).The remaining two deciduous species: *C. macrostachyus* and *C. africana* produced FBM of 410.72 and 308.53 g/m^3, respectively.

5.3.3. Fine root necromass

Dry season fine root necromass ranged from 99.53 to 182.14 g/m^3. The highest record was that of *C. africana* (182.14 g/m^3) and the lowest was of *P. falcatus*. *P. africana* and *C. macrostachyus* had 182.56 and 158.39 g/m^3 in that order. The two deciduous tree species together had more FNM than the evergreen total.

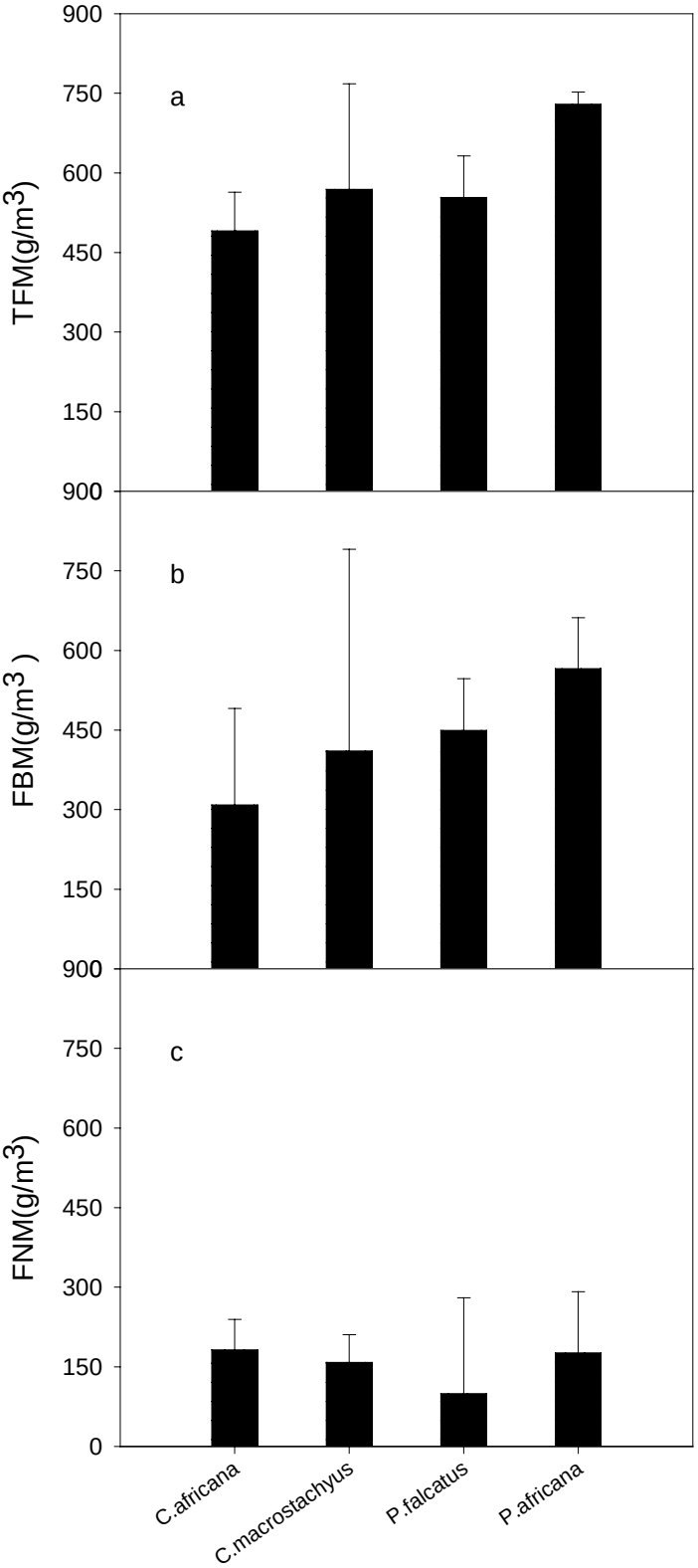

Fig. 8. Dry season total fine root mass(a), fine root biomass(b), and fine root necromass(c)

5.3.4. Vertical distribution

In the dry season too, total fine root mass declined sharply with depth (Fig. 9a). 55.29 to 60.76 % of the studied species TFM was concentrated in the upper 0-10 cm soil layer. Declined sharply, and ranged between 21.67 and 25.47 %, 13.95 and 20.38 %, 0.69 and 2.65 % in the depth intervals 10-20 cm, 20-30 cm, and 30-60 cm, respectively.

Similar trend was seen in fine root biomass (Fig. 9b). 62.62 % of FBM was concentrated in the upper 10 cm soil layer, which significantly dropped to 20.35 % in the 10-20 cm, 14.58 % was present in the depth interval 20-30 cm. The lowest depth (30-60 cm) sheltered 2.45 % of FBM.

Fine root necromass vertical distribution in the dry season is given in Fig. 9c. With increasing depth, fine root necromass decreased. 46.06 % of fine root necromass was concentrated in the upper 10 cm, 32.62 % in the 10-20 cm soil depth. The lower depths 20-30 and 30-60 cm FNM proportions were 18.73 and 2.59 %, respectively.

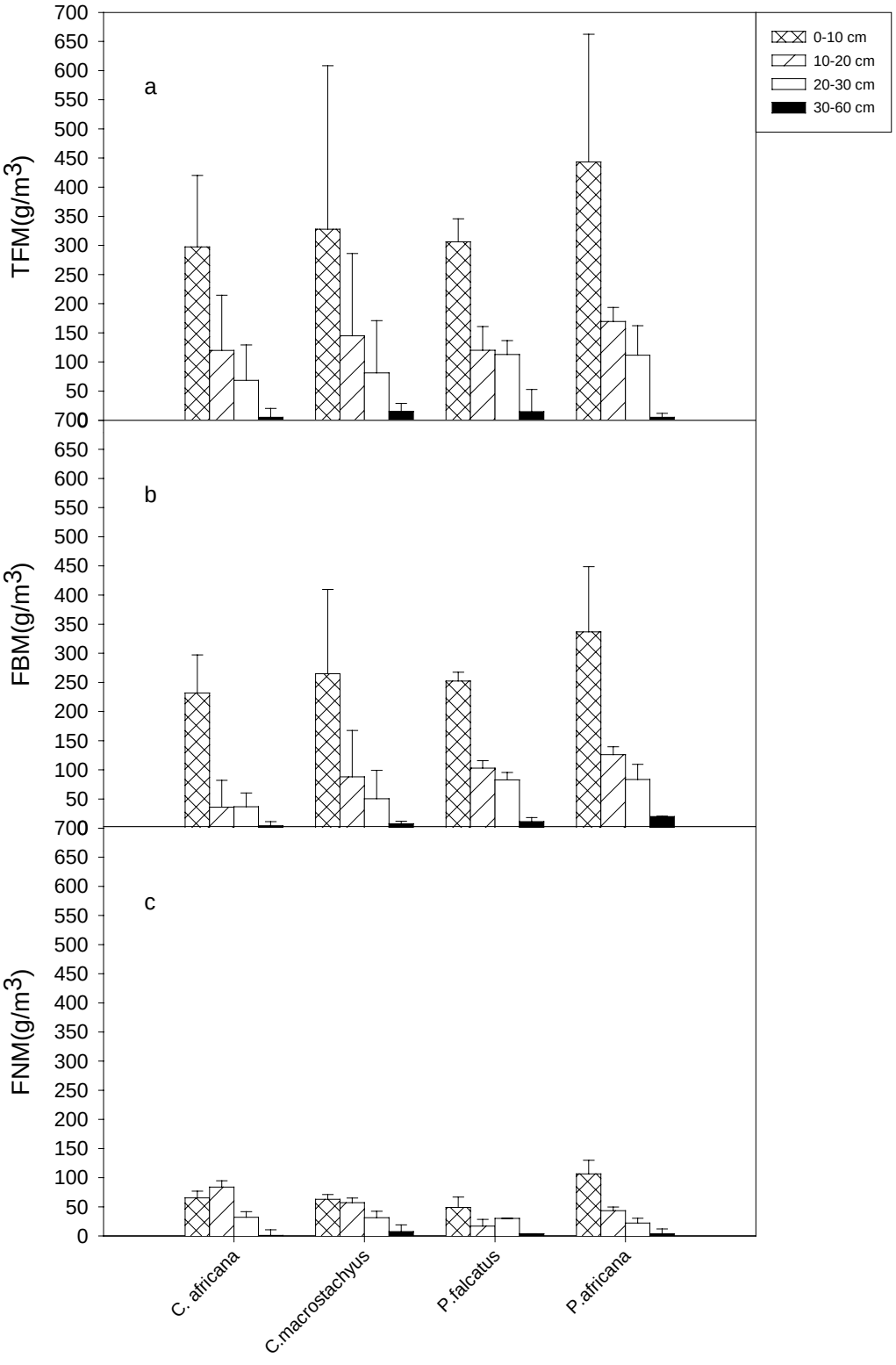

Fig.9. Dry season vertical distribution of total fine root mass (a), fine root biomass (b), and fine root necromass (c)

5.4. Seasonal variations

5.4.1. Total fine root mass, fine root biomass and necromass

Marked seasonal variation in the amount of total fine root mass, fine root biomass and necromass were observed in all the studied species. There were significance differences in fine root total mass of all the studied species among seasons ($P<0.05$). Maximum TFM was measured in the major rain season for all species followed by small rain and dry seasons (Fig. 10a).

Fine root biomass varied with seasons. Except, between small rain and dry seasons in the two evergreen species, seasonal differences in fine root biomass were significant ($p<0.05$). All species registered maximum FBM in the major rain season. However, species differed in their minimum biomass period. The two deciduous species had their minimum in the dry season. Whereas P. *africana* had equal FBM both in the small rain and dry seasons (584.03 g/m^3). Contrary to this, *P. falcatus* had slightly more FBM (449.16 g/m^3) in the dry season than small rain season (432.87 g/m^3) (Fig. 10b).

The accumulation of fine root necromass changed with seasons. All the studied species had maximum FNM during major rain season and minimum in the dry season. Except between small rain and dry seasons for *C. africana* the difference among seasons in all the studied species were significant ($P<0.05$).

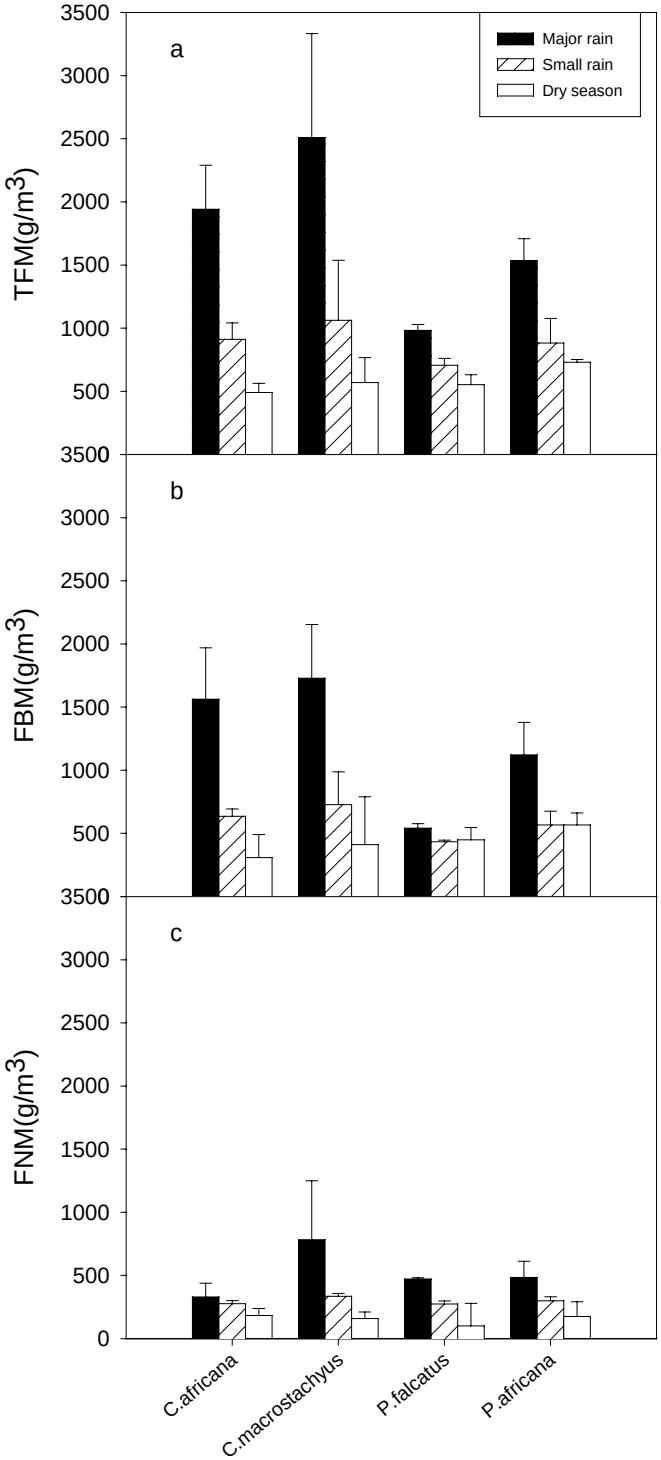

Fig. 10 Seasonal comparison of total fine root mass (a), fine root biomass (b), and fine root necromass (c)

5.4.2. Seasonality with depth

Depth-wise seasonal comparison of TFM for each studied species is shown in Table 3. All species had maximum TFM in the major rain season followed by small rain and dry season at all depths. Except for the major rain season TFM, that had showed significant difference with both small rain and dry seasons at depth intervals 0-10 and 10-20 cm depth- wise variations within species among seasons were not significant (P>0.05).

Table 3. Seasonal variations of total fine root mass (g/m^3) across depth within a species

		Depth (cm)			
Species	Season	0-10	10-20	20-30	30-60
C. africana	Small rain season	593.19[a]	170.91[a]	116.73[a]	12.97[a]
	Major rain season	938.8	721.23	282.86[a]	17.29[a]
	Dry season	297.48[a]	119.6[a]	68.49[a]	5.1[a]
C. macrostachyus	Small rain season	663.90[a]	211.62[a]	142.58[a]	44.48[a]
	Major rain season	1433.83	661.23	341.91[a]	74.19[a]
	Dry season	327.85[a]	145[a]	81.33[a]	14.93[a]
P. *falcatus*	Small rain season	475.36[a]	121.1[a]	70.73[a]	39.42[a]
	Major rain season	590.16	252.85	145.01[a]	23.79[a]
	Dry season	301.18[a]	120[a]	112.83[a]	14.68[a]
P. africana	Small rain season	582.09[a]	170.82[a]	111.33[a]	18.98[a]
	Major rain season	948.89	431.71	131.41[a]	29.93[a]
	Dry season	467.45[a]	169.43[a]	112.69[a]	17.52[a]

Means followed by the same letter in a column of the same species are not significantly different.

Depth-wise distribution of the studied species' fine root biomass also varied among seasons (Table 4). Maximum fine root biomass for all species was in the major rain season followed by small rain season at all depths. Exceptions were *P. falcatus*' higher FBM during the dry season at depth interval 10-20 and 20-30 cm than in other seasons and more *P. falcatus*' FBM during small rain than the major rain season at depth interval 30-60 cm. Moreover, *P. africanas*' higher FBM in the dry than small rain season at depth interval 20-30 cm

Table 4. Seasonal variations of fine root biomass (g/m^3) across depth within a species

		Depth (cm)			
Species	Season	0-10	10-20	20-30	30-60
C. africana	Small rain season	392.67[a]	131.59[a]	85.47[a]	6.89[a]
	Major rain season	770.08	585.89	249.57[a]	25.01[a]
	Dry season	232.01[a]	35.85[a]	36.56[a]	4.11[a]
C. macrostachyus	Small rain season	400[a]	189.20[a]	102.55[a]	33.58[a]
	Major rain season	883.58	554.48	256.52[a]	35.029[a]
	Dry season	264.99[a]	88.15[a]	50.18[a]	7.4[a]
P. falcatus	Small rain season	308.47[a]	63.40[a]	43.02[a]	17.98[a]
	Major rain season	360.73	94.35[a]	71.17[a]	14.91[a]
	Dry season	252.4[a]	102.93[a]	82.86[a]	10.97[a]
P. africana	Small rain season	367.74[a]	130.08[a]	71.54[a]	14.67[a]
	Major rain season	683.27	260.13[a]	94.87[a]	19.81[a]
	Dry season	360.77[a]	126.11[a]	83.34[a]	13.81[a]

Means followed by the same letter in a column of the same species are not significantly different.

Analysis of seasonal variations of necromass accumulation within a species under similar depth among seasons revealed inconsistent results. *C. africana* had higher FNM accumulation during small rain season than in other seasons at depth interval 0-10 cm. It was much higher to slightly more in dry season than small rain season at depth interval 10-20 and 20-30 cm, respectively. For *C. macrostachyus*, at all depths, FNM was much higher during major rain season than small and dry seasons. Small rain season measurement of *C. macrostachyus* FNM was also higher compared with dry season at all depths, except at depth interval 10-20 cm, where dry season measurement was higher. *P. falcatus* generally had more FNM during the major rain season than both small rain and dry season. Exception was depth interval 30-60 cm where more FNM accumulation during small rain season than major rain season was observed. Depth-wise comparison between small rain and dry season showed more FNM during small rain seasons at all depths apart from depth interval 20-30 cm where dry season FNM was slightly more. *P. africana* had much more FNM accumulation during major rain season at all depths than the other seasons; exception was slightly higher small rain season measurement at depth interval 20-30 cm. Also, apart from depth interval 10-20 cm, small rain season FNM was higher than that of the dry season at all depths.

Table 5. Seasonal variations of fine root necromass (g/m^3) across depth within a species

Species	Season	Depth (cm)			
		0-10	10-20	20-30	30-60
C. africana	Small rain season	200.52[a]	39.32[a]	31.26[a]	6.08[a]
	Major rain season	150.63[a]	135.32[a]	33.28[a]	10.4[a]
	Dry season	65.47[a]	83.75[a]	31.93[a]	0.99[a]
C. macrostachyus	Small rain season	263.9[a]	22.42[a]	40.03[a]	9.43[a]
	Major rain season	550.25[a]	106.75[a]	85.39[a]	40.67[a]
	Dry season	62.86[a]	56.85[a]	31.15[a]	7.53[a]
P. falcatus	Small rain season	166.89[a]	57.7[a]	27.71[a]	21.44[a]
	Major rain season	229.43[a]	158.5[a]	73.84[a]	8.88[a]
	Dry season	48.78[a]	17.07[a]	29.97[a]	3.71[a]
P. africana	Small rain season	214.35[a]	40.74[a]	39.79[a]	4.31[a]
	Major rain season	265.62[a]	171.57[a]	36.54[a]	10.12[a]
	Dry season	106.68[a]	43.32[a]	28.85[a]	3.71[a]

Means followed by the same letter in a column of the same species are not significantly different.

6. DISCUSSION

6.1. Seasonal variations

Fine root parameters measured showed pronounced seasonal variations. Almost all species had maximum total fine root mass, biomass and necromass during the main rain season and minimum in the dry season; On the other hand, *P. falcatus* had slightly more fine root biomass in the dry season than small rain season. Such pattern of seasonal variation (maximum fine root biomass in the rain season and minimum in the dry period) is in agreement with the results of studies made in the tropics, South Western Gahat, India (Parthasarathy, 1988; Visalakshi, 1994; Sundra Panda and Swamy, 1996). All attributed the seasonal pattern to change in soil moisture and temperature. In this study, peaks of fine root biomass in the major rain and partly in small rain season may be related to precipitation. These seasons received more rainfall (Fig. 2) as compared to dry season, and this might have created favorable condition for growth of fine root owing to favorable temperature and better availability of nutrients and water in the soil.

McGroddy and Silver (2000) found strongly and positively correlated root biomass with soil moisture. A significant relationship between fine root biomass and rainfall was also reported by Green *et al*. (2005) in the Danum forest, with low value of biomass occurring during dry period. A low dry season fine root biomass was also reported in an evergreen rain forest in Costa Rica (Sanford, 1989). In a forest in Panama, Cavelier *et al*. (1999) found that during the dry season, root growth was highest when the soil was irrigated, illustrating the importance of soil moisture in determining patterns of root growth. During

the dry season, the soil water content may be very low due to a decrease or no rainfall and as well as high evapotranspiration. Thus, the fine root in particular, may have subsequently suffered from drought.

However, our result was in contrary with the findings of Asferachew Abate (2004) who reported maximum fine root biomass during dry season. He argued that the higher soil moisture content during the wet season resulted in low fine root growth, whereas the low soil moisture level during the dry season might have resulted in high live fine root as root growth is stimulated to maximize moisture absorption.

Surprisingly, the fine root biomass of the evergreen *P. africana* seemed to be equal both in the dry and small rain seasons while *P. falcatus* had higher fine root biomass in the dry season compared with small rain season. This is difficult to explain but it was speculated that *P. falcatus* and *P. africana* may have drought insensitive root foraging strategy to acquire resources or the unusually wet dry season (NMA ‘’Bega’’ assessment report for the year 2007, pers.comm.) might have favored root growth in the dry season equivalent to small rain season. Moreover, Fritzsche *et al*. (2006) using isotopic and water potential evidences have indicated faster transport of water (re-distribution) both up and downward, and further showed highest top soil moisture for *P. falcatus* compared with exotic species during the dry season attributing it to hydraulically lifted water. Hydraulic lift is the passive movement of water from roots into soil layers with lower water potential, while other parts of the root system in moister soil layers, usually at depth, are absorbing water. Large quantities of water, amounting to an appreciable fraction of daily

transpiration, are lifted at night. This temporary partial re-hydration of upper soil layers provides a source of water, along with soil moisture deeper in the profile, for transpiration the following day and, under conditions of high atmospheric demand, can substantially facilitate water movement through the soil-plant-atmosphere system. Also, because soils tend to dry from the surface downward and nutrients are usually most plentiful in the upper soil layers, lifted water may provide moisture that facilitates favorable biogeochemical conditions for enhancing mineral nutrient availability, microbial processes, and the acquisition of nutrients by roots. Hydraulic lift may also prolong or enhance fine-root activity by keeping them hydrated. Alternatively, hydraulic lift may simply be the consequence of roots not possessing true rectifying properties (i.e., roots are leaky to water). The direction of water movement may also be downward or horizontal if the prevailing water gradient so dictates, i.e., inverse, or lateral, hydraulic lift. The hydraulically lifted water that constantly replenishes the topsoil coupled with reduced transpiration during the dry period (Fritzsche *et al*., 2006) might explain higher live fine root mass in *P. falcatus* during the dry season compared with the small rain.

Greater fine root biomass and low necromass were observed in all seasons at all depths. This might be due to the fine root either live longer, are decomposed faster or both.

6.2. Variation among Species

The two deciduous species were found to have more fine mass during the two wet season than the evergreens did. In contrast, in the dry season the evergreen species had more fine root concentration than the deciduous. This seasonal pattern seems to correspond roughly to leaf duration. Canopy senescence during dry season in deciduous species might have resulted in less carbon fixation that could have lessen the amount of photosynthate allocated to the root system leading to low fine root production. Mission *et al* (2006) reported tightly coupled fine root development to canopy photosynthesis where increase in root growth and photosynthesis coincided. Also it could be argued that there is little advantage for deciduous to invest in the fine root in the dry season, as there function is minimal due to absence of foliage. Moreover, the root system of different species may ramify the soil in different fashion, influenced by their requirement for microclimate, competitive ability apart from their genetic behavior (Parthasarathy, 1988).

Generally, summing up the three seasons performance, *Croton macrostachyus* > *Celtis africana* > *Prunus africana* > *Podocarpus falcatus* in total fine root amount, fine root biomass production and fine root necromass accumulation. As the species considered in the study are growing under similar environmental conditions, these differences are likely to be explained by genetic variations, age factor or both.

6.3. Vertical distribution

Fine root total mass, fine root biomass and necromass showed a decreasing pattern with increasing depths. Up to 47.4 -64.9 % of fine root total mass, 55-67 % of fine root biomass and 46.06-57.8 % of fine root necromass was present in the upper 10 cm soil layer in the present study. On the other hand the depth interval 10-20 cm sheltered 21.67-37.18, 17.13-29 and 20.35-27.35 % TFM, FBM and FNM, respectively. The lower 20-60 cm accounted for 0.69 to 20.385 TFM, 2.4 to 14.58 % FBM and 2.59 to 18.73 % FNM only. Previous studies on the vertical distribution of tree fine root have shown that the majority of the fine root were confined within the top 30 cm of the soil profile (Harris, 1977; Khiewtam, 1993). Safford and Bell (1972) reported that 87 % of fine root in the top 15 cm soil layer of 39 years old spruce plantation and Harris *et al*. (1977) obtained up to 71 % of fine root in the top 20 cm soil profile of *Pinus taeda* forest. Similar results were reported by McClaughery *et al*. (1982) for a hard wood forest.

Yeshanew Ashagrie (2004) showed a general decrease in the soil organic matter, nitrogen content, soil pH and an increase in clay content with increasing depth in the study sites (Table 1). Mulugeta Lemenih (2004) also reported from the same study area, a decrease in soil carbon and nitrogen content, available phosphate and potassium from the upper 10 cm to 10-20 cm soil layer. The same study also showed a decline in sand content from 64.4 to 38.2 % and an increase in clay fraction from 16 to 27 % in the upper 10 cm and 20-40 cm soil layer, respectively.

Large congregation of fine root on the upper soil layer in this study could be attributed to better aeration owing to high portion of sand, low bulk density (low clay content) and relatively high organic matter, and nitrogen content and higher pH value in this upper most layer compared with lower depths (Table 1).

Ford and Deans (1977) who reported greater fine root concentration in the surface soil layer attributed it to high nutrient concentration. Mayer and Gottsche (1971) ascribed decreased in fine root biomass in lower soil layers to the deterioration in nutrient status and biological condition. Kimmis and Hawks (1978) found the concentration of fine root in the upper soil profile in mid pine beech forest and white spruce sub-alpine forests was correlated with higher concentration of organic matter and nutrient and with favorable physical conditions. Fine root biomass was found to be inversely proportional to the clay content. Increased clay content at the lower depths (Table 1 and see also Mulugeta Lemenih, 2004) might have contributed to hindering the fine root growth at lower depth since it is usually associated with high bulk density. According to Nambiar and Sandas (1992) when bulk density increases, soil strength increases and aeration decrease leading to adverse effect on root growth. The Relatively higher acidity at lower depths might have also contributed to decrease in fine root biomass with depth. Jentschke and Drexhage (2001) attributed a decreased fine root production with increasing depth in the 40 year Norway spruce (*Picea abies*) to an increased acidity. As soil becomes more acidic most plant nutrients become more limited in supply, and few micronutrients become more soluble and toxic limiting root growth. Moreover acidic condition limits activities of microorganism, which in turn reduce miniralization, which results in less

availability of nitrogen, the most limiting nutrient in the tropical afromontane forest (Tanner, 1985).

The vertical distribution of fine root necromass was similar to that of biomass. The largest accumulation occurred in the upper layer over the examined soil profiles. Given more fine root production in the upper soil layer more death report is expected as the produced fine root sooner or later die at the end.

7. SUMMARY AND RECOMMENDATIONS

The present study revealed that total fine root mass, fine root biomass and necromass varied greatly with respect to seasons, species and depth.

All study species had the highest measurement of total fine root mass, fine root biomass and necromass during the major rain season and generally, minimum values were recorded in the dry season.

Total fine root mass, fine root biomass and fine root necromass of the two deciduous species during the two wet seasons were higher compared with their respective evergreen species, with the value greatest in *Croton macrostachyus* and then decreased, in the order, *Celtis africana* to *Prunus africana* to *Podocarpus falcatus* whereas in the dry season the evergreen species generally took the lead. This result partly suggests that the deciduous species have high potential for water and nutrient uptake during the wet season than the evergreen ones, which might give them a belowground competitive advantage over the evergreen species studied, in these particular seasons and vice versa.

Generally, the deciduous species were with maximum fine root biomass and necromass partly indicating their major contribution in the nutrient and carbon cycling through decomposing fine root. Showing also their role with respect to ecosystem maintenance and functioning.

The proportion of fine root sharply declined with depth. The upper portion of the soil layer sheltered the greatest amount of total fine root mass, fine root biomass and necromass accumulation. The degraded Afromontane forest of Munesa-Shashamane is in the risk of nutrient loss due to high rainfall, steep slopes and fragile nature of the soil (note the acid soil pH; Table 1). Hence in this context, the forest under investigation is dependent up on tight recycling of nutrients. The fine root system that has developed in the surface layer of the soil, and that particularly located in the upper 10 cm layer would facilitate rapid uptake of nutrients released by decomposing litter as these are not simply leached down but are transferred directly to the surface of roots, which are intermingled with the decaying matter. In addition, the roots would also intercept nutrients included in throughfall plus stem flow. The maximum accumulation of fine root mass of the studied species in the upper layer of the examined profile is therefore, helpful in mopping up the nutrient.

Usually procedures for fine root production studies must be adjusted for each site based on the magnitudes and periodicities of root growth. When tree species appear to have distinct modal or bimodal patterns of root growth, rough estimates of root production may be obtained of the maximum and minimum peak of live and dead root biomass, through intensive and frequent sampling during that time period; as root growth occurring at other times of the year will be neglected in comparison with this peak. Hence it is hoped that the results obtained in the present study provide useful information in this regard as it can be used to develop a less frequent sampling schedule for future fine root production estimation studies.

The result obtained on the fine root distribution and production also contributes to our understanding of the ecosystem processes and better management of tropical forests and agroforestry.

It is recommended that further work on the status of fine root mass, length, number of root tips, fine root turnover and other root parameters with regard to fluctuating environmental conditions over the seasons of the natural forest at ecosystem level is required in order to get more information to sustainably manage the ecosystem. It is especially necessary to use methods that provide more accurate estimate of fine root characteristics. Long-term root inventories using the minirhizotron technique are therefore recommended, and precise soil climate measurements should be implemented to monitor specific soil layers. Parallel studies on the aboveground compartments of trees (e.g. phenology, increments, photosynthetic activity, biomass partitioning) will be of a greater value.

8. REFERENCES

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DECLARATION

I, the undersigned, declare that this Thesis is my own work and all sources of materials have been duly acknowledged.

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