

**BIOMASS, LITTER PRODUCTION AND SELECTED NUTRIENTS IN
BRUGUIERA PARVIFLORA (ROXB.) WIGHT & ARN. DOMINATED
MANGROVE FOREST ECOSYSTEM AT KUALA SELANGOR, MALAYSIA**

MAHMOOD HOSSAIN

**DOCTOR OF PHILOSOPHY
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By

MAHMOOD HOSSAIN

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

December 2004

Biomass, litter production and nutrients in *Bruguiera parviflora* dominated mangrove forest ecosystem at Kuala Selangor, Malaysia

Dedicated

To

My Parents and Memory of My Grand Parents,

My Wife Sonchita for Years of Love and Care,

My Sweet Daughter Borno

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

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December 2004

Chairman: Misri Kusnan, Ph.D.

Faculty: Science

This study was carried out to investigate the standing biomass, litter dynamics and selected nutrients in soil, water and plant components in a *Bruguiera parviflora* dominated naturally growing unmanaged mangrove forest ecosystem in Kuala Selangor Nature Park, Malaysia. This study was initiated during September 2001 and ended on August 2003. The total above and below-ground biomass of *B. parviflora* seedlings, saplings and trees were 144.47 t/ha and 19.93 t/ha, respectively, and the net primary productivity of this forest was 27.44 t/ha/yr. The annual amount of small litter production and small litter standing crop were 1035 g/m² and 337.72 g/m², respectively. *Bruguiera parviflora* leaf litter showed higher microbial degradation (60% of initial dry mass) in wet month (November 02) than the dry month (20.17% of initial dry mass, July 02), but leaf litter loss due to feeding plus mechanical breakdown did not vary in dry and wet months. Soil parameters (pH, redox potential, air-dry moisture, organic matter, conductivity, salinity and cation exchange capacity) and nutrients (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) were measured in intermediate

(March), dry (July) and wet (November) seasons and found relatively higher organic matter (12.03-12.56%) and cation exchange capacity (37.31-38.23 m.e/100 g) in the intermediate seasons (March 02 and 03). Higher conductivity (11.25-11.81 mS/cm) and salinity (57.64-59.03 m.e/100 g) were observed during the dry seasons (July 02 and 03). Comparatively higher content of N (3.49-3.50 mg/g), P (0.33-0.34 mg/g), K (6.86-7.06 mg/g), C (63.29-67.63 mg/g) and Fe (11929.44-12866.67 µg/g) in soil were observed during the intermediate seasons (March 02 and 03). Higher conductivity (55.83-71.00 mS/cm) was observed in infiltration water followed by river water (18.17-22.17 mS/cm) and relatively higher conductivity of rainwater, canopy drip, river and infiltration water was found during the dry seasons (July 02 and 03). Nutrients (NH₄, NO₃, PO₄, K, Ca, Mg and SO₄) in rainwater, canopy drip, stem flow, river and infiltration water fluctuate with the seasons and comparatively higher K, Ca, Mg, SO₄, Cu, Fe and Zn were observed in infiltration water followed by river water. Nutrients (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) in different components of *B. parviflora* seedlings, saplings and trees were measured in intermediate (March), dry (July) and wet (November) seasons and reported comparatively higher N, P, K, Ca, Mg and Fe in plant components during the intermediate seasons (March 02 and 03) and relatively higher sulphur was found during the dry seasons (July 02 and 03). Nutrients content in different components of seedlings, saplings and trees of *B. parviflora* showed positive correlations with the soil nutrients level. The annual uptake range of N, P, K, Ca, Mg, S, Cu, Fe and Zn was 109.34-129.67 kg/ha, 16.70-25.65 kg/ha, 39.69-66.71 kg/ha, 153.84-240.41 kg/ha, 48.30-68.27 kg/ha, 100.93-177.05 kg/ha, 120.61-287.14 g/ha, 7981.31-14697.29 g/ha and 204.49-581.41 g/ha, respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**BIOJISIM, PENYEBARAN SARAP DAN NUTRIEN TERPILIH DALAM
EKOSISTEM HUTAN PAYA BAKAU DIDOMINASI *BRUGUIERA
PARVIFLORA* (ROXB.) WIGHT & ARN., DI KUALA SELANGOR,
MALAYSIA**

Oleh

MAHMOOD HOSSAIN

Disember 2004

Pengerusi: Misri Kusnan, Ph.D.

Fakulti: Sains

Kajian ini dijalankan bagi mengkaji jisim tetap, dinamik sarap dan nutrien terpilih dalam tanah, air dan komponen tumbuhan di dalam satu ekosistem hutan paya bakau semulajadi yang didominasi oleh *Bruguiera parviflora* di Taman Alam Kuala Selangor, Malaysia. Penyelidikan dilakukan dari bulan September 2001 hingga bulan Ogos 2003. Jumlah biojisim di atas dan dalam tanah bagi anak pokok, pokok muda dan pokok matang *Bruguiera parviflora* adalah masing-masing 144.47 t/ha dan 19.93 t/ha, dan produktiviti primer bersih adalah 27.44 t/ha/yr. Jumlah penghasilan tahunan sarap kecil dan sarap kecil tanaman dirian adalah masing-masing 1035 g/m² dan 337.72 g/m². Sarap daun *Bruguiera parviflora* mengalami degradasi mikrob yang lebih tinggi (60% daripada berat kering asal) dalam musim hujan (November 2002) berbanding musim kering (20.17% daripada berat kering, Julai 2002) tetapi kehilangan sarap daun disebabkan oleh pemakanan dan perpupuan mekanikal tidak berbeza dalam musim kering dan musim hujan. Parameter tanah (pH, potensi redoks, kelembapan udara, bahan organik, konduktiviti, saliniti dan keupayaan penukaran

kation) dan nutrien terpilih (N, P, K, Ca, Mg, S, C, Cu, Fe dan Zn) diukur semasa musim perantara (Mac), musim kering (Julai) dan musim hujan (November) dan didapati kandungan bahan organik (12.03-12.56%) dan keupayaan penukaran kation (37.31-38.23 m.e/100 g) ini adalah tinggi dalam musim pertengahan (Mac 2002 dan 2003). Manakala bacaan konduktiviti (11.25-11.81 mS/cm) dan saliniti (57.64-59.03 m.e/100 g) yang tinggi didapati semasa musim kering (Julai 2002 dan 2003). Kandungan yang tinggi bagi N (3.49-3.50 mg/g), P (0.33-0.34 mg/g), K (6.86-7.06 mg/g), C (63.29-67.63 mg/g) dan Fe (11929.44-12866.67 µg/g) dalam tanah didapati semasa musim pertengahan (Mac 2002 dan 2003). Konduktiviti yang lebih tinggi (55.83-71.00 mS/cm) didapati dalam air infiltrasi dan diikuti air sungai (18.17-22.17 mS/cm) dan bacaan konduktiviti adalah relatif lebih tinggi didapati pada air hujan, titisan air kanopi, saluran air, air sungai dan air infiltrasi semasa musim kering (Julai 2002 dan 2003). Nutrien (NH₄, NO₃, PO₄, K, Ca, Mg dan SO₄) dalam air hujan, titisan air kanopi, saluran air, air sungai dan air infiltrasi berbeza mengikut musim dan kandungan K, Ca, Mg, SO₄, Cu, Fe dan Zn yang lebih tinggi didapati dalam air infiltrasi dan diikuti oleh air sungai. Nutrien (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) dalam komponen anak pokok, pokok muda dan pokok matang *B. parviflora* diukur bagi musim pertengahan (Mac), musim kering (Julai) dan musim hujan (November) dan didapati bahawa kandungan P, K, Ca, Mg dan Fe yang tinggi dalam komponen tumbuhan semasa musim perantara (Mac 2002 dan 2003) dan nisbah sulfur yang tinggi didapati semasa musim kering (Julai 2002 dan 2003). Kandungan nutrien dalam komponen anak pokok, pokok muda dan pokok matang *B. parviflora* menunjukkan korelasi positif dengan tahap nutrient dalam tanah. Julat penyerapan tahunan N, P, K, Ca, Mg, S, C, Cu, Fe dan Zn adalah masing-masing 109.34-129.67 kg/ha, 16.70-25.65

kg/ha, 39.69-66.71 kg/ha, 153.84-240.41 kg/ha, 48.30-68.27 kg/ha, 100.93-177.05 kg/ha, 120.61-287.14 g/ha, 7981.31-14697.29 g/ha dan 204.49-581.41 g/ha.

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I certify that an Examination Committee met on 10 December 2004 to conduct the final examination of Mahmood Hossain on his Doctor of Philosophy thesis entitled “Biomass, Litter Production and Selected Nutrients in *Bruguiera parviflora* (Roxb.) Wight & Arn. Dominated Mangrove Forest Ecosystem at Kuala Selangor, Malaysia” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Umi Kalsom Bt Yusuf, Ph. D.

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Jambari Bin Hj Ali, Ph. D.

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Abdul Rahim Ismail, Ph. D.

Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Dato’ Dr. Abdul Latiff Mahmad, Ph. D.

Professor
Faculty of Science and Technology
Universiti Kebangsaan Malaysia
(Independent Examiner)

GULAM RUSUL RAHMAT ALI, Ph.D.

Professor/ Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

Misri Kusnan, Ph.D.

Lecturer
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Saberi Othman, Ph.D.

Professor
Faculty of Science and Technology
Universiti Pendidikan Sultan Idris
(Member)

Japar Sidik Bujang, Ph.D.

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

AINI IDERIS, Ph.D.

Professor / Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

Signature

MAHMOOD HOSSAIN

Date:

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LIST OF ABBREVIATIONS

AAS	=	Atomic Absorption Spectrophotometer
µg/g	=	Microgram per gram
ANOVA	=	Analysis of Variance
CEC	=	Cation Exchange Capacity
DBH	=	Diameter at Breast Height
DMRT	=	Duncan Multiple Range Test
g	=	Gram
ha	=	Hectare
Kg/ha	=	Kilogram per hectare
m.e./ 100g	=	Miliequivalent per 100 gram
mg/g	=	Milligram per gram
mS/cm	=	Mili Siemens per centimetre
mv	=	Mili volt
p	=	Probability
ppm	=	Part per million
ppt	=	Part per thousand
t/ha	=	Tonnes per hectare

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The term “mangrove” refers to an ecological group of evergreen woody plant species belonging to several families, but showed similarity in their physiological characteristics (succulent leaves, lenticels, coping with excess salt: salt gland and secretion, salt balance, selective ion transport) and structural adaptations (buttress, pneumatophore, knee roots, prop roots, aerial roots and viviparous seeds) to a similar habitat influenced by the tidal inundation in the tropical and subtropical sheltered coastline (Saenger *et al.*, 1983; Ball, 1988; Ricklefs and Latham, 1993; FAO, 1994; Field, 1995).

There are about 114 species of mangrove plants belonging to 66 genera and 43 families (Tomlinson, 1986). Mangroves are widely distributed to the regions between 30° north and south of the equator and some extend to the north in Bermuda (32°20'N) and Japan (31°22'N) and to the south in Australia (38°45'S), New Zealand (38°03'S) and the east coast of South Africa (32°59'S) (Spalding *et al.*, 1997). Walsh (1974) divided the mangrove vegetation into two regions. The Indo-Pacific region includes East Africa, Red sea, India, Southeast Asia, Southern Japan, Philippines, Australia, New Zealand, and Southern Pacific Archipelago. The west Africa-America region includes Atlantic coast of Africa, The Americas, Pacific coast of tropical America and Galapagos Island. He also mentioned that Indo-Pacific region is much higher in floral diversity than the West Africa-America region. The distribution pattern of world mangroves are believed to be influenced by temperature, rainfall, wind, tidal inundation, tidal current and wave action, salinity, geomorphology, soil types, soil aeration and nutrients availability (Spalding *et al.*, 1997).

Mangroves are economically and ecologically important as a natural renewable resource (Field, 1995). Mangroves are the sources of wood and non-wood forest products, including timber, fuelwood, charcoal, pulp, fodder, thatch, honey, wax and medicine (Ong, 1982; Aksornkoae, 1993; Field, 1995; FAO, 2003). Several commercially important fish, shellfish species and marine animals are known to spend at least part of their life cycle such as feeding, breeding and nursery grounds (Heald and Odum, 1970; MacNae, 1974; Matthes and Kapetsky, 1988; Arshad *et al.*, 1997). Moreover, mangroves provide shelter and habitat for diverse wildlife particularly, avifauna and mammals but relatively few ones live there permanently and even few ones are restricted (Liem and Haines, 1977; FAO, 1994). Mangroves help to stabilize shorelines in coastal streams and estuaries by protecting them against tidal bores and soil erosion due to wind, waves and water currents. Mangroves entrap the upland runoff sediments thus protecting nearshore reefs and reducing water turbidity (Aksornkoae, 1993; Hegazy, 1998; FAO, 2003). It also acts as windbreaker against the storms, especially in countries, which are frequently attacked by strong winds and cyclones,

such as Philippines, Vietnam, Bangladesh, India and Australia (FAO, 2003). Nutrients and heavy metals are found to sink in the mangrove forest and result in reduction of excessive amounts of pollutants (Silva *et al.*, 1990; Tam and Wong 1995; Lacerda, 1998; Mahmood and Saberi, 2000; Mahmood *et al.*, 2001; Macfarlane and Burchett, 2002).

The total area of world mangroves was about 15 million hectares at the end of 2000 (FAO, 2003) that are distributed in over 100 countries. At the present time, mangrove destruction is still continuing but at slower rate of 1.7% a year in 1980 to 1990 to 1% a year in 1990 to 2000. But, in some developing countries, the destruction rate is still higher than 1% (FAO, 2003). Mangrove forests are being converted into housing, industrial estates, airports, sea ports, resorts development, rice fields, salt extraction, oil-palm plantations, aquaculture ponds and pollutant dumping sites (Ong, 1982; Aksornkoae, 1993; Field, 1995; Arshad *et al.*, 1997; Alongi, *et al.*, 1998; FAO, 2003).

Malaysia contributes about 3.5% of the world mangrove forest and placed at the fifth position in terms of area coverage. Total mangroves area in Malaysia was about 650,000 ha, which constitute only 2% of the country's total land area in 1982 (Ong, 1982). In 1986, mangrove areas in Malaysia reduced to 646,000 ha (Anon, 1986). However, Peninsular Malaysia contains only 17% of the country's total mangrove forest, which mostly concentrates on the sheltered west coast, and almost continues from Kedah to Singapore. The latest inventory showed that there were about 641,000 ha of mangrove areas remained at the end of 1993 (ISME, 1993) and the mangroves are under sustainable yield management practices. Only a very small percentage of Malaysian mangroves fall within legally gazetted protected areas, 0.3% in Peninsular Malaysia, 0.2% in Sarawak and 1.3% in Sabah (Spalding *et al.*, 1997). During the 11 years (from 1982 to 1993) about 9,000 ha of mangrove forest were destroyed, which constituted 1.26% of yearly destruction rate and remains higher than the world average destruction rate. The destruction of mangrove areas in Malaysia are mainly due to the construction of sea ports, airport, industrial estate and converted to agricultural land (Ong, 1982). The depletion of mangroves results in serious environmental and economic constraint in the coastal region. Loss of mangrove environment leads to long-term impacts, such as loss of fisheries, loss of detritus, loss of flora and fauna population and even loss of coastal shoreline (Saenger *et al.*, 1983; FAO, 1994). Moreover, the destruction of mangrove resources impart negative effect on the ecological process of mangrove ecosystems, which can change the productivity, litter export and biogeochemistry of mangroves, food chain both of mangrove ecosystem and the neighbouring coastal ecosystem (Twilley and Chen, 1997).

The use and values of mangroves are linked to their ecological functions such as habitat quality, water quality, shoreline protection and aesthetics. However, the nature of these ecological functions can be attributed to the ecological processes (productivity, nutrient cycling, litter dynamics, succession and sedimentation contribute to the habitat and water quality of estuarine and coastal water) of mangroves. Irrespectively, the

combination of these ecological processes makes the mangroves most productive ecosystem in the coastal region. On the contrary, the productivity of mangrove forest depends on soil physiochemical properties, salinity, climatic factors (rainfall, temperature, evapotranspiration), available supply of nutrients, within stand nutrient cycling, as well as seasonal variability of these factors. Therefore, sustainable utilization of mangrove resources requires basic understanding of their physical and biological processes so as to formulate a best management plan considering the ecological and economical aspects.

A number of studies were conducted on physical and biological processes of mangrove ecosystems such as soil and water physiochemical characteristics (Boto, 1982; Macintosh *et al.*, 1990; Silva *et al.*, 1990; Aksornkoae, 1993; Tam *et al.*, 1995a; Ashton and Macintosh, 2002), standing biomass (Clough and Attiwill, 1975; Suzuki and Tagawa, 1983; Sukardjo and Yamada, 1992; Tam *et al.*, 1995b; Komiyama *et al.*, 2000), productivity (Day *et al.*, 1987; Amarasinghe and Balasubramaniam, 1992a, Clough, 1992; Sukardjo and Yamada, 1992; Day *et al.*, 1996), litter production (Duke *et al.*, 1981; Twilley *et al.*, 1997; Wafar *et al.*, 1997; Clough *et al.*, 2000) and litter decomposition (Robertson, 1988; Tam *et al.*, 1998; Ashton *et al.*, 1999; Ashton, 2002) at different mangroves in the world. Only one study postulated within stand cycling of macro-nutrients (N, P, K) with *Aegiceras corniculatum* and *Kandelia candel* in Shezhen, South China (Li, 1997). Jiao *et al.* (1997) studied the within stand cycling of heavy metals (Cu, Pb, Zn, Cd, Cr, Ni and Mn) with *Rhizophora stylosa* in Shankou mangrove, China, but they did not consider the seasonal fluctuation of nutrients in plant components and soil as well as nutrients in input sources. However, all the above studies were concerned with the parts of mangrove ecosystem processes rather than combined and simultaneous study in a particular mangrove forest.

Similar scenario was also observed in Malaysia. Most of the studies were concerned with the partial ecological processes in mangroves such as standing biomass, productivity and litter dynamics (Ong *et al.*, 1980; Putz and Chan, 1986; Gong *et al.*, 1984; Ong *et al.*, 1985a; Japar Sidik, 1989; Ong *et al.*, 1995) and only one study on nutrients flux (Gong and Ong, 1990). All the above studies were conducted in almost pure stand of *R. apiculata* in Matang mangrove reserve, which has been managed at sustainable yield basis for the production of timber, poles and fuel wood. In a managed mangrove forest, natural ecosystem processes are changed or modified compared to naturally growing unmanaged mangrove forest. Surprisingly, no attempt has been taken on the study of ecosystem process in a naturally growing unmanaged protected mangrove forest in Malaysia. But, the ecosystem processes in naturally growing unmanaged mangrove forest is more important to understand the actual role and function of a mangrove forest. Therefore, a combined and simultaneous study on different aspects of ecosystem processes such as standing biomass, primary productivity and seasonal fluctuation of litter dynamics, soil and water physiochemical properties, sediment accretion and erosion, nutrients input and output sources and

within stand nutrient cycling are prime important for the proper description of overall ecological processes in a naturally growing unmanaged mangrove forest.

1.2 Objectives

The general objectives of this study are

1. To estimate the net primary productivity.
2. To study nutrients status in different components of mangrove ecosystem (soil, water and plant components) over the time period.
3. To postulate within stand cycling of selected nutrients.

1.3 Literature Review

The ecological processes of mangroves consist of standing biomass, primary productivity, succession, litter dynamics, organic matter export, sedimentation and nutrients cycling (Twilley and Chen, 1997). The environmental factors such as coastal physiography, climate, tidal height, frequency of tidal inundation, wave and current, salinity, soil physiochemical properties vary from one mangroves to another and result in significant variation of ecological processes in different mangroves (Hutchings and Saenger, 1987; Clough, 1992; Aksornkoae, 1993).

1.3.1 Standing Biomass

Biomass of plants includes total dry weight of leaves, buds, flowers, fruits, branches, stems, above and below-ground roots in a certain time. The estimation of standing biomass and analysis of stand structure of mangrove forests are important for their management and often used for the comparison of potential forest productivity (Golley *et al.*, 1975; Clough and Attiwill, 1982; Aksornkoae, 1993).

Mangrove species at different places showed wide range of standing biomass from 460 t/ha in tall *Rhizophora* spp. dominated forest in Matang, Malaysia (Putz and Chan, 1986) to 6.80 t/ha in low *Avicennia marina* communities in Tuff Crater, New Zealand (Woodroffe, 1985). In general, tropical mangroves have higher standing biomass and more complicated structure than sub-tropical mangroves (Chapman, 1976; Saenger and Snedaker, 1993; Tam *et al.*, 1995b). Moreover, standing biomass and their proportion in the above and below-ground components of mangrove plants are not only affected by the geographical location and microclimates but also vary with the species, stand structure and age of stand (Lugo and Snedakar, 1974; Woodroffe, 1985; Steinke *et al.*, 1995; Tam *et al.*, 1995b).

1.3.1.1 Species and Stand Structure

The above and below-ground biomass of *Avicennia marina* (mean height 3.5 m) in Westernport Bay, Victoria, Australia were 8.60 t/ha and 14.60 t/ha, which made up 37.11 and 62.89% of total biomass, respectively (Clough and Attiwill, 1975). In a similar study, Briggs (1977) observed higher standing biomass of *A. marina* (mean height 7.5 m) at two different sites in a mangrove community near Sydney, Australia. The above-ground biomass varied from 100.20 to 129.50 t/ha and below-ground biomass varied from 144.40 to 160.20 t/ha and the proportion of above and below-ground biomass varied from 41.52-49.49% and 50.51-58.48%, respectively. The above and below-ground biomass of *A. marina* (4.56 m, 4.19 cm and 4500 stem/ha) in Beachwood mangrove forest, South Africa were estimated at 94.49 and 9.69 t/ha and the biomass proportion in above and below-ground components were 88.51 and 11.49%, respectively (Steinke *et al.*, 1995).

The above ground biomass of *A. germinans* in two different places of Campeche, Mexico varied from 17.40 to 73.00 t/ha, where mean height, mean DBH and density in two sites varied from 4 to 6 m, 4.90-7.70 cm, and 1590-1720 stem/ha, respectively (Day *et al.*, 1996).

The total above and below-ground biomass of *A. corniculatum* (mean height 3.85 m, mean DBH 19.56 cm and density of 794 stem/ha) and *Kandelia candel* (mean height 4.2 m, mean DBH 7.76 cm and density of 117 stem/ha) in Futin Natural Reserve, Shenzhen, China were 87.1 and 121.40 t/ha, respectively and the biomass proportion in above and below-ground components of *A. corniculatum* and *K. candel* were 71.26% and 28.74%; 63.05% and 36.95%, respectively (Tam *et al.*, 1995b). Li (1997) reported that *A. corniculatum* and *K. candel* in Shenzhen, South China together constituted 108.26 t/ha of above-ground biomass.

The above and below-ground biomass of *Bruguiera* spp. (mean height 10.69 m, mean DBH 9.33 cm and density of 208 tree/ha) in Khong Ngao Hatsaikao, Ranong, Thailand were 28.43 and 6.06 t/ha and made up 92% and 8% of total standing biomass, respectively (Tamai *et al.*, 1986). Steinke *et al.* (1995) reported that the above and below-ground biomass of *B. gymnorrhiza* (mean height 2.31 m, mean DBH 2.31 cm and density of 42500 stem/ha) in Beachwood mangrove forest, South Africa were higher of 74.67 t/ha and 9.69 t/ha, respectively, and the above and below-ground components contained 90.70 and 9.30%, respectively of total standing biomass.

Komiyama *et al.* (2000) reported that the above and below-ground biomass of *Ceriops tagal* (mean height 5.20 m, mean DBH 4.20 cm, density of 10010 stem/ha) in Satun Province, southern Thailand were 94.24 and 87.51 t/ha, which made up 51.85 and 48.15% of total biomass, respectively. The above-ground biomass of mixed mangrove (mean height 13.09 m, Mean DBH 12.15 cm, density of 849 stem/ha) in Pulau Langkawi, Malaysia was 115.56 t/ha (Norhayati and Latiff, 2001).

Rhizophora apiculata (mean height 10.57 m, mean DBH 11.1 cm and density of 998 tree/ha) in Khong Ngao Hatsaikao, Ranong, Thailand was estimated to produce 252.74 and 111.57 t/ha of above and below-ground biomass, respectively, and biomass proportion in shoot to roots was 69 and 31%, respectively (Tamai *et al.*, 1986). In a similar study, Gong and Ong (1990) reported that the above and below-ground biomass of *R. apiculata* (DBH range 1.11 to 24.51 cm) in Matang Mangrove Reserve, Peninsular Malaysia were 185.30 and 17.20 t/ha, respectively. The biomass proportion in leaves, branches, stems, stilts roots and below-ground roots were 1.6-25.7%, 1.1-23.0%, 16.5-85.2%, 4.5-46.7% and 3.3-19.7% respectively. The above-ground biomass of *R. mucronata* (mean height 7.20, mean DBH 26.40, density 2200 stem/ha) in Erumathivu, Dutch bay, Sri Lanka was higher of 240 t/ha (Amarasinghe and Balasubramaniam, 1992a).

1.3.1.2 Stand Age

Stand age appears as an important determinant of standing biomass in mangroves. Different aged (5 to 25 years) planted *R. apiculata* in Matang Mangrove Reserve, Peninsular Malaysia showed wide range (16 to 300 t/ha) of above-ground biomass (Ong *et al.*, 1985a). But, Putz and Chan (1986) reported much higher range (270-460 t/ha) of above-ground biomass of *R. apiculata* in 80 years old mixed mangroves at Pulau Kecil, Matang Mangrove forest, Peninsular Malaysia. Sukardjo and Yamada (1992) estimated 93.73 t/ha of above-ground biomass of 7 years old planted *R. mucronata* in Tritih, Java, Indonesia.

1.3.1.3 Factors Influencing the Biomass Proportion in Plant Components

Different mangrove species showed different trends of biomass allocation in different components. The proportion of above and below-ground biomass of any species varies widely among the mangroves in the world due to the variation of environmental parameters (Clough 1992). The favourable environmental condition for mangrove growth in the tropical areas contributes to higher proportion of above-ground biomass. On the contrary, higher proportion of below-ground biomass was observed in the sub-tropical areas with increasing latitude (Clough and Attiwill, 1975; Suzuki and Tagawa, 1983; Gong and Ong, 1990; Steinke *et al.*, 1995; Tam *et al.*, 1995b).

Apart from the environmental factors, the biomass proportion in different components of mangroves species also depends on plant architecture (Turner *et al.*, 1995). Tomlinson (1986) reported four different architectures of mangrove plants are found such as Attim's model (*Rhizophora* and *Lumnitzera racemosa*), Rauh's model (*Xylocarpus* and *Heritiera*), Pettit's model (*Avicennia*, *Sonneratia* and *Lumnitzera littorea*) and Aubreville's model for large flowered *Bruguiera* spp. (*B. gymnorhiza*). Each of the above plant architectural models varies considerably in their canopy

structure and even the same species vary in their branching complex at different stages of development (saplings and trees) (Tomlinson, 1986).

Diameter at breast height (DBH) has shown considerable influence on biomass proportion in above-ground components of different mangrove species. Clough and Scott (1989) studied the above-ground biomass of different mangrove species with DBH range from 5 cm to 25 cm in north-eastern Queensland, Australia. They reported that different species showed different patterns of biomass distribution with their above-ground components and significantly varied with DBH classes. The ranges of biomass proportion in leaf, branch and stem of *B. gymnorrhiza* were 3.20-23.10%, 9.50-25.80% and 51.10-85.30%; for *B. parviflora* 1.60-3.50%, 3.50-15.90% and 82.20-96%; for *C. tagal* 3.70-4.9%, 13.20-24.70% and 71.40-83.20%; for *R. apiculata* 1.70-6.20%, 9-18.20% and 57.90-73%; and for *X. granatum* 4-7%, 12.80-41.70% and 53.90-83.20%, respectively.

1.3.2 Net Primary Productivity

Primary productivity is the integrated effect of ecosystem photosynthesis and represents the fixation of solar energy in organic matter. Gross primary productivity is the overall photosynthetic production of dry matter before the loss of respiration. Net primary productivity is the part of gross primary productivity of photosynthetic plants that remains after the loss from respiration of those plants (Whittaker and Marks, 1975). Net primary productivity consists of biomass increment, small litter production (leaves, branches, flowers, fruits and fine roots), death of trees, loss of dissolved organic matter from roots and consumption of leaves and other plant components by herbivores in per unit time (Etherington, 1975; Waring and Schlesinger, 1985).

Net primary productivity in mangroves was estimated by summing of both above and below-ground biomass accumulation and litter production in per unit time (Clough and Attiwill, 1982). It has been reported that net primary productivity of mangroves varied with the stand density and growing seasons (Aksornkoae *et al.*, 1989 in Aksornkoae, 1993). Day *et al.* (1987) estimated the above-ground net primary productivity of mixed mangroves (*A. germinans*, *Laguncularia racemosa* and *R. mangle*) in Boca Chica and Estero Pargo, Mexico. They obtained higher net primary productivity (24.58 t/ha/yr) in Boca Chica where the mean stand height was 20 m. On the contrary, lower net primary productivity (16.06 t/ha/yr) was measured in Estero Pargo with 6 m of mean stand height. In a similar study, Day *et al.* (1996) estimated the above-ground net primary productivity of *A. germinans* in two different places of Campeche, Mexico. They obtained very lower above-ground net primary productivity (3.19-7.59 t/ha/yr), where mean height, mean DBH and density in two different sites varied from 4 to 6 m, 4.90-7.70 cm, and 1590-1720 stem/ha, respectively.

Stand age appears as an important determinant of net primary productivity in mangroves. Ong *et al.* (1985a) estimated comparatively higher above-ground net

primary productivity (28 t/ha/yr) in 10 years old plantation of *R. apiculata* in Matang Mangrove Reserve, Peninsular Malaysia and lower (10 t/ha/yr) in 5 years old plantation of *R. apiculata*. The net above-ground primary productivity of 80 years old *R. apiculata* in mixed mangroves at Pulau Kecil, Matang Mangrove forest was 17.70 t/ha/yr (Putz and Chan, 1986). In a similar study, Sukardjo and Yamada (1992) obtained 22.30 t/ha/yr of above-ground net primary productivity in 7 years old planted *R. mucronata* in Tritih, Java, Indonesia. But, above and below-ground net primary productivity of 20 years old planted *R. apiculata* in Matang mangrove forest reserve was 17 ± 5 t Carbon/ha/yr by considering the below-ground root turn over same as small litter production (5 t Carbon/ha/yr) (Ong *et al.*, 1995).

1.3.2.1 Factors Affecting the Net Primary Productivity

Apart from the stand structure, abiotic factors such as anoxic condition, tidal height, tidal inundation, nutrients availability, salinity and climatic factors have important influence on net primary productivity as well as growth of mangrove species (Clough and Attiwill, 1982; Hutchings and Saenger, 1987; Aksornkoae, 1993).

Mangroves grow in waterlogged soil that are commonly anaerobic. The aerobic and anaerobic condition of mangrove soil largely depends upon frequency and duration of tidal inundation, amount of soil organic matter, nitrate, iron and manganese (Alongi *et al.*, 1992). At low oxidation and reduction condition of soil, some essential elements are available and on the other hand, some are not available. Moreover, the formation of H₂S in anoxic condition appears as toxic to plant and hinders plant growth as well as net primary productivity (Clough, 1992).

Availability of nutrients is essential for plant growth (Jones, 1998), but the extent to which net primary productivity and growth of mangrove plants are influenced by nutrients availability, which is not yet clear. The interaction between redox potential and the availability of essential nutrients is very complex and this complexity is further increased by the heterogeneous nature of mangrove soil. Onuf *et al.* (1977) observed significant increase in growth of *Rhizophora* spp. in Fort Pierce, Florida in response to sewage application. Similarly, Boto and Wellington (1983) found increase rate of new leaves production in response to fertilizer application. In a comparison of mangrove forest productivity in Northern Australia and Papua New Guinea, Boto *et al.* (1984) reported that the availability of soil phosphorus was a major factor that influenced the potential primary productivity. On the contrary, Gong *et al.* (1991) failed to get any correlation between primary productivity and soil characteristics at thirty different sites in Peninsular Malaysia and East Malaysia.

Mangrove productivity, growth and survival are regulated by the salinity of soil and infiltration water (Teas, 1979; Hutchings and Saenger, 1987). However, soil salinity in

mangroves is influenced by soil texture, topography, duration and frequency of tidal inundation, depth of impervious sub-soil, amount and seasonality of rainfall, freshwater discharge of river, run-on from adjacent terrestrial areas and evaporation (Hutchings and Saenger, 1987). Mangrove species showed different tolerant range of salinity but the optimal range of salinity for mangrove growth is 10-30 ppt (Aksornkoar *et al.*, 1989 in Aksornkoar, 1993). High salinity impedes the net primary productivity and growth of mangroves by posing physiological stress due to the low osmotic potential of saline soil. Moreover, mangrove plants have to uptake sufficient inorganic ions to maintain the osmotic balance and at the same time avoid the adverse metabolic effects of high cytoplasmic concentration of these ions (Tomlinson, 1986). Amarasinghe and Balasubramaniam (1992a) studied the above-ground net primary productivity of *R. mucronata* in Erumathivu and Kala Oya, Sri Lanka. They observed comparatively higher (12.86 t/ha/yr) above-ground net primary productivity in Erumathivu than Kala Oya (8.58 t/ha/yr). *Rhizophora mucronata* community in Erumathivu received large amount of freshwater flow from the upstream compared to Kala Oya mangrove community and this attributes to negative relationship between salinity and net primary productivity.

The climatic factors such as rainfall, temperature, wind and potential evapotranspiration and their seasonal fluctuation play an important role in influencing the net primary productivity and growth of mangrove plants (Hutchings and Saenger, 1987). Mangroves showed higher net primary productivity and growth in equatorial climate with moderately higher temperature, rainfall and low ratio of precipitation to evapotranspiration and narrow range of seasonal variability of climatic condition. But, comparatively lower net primary productivity and growth rate of mangroves are expected in arid climates, such as coast of Pakistan or the Arabian Peninsular and with a pronounced seasonal asymmetry in rainfall (Clough, 1992).

1.3.3 Litter production

Litter production can be defined as the shedding of vegetation and reproductive plant structures and may be caused by senescence or stress, mechanical factors (e.g. wind), combination of these or by death and weathering of the whole plant in a given time period (Kozłowski, 1973). Litter production is the function and indicator of primary productivity and important for within stand nutrient cycling and export of nutrients and organic detritus to the estuarine ecosystem (Clough and Attiwill, 1982; Hutchings and Saenger, 1987).

Litter production rates in mangroves widely vary with the species and locations (Woodroffe *et al.*, 1988) and higher rate of litter production is usually observed in the tropical region compared to the sub-tropical region with the increasing latitude (Saenger and Snedaker, 1993). Apart from the geographical variation, litter production

in mangroves and percentage contribution of different litter components seems to be varied with forest type, species, stand density, age of stand and seasonal fluctuation of climatic condition.

1.3.3.1 Forest Types

The rate of litter production found to vary with mangrove forest types (riverine, overwash, fringe, basin and scrub). It has been reported that riverine forest produces higher amount of litter followed by overwash, fringe, basin and scrub mangrove forest in Florida and Puerto Rico (Pool *et al.*, 1975). *Rhizophora mangle* in Laguna de Terminos, Mexico showed higher litter production (12.06 t/ha/yr) in riverine mangrove forest compared to fringe (7.72 t/ha/yr) mangrove forest (Day *et al.*, 1987). Similarly, Amarasinghe and Balasubramaniam (1992a) reported that *R. mucronata* in estuarine mangrove forest produced higher amount of litter (6.24 t/ha/yr) than the fringing mangrove (4.41 t/ha/yr) in the northwest coast of Sri Lanka. Moreover, the proportion contribution of litter components varies from estuarine to fringe mangroves. On the contrary, *R. mangle* and *A. germinans* produced higher litter (7.93 t/ha/yr) in fringe than the basin mangrove forest (4.4 t/ha/yr) in southeast Mexico (Day *et al.*, 1996).

1.3.3.2 Species and Site

The rate of litter production and proportion of litter components in mangroves found to vary with the species and sites. Duke *et al.* (1981) reported that total annual litter production of *B. gymnorhiza*, *B. parviflora* and *S. alba* in Hinchinbrook Island, Australia were 11.4, 10.9 and 7.9 t/ha, respectively. But, *Rhizophora* spp. and *C. tagal* in Missionary Bay, Australia produced 9.6 and 8.5 t/ha/yr of total litter production, respectively. *Avicennia*, *Sonneratia* and *Rhizophora* stand in south Banjar Mangrove Forest Reserve at Kuala Selangor, Peninsular Malaysia showed different rate of litter production at 15.40, 14.00 and 15.80 t/ha/yr, respectively (Sasekumar and Loi, 1983).

Kandelia candel in a tidal shrimp pond, Hong Kong showed the annual range of litter production of 9.10-13.04 t/ha and leaves, wood and reproductive components contributed to 53.94%, 6.15% and 39.91%, respectively of the total litter production (Lee, 1989).

Avicennia marina, *R. stylosa* and *C. tagal* showed variation in litter production at different mangroves in Australia. The annual rate of litter production of *A. marina*, *R. stylosa* and *C. tagal* were 6.20 t/ha (1.10 t/ha to 15.98 t/ha), 9.65 t/ha (2.84 t/ha to 23.69 t/ha) and 6.75 t/ha (3.11 t/ha to 12.90 t/ha), respectively (Bunt, 1995). But, the naturally growing *A. marina* in Arabian Gulf region showed 16.97 t/ha/yr of litter production and peak litter fall was observed during the fruiting season (Hegazy, 1998).

Avicennia germinans in Guyana, South Africa produced 17.71 t/ha/yr of litter and the percentage contribution of leaf fall, fruits, flowers and wood parts of the total litter fall were 61.41%, 8.88%, 24.84% and 4.87%, respectively (Chale, 1996).

Wafar *et al.* (1997) extensively studied the litter production of *R. apiculata*, *R. mucronata*, *S. alba* and *A. officinalis* in Mandovi-Zuari estuaries mangrove forest, Central West Coast of India. They reported that higher litter production of 11.80 t/ha/yr was associated with *R. mucronata* and lower (7.00 t/ha/yr) for *S. alba*. Moreover, the percentage contribution of litter components varied from species to species and the percentage range of leaves, flowers, fruits and others varied from 43% to 68%, 3% to 8%, 10% to 19% and 10% to 39%, respectively.

Aksornkoae and Khemnark (1984) reported that the mean annual litter production in mixed mangroves, dominated by *Rhizophora* spp. in Amphoe Khlung, Northeastern coast of the Gulf of Thailand was 9.32 t/ha and correlated with the forest structure. Litter production of *A. germinans* stand in the Laguna de Mecoacan, Tabasco, Mexico correlated with tree density and yielded 6.14 t/ha of annual mean litter production. The proportion of litter components was 83% for leaves, 9% for branches, 8% for flowers and reproductive parts (Lopez-Portillo and Ezcurra, 1985). Similarly, Saberi (1989) mentioned that litter production in *R. mucronata* stand positively correlated with the stand density.

Twilley *et al.* (1986) studied the litter production of *A. germinans*, *R. mangle* and *Lumnitzera acemosa* in monospecies and mixed stands in southwest Florida and obtained higher amount of litter production (7.51-8.68 t/ha/yr) in mixed stand compared to monospecies stand (3.51-5.38 t/ha/yr).

1.3.3.3 Stand Age

Stand age seems to be an important factor that influences the litter production rate in mangroves. Gong *et al.* (1984) estimated the litter production in different aged (5 to 25 years old) *R. apiculata* stands in Matang Mangrove Reserve, Peninsular Malaysia and obtained highest annual litter fall (11.40 t/ha) in 25 years old stand followed by lower aged stands.

In a similar study, Clough *et al.* (2000) reported that annual litter production and proportion of different litter components of 6 to 36 years old *R. apiculata* stands in Ca Mau Province, southern Vietnam significantly varied with different aged stands. They observed higher (18.79 t/ha/yr) litter production in 12 years old stand and lower of 9.41 t/ha/yr in 9 years old stand. Moreover, proportion of litter components varied with the stand age. Leaves represented more than 75% of the total litter fall in stands 6 to 10 years of old stand, while leaf fall contributed only to 38% of total litter fall in 36 years old stands. Propagules represented less than 1% of the total litter fall in 6 to 12 old stand, but propagules contributed to 25.7% and 37.5% of total litter fall of 21 years and

36 years old stand, respectively. The contribution of flower to the total litter fall was also much higher in the stands of 21 and 36 years old at 5.8 and 6.1%, respectively, compared to the younger stands.

1.3.3.4 Abiotic Factors Influencing the Litter Production

It has been reported that higher rate of litter production in mangroves is usually observed during the dry season (Aksornkoae and Khemnark, 1984; Bunt, 1995). Dry season is associated with higher salt content in soil leads to higher rate of evapotranspiration and facilitates the plants to shed their leaves in energetically cheaper way (Lugo and Snedakar, 1975). Lopez-Portillo and Ezcurra (1985) reported that 74% variability in the seasonal litter production of *A. germinans* in the Laguna de Mecoacan, Tabasco, Mexico was associated with the seasonal temperature fluctuation and mean soil salinity.

Wind velocity, temperature, evaporation and rainfall showed significant influence on litter fall. Sasekumar and Loi (1983) conducted a litter fall study in *Avicennia*, *Sonneratia* and *Rhizophora* stands in south Banjar Mangrove Forest Reserve at Kuala Selangor, Peninsular Malaysia. They reported that wind, temperature, evaporation and rainfall were responsible for less than 50% of the variation in litter fall. Wind and temperature showed greater influence on litter production in the shoreward *Avicennia* and landwards *Rhizophora* stands. Again, about 21% variation of the litter production in the *Sonneratia* stand can be attributed by the meteorological parameters (wind, temperature, evaporation, rainfall), but wind and evaporation together contributed only to 14% of the effect.

Day *et al.* (1996) reported that litter production of *R. mangle* and *A. germinans* in southeastern Mexican mangrove forest increased with the increasing air temperature and rainfall. Similarly, *A. germinans* in Guyana, South Africa showed highest peak leaf fall during the months of higher temperature (30°C) associated with higher rainfall, while lower rate of leaf fall was observed during the months of comparatively lower temperature (28°C) associated with minimum rainfall (Chale, 1996). Irrespective to *A. germinans*, *A. corniculatum* and *K. candel* in Futian National Nature Reserve, China showed higher litter fall of during the summer rainy season and lower in the winter. The high temperature, longer duration of light, higher evapotranspiration rate and more freshwater flushing during the summer rainy months are probably the factors responsible for the greatest litter fall during the summer rainy season (Tam *et al.*, 1998).

The variability of litter production in mangroves may also depend on tidal range. Mackey and Smail (1995) measured the spatial and temporal variation of litter production of *A. marina* in low, mid and high tidal range at Brisbane River estuary, southeast Queensland, Australia. They reported that annual litter production varied

from 8.31 to 9.22 t/ha and higher rate of litter production was observed in the mid tidal level compared to low and high tidal level.

1.3.4 Leaf Litter Decomposition

The amount of nutrients and organic detritus export to the aquatic ecosystem from the mangroves depends on the litter decomposition rates (Lugo and Snedaker, 1974; Odum and Heald, 1975; Reice *et al.*, 1984; Valiela *et al.*, 1985; Twilley *et al.*, 1986; Robertson, 1988; Chale, 1993). The physical forces and grazing action of macro- and meiofauna fragment the mangrove leaf litter (Sasekumar, 1974; Mason, 1977; Valiela *et al.*, 1985) and decomposition continues through the microbial decay of detritus (Fell *et al.*, 1975; Cundell *et al.*, 1979; Bremer, 1995). Significant amount of nutrients and organic matter is released during the process of mangrove litter decomposition and has an important role in within stand nutrient cycling (Lu and Lin, 1990; Steink *et al.*, 1993a), tree productivity and mangrove related food chain (Ashton *et al.*, 1999). Mangrove leaf litter decomposition process and role of micro- and macro-organisms and the factors affecting the decomposition process were documented by numbers of researchers. Decomposition of organic matter occurs in three phases such as leaching of soluble components, microbial oxidation of refractory components such as cellulose and lignin, and physical and biological fragmentation (Mason, 1977; Valiela *et al.*, 1985).

1.3.4.1 Leaching

Leaching process in mangrove leaf litter decomposition was documented by Cundell *et al.* (1979). They studied the leaching process of *R. mangle* leaf litter that immersed in the seawater at Cove, Virginia Key, Florida. They reported that during the first 70 days of submergence, carbon content in degraded leaf litter decreased from 46.20% to 36.20%, while nitrogen content increased from 5.10 mg/g to 8.90 mg/g. They also reported that readily leachable carbohydrates and tannins were lost from the leaf litter from 14th and 28th days, respectively, and most of the carbohydrates and tannins leached from the leaf litter before the leaves were colonized by micro-organisms. The leaching of tannin, waxy cuticle and thick epidermis delayed the colonization of the micro-organisms. Leaching fraction contained readily absorbable organic compounds and nutrients. The natural situation of leaching was accelerated by the physical disturbances (Camilleri and Ribi, 1986). In a similar study, Twilley *et al.* (1986) reported that nutrients content at different stage of *R. mangle* and *A. germinans* leaf litter decomposition varied with the species and locations. They mentioned that decomposition of leaf litter is characterized by an initial leaching of soluble organic and inorganic compounds with subsequent colonization by bacteria, fungi and protozoans, which utilize the labile substance and initiate the breakdown of plant material result in physical and biological fragmentation.

Leaf litter of *A. marina* in Westernport Bay mangrove forest at Victoria, Australia showed significant wet loss due to leaching after 6 days for both moist (11% loss) and dry (14% loss) leaf litter and most of the leaching loss occurred within first 3 days. During the leaching phase, degraded leaf litter of *A. marina* makes loss of 20% of nitrogen, 35-40% of phosphorus, 60-85% of potassium, 30-40% of magnesium and 0-12% of calcium after 6 days (Van de Valk and Attiwill, 1984).

Aegiceras corniculatum, *A. marina* and *K. candel* leaf litter make loss of significant amount of C, N, P and K during the leaching phase at the initial stage of litter decomposition (Tam *et al.*, 1990). In a similar study, Wafar *et al.* (1997) reported that leaf litter of *R. apiculata*, *R. mucronata*, *S. alba* and *A. officinalis* in Mandovi-Zuari mangrove forest, Central West Coast of India showed similar trend in nutrient (N, P and C) loss during the study period of 100 days. Tam *et al.* (1998) reported that leaf litter of *A. corniculatum* and *K. candel* in Futian National Nature Reserve, China showed similar trend of nutrient (N, P and C) loss at different stages of leaf litter decomposition.

Recently, Davis *et al.* (2003) studied the leaching loss of *R. mangle* leaf litter in Everglades mangrove forest. They reported that leaching loss was about 33% of dry mass after 3 weeks. However, the leaching losses were rapid during the initial periods and the peak loss was observed after 2 days. Mean ratio of C:N increased from 105 to 115 and N:P increased from 74 to 95. Carbon mass in leaf litter declined significantly after 361 days, while the mass of nitrogen and phosphorus doubled, indicating long-term accumulation of them into the detritus.

1.3.4.2 Association of Micro-organisms in Litter Decomposition

Different saprophytic micro-flora involved in the decomposition process, but fungi are the primary decomposers of mangrove leaf litter because of their ability to degrade cellulose and lignin, which together form the major component of cell wall in the leaves (Hutchings and Saenger, 1987). Many mangrove fungi are found in both sub-tropical and the warm temperate region but the species diversity in the tropic is much higher. In Brunei 100 species were identified (Hyde, 1988), in Hong Kong 60 species (Vrijmoed *et al.*, 1994), in Australia 60 species (Kohlmeyer and Volkmann-Kohlmeyer, 1991) and in Malaysia 100 species (Alias *et al.*, 1995).

Fell *et al.* (1975) conducted a detail study on associated micro-organisms and their diversity at various stages of *R. mangle* leaf litter decomposition in Miami, Florida, Bahamas, Caribbean, India and Indo-Pacific regions. They reported that during the first two weeks of leaf litter degradation, there was considerable leaching of water soluble materials and carbon level drops by 32% and nitrogen content increased by 16% during the next 5 weeks. Fungi may have contribution in increasing the nitrogen content and bacterial nitrogen fixation on the leaves contributes to the nitrogen pool. They observed that some fungi associated with the leaves that are still attached with the trees. Within

the first 24 hours of submergence, the leaves are attacked by Phycomycetes of the genus *Phytophthora*, subsequently they are infested by a variety of other saprophytes such as *Fusarium* and *Penicillium*. In the second and third weeks the cellulolytic fungi (*Zalerion*, *Lulworthia*) have appeared and by the end of the third week the majority of the phycomycetes have disappeared. They also reported that number of micro-fauna increased approximately 2 to 13 animals/cm² of leaf surface during the first 6 days. The long-term study also showed that the peak micro-faunal density was 34 to 71 animals/cm². The majority of the animals were nematodes and copepods. Among the micro-fauna, 73% was nematodes, 21% copepods and 6% variety of other species.

Robertson (1988) studied the associated bacteria at different stages of *R. stylosa*, *A. marina* and *C. tagal* leaf litter decomposition in Chunda Bay mangrove forest, Queensland, Australia under continuously submersed condition and within the mid-intertidal zone. He reported that bacterial densities increased rapidly during the first 40 days and the density was three times higher in the submersed condition for all the species.

Bremer (1995) reported that green and senescent leaves of *S. alba* and *R. apiculata* in Morib mangrove forest, Malaysia contained terrestrial mycoflora (*Pestalotia*, *Trichoderma*, *Aspergillus*, *Penicillium* and *Alternaria*) and a number of yeast species. He isolated *Labyrinthula* and thraustochytrids after 24 hours of decay process of the both species and found to associate with the all stages of leaf litter decay process. In a similar study, Alias *et al.* (1995) isolated a total 100 species of higher marine fungi from mangrove wood, of which 63 species were new record for Malaysia. They reported that fungi diversity varied from site to site. Total 51 marine fungi were isolated from the mangrove wood at Kuala Selangor of which 43 species were Ascomycotina, 2 species were Basidiomycotina and 6 species of Deuteromycotina. But, 43 species of Ascomycotina, 2 species of Basidiomycotina and 9 species of Deuteromycotina were isolated from the Morib site. The highest species diversity was observed at Port Dickson site, which yielded 53 species of Ascomycotina, 1 species of Basidiomycotina and 11 species of Deuteromycotina.

1.3.4.3 Microbial Decomposition

Microbial decomposition rate of mangrove leaf litter varied with species (Tam *et al.*, 1990; Ashton *et al.*, 1999) and locations through out the world mangroves (Mackey and Smail, 1996). Twilley *et al.* (1986) studied the leaf litter degradation of *R. mangle* and *A. germinans* in mixed and monospecies stand of a basin mangrove forests in southwest Florida. They observed 89% and 79% of initial dry wet loss for *A. germinans*, while 54% and 35% for *R. mangle* in mixed mangroves and monospecies stand, respectively after 148 days.

It has been reported that significantly higher weight loss (87.3%) due to the microbial decomposition was observed with *K. candel* followed by *A. marina* (67.4%) and *A.*

corniculatum (39.8%) at the end of 12 weeks in Sai Keng mangrove forest Hong Kong (Tam *et al.*, 1990). Similarly, Tam *et al.* (1998) reported that 88% of initial dry weight of *K. candel* leaf litter was lost after 42 days and *A. corniculatum* leaf litter made loss of 68% of initial dry weight after 70 days in Futian National Nature Reserve, China.

Bremer (1995) studied the decomposition of *S. alba* and *R. apiculata* leaf litter at Morib mangrove forest, Malaysia under Watson's (1928) tidal inundation class 1. He reported that *S. alba* leaf litter decayed more rapidly than *R. apiculata*. At the end 7 weeks, 78% and 58% of initial dry mass of *S. alba* and *R. apiculata* leaf litter were lost, respectively.

Hegazy (1998) studied the leaf litter decomposition of *A. marina* in a naturally growing stand at Arabian Gulf region. He reported that 46.5% of initial dry weight was lost during the first 5 months and about 37% was lost over the subsequent months of the year.

Ashton *et al.* (1999) studied the leaf litter decomposition of *R. apiculata*, *R. mucronata*, *B. parviflora* and *S. alba* in Matang mangrove reserve forest, Peninsular Malaysia. They compared the leaf litter decomposition in the virgin jungle and cleared forest areas under Watson's (1928) tidal inundation class 4 and 3, respectively. They observed significantly higher rate of leaf litter decomposition in the virgin jungle and comparatively higher rate of litter decomposition was observed with *S. alba* followed by *R. mucronata*, *R. apiculata* and *B. parviflora*.

Different mesh sized litterbags and exposure conditions found to affect the microbial decomposition of leaf litter. Boonruang (1984) studied the leaf litter decomposition of *R. apiculata* and *A. marina* at Phuket Island, Western Peninsular of Thailand, by using three different mesh sized (1.5 mm, 2.5 mm and 20 mm) litterbags in mangrove forest and submersed in the seawater. He observed similar rate of initial dry mass loss of leaf litter with 1.5 mm and 2.5 mm mesh sized litterbags, while 20 mm mesh sized bags showed significantly faster rate of leaf litter decomposition in both exposure conditions. He also reported that *R. apiculata* leaf litter made loss of half of their initial weight in 40 days and *A. marina* in 20 days in the mangrove forest, which was comparatively faster than litter submersed in seawater. In another study, Stewart and Davies (1989) reported that significantly higher rate of leaf litter decomposition was observed in the coarse mesh bags (5 mm) than fine-mesh (180 µm) sized litterbags.

1.3.4.4 Feeding Plus Mechanical Breakdown by Micro- and Macro-Organisms

Sesarmid crabs (Smith, 1987; Robertson and Daniel, 1989; Smith *et al.*, 1989, Micheli, 1993; Steinke *et al.*, 1993b), gastropod snails (Slim *et al.*, 1996), nematodes, copepods (Aksornkoae and Khemnark, 1984) and amphipod (Poovachiranon *et al.*, 1986; Robertson and Duke, 1987) are responsible for the mechanical breakdown and

consumption of a portion of leaf litter in the mangrove forest. It was documented that sesamid crabs consumed significant amounts of mangrove detritus (Malley, 1978; Gearing *et al.*, 1984; Leh and Sasekumar, 1985) and act as an important group in the ecological functioning of the mangrove ecosystem (Robertson and Daniel, 1989; Lee, 1998).

Robertson (1986) studied the removal of *R. stylosa* leaf litter by crabs (*Sesarma messa*) from the mangrove forest at northeastern, Australia. He reported that the range of daily leaf litter removal by crabs was 0.24 to 0.66 g/m², which was 22.2 to 42% of the total daily litter production. He also observed that higher amount of leaf litter was removed during the day than the night and seasonal variation in removal of leaf litter was also observed. In another study, Japar Sidik (1989) reported that *R. apiculata* leaf litter loss due to feeding plus mechanical breakdown by crabs was 12.60% to 49% and 7.30% to 29.80% for 90 days during the dry and wet months, respectively at Matang Mangrove Forest Reserve, Malaysia under Watson's (1928) tidal inundation classes 3 and 4.

Ashton (2002) studied the grazing of *A. officinalis*, *B. gymnorhiza*, *B. parviflora* and *R. apiculata* leaf litter by sesamid crab in mangrove forest at Merbok estuary, Kedah, Peninsular Malaysia. He reported that 79% of the initial dry weight of leaf litter was grazed in 24 hours at high (*Bruguiera* zone) and low (*Rhizophora* zone) intertidal positions at upstream (Sungai Pasir) and downstream (Lower Merbok). He also observed significant numbers of leaves were taken down into the crab's burrows at *Bruguiera* zones, but there were no preferences for leaf species taken down into burrows in all sites.

1.3.4.5 Physical Factors Affecting the Litter Decomposition

Physical factors (wind, temperature, moisture, rainfall, salinity, tidal height, frequency of tidal inundation, current action and pH) play a significant role in leaf litter decomposition by accelerating the degradation process. Most of the physical factors are responsible for mechanical breakdown of litter into smaller size and also affect the role of micro- and macro-organisms in the decomposition process (Swift *et al.*, 1979; Lugo and Snedakar, 1974; Aksornkoae and Khemnark, 1984; Tam *et al.*, 1990; Dick and Osunkoya, 2000; Prause *et al.*, 2002).

Moisture content accelerates the litter decomposition process by creating favourable environmental condition for the decomposer organisms (Swift *et al.*, 1979). Hesse (1961) reported that optimum decomposition occurred at 50% moisture content and decomposition rates accelerated when rewetting followed by drying of the soil. Japar Sidik (1989) reported that *R. apiculata* leaf litter degradation was faster during the wetter months in Matang Mangrove Reserve, Peninsular Malaysia. Mackey and Smail (1996) studied the leaf litter decomposition of *A. marina* during the winter and summer seasons at two different tidal exposure conditions in Brisbane River estuary, Queensland, Australia. They observed significantly higher rate of leaf litter

decomposition during the summer season and at low tidal level. They also mentioned that the summer months are wetter and more humid, which enhanced the activity of microbial decomposers. Moreover, leaf litter decomposition rate depends on air and water temperature by affecting the population level of microbial decomposers or invertebrate. Apart from moisture content and tidal level, salinity has great influence on the rate of litter decomposition and comparatively higher rate of litter decomposition was usually observed in saline water than in fresh water (Heald, 1971; Odum and Heald, 1975).

1.3.5 Nutrient Sources to the Mangrove Forest

Adequate supply of nutrients is essential for maintaining the balance of the mangrove ecosystem (Boto, 1982). It has been reported that forest ecosystem usually receives nutrients from the rainwater, canopy drip, stem flow, runoff from surrounding land areas, decomposed organic matter and mineralization (Trudgill, 1988; Leite and Valle, 1990; Zulkifli *et al.*, 1997; Ranger and Turpault 1999; Gordon *et al.*, 2000). In addition with the above sources, tidal borne nutrients are an important source of nutrients to the mangrove ecosystems (Boto, 1982; Aksornkoae, 1993).

1.3.5.1 Rainfall

The most important nutrient in rainwater is nitrogen, and atmospheric nitrogen is converted to oxide during the thunderstorms. The nutrients composition in rainwater is influenced by local source of pollution, dust and sea born spray (Boto, 1982; Trudgill, 1988). Nutrients content in rainwater is relatively higher during the dryer months compared to the wet months (Schlesinger, 1978).

1.3.5.2 Canopy drip and Stem flow

Canopy drip and stem flow are reported to be the important source of nutrients in any forest ecosystem. Nutrients content in rainwater considerably increased during the interception of plant canopy and stem (Leite and Valle, 1990). This higher nutrients level is the result of leaching of cations from the foliage, branches and stems, although other process such as the rinsing of aerosols is intercepted by the canopy (Schlesinger, 1978). Nutrients content in canopy drip and stem flow is inversely related to the volume collected. Small storms and the initial phase of precipitation in large storms can effectively leach the nutrients from the plant canopy. These collections have higher concentrations, but the canopy drip and stem flow are collected during the later phase of large storms, which is relatively pure (Attiwill, 1966; Tukey, 1970). Moreover, nutrients content in canopy drip and stem flow vary with the plant species (Gordon *et al.*, 2000) and stages of plant development such as flowering, fruiting and appearance of new leaves (Leite and Valle, 1990).

1.3.5.3 Freshwater Input

Fresh water (excluding direct rainwater) flow from the surrounding land area to the mangrove forests is a potentially important source of nutrients. The nutrients are usually dissolved or absorbed on sediments, and nutrients input via freshwater are strongly seasonal (Boto, 1982). Valiela *et al.* (1978) found that fresh water entered the marsh through a variety of springs, channels and rivers. The amount of freshwater input can only be estimated by the calculation of freshwater requires to reduce the salinity of the marsh water to the value as measured at low tide.

1.3.5.4 Nitrogen Fixation

The ability of some organisms to covert molecular nitrogen to make available for plant uptake and it is an important source of nitrogen to the mangrove ecosystem. Nitrogen fixation is found to occur on the marsh surface, in the soil profile at a depth of 15 cm (mainly in the dense root zone). Most of nitrogen fixation is attributed to blue-green algae and photosynthetic bacteria (Alongi *et al.*, 1992). The algae and bacteria involved in N₂ fixation are unlikely to be homogenously distributed throughout the whole of the marsh areas (Haines *et al.*, 1977).

1.3.5.5 Decomposition of Organic Matter

The decomposition of litter and imported organic matter are important sources of nutrients in the mangrove ecosystem. Significant amount of nutrients are released during the litter decomposition process (Cundell *et al.*, 1979; Tam *et al.*, 1990; Davis *et al.*, 2003) and a proportion of these nutrients would be accumulated in the sediments and take part in internal nutrient cycling (Aksornkoae and Khemnark, 1984).

1.3.5.6 Tidal Born Nutrients

During the high tide, mangrove forest floor is usually flooded by the tidal water. The tidal water carry huge amount of sediment and nutrients to the mangrove both dissolved and particulate form. Moreover, extensive use of different types of fertilizer in the agricultural field may be washed into the water system such as channels and rivers. Finally these washed nutrients from agricultural field transported to the nearby mangrove forest (Boto, 1982).

1.3.5.7 Chemical Release from Soil

This mechanism of nutrient input is important in areas where tidal inundation is frequent. The ultimate result is that soils usually undergo considerable changes in redox potential. During the periods of low tidal amplitude these soils revert from a flooded, anaerobic to a partially aerobic state and consequently many nutrients, particularly manganese, iron, zinc, phosphorus and sulphur can undergo drastic chemical change

(Boto, 1982). Large changes in soil pH can occur due to changes in the sulphur oxidation states (Van Breemen, 1976) and strongly acidic conditions, as well as high redox potentials, both contribute to extensive chemical mobilization of certain nutrients.

1.3.6 Nutrient Export from the Mangrove Forest

Nutrients can leave mangrove forest through a variety of ways or means. The most important sources of nutrients output from the mangrove forest are tidal transport, denitrification and volatilisation.

1.3.6.1 Tidal Export

Leaching of nutrients, especially ammonia and nitrate could be controlled by the degree of soil permeability. Sandy soil allows a free exchange between the interstitial and the tidal waters and ultimately resulting in loss of inorganic nitrogen. On the other hand, in areas where soil is impermeable, the tidal water would be far less efficient in leaching nutrients (Boto, 1982). The export of mangrove detritus constitutes a significant energy source for coastal productivity, with positive impacts on fisheries and aquaculture (Tam *et al.*, 1990).

Large amount of organic matter mostly as litter is transported to the aquatic system (river or sea) due to the tidal influence. In some mangrove forests, litter get some time for decomposition mainly in less frequently inundated areas. Areas with frequently inundated by tidal water, litter usually fail to get any sufficient time for decomposition and most of the litter and organic matter are usually washed away by the tidal water. In this way, nutrients in the litters and organic matter are lost from cycling in the mangrove forest (Boto and Bunt, 1981; Tam *et al.*, 1990).

The estimated quantities of litter exported by tides also varied amongst the forest types. In mangrove forest of tropical America, 21 to 25 % of annual litter fall is transported from the forest area (Robertson, 1989) and 50 % of the annual litter is exported from managed Mantag mangrove forest in Malaysia (Ong and Gong, 1990).

1.3.6.2 Denitrification and Volatilisation

Losses of nitrogen from flooded, anaerobic soils can be very severe (Tusneem and Patrick, 1971) because of the process of denitrification i.e., the microbially catalysed reaction. Ammonia in the anaerobic zone of the soil diffuses towards the aerobic layer, which is usually very thin. Here it can be oxidized to nitrate and diffuse back down into the anaerobic zone where it is reduced, not to ammonia, but to nitrous oxide and/or nitrogen gas which can rapidly escape from the system by diffusion (Boto, 1982; Alongi *et al.*, 1992).

1.3.7 Nutrients in Mangrove Plants and Soil

Plants uptake nutrients from soil and translocate to the different components for different physiological functions (such as respiration, transpiration and photosynthesis) as well as for normal growth or metabolism or completing life cycle (Jones *et al.*, 1991; Marschner, 1995). Nutrient contents in plant components are influenced by metabolic requirements (Baker and Walker, 1990; Jones, 1998). Nutrients are absorbed by the mangrove plants, which are impeded by poor aeration in the rooting zone and result in coping with low nutrients availability (mainly nitrogen and phosphorus) (Boto, 1992; Li, 1997). This coping mechanism may affect uptake, distribution, loading and excretion of nutrients within the plant components (Tomlinson, 1986; Waisel *et al.*, 1986; Hutchings and Saenger, 1987). Moreover, nutrient contents in mangrove plant components not only differ from species to species but also differ from components of a plant at different stages of growth (Joshi *et al.*, 1974; Aksornkoae and Khemnark 1984; Jones *et al.*, 1991; Li, 1997; Mahmood *et al.*, 2001).

Clough and Attiwill (1975) reported that macronutrient (N, P, K, Ca, Mg, Na and C) contents in different components (leaves, branches, stem, roots and fruits) of *A. marina* in Westernport Bay, Australia varied widely. They observed comparatively higher N, Mg and Na in leaves, K and Ca in small branches diameter < 1 cm, P in fruits and C in branches diameter 1-3 cm. Lower contents of P, N, K and Na were found in stem and Ca, Mg and C in fruits.

In a similar study, Aksornkoae and Khemnark (1984) compared macronutrients (N, P, K, Ca, Mg and Na) in leaves, branches and stem of *R. apiculata*, *R. mucronata*, *Bruguiera* spp., *Avicennia* spp., *X. obovatus*, *X. moluccensis*, *Ceriops* spp., *Lumnitzera* spp., *Melaleuca crjuputi* and *Acrostichum aureum* in the mangrove forest of Amphoe Khlung, northeastern coast of the Gulf of Thailand. They observed wide variation of nutrients in different components of the above-mentioned species. The range of N, P, K, Ca, Mg and Na contents in leaves of different mangrove species were 7.70-22.4 mg/g, 0.50-1.80 mg/g, 3.30-11.40 mg/g, 0.60-14.60 mg/g, 1.30-3.20 mg/g, and 16.00-59.00 mg/g, respectively, for branches 5.70-14.70 mg/g, 0.40-1.40 mg/g, 1.90-10.80 mg/g, 0.10-9.40 mg/g, 0.50-1.30 mg/g and 10.00-35.00 mg/g, respectively and for stem 3.40-8.60 mg/g, 0.20-0.90 mg/g, 0.80-6.10 mg/g, 0.80-5.40 mg/g, 0.20-0.80 mg/g and 4.00-27.00 mg/g, respectively.

Macronutrients (N, P, K, Ca and Mg) and organic matter significantly varied in different components (leaves, branches, stem and roots) of *R. apiculata* in Matang Mangrove Reserve, Peninsular Malaysia. Nitrogen, phosphorus, potassium, calcium, magnesium and organic matter contents in different components varied from 4.00-16.40 mg/g, 0.70-0.90 mg/g, 0.60-5.20 mg/g, 1.10-4.40 mg/g, 2.00-7.70 mg/g and 87.09-95.32%, respectively. However, comparatively higher nutrient contents were observed in leaves and lower in stem (Gong and Ong, 1990).

Tam *et al.* (1995a) reported that macronutrients (N, P and K) in leaves of *A. corniculatum* and *K. candel* significantly varied in Futian mangrove forest at Shenzhen, China. Similarly, macronutrients (N, P and K) found to vary in different components of *A. corniculatum* and *K. candel* in Futian mangrove forest at Shenzhen, China. Comparatively higher nitrogen content (13.90 mg/g) was observed in leaf and lowest (4.40 mg/g) in roots, K was higher in roots (14.70 mg/g) and lowest in the stems (2.10 mg/g). P was abundant in the roots (1.70 mg/g) and branches (1.50 mg/g) but lowest in the stems (0.60 mg/g). N and P content in leaves of the two species were quite comparable, but *K. candel* leaves seem to have a slightly higher K. Overall, nutrient content in *A. corniculatum* were slightly higher than *K. candel* in terms of weighed mean values (Li, 1997).

Nutrients in mangrove plant components not only varied with the species but also varied with the sites (Lacerda *et al.*, 1985). Moreover, nutrients composition in plant components was found to vary with the age of the tissue (Jones, 1998). Lin and Wang (2001) reported that macronutrients (N, P, K, Ca, Mg, Na and Cl) in leaf of *K. candel*, *B. gymnorhiza* and *R. stylosa* in Fugong Town, Jiulongjiang Estuary Longhai, Fujian Province, China changed during the process of leaf senescence. Large amounts of N, P and K were retranslocated out of senescing leaves, while Cl, Na, Ca and Mg accumulated in senescing leaves. Moreover, retranslocation rate of nutrients varied with the species and also with the particular nutrients such as higher retranslocation of N, P and K that was observed in *B. gymnorhiza* than *K. candel* and *R. stylosa*. During the process of leaf senescence, more than 60% of N, 50% of P and 30% of K were retranslocated out of senescence leaves of *K. candel*, for *B. gymnorhiza* more than 80% of N, 60% of P and 30% of K, for *R. stylosa* 50% of N, 40% of P and 25% of K.

Micronutrients are also essential for plants and required in small amount for the normal growth and development (Adraino, 1986; Marschner, 1995). Silva *et al.* (1990) studied the micronutrients (Mn, Fe, Zn and Cu) content in different components (leaves, flowers, fruits, branches, stems, aerial roots and below ground roots) of *R. mangle* in Sepetiba Bay mangrove forest, Rio de Janeiro, Brazil. They reported that micronutrient contents significantly varied with the plant components. Higher content of Mn (101 µg/g) was observed in leaves, below-ground roots contained higher Fe (1011 µg/g), Zn (19.90 µg/g) and Cu (5.10 µg/g). But, lower content of Mn (15.30 µg/g) was found in below-ground roots and fruits contained lower Fe (3.20 µg/g), Zn (1.20 µg/g) and Cu (non detected). Similarly, micronutrients (Cu and Zn) in different components of *K. candel* in Tamshui estuary, Taiwan showed significant variation (Chiu and Chou, 1991). Irrespective to *R. mangle* and *K. candel*, *R. stylosa* in Yingluo Bay mangrove forest, China showed variation in micro-nutrient (Cu, Mn and Zn) contents in different components. Comparatively higher content of Cu, Zn and Mn was observed in branches, flowers and leaves, respectively, while lower contents of Cu, Zn and Mn were found in aerial roots, stem and barks, respectively (Jiao *et al.*, 1997).

Nutrient contents in a particular component of different mangrove species in a similar environmental condition or in different sites were found to vary. Sadiq and Zaidi (1994) studied the micronutrients (Cu, Mn, Fe and Zn) content in leaves of *A. marina* at two sides, one at the Saudi coast of the Arabian Gulf and another in the Gurmah Island. They reported that micronutrient contents in *Avicennia marina* leaves varied widely among the study sites and failed to get correlations between nutrient contents in sediments and mangrove leaves. In a similar study, Thomas and Fernandez (1997) reported that micronutrients (Cu, Fe, Mn, and Zn) in leaves of *A. officinalis*, *Acanthus ilicifolius*, *B. gymnorhiza*, *S. caseolaris* and *B. racemosa* in Kerala, India, significantly varied with the species and sampling events. However, higher Fe (4593 µg/g) and Mn (1281 µg/g) were observed in *B. racemosa*, Cu (101.70 µg/g) in *A. officinalis* and Zn (135.70 µg/g) in *Acanthus ilicifolius*. Apart from the mangroves leaves, Lian *et al.* (1999) investigated the micronutrients (Cu, Mn and Zn) in propagules of ten different mangrove species in Dongzhai Harbor National Nature Reserve of Hainan Island of China. They reported that elements content in propagules are species specific and Cu, Mn and Zn content in the propagules of different mangrove species ranged from 2.10 to 7.80 µg/g, 3.90 to 28 µg/g and 5.70 to 60 µg/g, respectively.

The rate of nutrients uptake by plants is positively related with the available nutrients level in soil (Kabata-Pendias and Pendias, 1984; MacFarlane and Burchett, 2002). Cai (1987) calculated the correlation between macronutrient (N, P and K) contents in *Aegiceras* sp. leaf and soil. He obtained fairly low or even negative correlation, the correlation coefficients for N, P and K were -0.33, -0.55 and -0.43, respectively. In another study, Thomas and Fernandez (1997) observed positive correlation between Fe, Mn and Cu contents in leaves of *A. officinalis* and the respective content in soil, but other mangrove species (*A. ilicifolius*, *B. gymnorhiza*, *S. caseolaris* and *B. racemosa*) showed negative correlations. It has been reported that the fluctuation in climatic condition, soil edaphic factors, available nutrients in the substrate and concentration of other nutrients can affect the nutrient contents in plant components considerably. Moreover, element characteristics, plant species, types of plant components, physiological age of the tissue and seasons (dry and wet) may influence the nutrient contents in plant components (Jones *et al.*, 1991; Walbridge, 1991).

Soil is the large potential nutrient pools for mangrove plants but large quantities of nutrients in the sediments are not readily available to plants because most of them are refractory (Li, 1997). The adsorption and desorption of nutrients in wetland soils depend on a combination of soil properties including pH, CEC (Cation Exchange Capacity), organic matter, clay content, redox potential, salinity, iron and manganese oxides, presence of other elements, and the altering aerobic and anoxic conditions (Harbison, 1986; Harter, 1992; Orson *et al.*, 1992; Tam and Wong, 1996; Shriadah, 1999).

Sukardjo *et al.* (1984) studied the nutrient (N, K, Ca, Mg and C) contents and physio-chemical properties of soil in different mangrove vegetation types at south Sumatra Province. They reported that soil nutrients level and physio-chemical properties significantly varied with the vegetation types. Tam and Wong (1996) studied the retention and distribution of heavy metals as well as nitrogen, phosphorus and potassium in two mangrove forest soils, one in Sai Keng, Hong Kong and the other in Futian Nature Reserve, Shenzhen, China. They reported that sandy soil (at Sai Keng mangrove forest) contained comparatively lower content of total N, P, K, Cu, Zn Mn, Cd, and Ni than the clay soil (at Futian mangrove forest).

Tam and Wong (1995) studied the spatial and temporal variation of macro (N, P and K) and micronutrients (Cu, Zn and Mn) in Sai Keng, Hong Kong. They reported that both macro and micronutrient contents in mangrove soil significantly varied with the sites and sampling time throughout the year. It has been reported that trace metals are transported on fine particles and organic matter carried by the tidal water (Lacerda *et al.*, 1988) and this may result in spatial heterogeneity in metal content in salt marsh (Vestergaard, 1979). Tidal inundation may responsible for wide variation of elements content in mangrove sediment (Mackey and Hodgkinson, 1995).

CHAPTER 2

STUDY AREA AND FOREST STRUCTURE

2.1 Introduction

The total extend of mangrove forest in Malaysia is about 641,000 ha. Peninsular Malaysia has only 17% (108,970 ha) of the total mangrove area and 93,387.29 ha are gazetted as reserve forests and rest of 15,582.71 ha are state land mangroves. Most of these forests are situated along the sheltered west coast in the states of Kedah, Perak, Selangor and Johor. Mangrove areas are under the jurisdiction of the respective State Forest Department. Selangor state alone accounts for about 24.12% (26,283.56 ha) of the total mangrove forest in Peninsular Malaysia (Ibrahim and Chan, 1995; Spalding *et al.*, 1997).

2.2 Study Area

The present study was conducted in 100 ha mangrove forest of Kuala Selangor Nature Park, which is a part of the extensive coastal belt of mangroves on the west coast of the Malay Peninsula. The mangrove areas in the Nature Park are totally protected since 1987 and situated at the mouth of Selangor river and extended to some areas along the Straits of Malacca in between latitudes 3°19'-3°20'N and longitudes 101°14'-101°15'E (Figure 2.1).

2.3 Rainfall

The mean annual rainfall in the study area is about 1790 mm. The lowest mean monthly rainfall (80 mm) occurred during July and highest mean monthly rainfall (242 mm) in November. Rainfall is distributed throughout the year but it can be divided into three seasons. The wet season is from September to December, which contributes to 46% of total annual rainfall. The intermediate season contributes to 31% of annual rainfall from January to April and the dry season contributes to 23% of annual rainfall from May to August (Figure 2.2). Based on monthly rainfall pattern, samplings in the present study were conducted during March – Intermediate season, July – Dry season and November – Wet season. The rainfall pattern during the 24 months of study period (September 2001 to August 2003) is presented in Figure 2.4 (Malaysian Metrological Service, 2003).

2.4 Temperature

The mean minimum and maximum temperature are 24°C and 32°C, respectively. The mean monthly temperature varied a little, lowest temperature (30°C) was observed during November and December and highest temperature (31.1°C) during May and June (Figure 2.3). The pattern of temperature fluctuation during the 24 months of study

period (September 2001 to August 2003) is presented in Figure 2.4 (Malaysian Metrological Service, 2003).

2.5 Tidal Characteristics

From the field observations, this mangrove forest is inundated only by the spring high tides, thus lies under Watson's (1928) tidal inundation class 4. The mangroves area becomes water logged just after the flooding and remains submersed. The reason may be due to the poor drainage. The range of spring high tide is 4.33 m from the datum level at Port Kelang, Selangor, nearest to the study site (Department of Survey and Mapping, 2003).

2.6 Vegetation

This mangrove forest appears as a strip with an average width of 200 m and varies from 150 to 250 m from seaward to landward. Twelve mangrove species from the families of Avicenniaceae, Rhizophoraceae, Sonneratiaceae and Euphorbiaceae are reported in the mangrove forest of Kuala Selangor Nature Park (Malayan Nature Society, Pers. Comm.). From the field observations, *Bruguiera parviflora* seems to be the dominant species and *Sonneratia griffithii* was also found to occur in the forest areas. Different mangrove species in the Kuala Selangor Nature Park are presented in Table 2.1.

2.7 Materials and Methods

2.7.1 Vegetation Structure

2.7.1.1 Structural Characteristics of Seedlings

The study on structural characteristics of seedlings was performed during September 2001 to December 2001. Three transect lines were randomly established from the shoreward margin at the right angles to the landward edge of the mangrove forest (Figure 2.1). Ten plots (1 m x 1 m) were taken randomly along the each transect and all seedlings (height < 1 m) inside the plots were identified and counted. Density, relative density, frequency and relative frequency of seedlings were calculated from the relationship given by Cintron and Novelli (1984) as shown below.

$$\text{Density (stem/ha)} = \frac{\text{Total number of individual stem}}{\text{Plot area (ha) x Number of sample plots}}$$

$$\text{Relative density (\%)} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} \times 100$$

$$\text{Frequency (\%)} = \frac{\text{Number of plots where individual species are present}}{\text{Total number of plots}} \times 100$$

$$\text{Relative frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Sum - frequency of all species}} \times 100$$

2.7.1.2 Structural Characteristics of Saplings and Trees

The study of saplings and trees structural characteristics was performed during September 2001 to December 2001. A total 20 plots (10 m x 10 m) were taken randomly from the three transects (mentioned in Section 2.7.1.1) and all saplings (diameter at breast height < 4 cm) and trees (diameter at breast height > 4 cm) inside the plots were identified and counted. Haga Clinometer (Germany) and graduated pole were used for measuring the total height (m) of trees and saplings, respectively. DBH (Diameter at Breast Height) was measured directly by using diameter tape for all saplings and trees. Density, relative density, frequency and relative frequency, mean DBH, mean height, basal area, relative dominance and importance value index of saplings and trees were calculated from the relationship given by Cintron and Novelli (1984). The equations for density, relative density, frequency and relative frequency are mentioned in Section 2.7.1.1. Complexity index was calculated from the relationship given by Holdridge *et al.* (1971) as follows.

$$\text{Basal area per hectare (m}^2\text{)} = \frac{\text{Total basal area of individual species (m}^2\text{)}}{\text{Sample plot area (ha) x Number of sample plots}}$$

$$\text{Mean DBH (cm)} = \sqrt{\frac{\text{Mean basal area per stem of individual species (cm}^2\text{)} \times 4}{\pi}}$$

Mean Height = Total height (m) of all stems in the sample plot/ Number of stems in the sample plots area

$$\text{Relative dominance (\%)} = \frac{\text{Total basal area of a species (cm}^2\text{)}}{\text{Basal area of all species (cm}^2\text{)}} \times 100$$

$$\text{Importance value (\%)} = (\text{Relative density} + \text{Relative frequency} + \text{Relative dominance}) / 3$$

$$\text{Complexity index} = \text{Number of species} \times \text{Stand density} \times \text{Stand basal area} \times \text{Stand height} \times 10^{-5}$$

2.7.1.3 DBH Increment in *B. parviflora* Saplings and Trees

Nine saplings and eighteen trees of *B. parviflora* were selected randomly (avoiding mechanically or insect damaged or infested with disease), DBH was measured and tagged during September 2001. The DBH of tagged saplings and trees were again measured at yearly interval for successive two years. Yearly average DBH increment in saplings and trees were tested by paired 't' (t-test, p<0.05) test by using SAS (6.12) statistical software.

2.7.1.4 Litter Standing Crop on Natural Litter Bed

The composition and distribution of natural litter bed (leaves, small branches, bracts and propagules) of this mangrove forest were observed from 18 randomly selected plots (1 m x 1 m) during the wet (November 2001), intermediate (March 2002), dry (July

2002), wet (November 2002), intermediate (March 2003) and dry (July 2003) seasons. All the collected litter from the individual plots were then put into separate labelled airtight plastic bag and placed into ice chest and brought back to the laboratory for further processing. The collected litter samples from each plot were washed thoroughly to remove all dirt and sediment particles, sorted into leaves, small branches (diameter < 2 cm), bracts and propagules. Leaves were again sorted into intact and broken leaves. Intact leaves indicate the comparatively freshly fallen leaves and broken leaves are the evidence of microbial degradation, grazing of macro-organisms and fragmentation by physical forces. The sorted litter was oven dried at 80°C until constant weight and weighted using electric balance to nearest 0.01 g and recorded. Total amount of litter standing crop and their components in different seasons were compared by two way analysis of variance followed by Duncan Multiple Range Test (DMRT, $p < 0.05$) by using SAS (6.12) statistical software.

2.7.2 Sediment Accretion and Erosion

Sediment accretion referred to the vertical thickness of sediment in certain area for a particular time period and erosion is the process of soil washing away in vertical direction. Soil accretion and erosion were measured by placing 36 solid tile bases (10 cm x 10 cm) randomly in the forest area. The tile bases were placed flatly at about 5 cm depth from the sediment surface, marked by numbered flags, and initial sediment height (cm) on each tile was recorded. Monthly sediment accretion and erosion were estimated by deducting the sediment height of previous month from the current month on the same tile base. This study was conducted for 20 months from December 2001 to July 2003. Means with standard error of monthly sediment accretion and erosion were calculated and multiple linear regression ($Y = b_1X_1 + b_2X_2 + b_0$) analysis was performed among the monthly sediment accretion/erosion, rainfall and number of spring high tides that flooded the forest floor, (where, Y was the sediment accretion/erosion, X_1 and X_2 were rainfall amount and number of spring high tides, respectively, b_1 , b_2 and b_0 were constant) by using SAS (6.12) statistical software.

2.8 General Observations and Results

2.8.1 Vegetation Structure

Five mangrove species belonging to the families of Avicenniaceae, Rhizophoraceae and Sonneratiaceae were recorded during the field sampling. The species were *Avicennia alba*, *Bruguiera parviflora*, *Rhizophora apiculata*, *R. mucronata* and *Sonneratia caseolaris*. However, *R. apiculata*, *R. mucronata* and *S. caseolaris* were found within 20-40 m at the seaward end and some time at the inner part of the forest at the depression areas, but *A. alba* was found sporadically throughout the forest. *Bruguiera parviflora* appears as dominant species with an importance value of 74.47% and 75.35% for saplings and trees, respectively, followed by *A. alba* and *R. mucronata* (Table 2.2).

Three strata (top, middle and lower) were observed in this mangrove forest. Trees constitute the top stratum of 8.90 to 10.28 m height, 2180 ± 105 trees/ha, DBH range 4 to 26 cm and 18.90 ± 8.14 m²/ha of basal area. *Avicennia alba* contributed to 70 ± 8 trees/ha, with 14.84 ± 6.64 cm mean DBH and 1.21 ± 0.25 m²/ha basal area, *B. parviflora* contributed to 2030 ± 143 trees/ha with 9.84 ± 1.66 cm mean DBH and 15.44 ± 6.67 m²/ha basal area, *R. mucronata* attained with 50 ± 12 trees/ha, mean DBH 16.35 ± 5.71 cm and 1.05 ± 0.40 m²/ha basal area and *S. caseolaris* contributed to 25 ± 12 trees/ha with 23.99 ± 7.53 cm mean DBH and 1.13 ± 0.42 m²/ha basal area. *Rhizophora apiculata* constituted 5 ± 0 trees/ha with mean DBH 13.35 ± 5.71 cm and 0.07 ± 0.01 m²/ha basal area. The DBH increment in selected trees was not significantly (t-test, $p > 0.05$) different in two consecutive years and the annual average DBH increment of *B. parviflora* trees was 0.39 cm, which was comparatively lower (0.51 cm/yr) than *B. parviflora* at Pulau Kecil, Matang mangroves (Putz and Chan, 1986) (Table 2.2).

Saplings constituted the middle stratum of 2.58 to 4.20 m height, 695 ± 57 saplings/ha and DBH range 1 to <4 cm and 0.28 ± 0.01 m²/ha of basal area. *Bruguiera parviflora* contributed to 565 ± 51 saplings/ha followed by *A. alba* (85 ± 14 saplings/ha) and *R. mucronata* (35 ± 25 saplings/ha), while a lower sapling density of 5 ± 0 saplings/ha was observed for *R. apiculata* and *S. caseolaris*. The mean DBH of *A. alba*, *B. parviflora*, *R. apiculata*, *R. mucronata* and *S. caseolaris* were 1.77 ± 0.02 , 2.37 ± 0.63 , 2.80 ± 0.03 , 1.71 ± 0.93 and 2.10 ± 0.01 cm, respectively. The DBH increment in selected saplings was not significantly (t-test, $p > 0.05$) different in two consecutive years. However, *B. parviflora* saplings showed comparatively higher annual average DBH increment (0.42 cm/yr) than the trees (Table 2.2).

The lower stratum (< 1 m height) consists of dense seedlings ($408,000 \pm 25458$ seedlings/ha). A higher abundance of *B. parviflora* seedlings at density of $380,500 \pm 28311$ seedlings/ha was found in the study site (Table 2.3). Other mangrove seedlings occurred in lesser abundance: *A. alba* ($10,500 \pm 1711$ seedlings/ha), *S. caseolaris* ($7,000 \pm 1879$ seedlings/ha), *R. apiculata* ($5,500 \pm 1599$ seedlings/ha) and *R. mucronata* ($4,500 \pm 1308$ seedlings/ha) (Table 2.3). Seedlings of *B. parviflora*, *R. apiculata* and *R. mucronata* were found at the vicinity of the parent trees. This indicated that propagules were not dispersed to other areas by the tides (tidal currents) and hence they established. Similar phenomenon of the occurrence of *B. parviflora* seedlings around the parent trees was reported by Abdulhadi and Suhardjono (1994) at Sei Kecil, Simpang Hilir, West Kalimantan mangrove forest, Indonesia. Moreover, seedlings and saplings of *B. parviflora* were comparatively more abundant in the gaps than the surrounded canopy.

The ground level consists of natural litter layer and the amount of small litter standing crop varied from 63.45 to 104.59 g/m². The amount of intact leaves, broken leaves, small branches, bracts and propagules varied from 16.14 to 31.47 g/m², 20.80 to 36.10

g/m², 13.70 to 19.26 g/m², 0.92 to 1.58 g/m² and 0.78 to 47.45 g/m², respectively. Different components of litter standing crop showed significant (ANOVA, DMRT, $p < 0.05$) variation among the plots and seasons (Appendix A). Comparatively higher amount of leaf litter standing crop was observed during the intermediate seasons (March 02 and 03) (Table 2.6) (ANOVA, DMRT, $p < 0.05$). Wide range of litter standing crop (1.53-2051 g/m²) was observed at different mangrove forests (Table 2.7). This wide range of variation may result from the species composition, stand structure, tidal inundation, river flow and meteorological events. The details on litter dynamics are discussed in litter production Chapter 5.

2.8.2 Sediment Accretion and Erosion

Monthly sediment erosion and accretion ranged from -0.34 to 0.32 cm and erosion was observed during May 02, Jun 02, July 02 and March 03. During the 20 months of study period, a total 1.69 cm sediment was accreted and constituted the monthly and yearly rates of 0.085 cm and 1.02 cm, respectively. A significant ($r = 0.73$, $p < 0.05$) relationship was observed among the monthly sediment accretion and erosion, rainfall and number of spring high tide that flooded the forest floor (Table 2.8) and the multiple linear regression equation was as follows:

$$\text{Sediment accretion/erosion} = 0.0016 \times \text{Rain} + 0.0107 \times \text{Number of tide} - 0.217$$

2.9 Discussion

2.9.1. Vegetation Structure

This mangrove forest has comparatively higher complexity index value (23.93) than the mangrove forest at Dutch Bay, Sri Lanka (1.95-22.16) (Amarasinghe and Balasubramaniam, 1992b) and Pulau Langkawi, Malaysia (13.64) (Norhayati and Latiff, 2001) (Table 2.4). The least complex stand is characterized by high stem density, lower species diversity, mean height and basal area, while complex stand comprises of higher species diversity, tall canopy, higher basal area and lower stem density (Pool *et al.*, 1977). Mangrove forest is characterised by poor species diversity, few or one strata, mainly even sized, undergrowth usually absent, few climbers and epiphytes and this is the uniqueness of mangroves compared to the terrestrial forest (Table 2.5) and the Plates 2.2 and 2.3 show the top stratum (trees), middle stratum (saplings) and lower strata (seedlings) in this mangrove forest.

2.9.2 Sediment Accretion and Erosion

Tide is the dominant factor of sediment dynamics in the mangroves and responsible for transportation, deposition and erosion of sediment (Cahoon and Reed, 1995; Wolanski, 1995). During the high tide, strong currents are able to carry sediment through the creek (Gross, 1972) and high shear stress of flood velocity with transported sediment creates higher concentration of suspended sediment (Reed, 1988). The carried sediment is

deposited on the marsh surface during the period of slack water and low velocity flow, and the export of sediment from the marsh system also depends upon the velocity of the ebb tide (Reed, 1988). In the present study, comparatively higher sediment accretion (0.32 cm) was observed during November 02 with higher amount of rainfall (286.3 mm) and higher number (11) of spring high tides, while relatively higher sediment erosion (-0.34 cm) was observed during March 03 with low amount of rainfall (24.9 mm) and grater number (10) of spring high tide (Figure 2.5). These findings suggested that spring high tides during the drier months may carry lower amount of suspended sediment and the ebb tides could transport away more sediment from the mangrove forest. On the contrary, spring high tides at wet season carry a lot of sediment into the mangrove and result in accretion, because the amount of sediment transported to the mangrove areas exceeds the amount of sediment export away from the mangroves.

Different rates of sediment accretion are observed at different mangrove areas in the world. Sediment accretion in this study is comparatively higher than *Rhizophora* spp. dominated mangrove forest at Mexico (Lynch *et al.*, 1989) and Northern Australia (Woodroffe, 1990). However, similar accretion rate was observed at Kuala Kemaman, Terengganu, Malaysia (Shahbudin, 1996) (Table 2.10). The rate of sediment accretion is also influenced by the mangrove vegetation pattern and the height of forest areas from the mean sea level (Spenceley, 1982). Mangrove roots system and pneumatophore play a significant role in trapping sediment particles by retarding the current velocity (Young and Harvey, 1996). The sediment trapping ability of mangroves is not only important for mangroves itself in terms of nutrient inputs into the system, but can play a major role in land building process and soil stability in the coastal areas.

Table 2.1: Mangrove species in the forest of Kuala Selangor Nature Park

Family	Species
Avicenniaceae	<i>Avicennia alba</i>
	<i>A. marina</i>
	<i>A. officinalis</i>
Rhizophoraceae	<i>Bruguiera cylindrica</i>
	<i>B. gymnorrhiza</i>
	<i>B. parviflora</i>
	<i>B. sexangula</i>
	<i>Rhizophora apiculata</i>
	<i>R. mucronata</i>
Sonneratiaceae	<i>Sonneratia alba</i>
	<i>S. caseolaris</i>
	<i>S. griffithii</i>
Euphorbiaceae	<i>Excoecaria agallocha</i>

Table 2.2: Forest structural attributes for saplings and trees

Species	Mean diameter (cm)	Mean height (m)	Basal area (cm ²)/ha	Basal area (cm ²)/stem	Density (no/ha)	Relative density (%)	Frequency (%)	Relative frequency (%)	Relative dominance (%)	Importance value	Average annual DBH increment (cm/year)
Saplings											
<i>A. alba</i>	1.77±0.02	2.55±0.14	207.85±29	2.45±0.01	85±14	12.23	60	32.44	7.37	17.35	NM
<i>B. parviflora</i>	2.37±0.63	3.92±0.12	2485.25±240	4.40±0.31	565±51	81.30	100	54.05	88.06	74.47	0.42
<i>R. apiculata</i>	2.80±0.03	4.20±0.02	30.75±13	6.15±0.02	5±0	0.72	5	2.70	1.09	1.50	NM
<i>R. mucronata</i>	1.71±0.93	3.64±0.44	80.90±32	2.31±0.01	35±25	5.03	15	8.11	2.87	5.34	NM
<i>S. caseolaris</i>	2.10±0.01	3.20±0.01	17.30±7	3.46±0.01	5±0	0.72	5	2.70	0.61	1.34	NM
Trees											
<i>A. alba</i>	14.84±6.64	9.69±0.70	12100±2555	172.86±34.67	70±8	3.21	60	30.77	6.42	13.47	NM
<i>B. parviflora</i>	9.84±1.66	10.27±0.08	154400±7669	76.06±0.14	2030±143	93.12	100	51.28	81.66	75.35	0.39
<i>R. apiculata</i>	13.35±0.06	8.90±0.02	700±304	140±0.02	5±0	0.22	5	2.57	0.38	1.06	NM
<i>R. mucronata</i>	16.35±5.71	10.24±0.58	10500±4005	210±25.57	50±12	2.29	15	7.69	5.57	5.18	NM
<i>S. caseolaris</i>	23.99±7.53	9.92±0.74	11300±4289	452±44	25±12	1.15	15	7.69	5.97	4.94	NM

NM = Not measured

Table 2.3: Forest structural attributes for seedlings

Species	Density (Seedlings/ha)	Relative density (%)	Frequency (%)	Relative frequency (%)
<i>Avicennia alba</i>	10500±1711	2.57	50	18.86
<i>Bruguiera parviflora</i>	380500±28311	93.26	100	37.74
<i>Rhizophora apiculata</i>	5500±1599	1.35	35	13.21
<i>R. mucronata</i>	4500±1308	1.1	35	13.21
<i>Sonneratia caseolaris</i>	7000±1879	1.72	45	16.98

Table 2.4: Comparison of structural characteristics of different mangrove forest

Location	Number of species	Density (Stem/ha)	Mean stand height (m)	Stand basal area (m ² /ha)	Complexity index	Source
Ten Thousand Island, USA (25°50'N, 81°30' W)	2-3	1800- 4000	6.30- 9.00	10.50- 38.50	3.40-27.70	Pool <i>et al.</i> (1977)
Puerto Rico (18°27'N, 65°57' W)	2-3	1380- 5690	8.50- 16.00	15.80- 35.00	11.20-30.80	
Costa Rica (10°N, 83°05' W)	2-4	1050- 1370	9.50- 16.00	20.32- 90.64	4.90-84.50	
Mexico (22°31'N, 105°40'W)	2-3	1480- 3120	8.00- 17.00	15.20- 60.80	8.50-49.70	
Ko Yao Yai, Thailand (7°55' N, 98° 35' E)	10	1821	21.8	35.9	142.52	Chansang (1984)
Boca Chica (18°20' N, 91°50' W)	3	3360	20	34.2	68.91	Day <i>et al.</i> (1987)
Estero Pargo, Mexico (18°40'N, 91°45' W)	3	7510	6	23.3	31.5	
Dutch bay, Sri Lanka (8°15'N, 79°50'E)	2-7	2200- 3600	3.90- 4.40	11.40- 19.99	1.95-22.16	Amarasinghe and Balasubramania m (1992b)
Pulau Langkawi, Malaysia (6°22' N, 99°48' E)	9	849	13.09	13.64	13.64	Norhayati and Latiff (2001)
Kuala Selangor, Malaysia (3°19'N, 101°14' E)	13	2875	8.68	19.18	23.93	This study

Table 2.5: Comparison of community characteristics among the mature phase of terrestrial forest and mangrove forest (Tomlinson, 1986; Smith, 1992)

Community characters	Terrestrial forest	Mangroves	This study
Species richness	Rich	Poor	Poor
Stratification	Many strata	Few or no strata	Three strata
Size distribution	Uneven sized	Mainly even sized	Tree DBH 8-12 cm contributed 48% of the stand
Large stems	Present	Present only in old and undisturbed stands	Few
Undergrowth	Sparse	Usually absent	Absent
Climbers	Many	Few	Absent
Epiphytes	Many	Few	Few
Litter layer	Huge	Less	Less

Table 2.6: Composition and distribution of litter standing crops (g/m^2) on natural litter bed at different seasons. Means with similar alphabet in the same column (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

Sampling season	Intact leaves (g)	Broken leaves (g)	Small branches (g)	Bract (g)	Propagules (g)	Total weight (g)
Wet season (November 01)	23.15 $\pm$ 1.63 ^B	24.63 $\pm$ 1.82 ^B	18.92 $\pm$ 2.85 ^A	1.00 $\pm$ 0.15 ^B	0	67.71 $\pm$ 3.73 ^C
Intermediate season (March 02)	31.47 $\pm$ 2.12 ^A	36.10 $\pm$ 3.00 ^A	19.26 $\pm$ 1.57 ^A	1.43 $\pm$ 0.13 ^A	1.22 $\pm$ 0.40 ^C	89.49 $\pm$ 4.24 ^B
Dry season (July 02)	18.98 $\pm$ 1.49 ^C	21.84 $\pm$ 1.77 ^C	15.41 $\pm$ 1.61 ^A	0.92 $\pm$ 0.15 ^C	47.45 $\pm$ 2.3 ^A	104.59 $\pm$ 3.60 ^A
Wet season (November 02)	24.28 $\pm$ 1.71 ^B	22.96 $\pm$ 1.83 ^C	15.12 $\pm$ 1.29 ^A	1.10 $\pm$ 0.19 ^B	0	63.45 $\pm$ 2.11 ^C
Intermediate season (March 03)	27.74 $\pm$ 1.89 ^A	29.79 $\pm$ 1.86 ^B	14.55 $\pm$ 1.31 ^A	1.58 $\pm$ 0.15 ^A	0.78 $\pm$ 0.30 ^C	74.44 $\pm$ 3.45 ^C
Dry season (July 03)	16.14 $\pm$ 1.90 ^C	20.80 $\pm$ 1.95 ^C	13.70 $\pm$ 2.23 ^A	1.02 $\pm$ 0.09 ^B	19.31 $\pm$ 2.3 ^B	70.97 $\pm$ 4.09 ^C

Table 2.7: Comparison of litter standing crop at different mangrove forests

Geographical location	Species	Dry weight (g/m ²)	Sources
Middle Harbour, Sydney, Australia (33°55'S, 151°10'E)	<i>Avicennia marina</i>	9-62	Goulter and Allaway (1979)
Matang Mangrove, Malaysia (4°50'N, 100° 36'E)	<i>Rhizophora apiculata</i> (Planted) <i>R. apiculata</i> <i>R. mucronata</i> <i>Bruguiera</i> spp.	144-599 248	Gong <i>et al.</i> (1984)
Motupore Island, Papua New Guinea (9°31'S, 147°17'E)	<i>R. stylosa</i>	50	Leach and Burgin (1985)
Southwest Florida (26°02' N, 81°45'W; 25°02' N, 81°34'W)	<i>Avicennia</i> spp. <i>Rhizophora</i> spp.	12-15 38-45	Twilley <i>et al.</i> (1986)
Mai Po Marshes, Hong Kong (22°31' N, 114°05' E)	<i>Kandelia candel</i>	959	Lee (1989)
Tritih, Java, Indonesia (7°58'S, 108°44'E)	<i>R. mucronata</i> (Planted)	1692-2051	Sukardjo and Yamada (1992)
Churute estuary, Ecuador (2°35'S, 79°40'W)	<i>Rhizophora</i> spp.	1.53-9.18*	Twilley <i>et al.</i> (1997)
Kuala Selangor, Malaysia (3°19'N, 101°14' E)	<i>B. parviflora</i>	63.45-104.59	This study

* Leaf litter only

Table 2.8: Analysis of variance of multiple linear regression analysis among the monthly sediment accretion/erosion, rainfall and number of spring high tides that flooded the forest floor

Source of variation	Degree of freedom	Sum of square	Mean square	F value	Pr > F	r value
Rainfall and number of spring high tides	2	0.408	0.2	9.714	0.002	0.0.73
Error	17	0.352	0.02			
Total	19	0.76				

Table 2.9: Intercept and multiple linear regression constants of rainfall and number of spring high tides that flooded the forest floor

Variable	DF	Degree of Freedom	Parameter Estimate	Standard Error	P> T
Intercept		1	-0.217	0.08	0.02
Rainfall		1	0.0016	0.004	0.01
Number of tide		1	0.0107	0.007	0.14

Table 2.10: Sediment accretion and erosion rate at different mangrove forest

Location	Species	Accretion rate (cm/yr)	Source
Magnetic island, North Queensland, Australia.	<i>Ceriops</i> sp.	-8.16 to 11.04	Spenceley (1982)
	<i>Rhizophora</i> sp.	-6.46 to 4.61	
	<i>Rhizophora</i> sp.	-3.84 to 4.00	
Mexico	<i>Rhizophora</i> sp.	0.30	Lynch <i>et al.</i> (1989)
Northern Australia	<i>Rhizophora</i> sp.	0.60	Woodroffe (1990)
Kuala Kemaman	<i>Rhizophora</i> sp.	0.64 to 1.46	Shahbudin (1996)
Terengganu, Malaysia			
Kuala Selangor, Malaysia	<i>Bruguiera parviflora</i>	1.02	This study

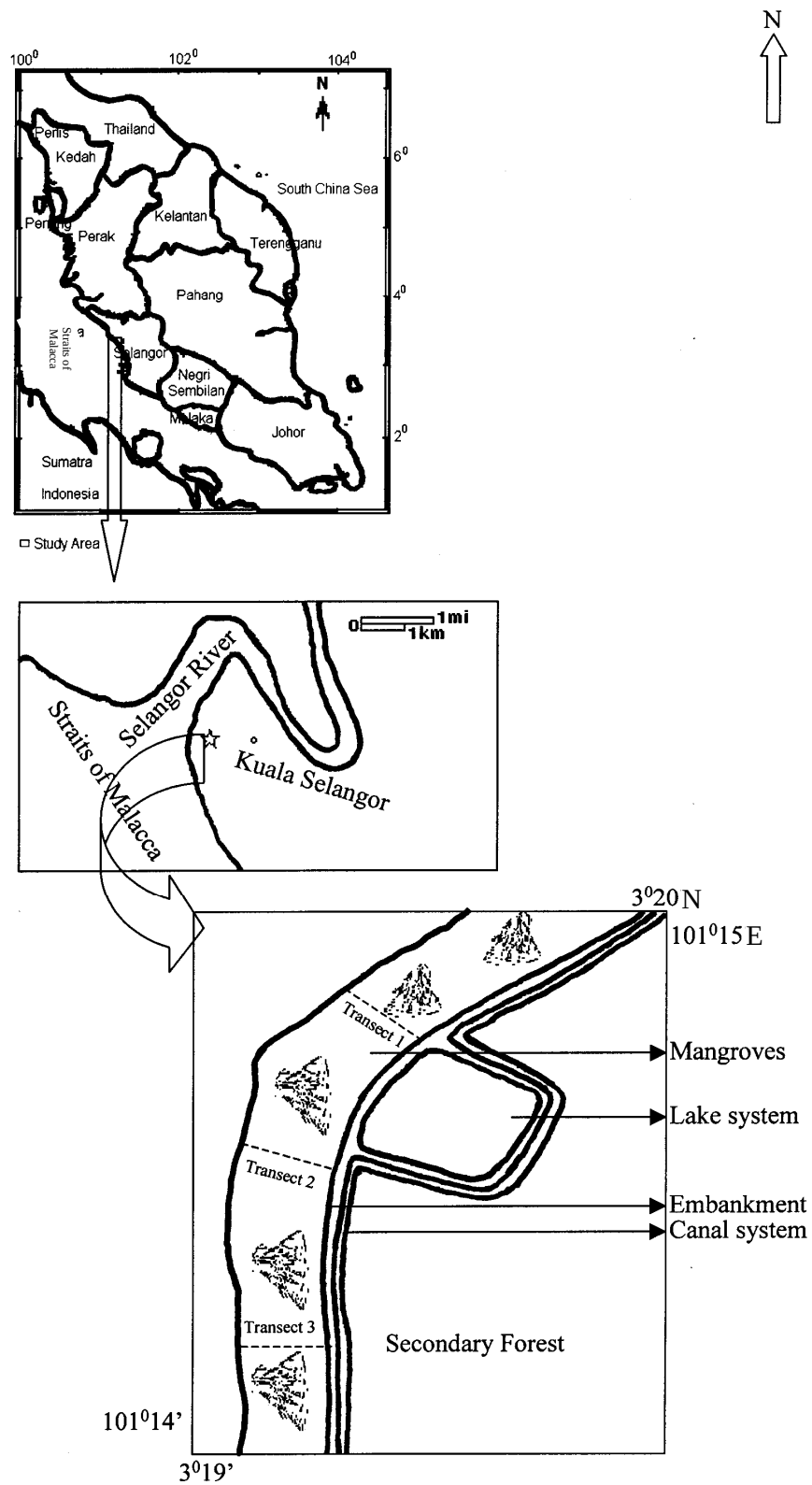


Figure 2.1: Map of the study area

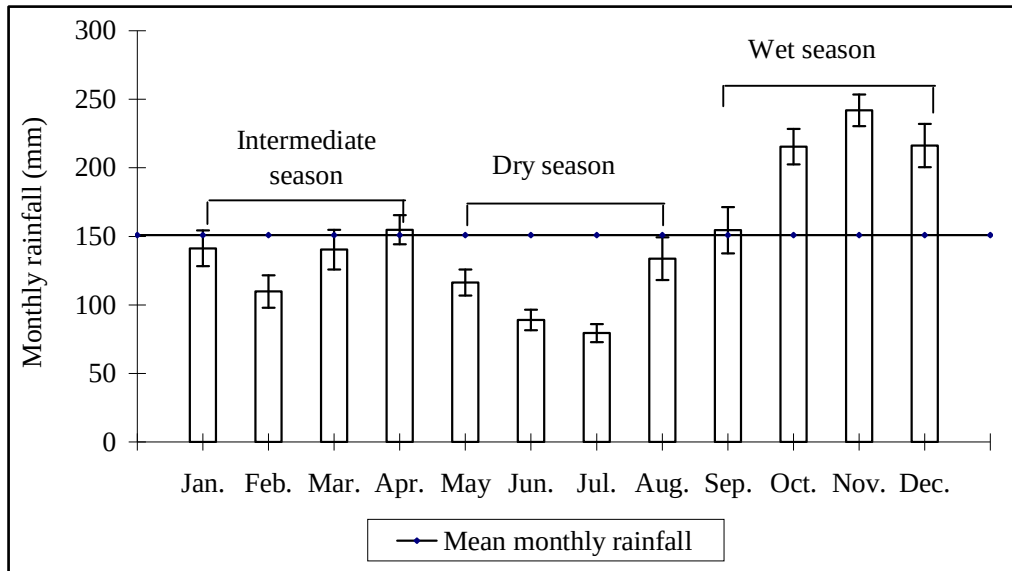


Figure 2.2: Monthly mean rainfall of last 20 years (1982-2001) at the meteorological station Tanjong Karang

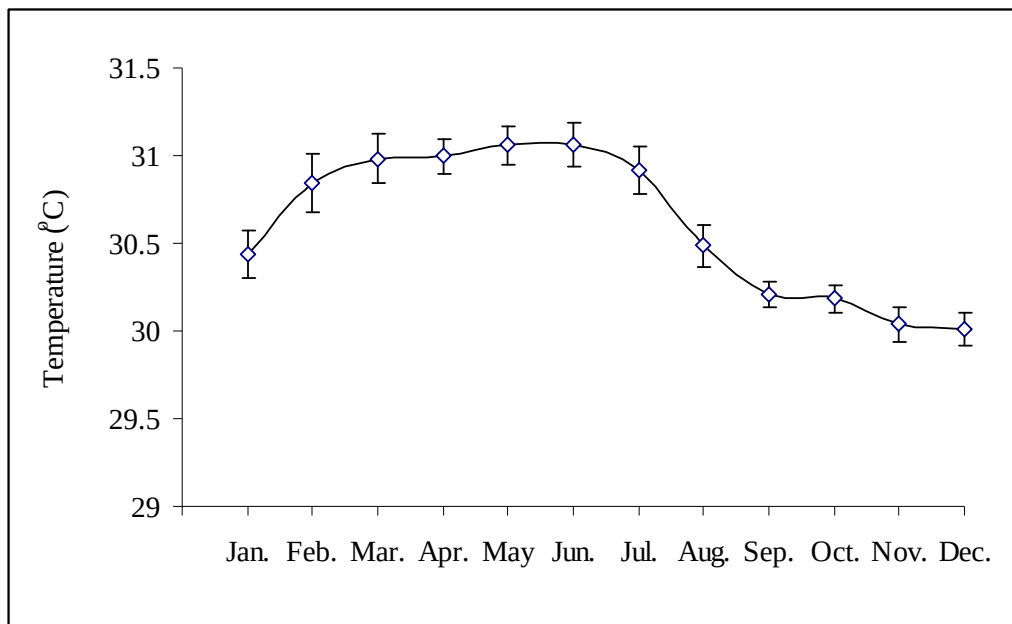


Figure 2.3: Monthly mean temperature at 2.00 pm for the last 20 years (1982-2001) at the meteorological station Tanjong Karang

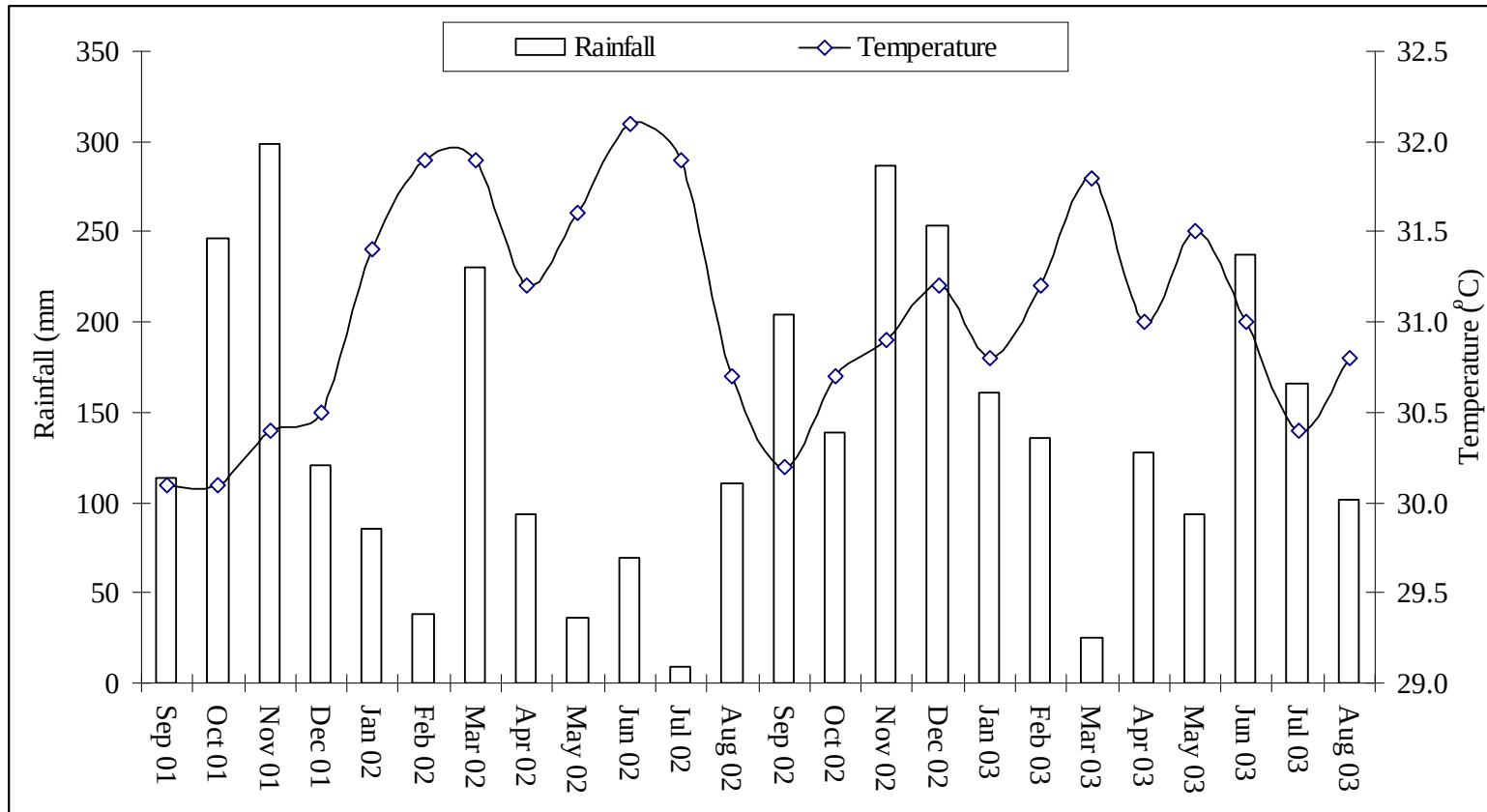


Figure 2.4: Monthly rainfall and temperature during the study period from September 2001 to August 2003 at the meteorological station Tanjong Karang nearest to the study area

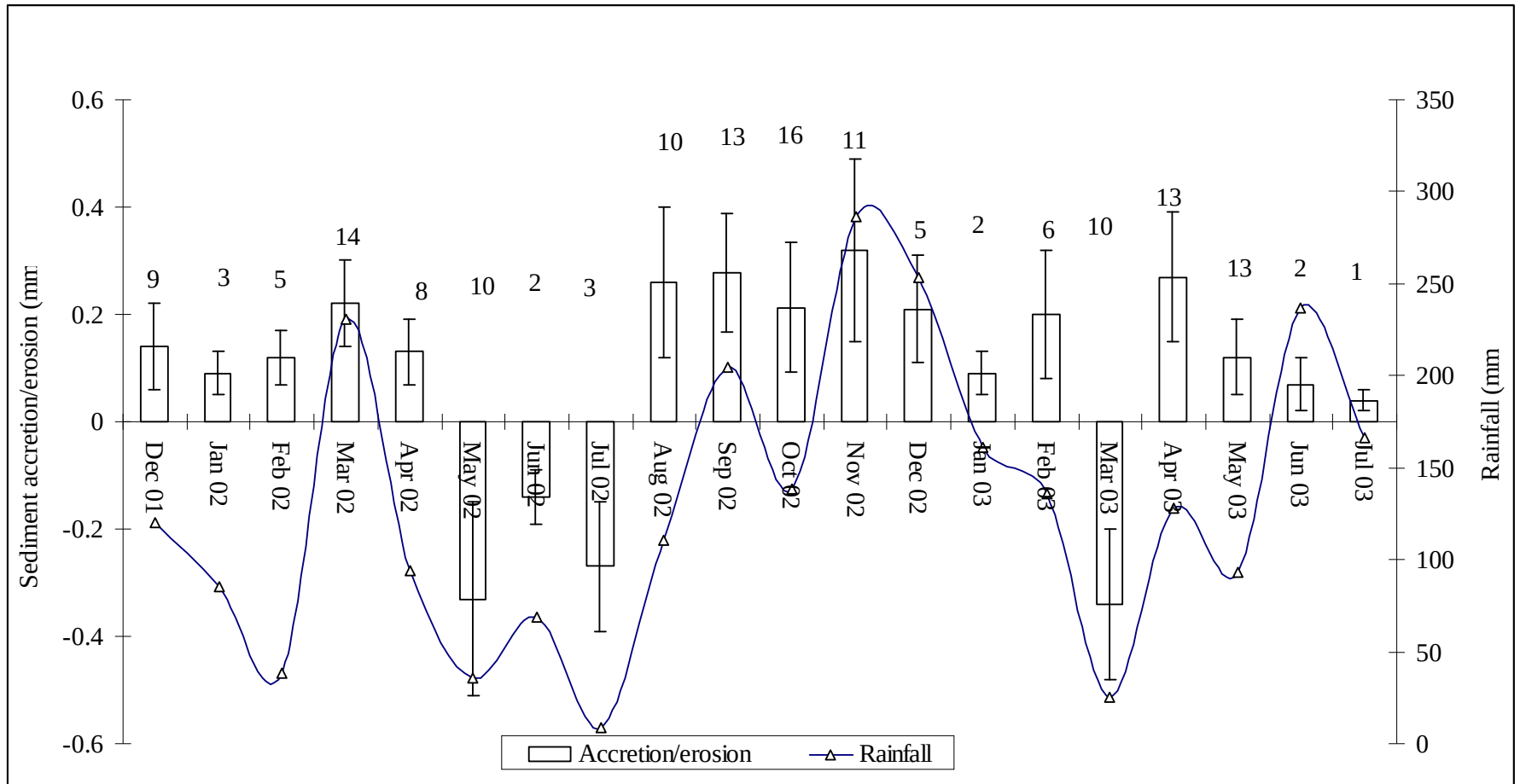


Figure 2.5: Sediment accretion and erosion during the study period of 20 months (December 2001 to July 2003) at Kuala Selagor Nature Park. Numbers on the bars represents number of spring high tide during the respective months

CHAPTER 3

SOIL AND WATER STUDY

3.1 Introduction

The distribution and composition of mangrove species are influenced by the soil and seawater characteristics (Aksornkoae, 1975 cited in Aksornkoae, 1993; Alongi *et al.*, 1993). Few studies have suggested that species distribution may be affected by the nutrient contents in soil (McKee, 1993; Ukpong, 1994). The variability of soil physio-chemical properties may be explained by the physical factors such as tidal amplitude, inundation period, micro-topography, and soil texture (Lacerda *et al.*, 1995). Different mangrove species dominated soils showed significant differences in soil physio-chemical properties (Nickerson and Thibodeau, 1985; Naidoo, 1980) and most of these differences have been attributed to the different capacity of a given mangrove species to alter soil condition adjacent to its root systems through specific physiological mechanisms such as releasing oxygen into the reducing soils (Nickerson and Thibodeau, 1985; Thibodeau and Nickerson, 1986). Adequate supply of nutrients is essential for maintaining the balance of the mangrove ecosystem (Boto, 1982; Aksornkoae, 1993). Rainwater, canopy drip, stem flow, runoff from surrounding land areas, decomposed organic matter and mineralization are the sources of nutrients in the terrestrial forest ecosystems (Trudgill, 1988; Leite and Valle, 1990; Zulkifli *et al.*, 1997; Ranger and Turpault 1999; Gordon *et al.*, 2000). In addition with the above sources, tidal borne nutrients are important source of nutrients to the mangrove ecosystems (Boto, 1982; Aksornkoae, 1993). Therefore, it is important to measure, compare and find out the relationship of soil and water parameters and nutrients for the proper description of a particular mangrove ecosystem.

3.1.1 Objectives

The objectives of this study were

1. To measure and compare the soil parameters (pH, redox potential, air-dry moisture, organic matter, conductivity, salinity, cation exchange capacity, texture and bulk density) in different seasons (intermediate, dry and wet).
2. To measure and compare the selected soil nutrients (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) in different seasons (intermediate, dry and wet).
3. To measure and compare the rainwater, canopy drip, stem flow, river water and infiltration water the parameters (pH, redox potential, conductivity and salinity) in different seasons (intermediate, dry and wet).
4. To measure and compare the selected nutrients (NH₄, NO₃, PO₄, K, Ca, Mg, SO₄, Cu, Fe and Zn) in rainwater, canopy drip, stem flow, river and infiltration water in different seasons (intermediate, dry and wet).

3.2 Materials and Methods

3.2.1 Soil Parameters and Nutrients

3.2.1.1 Soil Sampling and Processing

Nine samples of topsoil (up to 10 cm depth) were collected randomly from the study area during the wet season (November 2001), intermediate season (March 2002), dry season (July 2002), wet season (November 2002), intermediate season (March 2003) and dry season (July 2003) by using core sampler of 5 cm diameter. Collected soil samples were put into closed labelled plastic bags to minimize sample contamination and put into ice chest at low temperature during transportation and were brought to the laboratory for immediate processing. Samples were air-dried at room temperature and thoroughly mixed before crushing by using mechanical grinder (A10 manufactured by 1 KA-Labortechnik) and sieved through 2 mm mesh (Allen, 1974).

3.2.1.2 *In situ* pH and Redox Potential

pH is the measure of hydrogen ion activity in solution and is defined as the logarithm of the reciprocal of the hydrogen ion concentration. pH meter with automatic temperature compensator manufactured by Ciba-Corning Diagnostic Ltd. (accuracy ± 0.05), was used for pH determination of slurries of the sample in water (Beats, 1964). Fresh soil was taken in a 50 ml beaker and distilled water was added at 1:1 ratio to obtain sufficient depth to allow immersion of the pH electrode. Soil and water were mixed thoroughly by stirring and allowed to stand for a while and pH of the mixture was measured by using mentioned pH meter. Redox value indicates the extent of oxidation state of ionic species in the solution. Redox values of soil samples were determined in conjunction with *in situ* pH result by using the same pH meter (Allen, 1974).

3.2.1.3 Soil Texture

Texture of soil samples was determined by the pipette method (Black, 1965). Twenty gram of oven-dried, ground and sieved soil (<2 mm mesh) was taken in a tall beaker of 1000 ml capacity and 100 ml of 30% H₂O₂ was added and left overnight. The beaker was then heated on a hot plate and further quantities of H₂O₂ were added to oxidize the excess organic matter if necessary. Hundred ml of 0.2 N HCl and distilled water were added to bring the volume up to 400 ml and heated for 15 minutes. After cooling, the supernatant liquid was siphoned off and washing was done for 3 times with 400 ml of distilled water. After washing, 50 ml of Calgon (Sodium hexametaphosphate) solution of pH 8.3 was added and stirring was continued for 15 minutes. The contents were transferred into a stirrer for stirring. After stirring, the content was transferred into a 1000 ml cylinder through a 0.05 mm sieve. The content of cylinder was brought to 1000 ml by adding distilled water. The sand fraction left on the sieve was dried at 105°C and transferred onto a 0.2 mm sieve. Sieving operation was carried out for 5 minutes with a mechanical shaker. The fractions of >0.2 mm and 0.05-0.2 mm was weighed (mg). The cylinder was then placed in the water bath at 28°C. A plunger was

used to mix the contents. After 4 minutes, the pipette was introduced at a depth of 10 cm and 50 ml of aliquot was sampled. The contents of the pipette was transferred into previously weighed Ni-dish and dried at 105°C and weighted after cooling in a desiccator.

Calculation

1. Silt + Clay = y gram

$$\text{Silt + Clay (\%)} = \frac{(y - \text{weight of calgon} \times 1000 \times 100)}{\text{Vol of pipette} \times 20}$$

2. Clay = z gram

$$\text{Clay (\%)} = \frac{(z - \text{weight of calgon} \times 1000 \times 100)}{\text{Vol of pipette} \times 20}$$

$$\text{Silt (\%)} = (\text{Silt + Clay})\% - \text{Clay}\%$$

4. Sand fraction on sieve and bottom

$$\text{Sand (\%)} = \frac{s \times 100}{20}$$

5. 0.02 - 0.05 mm fraction by difference.

3.2.1.4 Bulk Density

Bulk density of soil samples were calculated from the mass and volume of clod (Black, 1965). The detail procedure and the basic equation are as follows.

$$\text{Bulk density (g/cm}^3\text{)} = \text{Weight (g)} / \text{Volume (cm}^3\text{)}$$

Air-dried clod was placed in a wire basket and weighed. The clod with the container was then dipped into melted paraffin and the excess allowed to drain. The weight of clod with paraffin and container was measured after solidification of adhering paraffin. It is weighted by suspending this system in water. The tare weight of the basket in air and water was determined. The clod was then broken to get the water content correlation. A sample of soil was taken to get it's weight before and after drying at 105°C.

Calculation

Oven-dried mass of the soil sample W_{ods} was calculated from the sub-sample, which was taken from the clod.

$$W_{ods} = \frac{W_{sa}}{1 + (P/100)}$$

Where

P = Percent weight, or an oven-dry basis, found in the sub-sample

W_{sa} = Net weight of clod in air.

Calculated bulk density

$$D_d \text{ (g/cm}^3\text{)} = \frac{d_w W_{ods}}{[W_{sa} - W_{spw} + W_{pa} - (W_{pa}d_w/d_p)]}$$

Where,

d_w = Density of water at temperature of determination

W_{ods} = Oven-dry weight of soil sample from clod

W_{spw} = Net weight of soil sample plus paraffin in water

W_{pa} = weight of paraffin coating in air

d_p = Density of paraffin (Approximately 0.9)

3.2.1.5 Air-dry Moisture Content

Air-dry moisture content of soil samples was measured by the weight loss procedure (Allen, 1974). One gram of 2 mm sieved and air-dried soil sample was taken in a porcelain cups and dried in an air-circulating oven at 105°C at 2 days to the constant weight. Percentage of air-dry moisture was calculated by the following equation.

Calculation

$$\text{Moisture (\%)} = \frac{\text{Loss in weight on drying (g)}}{\text{Initial sample weight (g)}} \times 100$$

3.2.1.6 Organic Matter Content

Soil organic matter content was determined by ignition method (Allen, 1974). This method measures the loss of organic matter due to ignition at high temperature. One gram soil sample of oven-dried at 105°C was taken in a porcelain cup and placed in a muffle furnace (Carbolite ELF 11/6, Thermal Engineering Services, England) and the temperature was raised slowly up to 450°C and kept at this temperature for four hours. After cooling to room temperature, the weight of the ignited sample was taken. Percentage of loss on ignition was calculated from the following calculation.

$$\text{Loss on ignition (\%)} = \frac{\text{Loss of weight (g)}}{\text{Oven dry weight (g)}} \times 100$$

3.2.1.7 Conductivity and Salinity

Conductivity of soil sample was measured from 1:5 extract solutions (Hesse, 1971). Twenty grams of sieved soil (2 mm mesh) were taken in a shaking bottle and 100 ml of distilled water was added. This mixture was shaken for 30 minutes and allowed to stand for 15 minutes to let the bulk of the soil settled down. The supernatant liquid was centrifuged and filtered. S-C-T meter (YSI 33), Yellow Springs Instruments Co. USA

was used to measure the conductivity of the liquid. Salinity (m.e./100 g) of soil samples was calculated from the conductivity result obtained from 1:5 extract (Hesse, 1971).

$$K_{25}^0 \text{ mS/cm} \times 10 = \text{Salts m.e. /dm}^3$$

$$K_{25}^0 \text{ mS/cm} \times 5 = \text{Salts m.e. /100g (For extraction 1:5)}$$

Where K_{25}^0 mS/cm is the conductivity at 25°C.

3.2.1.8 Cation Exchange Capacity

Cation exchange capacity (m.e./100 g) of soil samples was measured by distillation and titration method (Allen, 1974). Ten grams of air-dried sieved (2 mm mesh) soil was taken with 250 ml NH_4OAC extractant. Excess extractant removed by repeated washings of the residue with portion of industrial alcohol solution and all washing were rejected. Residue was leached with approximately 30 ml portion of KCl solution to displace adsorbed $\text{NH}_4^+\text{-N}$. Sufficient time was allowed for filtering in between additions and continued until 250 ml had been collected. $\text{NH}_4^+\text{-N}$ content was determined in the leachate by distillation of an aliquot with MgO followed by titration with M/140 HCl.

Calculation

If T (ml) of M/140 HCl were required for titration then,

$$\text{CEC (m.e. } 100 \text{ g}^{-1}) = \frac{T \text{ (ml)} \times \text{final leachate volume ml}}{1.4 \times \text{aliquot (ml)} \times \text{sample weight (g)}}$$

3.2.1.9 Determination of Total Nitrogen

Total nitrogen content in soil samples was measured by the sample digestion procedure described by Allen (1974). Air-dried sieved (2 mm) soil (0.20 g) was placed into a digestion tube and 4.4 ml of mixed digestion reagent (350 ml of H_2SO_4 to 0.42 g Selenium powder, 14 g Lithium sulphate and finally 420 ml of Hydrogen peroxide) was added. Digestion tubes were heated gently and temperature was increased after the initial vigorous reaction subsided and digested until clear. After the completion of digestion, 20 ml of deionized water was added and pH was adjusted to 4.00-6.00 by adding Sodium hydroxide and final volume was made up to 100 ml with deionized water.

Ammonium content in the digested samples was measured according to Weatherburn (1967). Ammonium stock solution was prepared by dissolving 0.2965 g Ammonium chloride (NH_4Cl) in 1000 ml deionized water. The stock solution was diluted to prepare different concentration of standard solution. One ml of solution A (2.5 g Phenol and 12.5 mg Natrium nitroprusside per 250 ml deionized water) and 1 ml of solution B (1.25 g Sodium hydroxide and 2.1 ml Natrium hypochloride per 250 ml deionized

water) were added with 1 ml of standard solution or samples. The mixture was incubated in water bath at 37°C for 20-30 minutes and absorbance was measured at 625 nm by UV-Visible Recording Spectrophotometer (SHIMADZU, UV- 160A, Japan). The total nitrogen content was calculated from the following calculation.

Total nitrogen content (mg/g) = (Ammonium content in sample x Atomic weight of Nitrogen)/Atomic weight of Ammonium

3.2.1.10 Determination of Total Phosphorus

Same digested sample solution that was used for total nitrogen was also used for measuring the total phosphorus content in soil samples. Total phosphorus content was measured according to Timothy *et al.* (1984). Mixed solution was prepared by adding 100 ml Ammonium molybdate (15 g in 500 ml deionized water), 250 ml H₂SO₄ (140 ml to 900 ml deionized water), 100 ml Ascorbic acid (27 g in 500 ml deionized water) and 50 ml Antimony potassium tartrate (0.34 g in 250 ml deionized water). Phosphate stock solution was prepared by diluting 1.433 g KH₂PO₄ in 1000 ml deionized water. Stock solution was diluted to prepare different concentration of standard solution. One ml of mixed solution was added with 10 ml of standard solution or sample. After 5 minute, absorbance was measured at 885 nm by UV-Visible Recording Spectrophotometer (SHIMADZU, UV- 160A, Japan). The total phosphorus content was calculated from the following calculation.

Total phosphorus content (mg/g) = (Phosphate content in sample x Atomic weight of Phosphorus)/Atomic weight of Phosphate

3.2.1.11 Determination of Total Potassium, Calcium, Magnesium, Copper, Iron and Zinc

Air-dried sieved soil (0.50 g) was placed into a digestion tube and 2.5 ml concentrated Nitric acid was added and heated cautiously to oxidize the organic matter and 3.5 ml of mixed acid (Perchloric acid 60%, Nitric acid and Sulphuric acid were mixed at a proportion of 2:4:1) was added to the predigested samples and digested until clear for 3 hours. After digestion, the extract was filtered by Whatman filter paper no 2 (medium) into a volumetric flask and diluted to 50 ml with deionized water (Allen, 1974). Atomic Absorption Spectrophotometer (PERKIN ELMER 4100, USA) was used for measuring the total calcium, magnesium, copper, iron and zinc concentration in the extract. Total potassium content (mg/g) in samples was measured by Flame photometer (PFP7, Jenway LTD, England). The standard curves of K, Ca, Mg, Cu, Fe and Zn were prepared from the commercial standard solution stock of 1000 ppm used for AAS. The standard solutions (1000 ppm) of K, Mg, Cu and Zn were diluted at the concentration of 1, 2 and 3 ppm to obtain standard curve and the standard curve of Ca and Fe were obtained from the dilution of standard stock solution (1000 ppm) into 2, 4 and 6 ppm.

3.2.1.12 Determination of Total Sulphur

Air-dried sieved soil (0.20 g) was placed into a digestion tube and 4 ml of concentrated Nitric acid was added and heated to oxidize the organic matter and finally 2 ml of 60% Perchloric acid was added and digested until dense white fumes appeared. After digestion, the extract was filtered into a volumetric flask and diluted to 50 ml with deionized water (Hesse, 1971).

Total sulphur content in samples extraction was measured by Barium chloride turbidity method (Tandon, 1993). Sulphur stock solution of 100 ppm was prepared by dissolving 0.543 g of Potassium sulphate (K_2SO_4) in 1000 ml deionized water. Zero, 10, 20, 30, 40, and 50 ml of stock solution was pipetted into 250 ml volumetric flasks and 25 ml salt buffer solution (50 g $MgCl_2 \cdot 6H_2O$, 4.1 g KNO_3 and 28 ml ethanol per liter) was added and made up to the mark with deionized water. The resulting solutions provide 0, 4, 8, 12, 16 and 20 ppm of Sulphur solutions, respectively and 10 ml each of above solutions are pipetted to 50 ml conical flask. Finally 1 ml of 6N HCl and 1 ml of 0.50% Gum acacia solutions (0.50 g powdered Gum acacia into 50 ml Glacial acetic acid and 50 ml deionized water) were added. The content was mixed thoroughly by swirling and 0.50 g of Barium chloride crystal was added and allowed for dissolving and absorbance was measured at 420 nm by UV-Visible Recording Spectrophotometer (SHIMADZU, UV- 160A, Japan) and standard curve was derived. Ten ml of sample aliquot was pipetted into 250 ml volumetric flask and the procedure described for standard curve preparation was followed.

3.2.1.13 Determination of Total Carbon

Total carbon content (%) was measured by combustion method (Allen 1974) by using Leco CR – 12 Carbon determinator, USA. The Leco CR – 12 Carbon determinator was calibrated with 0 to 80% of commercial carbon standard. 0.50 g of oven dried ($105^\circ C$) samples were measured and put into porcelain cup and placed inside the combustion chamber. During the combustion of samples, Leco CR – 12 Carbon determinator measures the peak of Carbon dioxide and give the direct results of carbon (%) in samples.

3.2.2 Water Parameters and Nutrients

3.2.2.1 Sampling and Processing

Different sampling procedures were followed for rainwater, canopy drip, stem flow, river and infiltration water. Samples were collected during the intermediate season (March 2002), dry season (July 2002), wet season (November 2002), intermediate season (March 2003) and dry season (July 2003).

Rainwater samples were collected by fixed funnel type collector (14 cm diameter) and six collectors were placed randomly in open place beside the forest area. To avoid

splashing in of soil particles, the funnels were mounted on stands about one meter above the ground level. Contamination due to insect and windblown debris was minimized by placing 1 mm nylon mesh overlain by a filter paper inside the funnel neck. Samples were collected just after the first shower during the previously mentioned sampling time. The collected samples were put into airtight container and placed into ice chest at low temperature for the transportation and samples were processed immediately after arrival at the laboratory.

Samples of canopy drip were also collected by fixed funnel type collector (14 cm diameter) as recommended by Reynolds and Neal (1991). Six collectors were placed randomly under the forest canopy by obeying the same principles for rainwater sampling. Samples were collected just after the first shower during the previously mentioned sampling time. The collected samples were put into airtight container and placed into ice chest at low temperature for the transportation and samples were processed immediately after arrival at the laboratory.

Samples of stem flow were collected according to Gordon *et al.* (2000). Stem flow was intercepted by using spiral collars of split plastic tubing and gravity fed through intact tubing into plastic containers that were hanged on tree stem at about 1 meter from the ground level. Collars height varied from 1.5 to 2 meters from the ground level. Six collars were placed randomly on six trees having the average diameter at breast height (DBH). Contamination due to insect and windblown debris was minimized by placing filter paper at the end of the intact tube. Samples were collected just after the first shower during the previously mentioned sampling. The collected samples were put into airtight container and placed into ice chest at low temperature for the transportation and samples were processed immediately after arrival at the laboratory.

Six samples of river surface water were collected by Vendorn water sampler during the previously mentioned sampling time. Samples of river surface water were transferred into the labelled airtight bottle and placed inside the ice chest at low temperature for the transportation to the laboratory and samples were processed immediately just after arrival at the laboratory.

Infiltration water samples were collected by digging hole (30 cm x 30 cm x 30 cm) and accumulation of infiltration water can usually be observed at the bottom of the hole (Pannier, 1984). Once the column was reach equilibrium, the water sample was rapidly displaced with suction bomb and transferred into the labelled airtight bottle and placed into ice chest for the transportation. Samples were processed immediately after arrival at the laboratory. Six water samples were collected during previously mentioned seasons.

Water samples were filtered by membrane filter paper whose pore size was 0.45 μm immediately after reaching at the laboratory. NO_3 , NH_4 , PO_4 and SO_4 content in different water samples were measured immediately upon sample processing. Fifty ml

of the filtrate from each sample was treated with 1 ml concentrated HNO_3 and kept into refrigerator for the analysis of potassium, calcium, magnesium, copper, iron and zinc within one month.

3.2.2.2 pH and Redox potential

pH and redox potential of water samples were measured directly following the same principle as described in Section 3.2.1.2.

3.2.2.3 Conductivity

Conductivity (mS/cm) of water samples was measured directly in the field by S-C-T meter (YSI 33, Yellow Springs Instruments Co. USA).

3.2.2.4 Salinity

River and infiltration water salinity (ppt) was measured directly in the field by S-C-T meter (YSI 33, Yellow Springs Instruments Co. USA).

3.2.2.5 Determination of Ammonium

Ammonium content (ppm) in water samples was measured by Phenol Hypochlorite procedure according to Weatherburn (1967) as mentioned in Section 3.2.1.9.

3.2.2.6 Determination of Nitrate

Nitrate content (ppm) in water samples was measured according to Kitamura *et al.* (1982). Nitrate standard solution of 1000 ppm was prepared by dissolving 1.63 g of dry KNO_3 in 1000 ml of deionized water. Standard solution was then diluted into different concentration. In 30 ml samples or standard solution, 0.50 ml of mixed solution (0.222 g $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 5.48 g $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ in 1000 deionized water) and 1 ml of 1N NaOH and 2 ml of Hydrazine sulphate solution (0.171 g $\text{N}_2\text{H}_6\text{SO}_4$ in 100 ml deionized water) were added and incubated in water bath at 33°C for 30 minutes. After incubation, 2 ml of Sulphanilamide solution (3 g $\text{N}_2\text{H}_8\text{C}_6\text{SO}_2$ in 100 ml 3N HCl) was added into the samples and stand for 15 minutes. Finally 2 ml of NED (0.50 g Naphthylethylenediamine dihydrochloride (NED) in 100 ml deionized water) was added into the solution and incubated at room temperature for 20 minutes and absorbance was measured at 540 nm by UV-Visible Recording Spectrophotometer (SHIMADZU, UV- 160A, Japan).

3.2.2.7 Determination of Phosphate

Phosphate content (ppm) in water samples was measured by following the procedure described by Timothy *et al.* (1984) as mentioned in Section 3.2.1.10.

3.2.2.8 Determination of Potassium, Calcium, Magnesium, Copper, Iron and Zinc

Calcium, Magnesium, Copper, Iron and Zinc content (ppm) in water samples were measured by Atomic Absorption Spectrophotometer (PERKIN ELMER 4100, USA) and potassium content in samples was measured by Flame photometer (PFP7, Jenway LTD, England). The detail of standard stock solution and preparation of calibration curves were described in the Section 3.2.1.11.

3.2.2.9 Determination of Sulphate

Sulphate content (ppm) in water samples was measured by barium chloride turbidity method according to Tandon (1993). Sulphate stock solution of 1000 ppm was prepared by dissolving 1.74 g of Potassium sulphate (K_2SO_4) in 1000 ml deionized water. The stock solution was diluted to prepare different concentrations of standard solution. Five ml of standard solution or sample was taken into 25 ml volumetric flask and 10 ml of Sodium acetate-acetic acid buffer solution (100 g Sodium acetate and 31 ml glacial Acetic acid per liter) was added to maintain the pH around 4.8. One ml of Gum acacia (2.50 g gum Acacia in one liter deionized water) and 1 g of Barium chloride were added and the volume was made up to 25 ml by adding deionized water. The content was mixed thoroughly by swirling and absorbance was measured at 490 nm by UV-Visible Recording Spectrophotometer (SHIMADZU, UV- 160A, Japan).

3.2.3 Statistical Analysis

Soil parameters (*in situ* pH, redox potential, air-dry moisture content, organic matter content, conductivity, salinity and cation exchange capacity), water parameters (pH, redox potential, conductivity and salinity) and nutrient contents in soil samples in different seasons were compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p < 0.05$) by using SAS (6.12) statistical software. Nutrients content in different water samples (rainwater, canopy drip, stem flow, river and infiltration water) at different seasons were compared by Two-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p < 0.05$) by using SAS (6.12) statistical software. Percentage values were transferred to arcsin before any statistical analysis.

Stepwise multiple regressions were conducted among soil parameters and nutrients. The stepwise multiple linear regression ($Y = b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_0$) analysis was performed among the soil parameters and each nutrient content by using SAS (6.12) statistical software (where, Y was the soil nutrients content, $X_1, X_2, X_3, X_4, X_5, X_6$ and X_7 were pH, redox potential, air-dry moisture, organic matter, conductivity, salinity and cation exchange capacity, respectively, $b_1, b_2, b_3, b_4, b_5, b_6, b_7$ and b_0 were constant). Pearson correlation analysis was conducted among each nutrient content in rainwater and canopy drip, rainwater and stem flow, river and

infiltration water, soil and water (rainwater, canopy drip, stem flow, river and infiltration water) by using SPSS (11.0) statistical software.

3.3 Results

3.3.1 Soil and Water Parameters

3.3.1.1 pH

Soil pH varied from 6.77 ± 0.05 to 7.07 ± 0.04 . Neutral pH, 7.07 ± 0.04 and 7.00 ± 0.04 were observed during the wet season (November 01) and dry season (July 02), respectively, but a relatively lower soil pH (6.77 ± 0.05) was found during the wet season (November 02) (ANOVA, DMRT, $p < 0.05$). Similar soil pH was observed during the wet season (November 01) and dry season (July 02), intermediate seasons (March 02 and 03) and dry season (July 03) (Table 3.1).

Rain water, canopy drip, river and infiltration water pH varied from 6.33 ± 0.07 to 6.91 ± 0.03 , 6.34 ± 0.07 to 6.72 ± 0.03 , 6.56 ± 0.08 to 6.92 ± 0.03 and 6.27 ± 0.08 to 7.05 ± 0.06 , respectively. But, stem flow showed acidic pH (5.40 ± 0.05 - 6.18 ± 0.06). Comparatively higher pH (6.91 ± 0.03) of rainwater and infiltration water (7.05 ± 0.06) was observed during the dry season (July 02) and lower in dry season (July 03) and wet season (November 02), respectively (ANOVA, DMRT, $p < 0.05$). A relatively higher pH (6.72 ± 0.03) of canopy drip, stem flow (6.18 ± 0.06) and river water (6.92 ± 0.03) was recorded during the intermediate season (March 02) (Table 3.2) (ANOVA, DMRT, $p < 0.05$).

3.3.1.2 Redox potential

Soil redox potential varied from 2.28 ± 2.64 to 15.89 ± 2.07 mv. Comparatively lower redox values 2.28 ± 2.64 and 3.06 ± 2.66 mv were observed during the wet season (November 01) and dry season (July 02), respectively (ANOVA, DMRT, $p < 0.05$), but rest of the seasons showed similar redox potential ranged from 7.57 ± 2.74 to 15.89 ± 2.07 mv (Table 3.1).

Redox potential of rain water, canopy drip, stem flow, river and infiltration water varied from 1.68 ± 0.37 to 126.00 ± 20.84 mv, 11.84 ± 0.74 to 120.33 ± 10.97 mv, 46.00 ± 0.58 to 143.00 ± 2.65 mv, 2.50 ± 0.67 to 23.01 ± 1.89 mv and -20.93 ± 0.24 to 48.00 ± 1.73 mv, respectively. Comparatively higher redox value (126.00 ± 20.84 mv) was recorded for rainwater and canopy drip (120.33 ± 10.97 mv) during the dry season (July 03) (ANOVA, DMRT, $p < 0.05$), but relatively lower values of 1.68 ± 0.37 mv and 11.84 ± 0.74 mv were recorded for wet season (November 02) and intermediate season (March 02), respectively (ANOVA, DMRT, $p < 0.05$). Stem flow showed comparatively higher redox potential (143.00 ± 2.65 mv) during the intermediate season (March 03) (ANOVA, DMRT, $p < 0.05$). River water and infiltration water showed relatively higher

redox values of 23.01 ± 1.89 and 48.00 ± 1.73 mv, respectively, during the wet season (November 02) (ANOVA, DMRT, $p < 0.05$). Relatively lower redox value (2.50 ± 0.67 mv) of river and infiltration water (-20.93 ± 0.24) was recorded during intermediate season (March 02) and dry season (July 02), respectively (Table 3.2) (ANOVA, DMRT, $p < 0.05$).

3.3.1.3 Conductivity

Soil conductivity showed fluctuation among the intermediate, dry and wet seasons. Comparatively higher soil conductivity (11.25 ± 0.08 - 11.81 ± 0.06 mS/cm) was observed during the dry seasons (July 02 and 03) followed by (9.75 ± 0.06 - 10.17 ± 0.11 mS/cm) intermediate seasons (March 02 and 03) and (7.81 ± 0.08 - 8.14 ± 0.05 mS/cm) in wet seasons (November 01 and 02) (Table 3.1) (ANOVA, DMRT, $p < 0.05$).

Conductivity of rainwater, canopy drip, stem flow, river water and infiltration water varied from 0.08 ± 0.001 to 0.29 ± 0.001 mS/cm, 0.13 ± 0.001 to 0.35 ± 0.001 mS/cm, 0.09 ± 0.001 to 0.10 ± 0.001 mS/cm, 18.17 ± 0.17 to 22.17 ± 0.17 mS/cm and 55.83 ± 0.44 to 71.00 ± 0.58 mS/cm, respectively. Rain water, canopy drip and river water conductivity were relatively higher during the dry season (July 02) at 0.29 ± 0.001 , 0.35 ± 0.001 and 22.17 ± 0.17 mS/cm, respectively (ANOVA, DMRT, $p < 0.05$). Stem flow showed relatively higher conductivity of 0.10 ± 0.001 mS/cm during the intermediate season (March 03) and 71.00 ± 0.58 mS/cm of conductivity was observed in infiltration water during the dry season (July 03) (ANOVA, DMRT, $p < 0.05$). A relatively lower conductivity (0.08 ± 0.001 - 0.09 ± 0.001 mS/cm) of rainwater and canopy drip (0.13 ± 0.001 - 0.15 ± 0.001 mS/cm) was observed in intermediate seasons (March 02 and 03) (ANOVA, DMRT, $p < 0.05$). However, stem flow, river and infiltration water showed comparatively lower conductivity of 0.09 ± 0.001 , 18.17 ± 0.17 and 55.83 ± 0.44 mS/cm, respectively during the wet season (November 02) (Table 3.2) (ANOVA, DMRT, $p < 0.05$).

3.3.1.4 Salinity

Soil salinity showed the similar pattern to soil conductivity. Comparatively higher soil salinity (57.64 ± 0.51 - 59.03 ± 0.29 m.e./100 g) was observed during the dry seasons (July 02 and 03) followed by 48.75 ± 0.30 - 50.83 ± 0.56 m.e./100 g in intermediate seasons (March 02 and 03) and 39.03 ± 0.41 - 40.69 ± 0.27 m.e./100 g in wet seasons (November 01 and 02) (Table 3.1) (ANOVA, DMRT, $p < 0.05$).

River water showed comparatively higher salinity (30 ± 0.01 ppt) during the dry season (July 02 and 03) and intermediate seasons (March 02 and 03) and lower salinity (25 ± 0.01 ppt) was observed during the wet season (November 02) (ANOVA, DMRT, $p < 0.05$). A relatively higher salinity (40-41 ppt) was observed for infiltration water

during the dry seasons (July 02 and 03) followed by 37 ± 0.01 - 38 ± 0.01 ppt in intermediate seasons (March 02 and 03) and 34 ± 0.02 ppt in wet season (November 02) (Table 3.2) (ANOVA, DMRT, $p<0.05$).

3.3.1.5 Soil Texture and Bulk Density

Soil texture of the studied mangrove forest was clay and the mean percentage of clay, silt and sand were 64.24 ± 0.52 , 34.42 ± 0.89 and 1.34 ± 0.50 , respectively, and soil bulk density was 0.63 ± 0.01 gm/cm³ (Table 3.3).

3.3.1.6 Soil Air-dry Moisture Content

Soil air-dry moisture content varied from 8.06 ± 0.15 to $11.20\pm0.04\%$. Relatively higher soil air-dry moisture ($11.20\pm0.04\%$) was observed during the wet season (November 02) and lower ($8.06\pm0.15\%$) in dry season (July 02) (Table 3.1) (ANOVA, DMRT, $p<0.05$).

3.3.1.7 Organic Matter

Comparatively higher amount of organic matter (12.03 ± 0.02 - $12.56\pm0.11\%$) was observed during the intermediate seasons (March 02 and 03) followed by 10.86 ± 0.11 - $11.25\pm0.08\%$ in dry seasons (July 02 and 03) and 10.22 ± 0.09 - $10.33\pm0.10\%$ in wet seasons (November 01 and 02) (Table 3.1) (ANOVA, DMRT, $p<0.05$).

3.3.1.8 Soil Cation Exchange Capacity

Soil cation exchange capacity (CEC) varied from 34.53 ± 0.04 to 38.23 ± 0.29 m.e./100 g and comparatively higher soil CEC (37.31 ± 0.22 - 38.23 ± 0.29 m.e./100 g) was recorded during the intermediate seasons (March 02 and 03) and lower (34.53 ± 0.04 m.e./100 g) in dry season (July 02) (Table 3.1) (ANOVA, DMRT, $p<0.05$).

3.3.2 Soil and Water Nutrients

3.3.2.1 Ammonium

Comparatively higher ammonium content (0.47 ± 0.01 - 0.51 ± 0.01 ppm) in rainwater was observed during the dry seasons (July 02 and 03) and lower (0.16 ± 0.01 ppm) in intermediate season (March 02) (ANOVA, DMRT, $p<0.05$). Canopy drip contained a relatively higher ammonium (1.03 ± 0.02 ppm) during the wet season (November 02) and lower (0.40 ± 0.01 - 0.42 ± 0.01 ppm) in the intermediate seasons (March 02 and 03) (ANOVA, DMRT, $p<0.05$). Comparatively higher ammonium (0.59 ± 0.02 ppm) in stem flow was observed during the dry season (July 02) and lower (0.30 ± 0.00 - 0.31 ± 0.00 ppm) in intermediate seasons (March 02 and 03) (ANOVA, DMRT, $p<0.05$). River

water contained comparatively higher ammonium (0.55 ± 0.01 ppm) during the wet season (November 02) and lower (0.32 ± 0.00 ppm) in intermediate season (March 03) (ANOVA, DMRT, $p < 0.05$). Infiltration water contained relatively higher ammonium (0.64 ± 0.00 ppm) in the intermediate season (March 02) and lower (0.49 ± 0.01 ppm) in dry season (July 03) (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.2 Nitrate

Comparatively higher nitrate content (0.07 ± 0.00 ppm) in rainwater was observed during the dry season (July 03) and lower (0.01 ± 0.00 ppm) in intermediate season (March 02) (ANOVA, DMRT, $p < 0.05$). A relatively higher nitrate (0.07 ± 0.00 - 0.08 ± 0.00 ppm) in canopy drip was found during the wet season (November 02) and intermediate seasons (March 02 and 03) followed by 0.05 ± 0.00 - 0.06 ± 0.00 ppm in the dry seasons (July 02 and 03) (ANOVA, DMRT, $p < 0.05$). Stem flow contained comparatively higher nitrate (0.08 ± 0.00 ppm) during the wet season (November 02) and lower (0.02 ± 0.00 ppm) in intermediate season (March 02) (ANOVA, DMRT, $p < 0.05$). Nitrate in river and infiltration water varied from 0.01 ± 0.00 to 0.03 ± 0.00 ppm and comparatively higher content (0.03 ± 0.00 ppm) was found during the dry season (July 02) (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.3 Nitrogen

Total nitrogen in soil varied from 3.41 ± 0.02 to 3.50 ± 0.01 mg/g. The higher nitrogen content (3.49 ± 0.01 - 3.50 ± 0.01 mg/g) was found during the intermediate seasons (March 02 and 03) and lower (3.41 ± 0.02 mg/g) in wet season (November 01) (Figure 3.1) (ANOVA, DMRT, $p < 0.05$).

3.3.2.4 Phosphate

Rainwater showed similar content (0.01 ± 0.00 ppm) of phosphate in different seasons (intermediate, dry and wet). Comparatively higher phosphate (0.09 ± 0.00 ppm) in canopy drip was observed during the dry season (July 02) and lower (0.04 ± 0.00 ppm) in intermediate season (March 03) and dry season (July 03) (ANOVA, DMRT, $p < 0.05$). Phosphate in stem flow varied from 0.01 ± 0.00 to 0.02 ± 0.00 ppm and comparatively higher content (0.02 ± 0.00 ppm) was observed during the intermediate season (March 02) (ANOVA, DMRT, $p < 0.05$). Comparatively higher phosphate (0.05 ppm) in river and infiltration water (0.11 ± 0.00 ppm) was found during the intermediate season (March 02) and relatively lower phosphate content of 0.02 ± 0.00 and 0.01 ± 0.00 ppm were observed in river and infiltration water, respectively in the wet season (November 02) (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.5 Phosphorus

Comparatively higher total soil phosphorus (0.34 ± 0.00 mg/g) was observed during the intermediate season (March 02) and lower content (0.31 ± 0.00 mg/g) was found during the wet season (November 02) and dry season (July 02) (Figure 3.2) (ANOVA, DMRT, $p < 0.05$).

3.3.2.6 Potassium

Total potassium content in soil varied from 4.33 ± 0.03 to 7.06 ± 0.02 mg/g. The relatively higher potassium (7.06 ± 0.02 mg/g) was observed during the intermediate season (March 02) and lower (4.33 ± 0.03 mg/g) in wet season (November 02) (Figure 3.3) (ANOVA, DMRT, $p < 0.05$).

Rainwater and canopy drip showed comparatively higher potassium content of 0.33 ± 0.00 and 4.49 ± 0.10 ppm, respectively, during the intermediate season (March 02) (ANOVA, DMRT, $p < 0.05$). Rainwater and canopy drip contained relatively lower potassium content of 0.21 ± 0.00 and 2.34 ± 0.00 ppm, respectively, in the dry season (July 02) (ANOVA, DMRT, $p < 0.05$). Stem flow showed relatively higher potassium (2.61 ± 0.11 ppm) during the intermediate season (March 02) and lower (0.50 ± 0.01 ppm) in wet season (November 02) (ANOVA, DMRT, $p < 0.05$). Comparatively higher potassium (45.96 ± 0.00 ppm) was observed in river water during the dry season (July 02) and lower (20.05 ± 0.04 ppm) in intermediate season (March 03) (ANOVA, DMRT, $p < 0.05$). Infiltration water showed relatively higher potassium (348.89 ± 3.61 ppm) during the intermediate season (March 02) and lower (60.12 ± 0.17 ppm) in dry season (July 03) (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.7 Calcium

Comparatively higher total soil calcium content (3.61 ± 0.04 mg/g) was observed during the intermediate seasons (March 03) and lower (3.06 ± 0.03 mg/g) in dry season (July 03) (Figure 3.4) (ANOVA, DMRT, $p < 0.05$).

Relatively higher calcium content of 2.45 ± 0.00 , 20.12 ± 0.00 , 8.00 ± 0.28 and 926.23 ± 0.17 ppm was found in rainwater, canopy drip, stem flow and infiltration water, respectively during the intermediate season (March 03) (ANOVA, DMRT, $p < 0.05$). Rainwater showed comparatively lower calcium (1.40 ± 0.00 ppm) during the dry season (July 03) (ANOVA, DMRT, $p < 0.05$). Canopy drip, stem flow and infiltration water showed comparatively lower calcium of 9.00 ± 0.00 , 3.00 ± 0.00 and 329.56 ± 0.23 ppm, respectively during the dry season (July 02) (ANOVA, DMRT, $p < 0.05$). River water contained comparatively higher calcium (76.00 ± 0.33 ppm) during the dry season (July 02) (ANOVA, DMRT, $p < 0.05$).

02) and lower (54.00 ± 0.14 ppm) in wet season (November 02) (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.8 Magnesium

Total magnesium content in soil varied from 8.28 ± 0.05 to 10.83 ± 0.09 mg/g. The higher magnesium content (10.83 ± 0.09 mg/g) was found during the intermediate season (March 02) and lower (8.28 ± 0.05 mg/g) in dry season (July 03) (Figure 3.5) (ANOVA, DMRT, $p < 0.05$).

The higher magnesium (2.50 ± 0.00 ppm) in rainwater was observed during the intermediate season (March 03) and lower (1.30 ± 0.00 ppm) in dry season (July 03) (ANOVA, DMRT, $p < 0.05$). Canopy drip and stem flow contained relatively higher magnesium of 7.00 ± 0.24 and 4.50 ± 0.11 ppm, respectively, during the dry season (July 02) and lower (1.00 ± 0.00 ppm) in wet season (November 02) (ANOVA, DMRT, $p < 0.05$). Comparatively higher magnesium contents of 271.00 ± 2.14 and 2356.33 ± 8.47 ppm were observed in river and infiltration water, respectively during the intermediate season (March 02) (ANOVA, DMRT, $p < 0.05$). Relatively lower contents of 163.00 ± 0.17 and 2012.00 ± 0.67 ppm were found in river and infiltration water during the intermediate season (March 03) and dry season (July 02), respectively (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.9 Sulphate

The higher sulphate (14.42 ± 0.36 ppm) was observed in rainwater during the dry season (July 02) and lower (2.24 ± 0.01 ppm) in intermediate season (March 03) (ANOVA, DMRT, $p < 0.05$). A relatively higher sulphate contents of 41.19 ± 0.13 and 14.56 ± 0.35 ppm were found in canopy drip and stem flow, respectively during the intermediate season (March 02) (ANOVA, DMRT, $p < 0.05$). Sulphate in river and infiltration water varied from 305.44 ± 3.48 to 908.90 ± 41.82 ppm and 1559.23 ± 8.79 to 4460.86 ± 148.21 ppm, respectively and comparatively higher content was found in the dry seasons (July 02 and 03) followed by intermediate seasons (March 02 and 03) and wet season (November 02) (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.10 Sulphur

The higher total sulphur content (9.82 ± 0.07 mg/g) in soil was observed during the dry season (July 02) followed by 8.35 ± 0.11 mg/g in the dry season (July 03) and lower (3.22 ± 0.07 mg/g) was found in the wet season (November 01) (Figure 3.6) (ANOVA, DMRT, $p < 0.05$).

3.3.2.11 Carbon

Higher carbon (67.63 ± 0.11 mg/g) was observed during the intermediate season (March 02) followed by 63.29 ± 0.08 mg/g in the intermediate season (March 03) and lower carbon (44.84 ± 0.05 mg/g) in the wet season (November 02) (Figure 3.7) (ANOVA, DMRT, $p < 0.05$).

3.3.2.12 Copper

Higher total soil copper (25 ± 0.37 µg/g) was found during the intermediate season (March 02) and lower (14.72 ± 0.36 µg/g) in the intermediate season (March 03) (Figure 3.8) (ANOVA, DMRT, $p < 0.05$).

Rainwater, canopy drip and stem flow showed similar copper content (0.01 ± 0.00 ppm) in different seasons (intermediate, dry and wet). But, copper content in river and infiltration water varied from 0.01 ± 0.00 to 0.02 ± 0.00 ppm and 0.06 ± 0.00 to 0.07 ± 0.00 ppm, respectively (Table 3.4).

3.3.2.13 Iron

Total iron in soil varied from 7165 ± 38.32 to 12866.67 ± 57.74 µg/g. Comparatively higher iron (12866.67 ± 57.74 µg/g) was found during the intermediate season (March 02) followed by 11929.44 ± 31.27 µg/g in the intermediate season (March 03) and lower content (7165 ± 27.76 µg/g) was observed in dry season (July 02) (Figure 3.9) (ANOVA, DMRT, $p < 0.05$).

Similar content of iron (0.03 ± 0.00 ppm) was observed in rainwater, canopy drip and stem flow in different seasons (intermediate, dry and wet). But, iron content in river and infiltration water varied from 0.02 ± 0.00 to 0.04 ± 0.00 ppm and 0.41 ± 0.00 to 0.84 ± 0.00 ppm, respectively. Comparatively higher iron content (0.84 ± 0.00 ppm) in infiltration water was observed during the intermediate season (March 02) followed by 0.74 ± 0.00 ppm in the intermediate season (March 03) and lower (0.41 ± 0.00 ppm) in the dry season (July 02) (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.14 Zinc

Total zinc content in soil varied from 63.61 ± 0.40 to 96.22 ± 0.22 µg/g and comparatively higher zinc (96.22 ± 0.22 µg/g) was observed during the intermediate season (March 02) and lower (63.61 ± 0.40 µg/g) in wet season (November 01) (Figure 3.10) (ANOVA, DMRT, $p < 0.05$).

Similar content of zinc (0.02 ± 0.00 ppm) was found in rainwater, canopy drip and stem flow in different seasons (intermediate, dry and wet). Zinc content in river and

infiltration water varied from 0.05 ± 0.00 to 0.07 ± 0.00 ppm and 0.12 ± 0.00 to 0.16 ± 0.00 ppm, respectively. Comparatively higher zinc (0.07 ± 0.00 ppm) in river and infiltration water (0.16 ± 0.00 ppm) was observed during the intermediate season (March 02) and wet season (November 02), respectively (Table 3.4) (ANOVA, DMRT, $p < 0.05$).

3.3.2.15 Water and Soil Nutrients Relationship

Phosphorus in soil was significantly ($p < 0.05$) correlated with the phosphate content of stem flow and river water. Soil potassium content was found to correlate significantly ($p < 0.05$) with the potassium content in canopy drip, stem flow and infiltration water. Calcium in soil and rainwater, canopy drip and infiltration water, magnesium in soil and infiltration water, sulphur in soil and sulphate in river and infiltration water showed significant ($p < 0.05$) correlation. Similarly, iron in soil showed significant ($p < 0.05$) correlation with river and infiltration water. Zinc in soil showed significant ($p < 0.05$) correlation with rainwater and stem flow (Table 3.5).

3.3.2.16 Relationship among Rainwater and Canopy drip, Rainwater and Stem flow, River and Infiltration water Nutrient Content

Significant ($p < 0.05$) positive correlations were observed with NH_4 and Ca among the rain water and canopy drip. Rain water and stem flow showed significant ($p < 0.05$) positive correlation with the content of NH_4 . River and infiltration water also showed significant ($p < 0.05$) positive correlations with the content of PO_4 , SO_4 and Fe (Table 3.9).

3.4 Discussion

3.4.1 Soil Parameters and Nutrients

The soil pH and redox potential in this mangrove forest varied little in different seasons (intermediate, dry and wet) and this seasonal fluctuation may be related to the aerobic and anaerobic condition of soil (Aksornkoae, 1993), which may largely depend on the frequency and duration of tidal inundation. According to Oliver (1982), soil moisture content in mangroves showed positive relationship with rainfall, runoff from surrounding land areas and tidal flooding. Similarly, comparatively higher soil air-dry moisture content was observed during the wet seasons (November 01 and 02) and intermediate season (March 02), which were associated with higher amount of rainfall (Figure 2.4, Chapter 2) and higher number (10-14 tide/month) of spring high tide that flooded the forest floor.

Dry seasons (July 02 and 03) were characterized by lower amount of rainfall (8.90-166.30 mm) and relatively higher temperature (30.4 - 31.9°C) (Figure 2.4, Chapter 2). The consequences were low amount of freshwater flow and relatively higher temperature, which may increase the evaporation rate and results in comparatively

higher soil salinity, ultimately leading to increase conductivity during the dry seasons (July 02 and 03). In this study, comparatively higher soil cation exchange capacity was observed during the intermediate seasons (March 02 and 03). Soil cation exchange capacity was also found to fluctuate with the soil organic matter and iron content (Table 3.1 and Figure 3.9). Similarly, Adriano (1986) explained that soil cation exchange capacity is related to the clay content, organic matter, iron, manganese and aluminium oxides. Present study showed higher cation exchange capacity (34.53 ± 0.04 – 38.23 ± 0.29 m.e./100 g) than loamy-clayey soil (1.50–33.05 m.e./100 g) in Ranong mangrove forest, Thailand (Macintosh *et al.*, 1990), silty-clayey soil (28.56 m.e./100 g) in Mai Po mangrove forest, Hong Kong (Tam *et al.*, 1995a) and sandy-clayey soil (4.03–21.13 m.e./100 g) in Sepang Lukut mangrove forest, Peninsular Malaysia (Mahmood *et al.*, 2001) (Table 3.7). This comparison explains that soil cation exchange capacity is positively related with the clay content.

Comparatively higher soil organic matter was observed during the intermediate seasons (March 02 and 03), which coincided with the higher amount of leaf litter standing crops during the intermediate seasons (March 02 and 03) (Table 2.6, Chapter 2). Litter standing crop is an obvious source of soil organic matter through the decomposition (Aksornkoae, 1993; Tam *et al.*, 1995a) and this could be the reason for observing higher organic matter in soil, which is associated with the higher amount of litter standing crop in this mangrove forest. On the contrary, soil texture may have influence on organic matter content. Present study showed comparatively higher organic matter (10.22 ± 0.09 – $12.56 \pm 0.11\%$) compared to sandy soil (4.71%) in Sepang Lukut mangrove forest, Peninsular Malaysia (Mahmood *et al.*, 2001) (Table 3.7). This comparison explains that soil organic matter increases along with the percentage of clay content. However, a wide range of variation in soil parameters at different mangroves was observed (Table 3.7) and this variation may be the result of combined effect of tidal height, frequency of tidal inundation, inundation period, micro-topography, and soil texture (Lacerda *et al.*, 1995).

Relatively higher contents of nitrogen, phosphorus, potassium, carbon and iron in soil were observed during the intermediated seasons (March 02 and 03) and soil organic matter showed significant ($p < 0.05$) influence on their contents and the significant (ANOVA, $p < 0.05$) stepwise multiple linear regression models also describe the relationship among the soil nutrients and parameters (Table 3.6). These significant relationships among soil organic matter and nutrients indicate the potential source of these nutrients to the soil from the organic matter. It has been reported that variation in soil parameters and input of nutrients to soil may result in variation in soil nutrient levels (Boer, 1996; Gleason *et al.*, 2003). Present study showed higher N, P, K and Mg in soil than the mixed mangroves (*Rhizophora* spp., *Bruguiera* spp. and *Sonneratia* spp.) at Banyuasia mangrove, South Sumatra (Soekardjo and Kartawinata, 1979). *Rhizophora mangle* dominated forest at Sepetiba Bay, Rio de Janeiro, Brazil (Silva *et al.*, 1990) and planted *Avicennia marina* forest at Saudi coast of the Arabian Gulf,

Saudi Arabia (Sadiq and Zaidi, 1994) contained lower Cu, Fe and Zn in soil. Mixed mangrove forest (*Aegiceras corniculatum*, *Xylocarpus* spp. *B. parviflora*, *Rhizophora* spp. and *A. marina*) at Sematan mangrove, Sarawak (Ashton and Macintosh, 2002) contained lower amount of N, S and C in soil than the present study (Table 3.8).

3.4.2 Water Parameters and Nutrients

Comparatively acidic pH (5.40 ± 0.05 - 6.72 ± 0.03) was observed in canopy drip and stem flow than the rainwater (Table 3.2). According to Trudgill (1988), different organic acids usually leach during the interception of rainwater by the forest canopy and this could be the reason for observing comparatively lower pH in canopy drip and stem flow. Moreover, higher conductivity of canopy drip and stem flow compared to rainwater may be the evidence of cation leaching from the tree canopy. River and infiltration water pH ranged from 6.32 ± 0.03 to 7.05 ± 0.06 , which is comparable with Sepang Lukut Mangrove forest, Malaysia (5.78 to 6.92) (Mahmood *et al.*, 2001) and Sematan mangrove forest, Sarawak, Malaysia (6.80 to 7.20) (Ashton and Macintosh, 2002). Comparatively higher conductivity and salinity of river and infiltration water, which were observed during the dry seasons (July 02 and 03) and intermediate seasons (March 02 and 03), which may be due to the lower amount of freshwater flow (rainfall) compared to the wet seasons (Figure 2.4, Chapter 2).

Nutrient contents not only fluctuated with the seasons but also varied significantly (ANOVA, $p < 0.05$) at different types of water samples (rainwater, canopy drip, stem flow, river and infiltration water) (Appendix A). Relatively higher content of NH_4 , NO_3 , PO_4 , K, Ca, Mg and SO_4 were observed in canopy drip followed by stem flow and rainwater. Macronutrient contents in rainwater, canopy drip and stemflow fluctuated in different seasons (intermediate, dry and wet), but Cu, Fe and Zn remained in similar content. Similarly, Leite and Valle (1990) observed seasonal fluctuation of nutrients (N, P, K, Ca and Mg) in rainwater and canopy drip, and canopy drip contained relatively higher nutrients than rainwater under the cacao ecosystem in Bahia, Brazil. Macronutrients (except NO_3) in rainwater showed positive correlations with canopy drip and stem flow and Cu, Fe and Zn showed negative correlations (Table 3.9). These positive correlations of nutrients in rainwater and canopy drip and stem flow are suggesting the considerable leaching of nutrients during the canopy interception. According to Trudgill (1988) and Leite and Valle (1990), rainwater nutrients are augmented by canopy leaching and results in comparatively higher nutrient contents in canopy drip and stem flow. However, nutrient contents in rainwater vary from place to place and also vary with the time. It has been reported that areas close to the sea have greater influences of sea born spray on nutrients composition of rainwater (Yaalon and Lomas, 1976). Moreover, local sources of pollution such as quarry dust, road dust and the industrial emission may have considerable influence on rainwater nutrient contents (Trudgill, 1988). Apart from the abiotic factors, nutrient contents in canopy drip and stem flow vary from species to species (Gordon *et al.*, 2000), stages of plant

development such as flowering, fruiting and appearance of new leaves (Leite and Valle, 1990).

According to Boto (1982), the tidal water is an obvious source of nutrients to the mangroves and nutrients are usually dissolved and bounded to sediment particles. Tidal water carry large amount of sediment during the rainy season (Milliman and Meade, 1983) and this could be the reason for observing relatively higher content of nutrients (NH_4 , PO_4 , Mg, Fe and Zn) in the river water during the wet and intermediate seasons. Moreover, NO_3 , PO_4 , Mg, SO_4 , Cu and Fe showed positive correlations between river and infiltration water and significant (ANOVA, $p < 0.05$) simple linear regression relationship (Tables 3.9), which could be the evidence of nutrients exchange among the river and infiltration water.

3.4.3 Water and Soil Nutrients Relationship

Apart from the organic matter, this mangrove forest is receiving nutrients from rainwater, canopy leaching and tidal water. According to Golley *et al.* (1975), considerable amount of nutrients is leached from the tree foliage, branches and stem during the interception of rainwater. The nutrients in rainwater and leached nutrients from tree canopy and stem ultimately reach to the soil and can increase the soil nutrients level. Similarly, the positive correlations of nutrients in soil and rainwater, canopy drip and stem flow (Table 3.5) suggest the input of nutrients to this mangrove soil from rainwater and canopy leaching. Moreover, the positive correlations of among soil nutrients (N, P, Mg, S, Cu, Fe and Zn), river and infiltration water (Table 3.5) are the evidence of nutrients input through the tidal water in the studied mangrove forest.

Table 3.1: Soil parameters at different seasons. Means with similar alphabet in the same column (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

Sampling seasons	pH (<i>In situ</i>)	Redox potential (mv)	Air-dry moisture content (%)	Organic matter (%)	Soil conductivity (mS/cm)	Soil salinity (m.e./100 g)	CEC (m.e/100g)
Wet season (November 01)	7.07±0.04 ^A	2.28±2.64 ^B	10.44±0.23 ^B	10.33±0.10 ^E	8.14±0.05 ^C	40.69±0.27 ^C	36.48±0.32 ^C
Intermediate season (March 02)	6.86±0.02 ^B	15.89±2.07 ^A	10.30±0.14 ^B	12.56±0.11 ^A	9.75±0.06 ^B	48.75±0.30 ^B	38.23±0.29 ^A
Dry season (July 02)	7.00±0.04 ^A	3.06±2.66 ^B	8.06±0.15 ^D	10.86±0.11 ^D	11.81±0.06 ^A	59.03±0.29 ^A	34.53±0.04 ^E
Wet season (November 02)	6.77±0.05 ^C	14.56±2.85 ^A	11.20±0.04 ^A	10.22±0.09 ^E	7.81±0.08 ^C	39.03±0.41 ^C	35.59±0.07 ^D
Intermediate season (March 03)	6.83±0.02 ^B	10.22±1.56 ^A	8.78±0.15 ^C	12.03±0.02 ^B	10.17±0.11 ^B	50.83±0.56 ^B	37.31±0.22 ^B
Dry season (July 03)	6.95±0.02 ^B	7.57±2.74 ^A	8.67±0.18 ^C	11.25±0.08 ^C	11.25±0.08 ^A	57.64±0.51 ^A	36.40±0.07 ^C

*Number of observation was 9; ± Standard error

Table 3.2: Water (rainwater, canopy drip, stemflow, river and infiltration water) parameters at different seasons. Means with similar alphabet in the same column (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

Sample types and sampling seasons	pH	Redox potential (mv)	Conductivity (mS/cm)	Salinity (ppt)
Rain water				
Intermediate season (March 02)	6.79±0.05 ^A	9.74±1.29 ^B	0.08±0.001 ^D	-
Dry season (July 02)	6.91±0.04 ^A	3.34±1.13 ^B	0.29±0.001 ^A	-
Wet season (November 02)	6.91±0.03 ^A	1.68±0.37 ^B	0.14±0.001 ^C	-
Intermediate season (March 03)	6.39±0.03 ^B	105.67±5.61 ^A	0.10±0.001 ^D	-
Dry season (July 03)	6.33±0.07 ^B	126.00±20.84 ^A	0.21±0.001 ^B	-
Canopy drip				
Intermediate season (March 02)	6.72±0.03 ^A	11.84±0.74 ^B	0.15±0.001 ^C	-
Dry season (July 02)	6.67±0.08 ^A	12.10±0.55 ^B	0.35±0.001 ^A	-
Wet season (November 02)	6.34±0.07 ^B	35.40±5.43 ^B	0.16±0.001 ^C	-
Intermediate season (March 03)	6.45±0.06 ^B	115.67±6.86 ^A	0.13±0.001 ^D	-
Dry season (July 03)	6.36±0.06 ^B	120.33±10.97 ^A	0.31±0.001 ^B	-
Stem flow				
Intermediate season (March 02)	6.18±0.06 ^A	46.00±0.58 ^D	0.10±0.001 ^A	-
Dry season (July 02)	5.40±0.05 ^C	84.20±1.02 ^C	0.09±0.001 ^B	-
Wet season (November 02)	6.13±0.08 ^A	80.57±2.71 ^C	0.09±0.001 ^C	-
Intermediate season (March 03)	5.98±0.04 ^B	143.00±2.65 ^A	0.10±0.001 ^A	-
Dry (July 03)	5.84±0.04 ^B	105.33±5.18 ^B	0.10±0.001 ^A	-
River water				
Intermediate season (March 02)	6.92±0.03 ^A	2.50±0.67 ^D	20.00±0.30 ^B	30±0.01 ^A
Dry season (July 02)	6.91±0.05 ^A	5.83±1.31 ^C	22.17±0.17 ^A	30±0.01 ^A
Wet season (November 02)	6.56±0.08 ^C	23.01±1.89 ^A	18.17±0.17 ^C	25±0.01 ^B
Intermediate season (March 03)	6.69±0.06 ^B	11.93±3.60 ^B	19.50±0.29 ^D	30±0.01 ^A
Dry season (July 03)	6.92±0.08 ^A	6.17±1.38 ^C	21.17±0.17 ^B	30±0.01 ^A
Infiltration water				
Intermediate season (March 02)	6.32±0.03 ^C	42.00±2.65 ^B	61.67±1.67 ^B	37±0.01 ^B
Dry season (July 02)	7.05±0.06 ^A	-20.93±0.24 ^C	70.17±0.44 ^A	41±0.02 ^A
Wet season (November 02)	6.27±0.08 ^C	48.00±1.73 ^A	55.83±0.44 ^C	34±0.02 ^C
Intermediate season (March 03)	6.52±0.05 ^B	39.47±2.84 ^B	63.33±1.68 ^B	38±0.01 ^B
Dry season (July 03)	7.03±0.03 ^A	-17.30±1.77 ^C	71.00±0.58 ^A	40±0.02 ^A

Table 3.3: Soil texture and bulk density

Clay % (<2 μ)	Silt % (2-50 μ)	Sand % (> 50 μ)	Soil texture Class (USDA)	Bulk density (gm/cm ³)
64.24±0.52	34.42±0.89	1.34±0.50	Clay	0.63±0.01

*Number of observation was 9

Table 3.4: Nutrient contents (ppm) in rainwater, canopy drip, stem flow, river and infiltration water at the different seasons. Means with similar alphabet in the same row (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

Sample Types	Intermediate season (March 02)	Dry season (July 02)	Wet season (November 02)	Intermediate season (March 03)	Dry season (July 03)
Ammonium					
Rain water	0.16±0.01 ^D	0.51±0.01 ^A	0.41±0.01 ^B	0.31±0.01 ^C	0.47±0.01 ^A
Canopy drip	0.40±0.01 ^D	0.88±0.00 ^B	1.03±0.02 ^A	0.42±0.01 ^D	0.74±0.01 ^C
Stem flow	0.31±0.00 ^C	0.59±0.02 ^A	0.50±0.01 ^B	0.30±0.00 ^C	0.50±0.01 ^B
River water	0.34±0.01 ^C	0.38±0.01 ^B	0.55±0.01 ^A	0.32±0.00 ^D	0.35±0.01 ^C
Infiltration water	0.64±0.00 ^A	0.62±0.01 ^B	0.51±0.00 ^C	0.52±0.00 ^C	0.49±0.01 ^D
Nitrate					
Rain water	0.01±0.00 ^E	0.06±0.00 ^B	0.04±0.00 ^C	0.03±0.00 ^D	0.07±0.00 ^A
Canopy drip	0.07±0.00 ^B	0.05±0.00 ^D	0.08±0.00 ^A	0.07±0.00 ^B	0.06±0.00 ^C
Stem flow	0.02±0.00 ^D	0.03±0.00 ^C	0.08±0.00 ^A	0.05±0.00 ^B	0.03±0.00 ^C
River water	0.02±0.00 ^B	0.03±0.00 ^A	0.01±0.00 ^C	0.02±0.00 ^B	0.02±0.00 ^B
Infiltration water	0.02±0.00 ^B	0.03±0.00 ^A	0.01±0.00 ^C	0.01±0.00 ^C	0.01±0.00 ^C
Phosphate					
Rain water	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A
Canopy drip	0.05±0.00 ^C	0.09±0.00 ^A	0.07±0.00 ^B	0.04±0.00 ^D	0.04±0.00 ^D
Stem flow	0.02±0.00 ^A	0.01±0.00 ^B	0.01±0.00 ^B	0.01±0.00 ^B	0.01±0.00 ^B
River water	0.05±0.00 ^A	0.03±0.00 ^B	0.02±0.00 ^C	0.03±0.00 ^B	0.03±0.00 ^B
Infiltration water	0.11±0.00 ^A	0.09±0.00 ^B	0.01±0.00 ^E	0.04±0.00 ^D	0.05±0.00 ^C
Potassium					
Rain water	0.33±0.00 ^A	0.21±0.00 ^D	0.33±0.00 ^A	0.30±0.01 ^B	0.25±0.00 ^C
Canopy drip	4.49±0.10 ^A	2.34±0.00 ^C	2.39±0.04 ^C	2.65±0.02 ^B	2.65±0.02 ^B
Stem flow	2.61±0.11 ^A	2.34±0.00 ^B	0.50±0.01 ^D	2.34±0.01 ^B	2.14±0.00 ^C
River water	34.06±0.60 ^C	45.96±0.00 ^A	21.00±0.00 ^E	20.05±0.04 ^D	38.10±0.24 ^B
Infiltration water	348.89±3.61 ^A	64.11±0.99 ^D	154.00±0.00 ^C	327.14±0.92 ^B	60.12±0.17 ^D
Calcium					
Rain water	2.30±0.02 ^B	1.60±0.00 ^D	2.00±0.00 ^C	2.45±0.00 ^A	1.40±0.00 ^E
Canopy drip	16.54±0.04 ^C	9.00±0.00 ^E	19.50±0.00 ^B	20.12±0.00 ^A	10.13±0.00 ^D
Stem flow	5.91±0.11 ^C	3.00±0.00 ^D	7.50±0.00 ^B	8.00±0.24 ^A	6.22±0.17 ^C
River water	68.13±0.12 ^B	76.00±0.33 ^A	54.00±0.14 ^E	63.00±0.17 ^C	66.45±0.17 ^C
Infiltration water	568.22±1.57 ^B	329.56±0.23 ^E	498.00±0.33 ^C	926.23±0.17 ^A	444.23±0.17 ^D
Magnesium					
Rain water	2.00±0.00 ^C	1.87±0.00 ^D	2.10±0.00 ^B	2.50±0.00 ^A	1.30±0.00 ^E
Canopy drip	5.33±0.07 ^B	7.00±0.24 ^A	1.00±0.00 ^E	4.50±0.00 ^C	3.10±0.00 ^D
Stem flow	4.11±0.06 ^B	4.50±0.11 ^A	1.00±0.00 ^D	4.00±0.17 ^B	2.13±0.00 ^C
River water	271.00±2.14 ^A	245.00±0.24 ^B	188.00±0.17 ^D	163.00±0.17 ^E	200.17±0.24 ^C
Infiltration water	2365.33±8.47 ^A	2012.00±0.67 ^E	2123.00±0.00 ^C	2216.36±0.17 ^B	2059.00±0.17 ^D
Sulphate					
Rain water	6.99±0.11 ^B	14.43±0.36 ^A	5.32±0.06 ^C	2.24±0.01 ^D	7.03±0.36 ^B
Canopy drip	41.19±0.13 ^A	33.49±1.86 ^B	5.69±0.12 ^E	12.51±0.07 ^D	23.39±0.68 ^C
Stem flow	14.56±0.35 ^A	10.35±0.20 ^B	9.32±0.18 ^C	8.28±0.01 ^D	7.18±0.21 ^E
River water	611.58±1.18 ^B	908.90±82.07 ^A	305.44±3.48 ^C	511.11±0.52 ^B	797.78±41.82 ^A

Infiltration water 2527.46±6.38^C 4460.86±148.21^A 1559.23±8.79^E 1953.59±1.07^D 3129.55±31.17^B

Table 3.4: (Cont'd)

Sample Types	Intermediate season (March 02)	Dry season (July 02)	Wet season (November 02)	Intermediate season (March 03)	Dry season (July 03)
Copper					
Rain water	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A
Canopy drip	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A
Stem flow	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A	0.01±0.00 ^A
River water	0.02±0.00 ^A	0.02±0.00 ^A	0.01±0.00 ^B	0.01±0.00 ^B	0.02±0.00 ^A
Infiltration water	0.07±0.00 ^A	0.07±0.00 ^A	0.06±0.00 ^B	0.07±0.00 ^A	0.07±0.00 ^A
Iron					
Rain water	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A
Canopy drip	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A
Stem flow	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A	0.03±0.00 ^A
River water	0.04±0.00 ^A	0.02±0.00 ^B	0.02±0.00 ^B	0.04±0.00 ^A	0.02±0.00 ^B
Infiltration water	0.84±0.00 ^A	0.41±0.00 ^E	0.44±0.00 ^C	0.74±0.00 ^B	0.43±0.00 ^D
Zinc					
Rain water	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A
Canopy drip	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A
Stem flow	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A	0.02±0.00 ^A
River water	0.07±0.00 ^A	0.06±0.00 ^B	0.05±0.00 ^C	0.06±0.00 ^B	0.06±0.00 ^B
Infiltration water	0.14±0.00 ^C	0.12±0.00 ^D	0.16±0.00 ^A	0.15±0.00 ^B	0.14±0.00 ^C

Table 3.5: Pearson correlation among water and soil nutrients

Water nutrients	Soil nutrients	Correlation coefficient (r)				
		Rain water	Canopy drip	Stem flow	River water	Infiltration water
NH ₄	N	-0.11	0.50	0.26	0.25	0.31
NO ₃		-0.18	0.51	0.29	-0.40	0.06
PO ₄	P	0.54	-0.65	0.78*	0.79*	0.49
K	K	0.33	0.75*	0.75*	-0.14	0.84*
Ca	Ca	0.97*	0.82*	0.56	-0.28	0.89*
Mg	Mg	0.55	0.22	0.44	0.33	0.98*
SO ₄	S	0.72	0.70	0.01	0.98*	0.95*
Cu	Cu	0.02	0.30	0.01	0.38	0.23
Fe	Fe	-0.07	-0.16	-0.16	0.98*	0.98*
Zn	Zn	-0.80*	0.01	0.87*	0.35	0.52

* values are significant at p<0.05 level

Table 3.6: Stepwise multiple linear regression among soil parameters and nutrients

Soil nutrients	Soil parameters	Regression models	r value
Nitrogen	Organic matter	$Y = 0.04 X_4 + 2.74$	0.93
Phosphorus	Organic matter	$Y = 0.005 X_4 + 0.006 X_7 - 0.002$	0.97
	CEC		
Potassium	Organic matter	$Y = 1.37 X_4 - 21.19$	0.97
Calcium	NP		
Magnesium	CEC	$Y = 0.63 X_7 - 13.73$	0.85
Sulphur	Salinity	$Y = 0.28 X_6 - 7.34$	0.95
Carbon	Organic matter	$Y = 11.74 X_4 - 0.15 X_6 - 168.25$	0.98
	Salinity		
Iron	Organic matter	$Y = 3110.88 X_4 - 153.05 X_6 - 43979.49$	0.97
	Salinity		
Copper	NP		
Zinc	Redox potential	$Y = 2.05 X_2 + 0.43 X_6 + 41.45$	0.98
	Salinity		

*NP: No parameters are significant at $p < 0.05$ level, CEC: Cation exchange capacity; $X_1, X_2, X_3, X_4, X_5, X_6$ and X_7 were pH, redox potential, air-dry moisture, organic matter, conductivity, salinity and cation exchange capacity, respectively

Table 3.7: Comparison of soil parameters in different mangrove forest

Location	Species	Soil parameters						Source
		PH <i>In situ</i>	Organic matter (%)	Conductivity (mS/cm)	Salinity (m.e./100g)	CEC (m.e./100g)	Soil texture	
Ranong mangrove forest, Thailand	<i>Rhizophora</i> spp. <i>Bruguiera</i> spp. <i>Ceriops tagal</i> <i>Xylocarpus</i> spp.	6.00-8.00				1.50-33.05	Loamy-clayey	Macintosh <i>et al.</i> (1990)
Mai Po mangrove forest, Hong Kong (22°32'N114°03'E)	<i>Avicennia marina</i> <i>A. corniculatum</i> , <i>Kandelia candel</i>	4.20-7.00		1.40-2.20		28.56	Silty - clayey	Tam <i>et al.</i> (1995a)
Sepang Lukut mangrove forest, Malaysia (2°23'N, 101°42'E)	<i>Rhizophora mucronata</i>	5.60-7.08	4.71-20.46	8.50-19.77	42.51-98.83	4.03-21.13	Sandy -clayey	Mahmood <i>et al.</i> (2001)
Sematan Mangrove, Sarawak (1°48'N, 109°47'E)	<i>A. corniculatum</i> <i>Xylocarpus</i> spp. <i>B. parviflora</i> <i>Rhizophora</i> spp. <i>A. marina</i>	5.15-6.70						Ashton and Macintosh (2002)
Kuala Selangor mangrove forest, Malaysia (3°19'N, 101°14' E)	<i>B. parviflora</i>	6.77-7.07	10.22-12.56	7.81-11.81	39.03-59.03	34.53-38.23	Clayey	This study

Table 3.8: Comparison of soil nutrients in different mangrove forest

Location	Species	Nutrients										Source
		N (mg/g)	P (mg/g)	K (mg/g)	Ca (mg/g)	Mg (mg/g)	S (mg/g)	C (mg/g)	Cu (µg/g)	Fe (µg/g)	Zn (µg/g)	
Banyuasia mangrove, South Sumatra (2°30'N, 105°30'E)	<i>Rhizophora</i> spp <i>Bruguiera</i> spp. <i>Sonneratia</i> spp.	1.90- 3.50	0.12- 0.27	1.55- 1.71	2.11- 6.91	4.98- 6.46		33.20- 123.10				Soekardjo and Kartawinata (1979)
Sepetiba Bay mangrove forest, Rio de Janeiro, Brazil	<i>Rhizophora mangle</i>								2.10- 3.30	4856.00- 8276.00	16.00- 22.00	Silva <i>et al.</i> (1990)
Saudi coast of the Arabian Gulf, Saudi Arabia	<i>Avicennia marina</i> (Planted)		0.14						1.83	1593.00	7.28	Sadiq and Zaidi (1994)
Mai Po mangrove forest, Hong Kong (22°32'N 114°03'E)	<i>Aegiceras</i> <i>corniculatum</i> , <i>Kandelia candel</i> , <i>A. marina</i>	0.40- 2.50	0.30- 1.80	16.00				4.00- 45.00	41.10		146.10	Tam <i>et al.</i> (1995a)
Yiagluo Bay, China (21°28'N, 119°43'E)	<i>R. stylosa</i>								18.90	46.60		Jiao <i>et al.</i> (1997)
Futian mangrove forest, South China (22°32' N, 114°05' E)	<i>A. corniculatum</i> , <i>K. candel</i>	1.69	1.54	16.40								Li (1997)
Kerala, India (9°37' N, 76°26'E)	<i>A. officinalis</i> <i>B. gymnorhiza</i> <i>S. caseolaris</i>							5.10- 76.50	28.00- 758.00	77603- 123636	100.00- 1880.00	Thomas and Fernandez (1997)
Sematan mangrove, Sarawak (1°48'N, 109°47'E)	<i>A. corniculatum</i> <i>Xylocarpus</i> spp. <i>B. parviflora</i> <i>Rhizophora</i> spp. <i>A. marina</i>	0.80- 2.90					0.40- 9.50	11.80- 52.50				Ashton and Macintosh (2002)
Kuala Selangor mangrove forest, Malaysia (3°19'N, 101°14' E)	<i>B. parviflora</i>	3.41- 3.50	0.31- 0.34	4.33- 7.06	3.06- 3.61	8.28- 10.83	3.22- 9.82	44.84- 67.63	14.72- 25.00	7631- 12867	63.61- 96.22	This study

Table 3.9: Pearson correlation among rainwater and canopy drip, rainwater and stem flow, river and infiltration water

Nutrients	Correlation coefficient (r)		
	Rain water and canopy drip	Rain water and stem flow	River and infiltration water
NH ₄	0.74*	0.82*	-0.22
NO ₃	-0.57	0.04	0.40
PO ₄	0.04	0.12	0.76*
K	0.51	0.34	-0.55
Ca	0.87*	0.55	-0.37
Mg	0.05	0.30	0.27
SO ₄	0.59	0.21	0.88*
Cu	0.03	-0.14	0.61
Fe	-0.22	-0.22	0.97*
Zn	-0.06	-0.35	-0.48

* values are significant at p<0.05 level

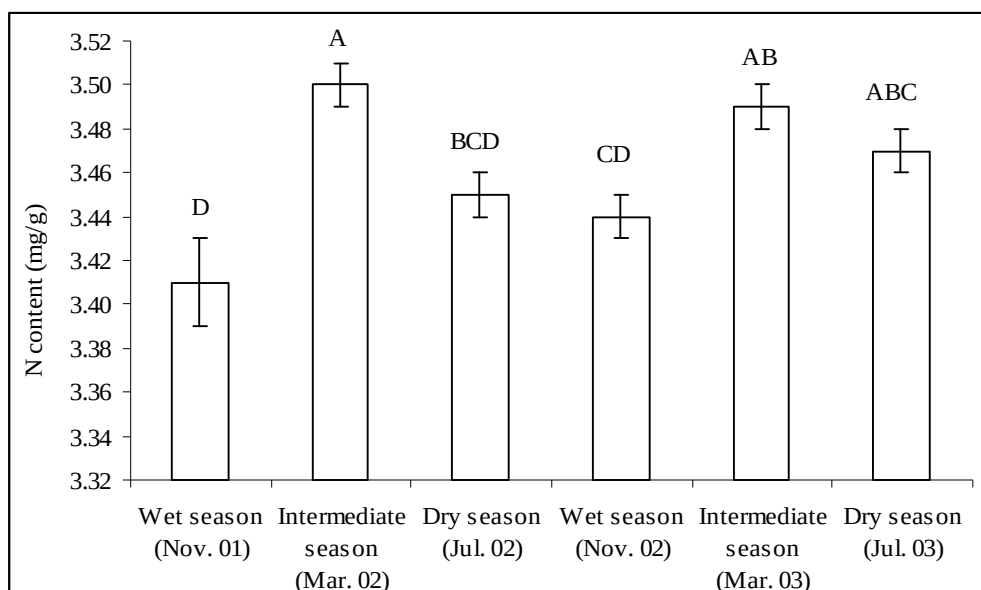


Figure 3.1: Total nitrogen content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

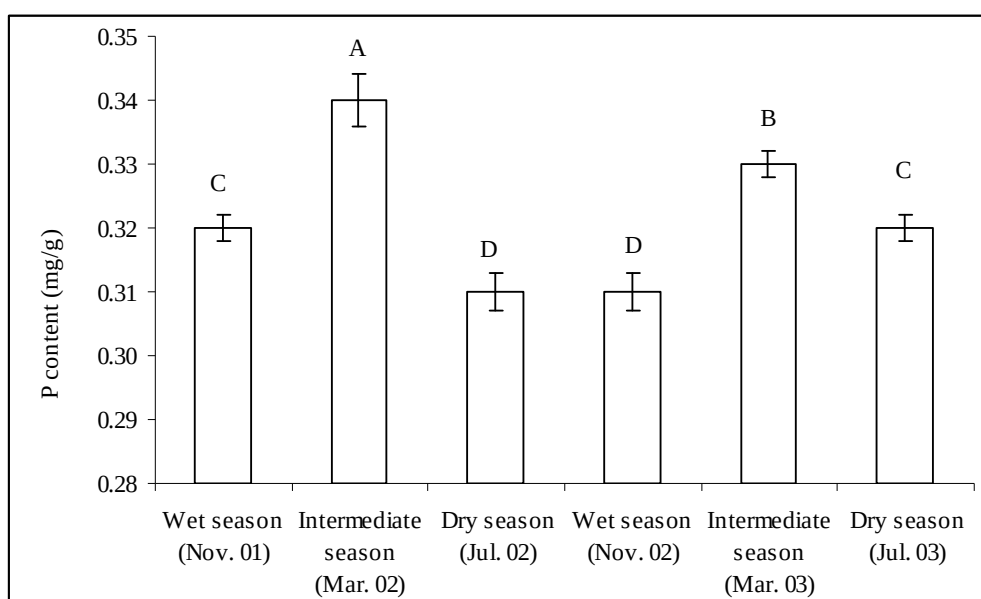


Figure 3.2: Total phosphorus content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

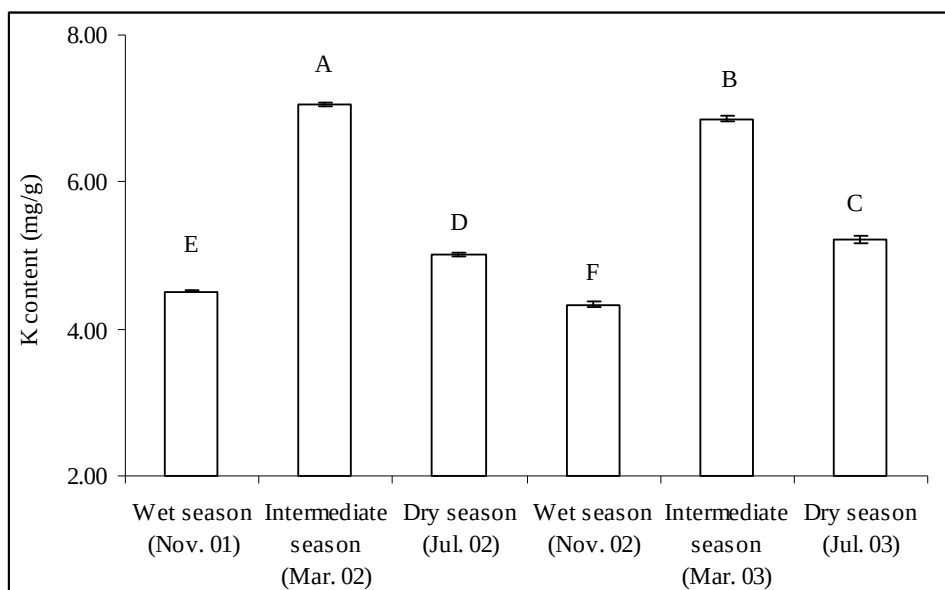


Figure 3.3: Total potassium content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

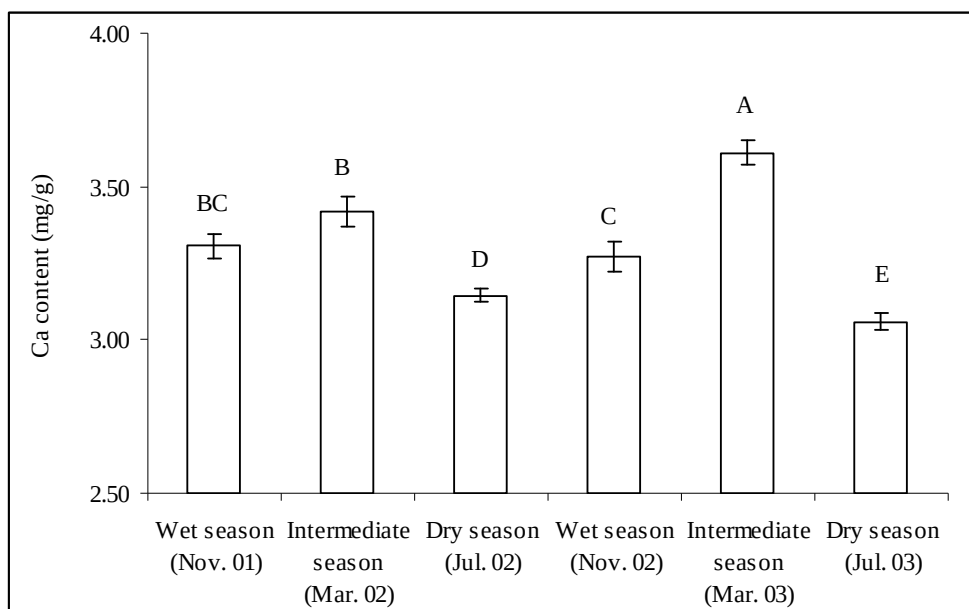


Figure 3.4: Total calcium content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

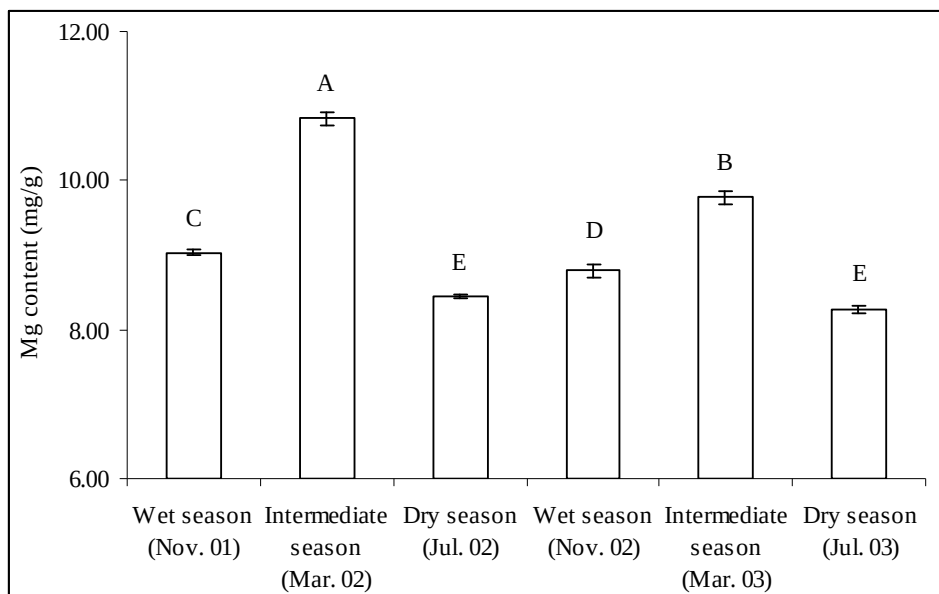


Figure 3.5: Total magnesium content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

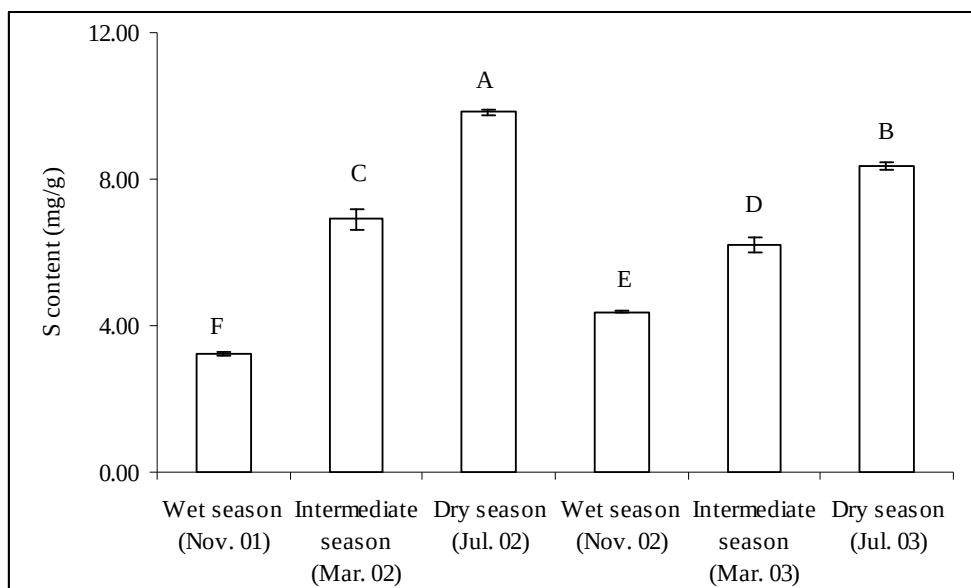


Figure 3.6: Total sulphur content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

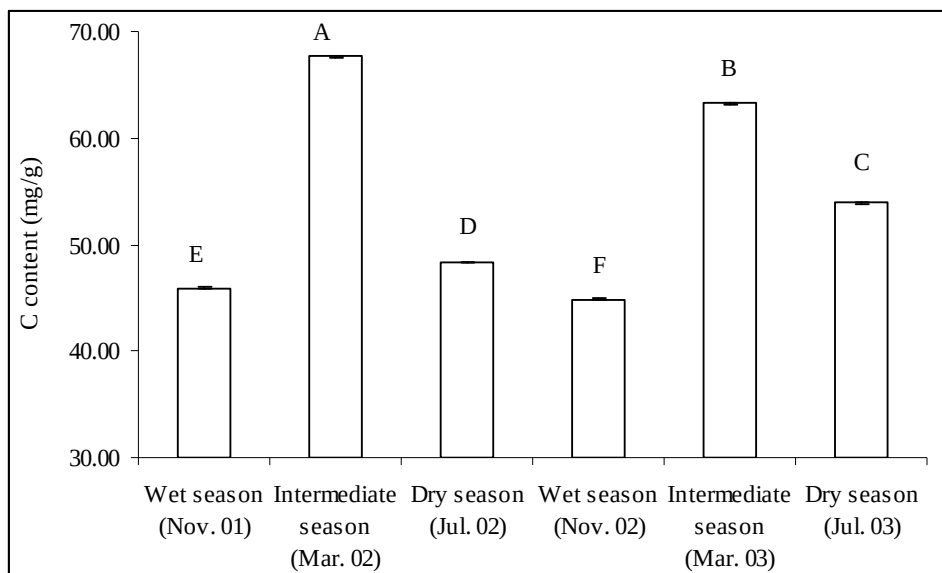


Figure 3.7: Total carbon content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

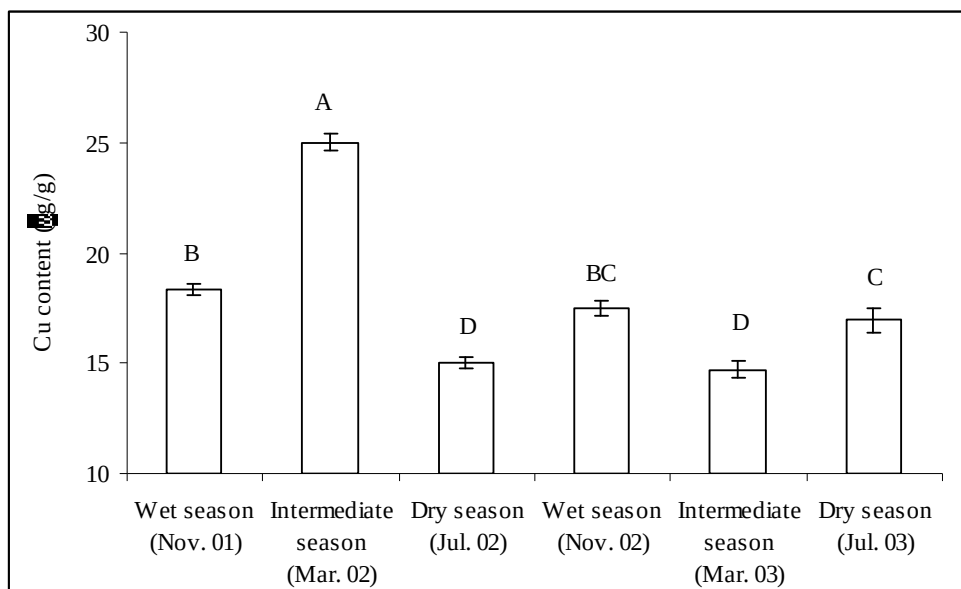


Figure 3.8: Total copper content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

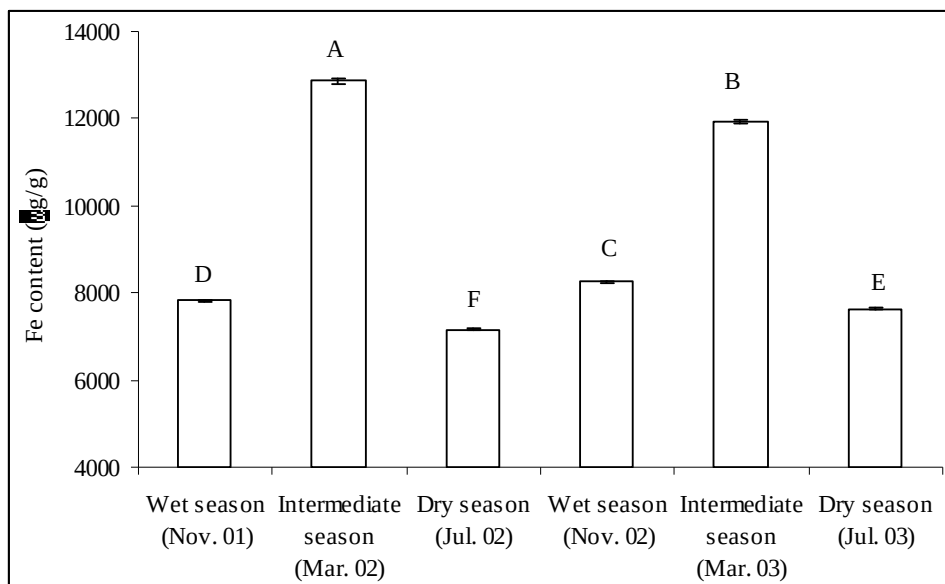


Figure 3.9: Total iron content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

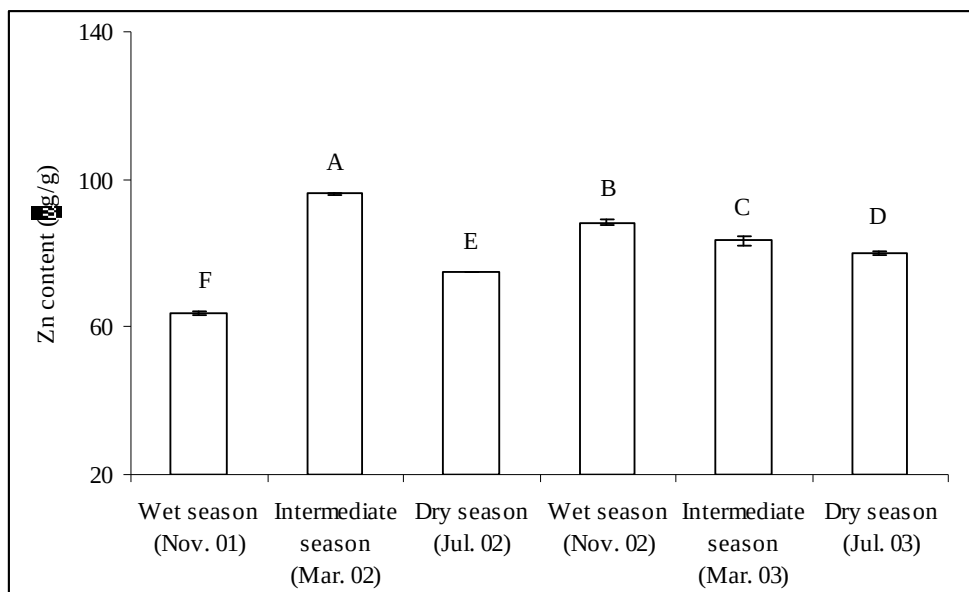


Figure 3.10: Total zinc content in soil at different seasons. Means with similar alphabet on the bars (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

CHAPTER 4

BIOMASS STUDY

4.1 Introduction

Mangrove communities are characterized by highly productive, higher biomass and higher litter production compared to other terrestrial plant communities (Lugo and Snedaker, 1974). The management of mangrove ecosystems requires basic understanding of their productivity. Net productivity consists of increment in biomass per unit time, the turnover of litter (leaves, small branches, fruits and flowers) and fine roots, herbivory and loss of dissolved organic materials from roots (Ong *et al.*, 1995). Standing forest biomass is not a direct measurement of primary productivity, but is often used for comparison of potential productivity. However, annual biomass increment is an important indicator of forest productivity (Clough and Attiwill, 1982; Hutchings and Saenger, 1987).

Biomass studies of mangrove forest throughout the world from 1975 to 2001 are shown in Figure 4.1. Most of the biomass studies of mangrove forest focused on trees as the main component of forest productivity. However, saplings were included in some studies (Ong *et al.*, 1985a; Putz and Chan, 1986; Tamai *et al.*, 1986; Clough and Scott, 1989; Gong and Ong, 1990; Clough, 1992) with the trees. These authors fitted saplings and trees using same allometric equations for the biomass estimation of each component. Very few studies have estimated the sapling biomass by using separate allometric relationships (Turner *et al.*, 1995), but biomass studies of seedlings are still lacking in mangrove forest. Different mangrove species at different places showed wide range of standing biomass. The biomass ranged from 460 t/ha in tall *Rhizophora* spp. dominated forest in Matang, Malaysia (Putz and Chan, 1986) to 6.8 t/ha in low *Avicennia marina* communities in Tuff Crater, New Zealand (Woodroffe, 1985). However, mangrove species also showed different trends of biomass allocation in different components (Steinke *et al.*, 1995; Tam *et al.*, 1995b; Suzuki and Tagawa, 1983; Clough and Attiwill, 1975; Gong and Ong, 1990). Different tree species usually vary in their architecture from open to close canopy and also with the stand density and forest types (Clough and Scott, 1989), so it is preferable to use species specific allometric equations for biomass estimation (Ketterings *et al.*, 2001).

Bruguiera parviflora constitutes about 80% of the growing stock of the present studied mangrove forest. This species is the least studied among the mangrove communities in Malaysia as well as elsewhere. *Bruguiera parviflora* serves as a nurse crop by modifying suitable site condition for the climax species in the process of succession (Watson, 1928; Noakes, 1952; Chapman, 1976).

4.1.1 Objectives

The objectives of this study were

1. To derive suitable allometric relationships for biomass estimation of saplings and trees of *B. parviflora*.
2. To estimate the above and below-ground biomass of *B. parviflora* at seedling, sapling and tree stages.
3. To estimate the pattern of biomass allocation in different components of seedlings, saplings and trees.
4. To estimate yearly biomass increment in saplings and trees of *B. parviflora*.

4.2 Materials and Methods

4.2.1 Seedling Biomass

Biomass study of *B. parviflora* seedlings (less than one meter in height) was done by quadrat sampling method with randomly selected nine plots (1 m x 1 m) during February 2002 to March 2002. All *B. parviflora* seedlings inside the plots were collected with their root system. Seedlings roots were excavated during the high tide that flooded the forest floor. Tidal water facilitated to soften the soil. In addition with the tidal water, low-pressure water jet was used to loose the soil from the collar region of seedlings and surrounding areas at 50 cm radius. Once the soil was sufficiently loosed around the seedlings, they were pulled by hand to uproot. The collected seedlings from each plot were then separated into leaves, stems and roots. The fresh weight of each component was measured and recorded in the field at plot basis. Sub-samples from each component (about 0.25 kg) were brought back to the laboratory for obtaining fresh weight to oven dry weight conversion ratios of samples at 80° C to constant weight for 5 days. The oven-dry weight (kg) of seedling components was calculated from the respective fresh to oven-dry weight (kg) conversion ratios and finally biomass of seedling components was expressed in t/ha.

4.2.2 Sapling and Tree Biomass

Ten saplings and six trees of *B. parviflora* were selected randomly (avoiding mechanically or insect damaged or infested with disease) to cover the range of Diameter at Breast Height (DBH) from 1 to <4 cm and 4 to 16 cm, respectively. Separation of saplings and trees in DBH range were done based on stand structural characteristics, which were described in Section 2.8.1, Chapter 2. The Biomass study of saplings and trees of *B. parviflora* was initiated from February 2002 and ended on March 2002. The selected saplings and trees were felled at ground level, and they were uprooted as well. The above ground components of the individual sapling and tree were then separated into leaves, buds, flowers (for trees), bigger branches (diameter > 2 cm), smaller branches (diameter < 2 cm) and stems. Buttress roots were included with stems, and stems were cut into suitable sizes for weighing. One stem section of 50 cm length for saplings and one section of 1 m length for trees were collected from the base,

middle and upper portion of the stem for each sapling and tree. These stem sections were then debarked in the field by using knife. Special care was taken so that stem wood was not cut during the debarking operation. The debarked stems and bark were weighed and the fresh weight of total bark was calculated from the ratio of fresh weight of debarked stem and its bark weight. The root system of each sapling and tree was excavated carefully followed by the buttress roots by using water jet and portable winch. The roots were washed properly, air-dried and sorted into bigger roots (diameter > 1 cm) and smaller roots (diameter < 1 cm). All the components of the individual sapling and tree were weighed (fresh weight) in the field.

Three disks (2 cm thick) of stems and bigger branches (for trees) and sub-samples (about 0.25 kg) from other components of saplings and trees were taken randomly and brought back to the laboratory for calculating fresh weight to oven dry weight conversion ratios of samples at 80°C to constant weight. The oven dry constant weight of disks (2 cm thick) of stems and bigger branches was measured after 30 days, while the oven dry constant weight of other plant components was measured after 10 days. The oven-dry weight (kg) of different components was calculated from the conversion ratios of the corresponding components. Saplings and trees were considered as two different components of the forest in terms of biomass study. Allometric relationships between Diameter at Breast Height (DBH) and oven-dry weight of saplings and trees components were developed for biomass estimation. Finally, biomass of sapling and tree components was expressed in t/ha.

4.2.3 Yearly Biomass Increment in Saplings and Trees

Nine saplings and eighteen trees of *B. parviflora* were selected randomly (avoiding mechanically or insect damaged or infested with disease), DBH was measured and tagged during September 2001. The DBH of tagged saplings and trees were measured at yearly interval for successive two years. The biomass of each tagged sapling and tree was estimated by using the derived allometric equations for biomass estimation. The yearly biomass increment in each tagged sapling and tree was calculated by subtracting the initial biomass from the final biomass (Day *et al.*, 1996). Finally, yearly biomass increment in different components (stems, bark, branches, leaves, buds and roots) of saplings and trees was expressed in t/ha.

4.2.4 Relationship Between Biomass of Components and DBH of Saplings and Trees

The oven-dry biomass values of saplings and trees components and their respective Diameter at Breast Height (DBH) values were subjected to a linear regression analysis. Following two regression models were tried:

1. Biomass = A + B. DBH
2. Log₁₀ Biomass = A + B Log₁₀ DBH

Where, DBH = Diameter at Breast Height in cm; A = intercept; B = slope

4.2.5. Statistical Analysis

Conversion ratios of fresh weight to oven dry weight of different components of seedlings, saplings and trees were compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p < 0.05$) by using SAS (6.12) statistical software. Significant test of regression slopes and coefficients of different equations of saplings and trees components were tested and biomass increment in successive two years in selected saplings and trees was tested by pair “t” test (t-test, $p < 0.05$) by using SAS (6.12) statistical software.

4.3 Results

4.3.1 Fresh Weight to Oven-dry Weight Conversion Ratios

Different components of seedlings, saplings and trees showed different conversion ratios of fresh weight to oven-dry weight. The conversion ratios of similar components such as leaves of seedlings, saplings and trees, smaller branches of saplings and trees, stems of seedlings, bark of saplings and trees varied significantly (ANOVA, DMRT, $p < 0.05$) (Table 4.1).

4.3.2. Allometric Relationships

Allometric relationships between oven-dry biomass of different components such as leaves, buds, flowers (for trees), branches, stems, bark and roots of saplings and trees and their DBH were calculated by the equation of untransformed $\text{Biomass} = A + B \cdot \text{DBH}$. Where, A and B are regression constants. All the equations were significant ($p < 0.05$) and the regression coefficient (R^2) values for all the components were ranged from 0.89 to 0.97 (Table 4.2).

Comparatively higher values of regression coefficients (R^2) (ranged from 0.89 to 0.99) were observed, when oven-dry weight of saplings and trees components were plotted against DBH on a log-log scale in following equation:

$$\text{Log}_{10} \text{Biomass} = A + B \text{Log}_{10} \text{DBH}$$

Where, A and B are regression constants. All regression equations both for saplings and trees were highly significant ($p < 0.05$) (Table 4.3). Based on regression coefficients (R^2) values, the Log_{10} transformation equation ($\text{Log}_{10} \text{Biomass} = A + B \text{Log}_{10} \text{DBH}$) is more accurate for biomass estimation (Rapp, 1999).

The equation ($\text{Log}_{10} \text{Biomass} = A + B \text{Log}_{10} \text{DBH}$) can be written as:

$$\text{Biomass} = A_A \times \text{DBH}^B$$

Where B has the same value as in the first equation ($\text{Log}_{10} \text{Biomass} = A + B \text{Log}_{10} \text{DBH}$) and A_A is the antilog of A.

The regression slopes and coefficients of different equations of saplings and trees components differed significantly (t-test, $p < 0.05$) (Appendix A). Therefore, different allometric equations were used in biomass estimation of different components of saplings and trees.

4.3.3 Biomass of Seedlings, Saplings and Trees

The above and below-ground biomass of saplings and trees are expressed in area basis and calculated from the saplings and trees having mid DBH of the respective DBH classes (Cintron and Novelli, 1984) by using the best fitted allometric equations ($\text{Biomass} = A_A \times \text{DBH}^B$). Diameter classes and density of *B. parviflora* saplings and trees are presented in Table 4.4.

The above and below-ground biomass of seedlings, saplings and trees of *B. parviflora* were 1.12, 0.89 and 142.46 t/ha; 0.25, 0.14 and 18.93 t/ha, respectively, which made up 144.47 t/ha and 19.32 t/ha of total above and below-ground biomass of seedlings, saplings and trees, respectively (Table 4.5). Seedlings, saplings and trees showed different biomass proportions in their components. The mean percentage of above and below-ground biomass for seedlings, saplings and trees were 81.75, 84.48 and 88.82%; 18.25, 15.52, and 11.18%, respectively (Table 4.6).

4.3.4 Yearly Biomass Increment in Saplings and Trees

Best-fitted allometric equations ($\text{Biomass} = A_A \times \text{DBH}^B$) were used to calculate the yearly biomass increment in different components of saplings and trees. Biomass increment in selected saplings and trees was not significantly (t-test, $p > 0.05$) different in two consecutive years. The yearly average biomass increment in saplings and trees was 0.58 ± 0.01 and 16.51 ± 0.63 t/ha, respectively (Table 4.7).

4.4 Discussion

Biomass studies of mangroves at different places in the world are shown in Figure 4.1. The most studied species are *Avicennia marina*, *Aegiceras corniculatum*, *A. germinans*, *B. gymnorhiza*, *Ceriops tagal*, *Kandelia candel*, *R. apiculata* and *R. mucronata*. In the present study, *B. parviflora* showed comparatively higher above-ground biomass than mixed mangroves (*R. apiculata*, *R. mucronata*, *B. gymnorhiza*, *B. parviflora*, *C. tagal*, *Xylocarpus granatum*) in Pulau Langkawi, Malaysia (Norhayati and Latiff, 2001), *C. tagal* in Satun, Thailand (Komiyama *et al.*, 2000), *A. corniculatum* and *K. candel* in Shenzhen, South China (Li, 1997), *B. gymnorhiza* and *A. marina* in Mgeni mangrove forest, South Africa (Steinke *et al.*, 1995), *A. corniculatum* and *K. candel* in Shenzhen, China (Tam *et al.*, 1995b), *R. mucronata* and *B. gymnorhiza* in Japan (Suzuki and Tagawa, 1983) and *A. marina* in Victoria, Australia (Clough and Attiwill, 1975). The different biomass values at different mangroves may be the result of variation in their forest structure (Table 4.8).

Stand age may be one of the reasons for observing variation in biomass of mangrove species at different places. Different age *R. apiculata* stands in Matang mangrove showed wide differences in their above-ground biomass and the biomass of 5, 10, 15 and 25 years old stands were 16, 180, 200 and 300 t/ha, respectively (Ong *et al.*, 1985a). Apart from the forest structure, geographical location appears as an important

determinant of mangrove forest biomass. A significant negative correlation ($r=-0.65$, $p<0.05$) was observed when the available published above-ground biomass values of mangroves (Table 4.8) were plotted against the latitude (Figure 4.2). This relationship explains that above-ground biomass of mangroves is highest at the tropical region and decrease towards the subtropical region. In general, species diversity, tree height, density and total biomass were found to increase with the decreasing latitude (Saenger and Snedaker, 1993; Tam *et al.*, 1995b).

According to Kozlowski *et al.* (1991), the proportion of biomass in different components of plants is important for understanding the photosynthate allocation for the growth of roots, stems, branches and leaves. *Bruguiera parviflora* showed comparatively higher percentage (18.25%) of below-ground biomass in seedlings and saplings (15.52%) compared to trees (11.18%) (Table 4.6). Similarly, Tomlinson (1986) reported that higher proportions of root development usually were observed during the early stages (seedlings and saplings) of mangrove plant growth to facilitate anchorages against the tidal inundation and current. A higher biomass proportion in stems and leaves was observed with the lower DBH classes of trees and their proportions decreased with the increasing DBH (Table 4.6). Irrespectively, *R. apiculata* and *R. stylosa* in the north-eastern Australia showed higher proportion of biomass in leaves and stems in lower DBH classes (Clough, 1992). In this study, *B. parviflora* trees showed comparatively higher percentage of above-ground biomass and relatively lower percentage of below-ground biomass than *A. corniculatum*, *K. candel* and *A. marina* in Shenzhen, China (Tam *et al.*, 1995b), *R. apiculata* in Matang, Malaysia (Gong and Ong, 1990) and *Rhizophora* sp. and *Bruguiera* sp. in Ranong, Thailand (Tamai *et al.*, 1986) (Table 4.9). However, the ratio of above and below-ground biomass was found to vary from site to site and a positive correlation ($r=0.48$) was observed when the available published below-ground biomass values (Table 4.8) were plotted against the latitude (Figure 4.3). This relationship explains that the balance of above and below-ground biomass shifts progressively to an increasing allocation of below-ground biomass with the increasing latitude. It has been reported that the standing biomass and their proportion in the above and below-ground components of mangrove plants was not only affected by the geographical location and microclimates but also related to the species composition, community structure, age and species-specific architecture (Lugo and Snedakar, 1974; Woodroffe, 1985; Steinke *et al.*, 1995; Tam *et al.*, 1995b) and the methods of roots biomass estimation (Turner *et al.*, 1995; Gong and Ong, 1990; Komiyama *et al.*, 1987). Four different architectures of mangrove plants are found such as Attim's model (*Rhizophora* and *Lumnitzera racemosa*), Rauh's model (*Xylocarpus* and *Heritiera*), Pettit's model (*Avicennia*, *Sonneratia* and *Lumnitzera littorea*) and Aubreville's model for large flowered species of *Bruguiera* (*B. gymnorrhiza*) (Tomlinson, 1986). Different mangrove species at different stages of development (seedlings, saplings and trees) usually varied in their branch complex (Tomlinson, 1986). So, seedlings, saplings and trees of the same species may vary in the pattern of biomass allocation in different plant components.

Bruguiera parviflora in this mangrove forest showed comparatively higher annual biomass increment than *A. germinans* in Campeche, Mexico (Day *et al.*, 1996), *R. mucronata* in Dutch bay, Kala Oya and Erumathivu, Sri Lanka (Amarasinghe and Balasubramaniam, 1992a) and Mixed mangroves in Pulau Kecil, Matang Mangrove, Malaysia (Putz and Chan, 1986) (Table 4.8). It has been reported that annual biomass increment is highly variable, both locally and regionally (Clough, 1992). Moreover, annual biomass increment of a species in a particular site is not uniform, initial growth is very rapid and then gradually declines (Hutchings and Saenger, 1987). Similarly, ten years old *R. apiculata* stands in Matang, Malaysia showed highest mean annual biomass increment (18 t/ha/yr) while, the mean annual biomass increment for 15 and 25 years old stand were 13 and 12 t/ha/yr, respectively (Ong *et al.*, 1985a). Mangroves growth may be related to the tidal flushing, salinity, nutrient status and other soil characteristics (Clough and Attiwill, 1982). It has been well documented that the rate of annual biomass increment may be close to zero in mangrove communities growing on harsh climatic condition or hypersaline saltpans, but mangroves growing in areas of high rainfall and low to moderate salinity in the wet humid tropics (Indo-Pacific area) showed higher rate of above-ground annual biomass increment up to 45 t/ha/yr (Clough, 1992).

The Log₁₀ transformation ($\text{Log}_{10} \text{Biomass} = A + B \text{Log}_{10} \text{DBH}$) and the power curve ($\text{Biomass} = A_A \times \text{DBH}^B$) were found to accept for good description of the relationship between above-ground biomass and DBH in mangroves (Ong *et al.*, 1985a; Putz and Chan, 1986; Clough and Scott, 1989; Clough *et al.*, 1997) and other terrestrial forest (Whittaker and Marks, 1975; Ketterings *et al.*, 2001). The derived biomass relationships ($\text{Biomass} = A_A \times \text{DBH}^B$) for different components of *B. parviflora* saplings and trees were compared with the biomass studies of Ong *et al.* (1985a) and Clough and Scott (1989). Both of the previous studies did not distinguish *B. parviflora* saplings from the trees but in this comparison, DBH ranges from 1 to <4 cm and 4 to 16 cm are considered as saplings and trees, respectively. Present biomass relationships and their comparisons with the study of Ong *et al.* (1985a) and Clough and Scott (1989) are presented in Figures 4.4 to 4.18.

In the present study, saplings of 1.5 and 2.5 cm DBH contained about 4 to 13% and 5 to 27% lower total above-ground biomass than the study of Ong *et al.* (1985a) and Clough and Scott (1989), respectively, while saplings of 3.5 cm DBH showed about 2 and 7% higher total above-ground biomass compared to the study of Ong *et al.* (1985a) and Clough and Scott (1989), respectively (Figure 4.4). Present study estimated about 8 to 13% higher biomass in saplings stems than the study of Ong *et al.* (1985a) at the DBH 2.5 to 3.5 cm (Figure 4.5). But, present study showed about 12 to 45% lower stem biomass compared to the study of Clough and Scott (1989) up to 2.5 cm DBH and remained about 6% higher at 3.5 cm DBH (Figure 4.5). Saplings of this study possess about 39 to 48% higher biomass of branches than the study of Clough and Scott (1989) and about 51 to 122% lower leaf biomass than the study of Ong *et al.* (1985a) (Figures 4.7 and 4.8).

Trees of this study showed about 11 to 17% and 37 to 43% higher total above-ground biomass compared to the study of Ong *et al.* (1985a) and Clough and Scott (1989), respectively (Figure 4.11). Stem contained similar biomass up to 9 cm DBH and remained about 16% lower at 15 cm DBH with the study of Ong *et al.* (1985a), while present study estimated about 18-24% higher biomass than the study of Clough and Scott (1989) (Figure 4.12). Trees of this study showed about 78 to 83% and 71 to 92% higher biomass of branches and leaves, respectively compared to the study of Clough and Scott (1989) (Figures 4.14 and 4.15) and about 3 to 58% higher leaf biomass than Ong *et al.* (1985a) (Figure 4.15). The variations in the biomass of different components of *B. parviflora* saplings and trees among the present study and the study of Ong *et al.* (1985a) and Clough and Scott (1989) are related to the differences of coefficients in allometric equations of these study (Tables 4.3 and 4.10). According to Clough (1992), the allometric coefficients values of the same species vary at different localities and depend on site dependent factors such as tree density, species composition (monoculture and mixed culture) and management practices.

Table 4.1: Fresh weight to oven-dry weight conversion ratios of different components of seedlings, saplings and trees. Means with similar alphabet in the same row are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Conversion ratios		
	Seedlings	Saplings	Trees
Leaves	0.26±0.004 ^C	0.29±0.002 ^B	0.34±0.001 ^A
Buds		0.30±0.002 ^A	0.30±0.002 ^A
Flowers			0.33±0.001
Smaller branches		0.43±0.004 ^B	0.50±0.004 ^A
Bigger branches			0.61±0.002
Stems	0.38±0.007 ^B	0.65±0.001 ^{A*}	0.65±0.008 ^{A*}
Bark		0.55±0.005 ^A	0.47±0.005 ^B
Bigger roots		0.27±0.003 ^A	0.27±0.002 ^A
Smaller roots	0.33±0.004 ^A	0.31±0.002 ^B	0.31±0.002 ^B

* Stems without bark; ± SE

Table 4.2: Regression constants (A and B) and co-efficient (R^2) values of different components of saplings and trees based on calculation using the equation

$$\text{Biomass} = A + B \cdot \text{DBH}$$

Plant components	A (Intercept)	B (Slope)	R^2 (Regression coefficients)	F (Calculated)
Saplings				
	Biomass = A + B. DBH			
Total above ground	- 1824.40	1523.90	0.95	161.83
Roots	- 171.18	185.76	0.93	113.38
Stems without bark	-1266.20	1052.60	0.96	177.04
Bark	-174.41	144.99	0.96	177.03
Branches	- 268.64	220.87	0.89	66.99
Leaves	- 143.35	127.96	0.89	66.27
Buds	- 8.1042	7.632	0.96	192.85
Trees				
	Biomass = A + B. DBH			
Total above ground	- 71.428	16.011	0.96	109.44
Roots	- 12.204	2.4717	0.91	43.26
Stems without bark	-37.531	8.7115	0.97	129.37
Bark	-5.1116	1.1874	0.97	129.61
Branches	- 22.967	4.7601	0.92	52.74
Leaves	- 5.0373	1.1816	0.97	125.90
Buds	- 0.2636	0.0603	0.97	121.27
Flowers	- 0.2796	0.0563	0.91	41.57

DBH in centimetre, and Biomass in gram for saplings and kilogram for trees

Table 4.3: Regression constants (A and B) and co-efficient (R^2) values of different components of saplings and trees based on calculation using the equation

Log ₁₀ Biomass = A + B Log ₁₀ DBH				
Plant components	A (Intercept)	B (Slope)	R ² (Regression coefficients)	F (Calculated)
Saplings				
Log ₁₀ Biomass = A + B Log ₁₀ DBH				
Above ground biomass	2.0554	2.7877	0.99	635.59
Roots	1.6467	1.9002	0.89	71.27
Stems without bark	1.8353	2.9198	0.99	554.48
Bark	0.9744	2.9198	0.99	554.49
Branches	1.2468	2.6413	0.92	93.18
Leaves	1.2480	2.2493	0.98	365.20
Buds	0.0819	2.1884	0.96	211.92
Trees				
Log ₁₀ Biomass = A + B Log ₁₀ DBH				
Above ground biomass	-0.7045	2.5336	0.99	660.30
Roots	-1.9111	2.8437	0.99	492.39
Stems without bark	-0.8847	2.4701	0.99	350.64
Bark	-1.7456	2.4660	0.99	352.96
Branches	-1.4437	2.6906	0.99	1147.39
Leaves	-1.8391	2.5486	0.98	186.56
Buds	-3.0774	2.4866	0.98	243.59
Flowers	-3.5143	2.7974	0.98	154.62

DBH in centimetre, and Biomass in gram for saplings and kilogram for trees

Table 4.4: Diameter classes and density of *B. parviflora* saplings and trees

Diameter class (cm)	Nos. of trees in 20 sample plots	Trees or saplings/ha	Percentage contribution of DBH classes in the sample plots
Saplings			
1-2	47	235±18	41.59±4.34
2-3	38	190±19	33.63±3.33
3-<4	28	140±8	24.78±2.34
Trees			
4-6	56	280±20	13.79±0.44
6-8	71	355±19	17.49±0.88
8-10	92	460±27	22.66±2.13
10-12	102	510±12	25.12±1.98
12-14	60	300±12	14.78±1.23
14-16	25	125±34	6.16±0.56

Table 4.5: Biomass of different components of seedlings, saplings and trees of *B. parviflora*

Diameter classes (cm)	Total above and below ground biomass (t/ha)	Total above ground biomass (t/ha)	Roots biomass (t/ha)	Stems with bark (t/ha)	Stems without bark (t/ha)	Bark (t/ha)	Branches (t/ha)	Leaves (t/ha)	Buds (kg/ha)	Flowers (kg/ha)
Seedlings	1.37	1.12	0.25	0.72				0.40		
Saplings										
1-2	0.10	0.08	0.02	0.06	0.05	0.01	0.01	0.01	0.69	
2-3	0.33	0.28	0.05	0.21	0.19	0.02	0.04	0.03	1.70	
3-<4	0.60	0.53	0.07	0.42	0.37	0.05	0.07	0.04	2.62	
Total	1.03	0.89	0.14	0.69	0.61	0.08	0.12	0.08	5.01	
Trees										
4-6	3.58	3.25	0.33	2.21	1.95	0.26	0.77	0.25	12.25	7.58
6-8	10.73	9.63	1.10	6.44	5.67	0.77	2.40	0.73	35.87	24.63
8-10	26.52	23.59	2.93	15.52	13.65	1.87	6.12	1.80	86.83	64.46
10-12	49.23	43.49	5.74	28.24	24.84	3.40	11.64	3.33	158.56	125.28
12-14	44.51	39.08	5.43	25.09	22.07	3.02	10.73	3.00	141.30	117.59
14-16	26.82	23.42	3.40	14.89	13.10	1.79	6.57	1.80	84.04	73.12
Total	161.39	142.46	18.93	92.39	81.28	11.11	38.23	10.91	518.85	412.66
Grand total	163.79	144.47	19.32	93.80		11.19	38.35	11.39	523.86	412.66

Table 4.6: Biomass proportion in different components of seedlings, saplings and trees of *B. parviflora*

Plant stages	Diameter classes (cm)	Total above ground components (%)	Roots (%)	Stems with bark (%)	Branches (%)	Leaves (%)	Buds (%)	Flowers (%)
Seedlings								
Mean ± SE		81.75±1.95	18.25±1.94	52.55±2.40		29.20±2.04		
Saplings	1-2	80.14	19.86	59.59	9.93	9.93	0.69	
	2-3	84.93	15.07	63.32	12.06	9.04	0.51	
	3-<4	88.38	11.62	69.69	11.62	6.64	0.43	
Mean ± SE		84.48±2.39	15.52±2.39	64.20±2.95	11.20±0.65	8.54±0.98	0.54±0.08	
Trees	4-6	90.78	9.22	61.74	21.51	6.98	0.34	0.21
	6-8	89.75	10.25	60.02	22.37	6.80	0.33	0.23
	8-10	88.95	11.05	58.51	23.08	6.79	0.33	0.24
	10-12	88.34	11.66	57.36	23.65	6.76	0.32	0.25
	12-14	87.80	12.20	56.37	24.11	6.74	0.32	0.26
	14-16	87.32	12.68	55.53	24.50	6.71	0.31	0.27
Mean ± SE		88.82±0.52	11.18±0.52	58.26±0.95	23.20±0.46	6.80±0.04	0.33±0.00	0.24±0.01

Table 4.7: Yearly average biomass increment in different components of saplings and trees

	Plant components						Total (t/ha)
	Stems with bark (t/ha)	Stems without bark (t/ha)	Bark (t/ha)	Branches (t/ha)	Leaves (t/ha)	Buds (t/ha)	Roots (t/ha)
Saplings							
1 st year	0.42	0.37	0.05	0.06	0.04		0.05
2 nd year	0.44	0.39	0.05	0.06	0.03		0.05
Average	0.43±0.01	0.38±0.01	0.05±0.00	0.06±0.00	0.04±0.01		0.05±0.00
Trees							
1 st year	8.76	7.71	1.05	3.94	1.07	0.05	2.06
2 nd year	9.39	8.26	1.13	4.28	1.15	0.05	2.26
Average	9.08±0.32	7.99±0.27	1.09±0.04	4.11±0.17	1.11±0.04	0.05±0.00	2.16±0.10

Table 4.8: Comparison of standing biomass and yearly biomass increments in above-ground components of different mangrove species at different places

Location	Species	Stand characteristics	Above-ground biomass (t/ha)	Below-ground biomass (t/ha)	Biomass increment (t/ha/yr)	Sources
Victoria, Australia (38°20'S, 145°12'E)	<i>Avicennia marina</i>	Mean height 3.50 m	86.00	146.00	NM	Clough and Attiwill (1975)
Sydney, Australia (33°50'S, 151°09'E)	<i>A. marina</i>	Mean height 7.50 m	128.30	NM	NM	Briggs (1977)
Thailand	<i>Rhizophora apiculata</i>	Mean height 11.00 m	159.00	NM	NM	Christensen (1978)
Japan	<i>R. mucronata</i>	Mean height 5.50 m	108.10	NM	NM	Suzuki and Tagawa (1983)
	<i>Bruguiera gymnorhiza</i>	Mean height 5.50 m	97.60	NM		
	<i>R. apiculata</i> (Planted)	Stand age 5 to 25 years	16-300	NM	3.00-18.00	Ong <i>et al.</i> (1985a)
Pulau Kecil, Matang Mangrove, Malaysia (4°48'N, 100°35'E)	<i>R. apiculata</i>	DBH ranged from 10 to 60 cm, and density 294-675 stem/ha	270-460	NM	6.70	Putz and Chan (1986)
Matang Mangrove, Malaysia (4°50'N, 100°36'E)	<i>R. apiculata</i>	DBH ranged from 1.11 to 24.51 cm	185.30	17.20	NM	Gong and Ong (1990)
Dutch bay, Kala Oya and Erumathivu, Sri Lanka (8°15' N, 79°50'E)	<i>R. mucronata</i>	Mean DBH 8.12-26.40 cm, mean height 3.90-7.20 m, density 800-2200 stem/ha	71-240	NM	2.87-6.19	Amarasinghe and Balasubramaniam (1992a)

NM: Not measured

Table 4.8 (Cont'd)

Location	Species	Stand characteristics	Above-ground biomass (t/ha)	Below-ground biomass (t/ha)	Biomass increment (t/ha/yr)	Sources
Tritih, Java, Indonesia (7°8'S, 108°44'E)	<i>R. mucronata</i> (Planted)	DBH ranged from 2.26 to 7.95 cm, mean height 5.20-7.10 m, density 3200-3400, 7 years old stand	93.73	NM	13.75-14.60	Sukardjo and Yamada (1992)
Shenzhen, China (22°31'N, 114°05'E)	<i>Aegiceras corniculatum</i>	Mean DBH 19.56 cm, mean height 3.85 m and density 794 stem/ha	68.07	27.46	NM	Tam <i>et al.</i> (1995b)
	<i>Kandelia candel</i>	Mean DBH 7.76 cm, mean height 4.20 m and density 117 stem/ha	8.49	1.27	NM	
Mgeni, South Africa (29°48'S, 31°03'E)	<i>B. gymnorhiza</i>	Mean DBH 2.31 cm, mean height 2.66 m and density 42500 stems/ha	74.67	9.69	NM	Steinke <i>et al.</i> (1995)
	<i>A. marina</i>	Mean DBH 4.19 cm, mean height 4.56 m and density 4500 stem/ha	94.49	9.69	NM	
Campeche, Mexico (18°40'N, 91°40'W)	<i>A. germinans</i>	Mean DBH 4.90-7.70 cm, mean height 4-6 m, density 1590-1720 stem/ha	17.40-73.00	NM	0.5-2.61	Day <i>et al.</i> (1996)
Shenzhen, South China (22°32'N, 114°03'E)	<i>A. corniculatum</i> and <i>K. candel</i>	Mean height 4.50 m	108.26	NM	15.92	Li (1997)
Satun, Thailand (6°40'N, 100°01'E)	<i>Ceriops tagal</i>	Mean DBH 4.20 cm, mean height 5.20 m and density 10010 stem/ha	92.24	87.51	NM	Komiyama <i>et al.</i> (2000)

NM: Not measured

Table 4.8 (Cont'd)

Location	Species	Stand characteristics	Above-ground biomass (t/ha)	Below-ground biomass (t/ha)	Biomass increment (t/ha/yr)	Sources
Pulau Langkawi, Malaysia (6°22'N, 99°48'E)	<i>R. apiculata</i> <i>R. mucronata</i> <i>B. gymnorhiza</i> <i>B. parviflora</i> <i>C. tagal</i> <i>Xylocarpus granatum</i>	Mean DBH 12.15 cm, mean height 13.09 m, density 849 stem/ha	115.56	NM	NM	Norhayati and Latiff (2001)
Kuala Selangor, Malaysia (3°19'N, 101°14'E)	<i>B. parviflora</i>	Mean DBH, mean height, and density of saplings and trees were 2.37 cm, 3.92 m and 565 saplings/ha; 9.84 cm, 10.27 m and 2030 trees/ha, respectively	144.47	19.32	13.67	This study

NM: Not measured

Table 4.9: Comparison of biomass proportion in different components of mangrove species at different places

Location	Species	Total above ground components (%)	Root (%)	Stem (%)	Branch (%)	Leaves (%)	Reproductive components (%)	Sources
Ranong, Thailand 9°50'N, 98°35'E	<i>Rhizophora</i> sp.	69.36	30.64	52.83	14.51	1.85	0.17	Tamai <i>et al.</i> (1986)
	<i>Bruguiera</i> sp.	82.41	17.58	62.83	15.46	4.00	0.12	
Matang, Malaysia (4°50'N, 100°36'E)	<i>R. apiculata</i>	75.50	24.50	55.00	12.00	8.50		Gong and Ong (1990)
Shenzhen, China (22°31'N, 114°05'E)	<i>Aegiceras corniculatum</i>	71.26	28.74	35.95	28.73	5.52		Tam <i>et al.</i> (1995b)
	<i>Kandelia candel</i>	63.05	36.95	28.77	26.59	7.69		
	<i>Avicennia marina</i>	86.99	13.01	29.82	50.51	6.35		
Mgeni, South Africa (29°48'S, 31°03'E)	<i>B. gymnorhiza</i>			86.00		13.18	0.82	Steinke <i>et al.</i> (1995)
	<i>A. marina</i>			94.68		5.32		
Satun, Thailand (6°40'N, 100°01'E)	<i>Ceriops tagal</i>	50.20	49.80	29.68	13.13	7.39		Komiyama <i>et al.</i> (2000)
Pulau Langkawi, Malaysia (6°22'N, 99°48'E)	<i>B. parviflora</i>			90.00	9.10	0.90		Norhayati and Latiff (2001)
Kuala Selangor, Malaysia (3°19'N, 101°14'E)	<i>B. parviflora</i>	81.75	18.25	52.55		29.20		This study
	Seedlings	84.48	15.52	64.20	11.20	8.54	0.54	
	Saplings							
	Tree	88.82	11.18	58.26	23.20	6.80	0.57	

Table 4.10: Comparison of regression constants (A and B) and co-efficient (R^2) values of allometric relationships between diameter at breast height (DBH, cm) or girth at breast height (GBH, cm) and oven-dry weight (kg) of various components of *B. parviflora* trees

Plant components	Equation	A	B	R^2	Source and location
Total above ground biomass	Biomass = $A_A \times GBH^B$	-2.1674	2.6236	0.98	Matang mangrove, Malaysia Ong <i>et al.</i> (1985a)
Stem		-2.4559	2.7486	0.98	
Leaf		-2.2146	1.7908	0.87	
Total above ground biomass	Biomass = $A_A \times DBH^B$	-0.7749	2.4167	0.99	North-eastern Queensland, Australia Clough and Scott (1989)
Stem		-0.8661	2.4037	0.99	
Branch		-1.9403	2.4639	0.89	
Leaf		-1.5716	1.4070	0.62	

* A_A = antilog of A.

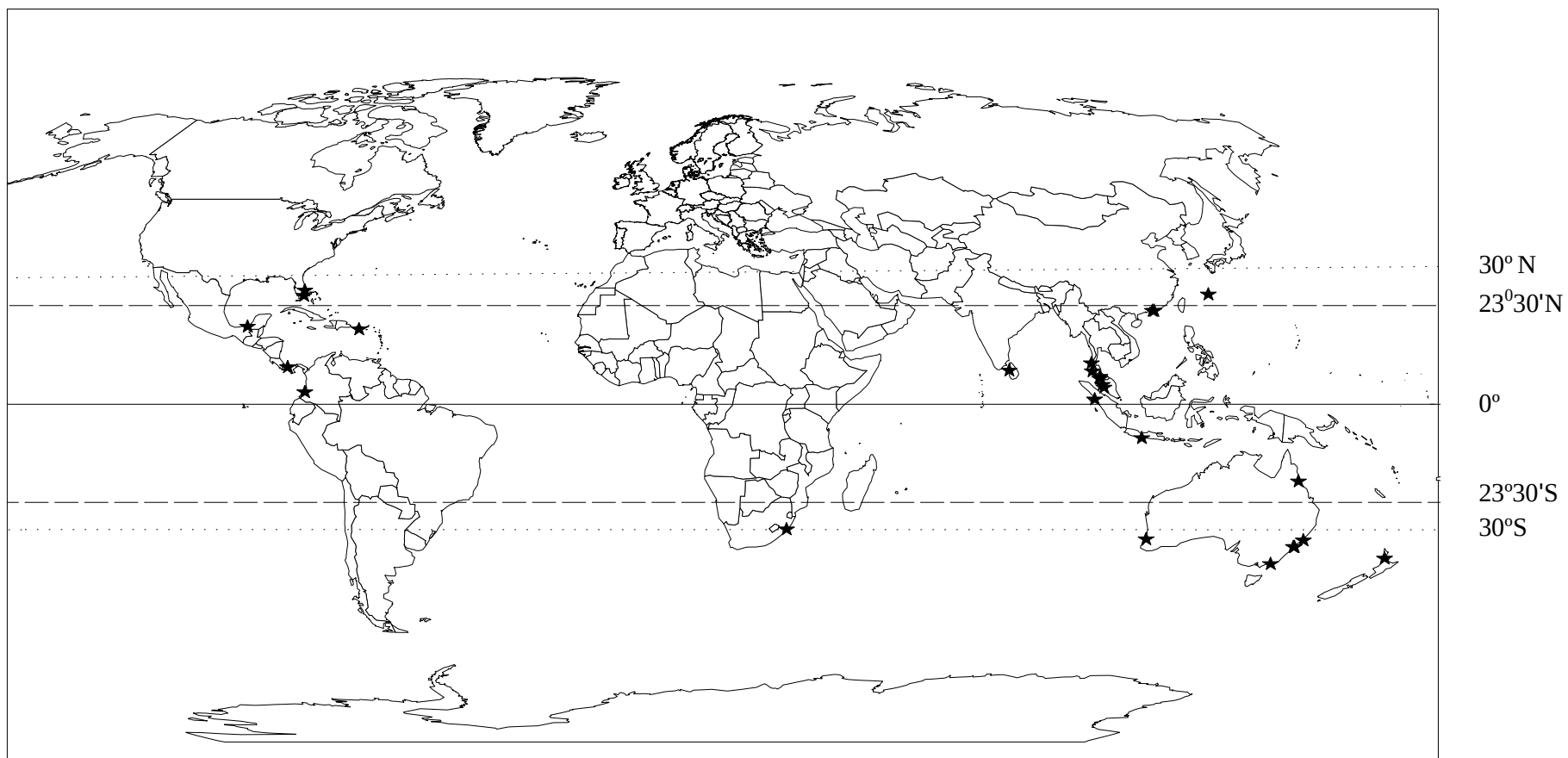


Figure 4.1 World map showing the biomass studies in mangroves (**)

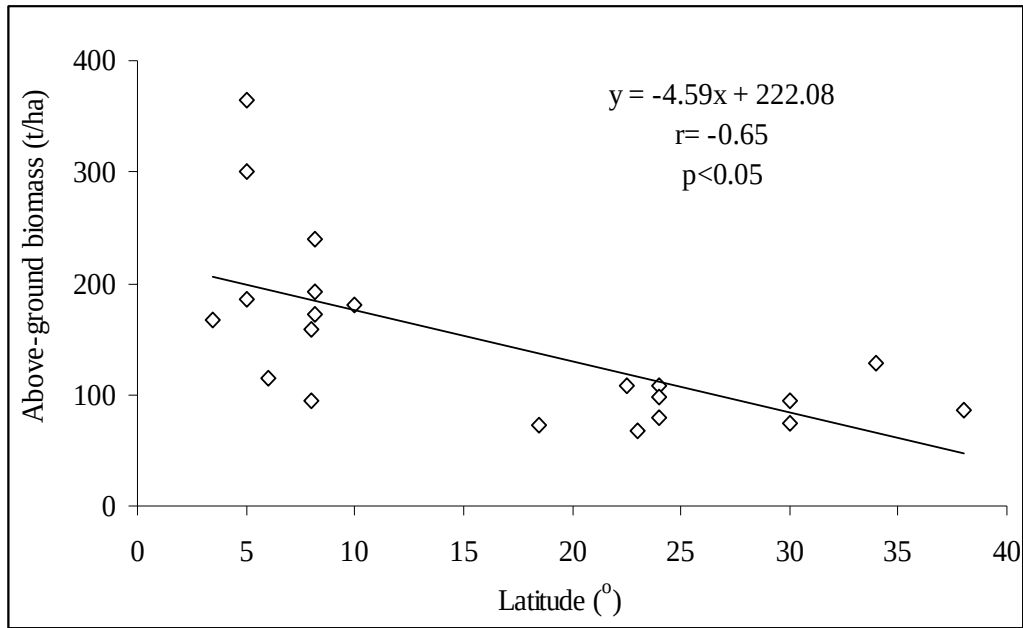


Figure 4.2: Relationship between above-ground biomass and latitude

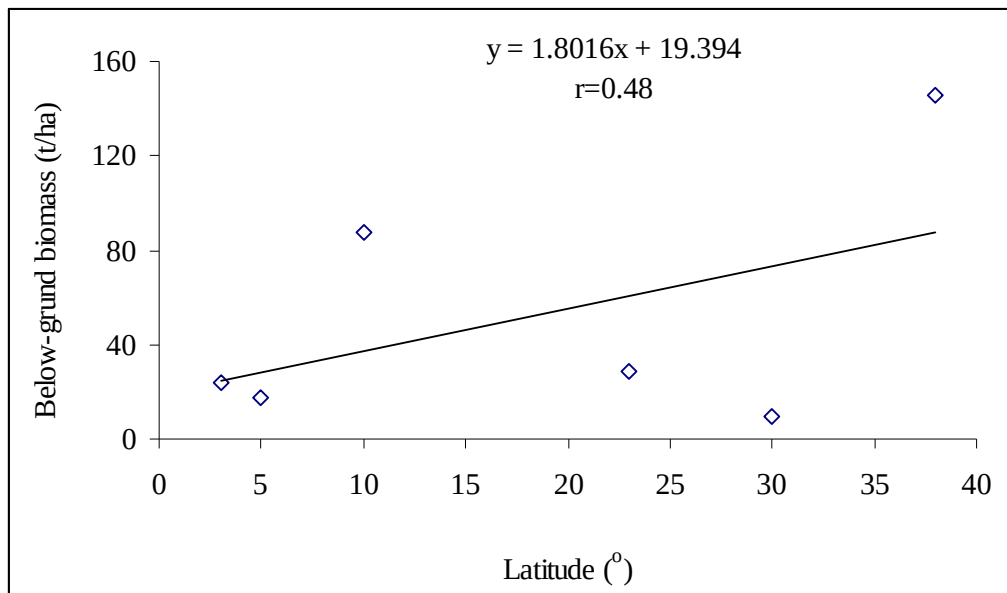


Figure 4.3: Relationship between below-ground biomass and latitude

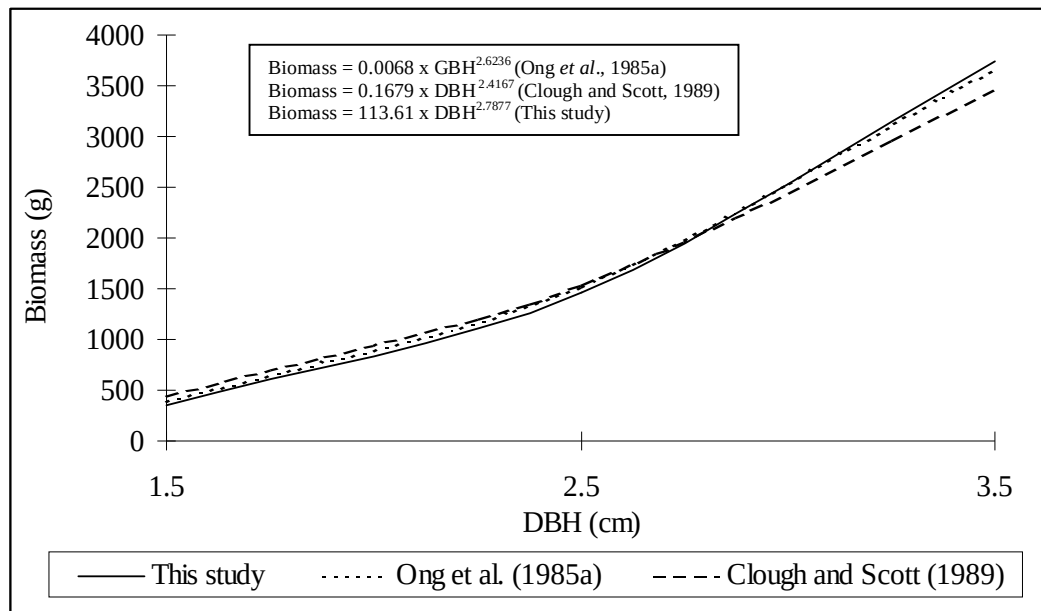


Figure 4.4: Total above-ground biomass of saplings

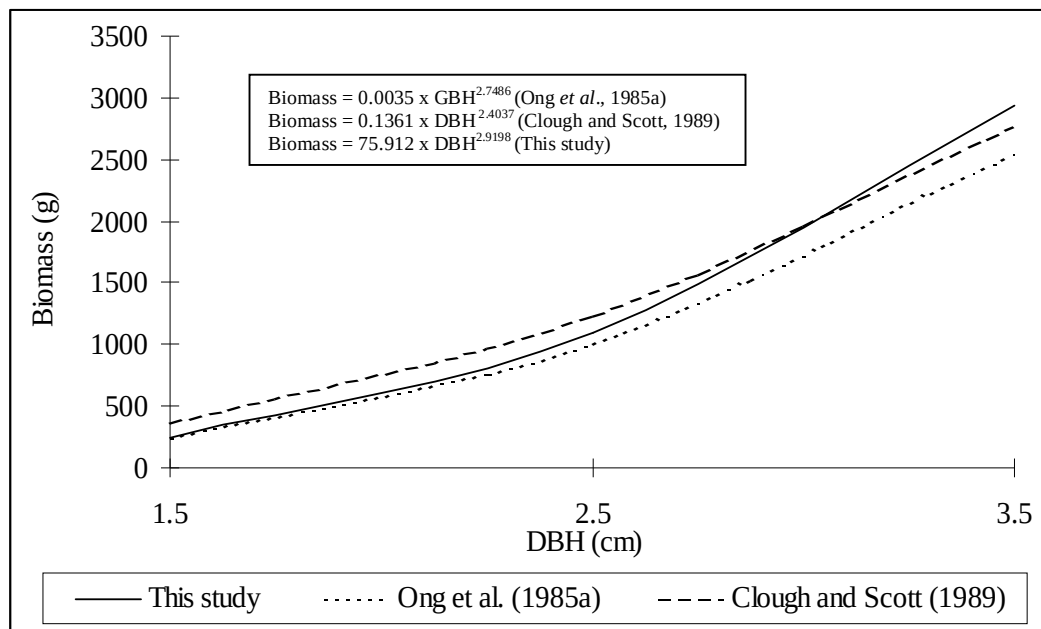


Figure 4.5: Biomass of saplings stems (with bark)

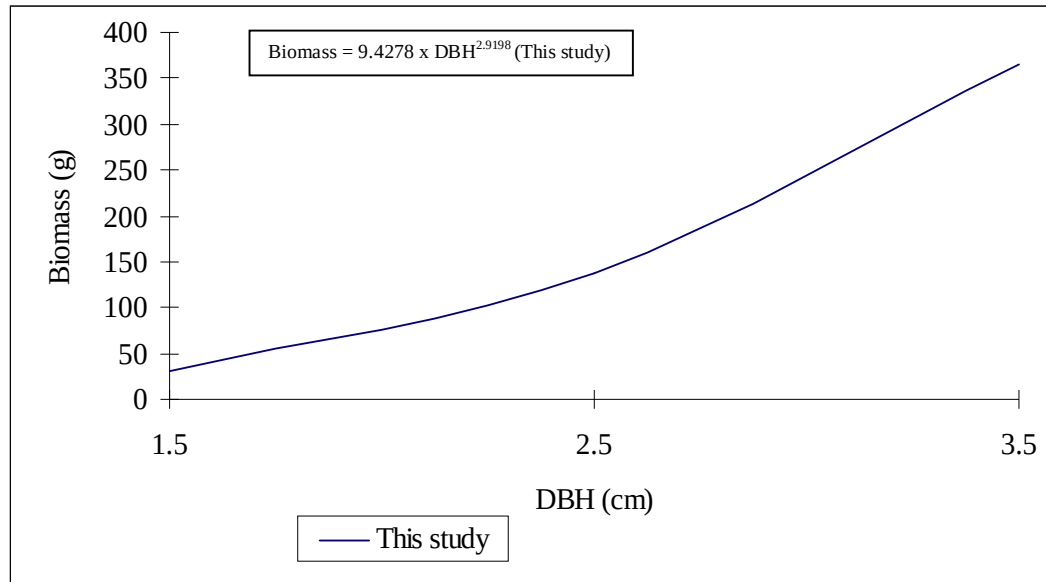


Figure 4.6: Biomass of sapling bark

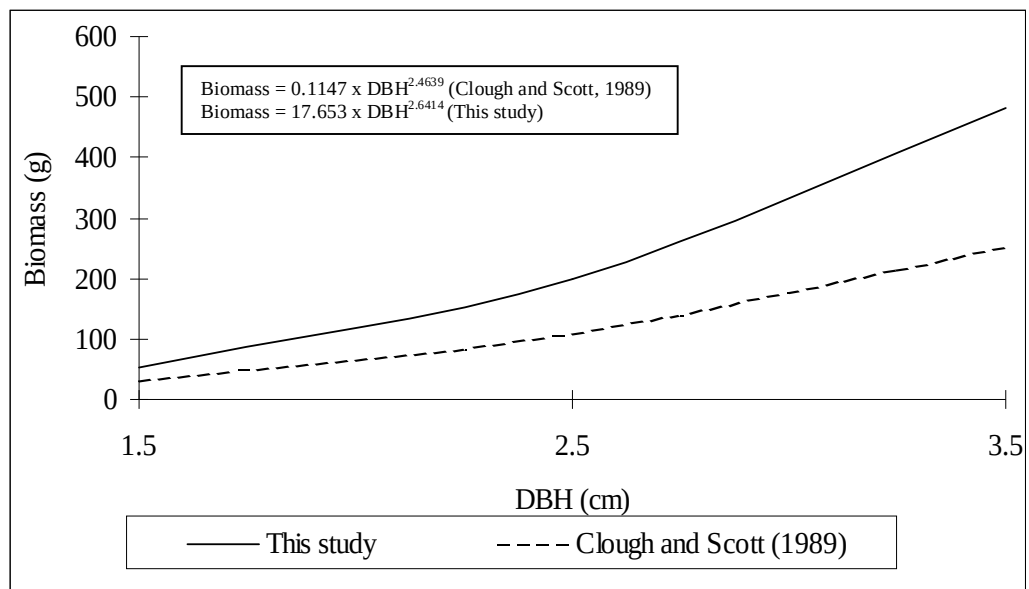


Figure 4.7: Biomass of saplings branches

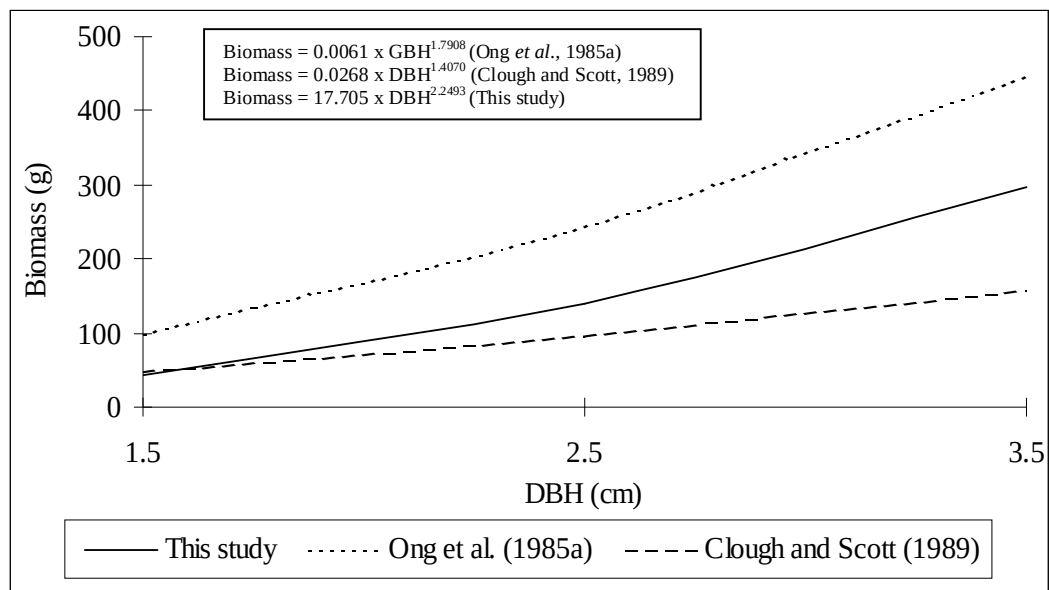


Figure 4.8: Biomass of saplings leaves

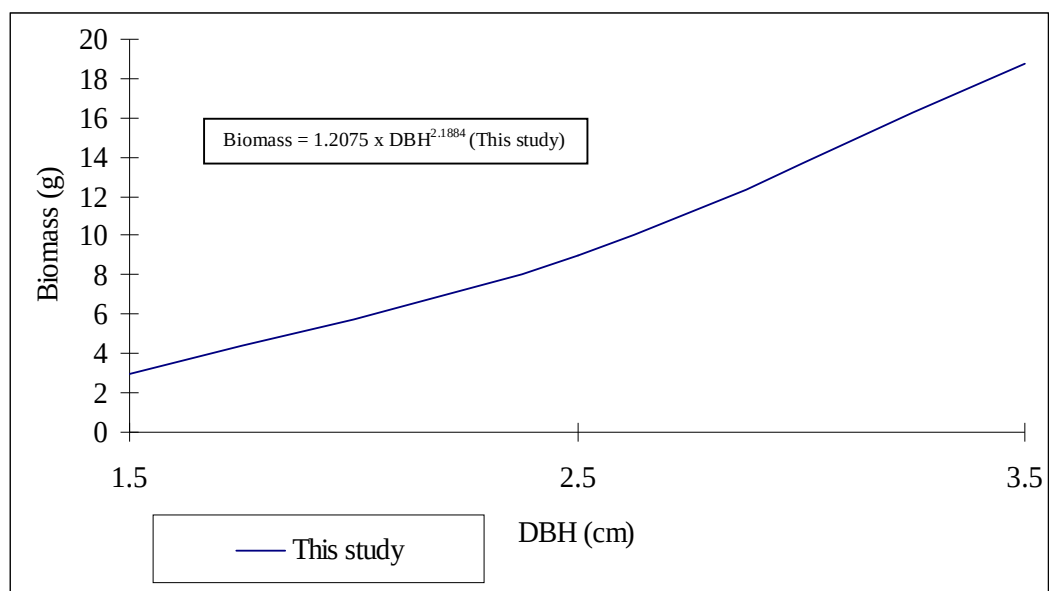


Figure 4.9: Biomass of saplings buds

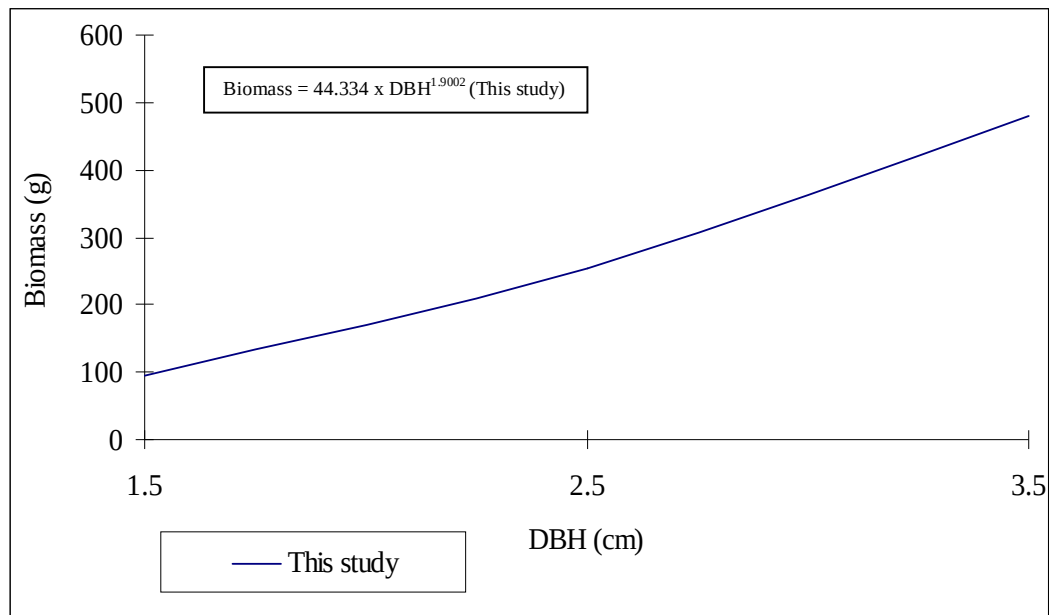


Figure 4.10: Biomass of saplings roots

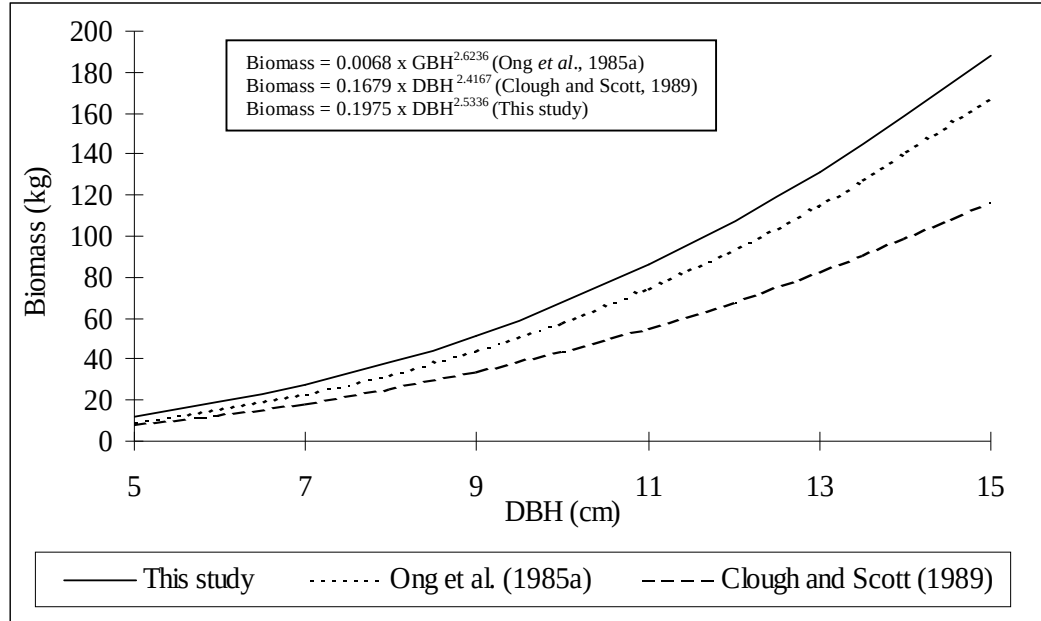


Figure 4.11: Total above-ground biomass of trees

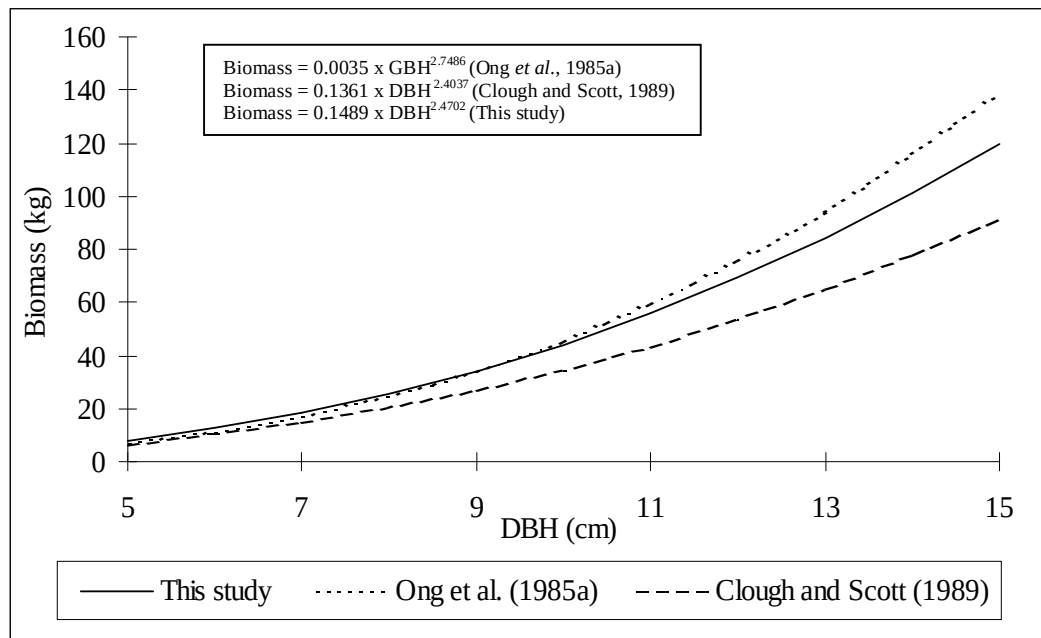


Figure 4.12: Biomass of trees stems (with bark)

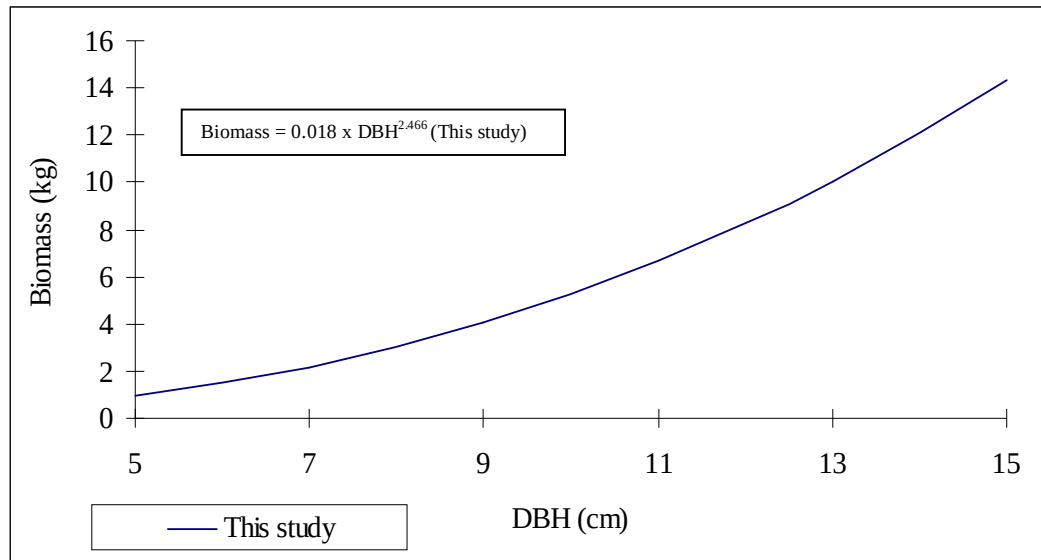


Figure 4.13: Biomass of tree bark

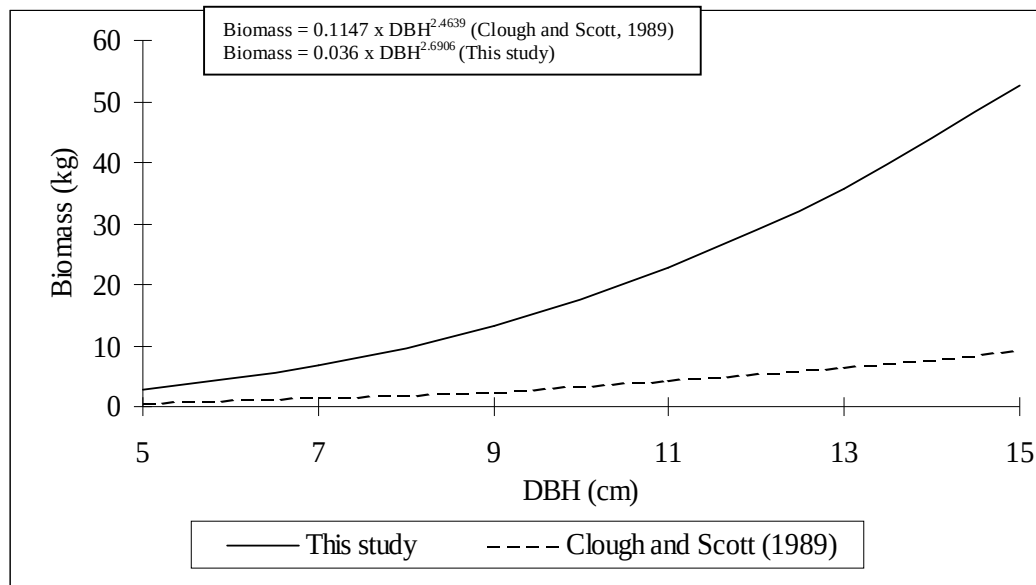


Figure 4.14: Biomass of trees branches

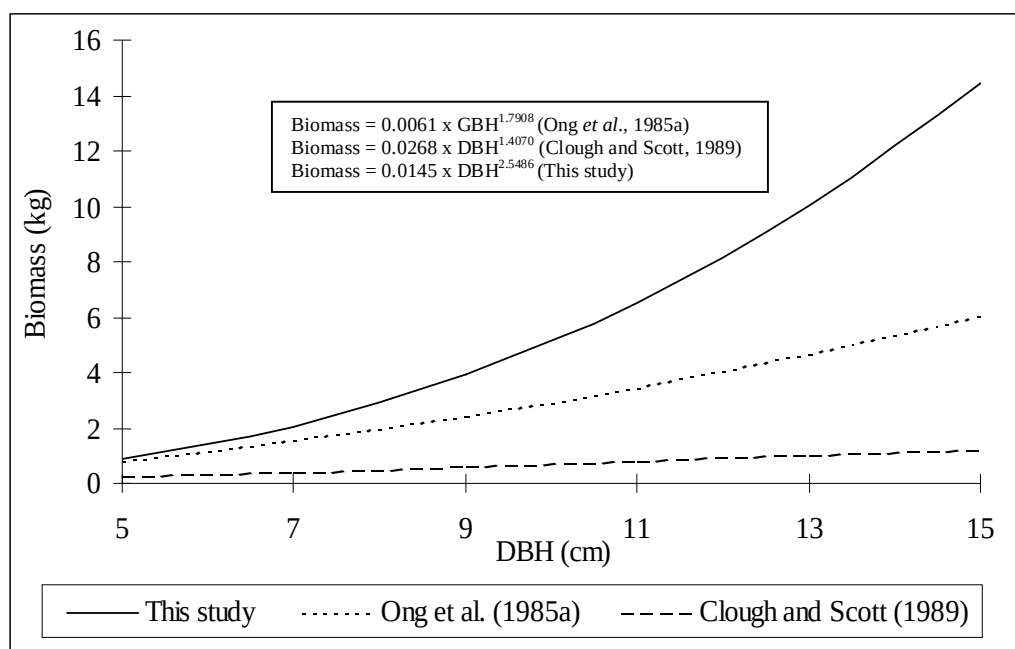


Figure 4.15: Biomass of trees leaves

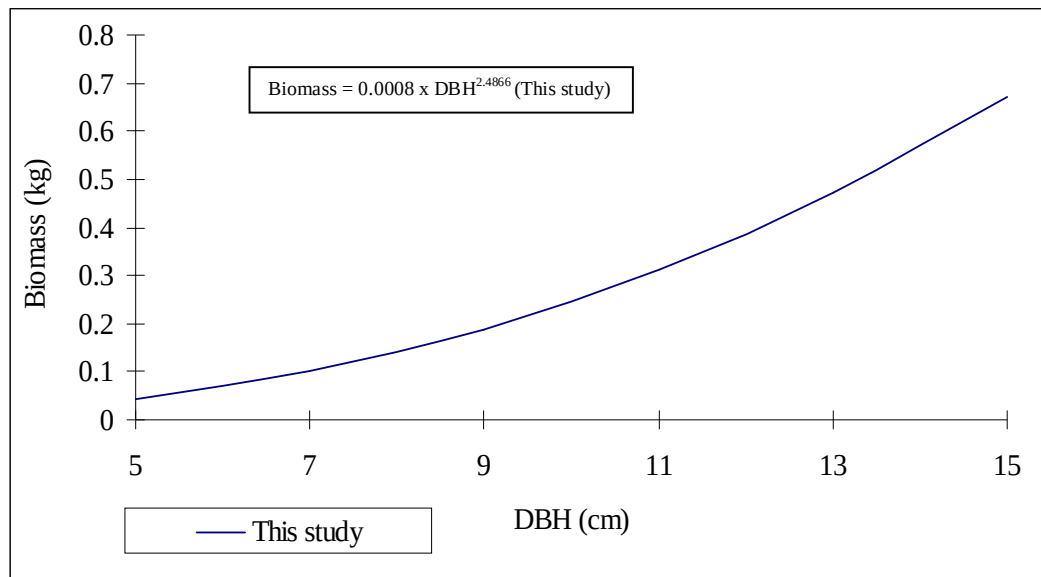


Figure 4.16: Biomass of trees buds

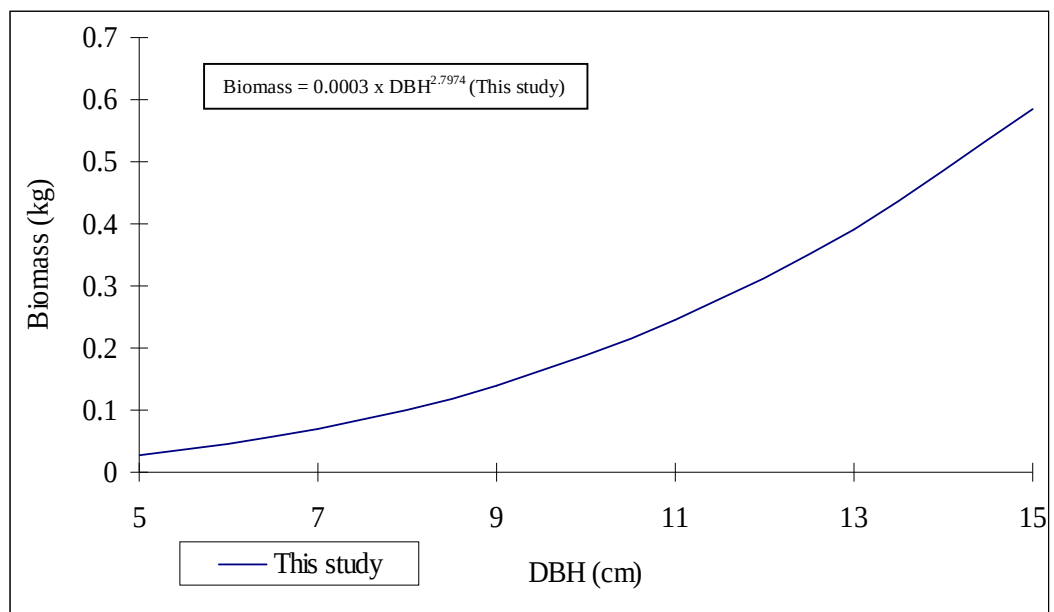


Figure 4.17: Biomass of trees flower

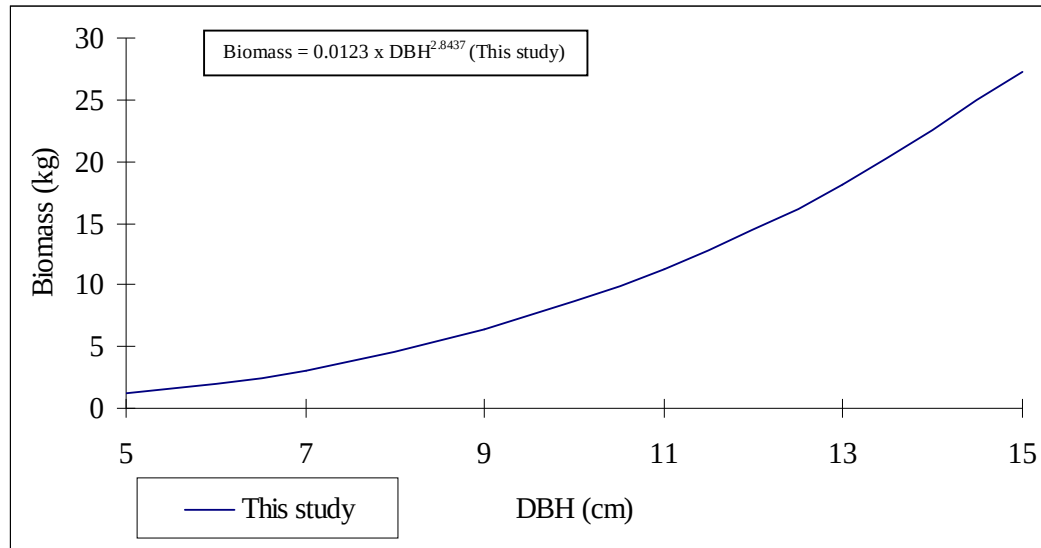


Figure 4.18: Biomass of trees roots

CHAPTER 5

LITTER PRODUCTION

5.1 Introduction

Litter production in mangrove ecosystems represents an essential component of organic matter production and decomposition cycle, which is the fundamental ecosystem process. Litter production is the function and indicator of primary productivity and important for within stand nutrient cycling and export of nutrients and organic detritus to the estuarine ecosystem (Boto and Bunt, 1981; Gong *et al.* 1984; Gong and Ong, 1990; Lu and Lin, 1990; Steink *et al.*, 1993ab; Lee, 1995; Ashton *et al.*, 1999). Similarly, Bunt *et al.* (1979) reported that litter production is about 30-60% of the total primary production and has significant importance on detritus based food webs in the coastal environment and coastal fisheries (Odum and Heald, 1975; Ong *et al.*, 1985a; Lee, 1995). The amount of organic matter export to the aquatic ecosystem from the mangroves depends on the litter decomposition rates, while decomposition rates depend on the degree and frequency of tidal inundation, climatic and edaphic factors and presence or absence of litter consuming fauna within the mangrove forest (Reice *et al.*, 1984; Valiela *et al.*, 1985; Twilley *et al.*, 1986; Robertson, 1988; Chale, 1993). In general, the litter production and litter breakdown rates not only vary with species but also vary geographically (Tam *et al.*, 1998; Ashton *et al.*, 1999).

5.1.1 Objectives

The objectives of this study were

1. To estimate the litter production and its various components under *Bruguiera parviflora* dominant stand.
2. To estimate the litter standing crop and its various components under *B. parviflora* dominant stand.
3. To study the *B. parviflora* leaf litter degradation in the studied mangrove forest.

5.2 Materials and Methods

5.2.1 Litter Production

Litter production study was conducted monthly for 20 months (December 2001 to July 2003). Litter trap was made of a square metal frame of 1 m x 1 m mouth area to which a conical nylon bag (0.50 m depth and 1 mm mesh) was attached. Eighteen litter traps were set randomly under the forest canopy by following the principles of Brown (1984). The traps were suspended under the tree canopy by nylon rope between trees at a height of 1.50 m above the ground level (beyond the reach of high tides). The trapped litter was collected at monthly interval and put into separate labelled airtight plastic bag and placed into ice chest and brought back to the laboratory for further processing. The collected litter from each trap was then put into separate labelled plastic bag and

brought back to the laboratory for processing. The trapped litter of individual catcher was sorted into leaves, small branches, bracts, flowers and propagules. The sorted litter was then oven dried at 80°C until constant weight for 5 days, weighted by using electric balance (nearest to 0.01 g) and recorded. Daily litter fall rate was calculated by dividing the respective monthly total litter production and their components with the collection days. Daily litter fall rate was compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p < 0.05$) by using SAS (6.12) statistical software and Non-metric Multi-dimensional Scaling (MDS) was performed by using Polymouth Routines in Multivariate Ecological Research (PRIMER) v5 software. The stepwise multiple linear regression ($Y = b_1X_1 + b_2X_2 + b_3X_3 + b_0$) analysis was performed among litter fall rate (total litter fall and leaf litter) and meteorological data (rainfall, temperature and relative humidity) by using SAS (6.12) statistical software (where, Y was the litter fall rate, X_1 , X_2 and X_3 , were rainfall, temperature and relative humidity, respectively, b_1 , b_2 , b_3 and b_0 were constant).

5.2.2 Litter Standing Crop

Monthly yield of litter standing crop was measured for 20 months (December 2001 to July 2003). One permanent plot of 1 m x 1 m was established nearby to the each litter trap on the forest floor and a marked flag was set at each corner of the permanent plot. A total of 18 permanent plots were established in the forest area and all the litter on the forest floor (L horizon) inside the plots were removed properly. Litter standing crop was collected at monthly interval from the previously established permanent plots. All the collected litters from the individual plot were then put into separate labelled plastic bag placed into ice chest and brought back to the laboratory for further processing. The collected litter from each plot was washed thoroughly to remove all the dirt and sediment and sorted into intact leaves, broken leaves, small branches, bracts, and propagules. The sorted litter was then oven dried at 80°C until constant weight for 5 days, weighted by electric balance nearest to 0.01 g and recorded. Daily rate of litter standing crop was calculated by dividing the respective monthly total amount of litter standing crop and their components with the collection days. Daily rate of litter standing crop was compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p < 0.05$) by using SAS (6.12) statistical software and Non-metric Multi-dimensional Scaling (MDS) was performed by using Polymouth Routines in Multivariate Ecological Research (PRIMER) v5 software.

5.2.3 Leaf Litter Degradation

5.2.3.1 Collection of Leaf Litter and Sorting

Leaf litter degradation experiments were conducted during the dry months (July 2002 to November 2002) and wet months (November 2002 to March 2003) with a mean total rainfall of 177.71 mm/month and 187.63 mm/month, respectively. Bulk samples of freshly senescent yellowish leaves of *B. parviflora* were collected from the litter layer.

Collected leaf samples were sorted into three size classes as 10 to <15, 15 to <20 and 20 to 30 cm², respectively and each group of sample consisted of six leaves (two leaves from every classes).

5.2.3.2 Preparation of Leaf Litter Bags and Leaf Litter on Strings

Litterbags were prepared by placing each set of sample (previously grouped) in 300 x 150 mm nylon bag with 1 mm² mesh size. To prevent the leaves from folding and clumping they were laid flat and placed in the bag. A total 110 sets of litterbags were prepared and coded. Leaf litter on strings were prepared by sewing each set of sample (previously grouped) onto monofilament nylon string through the lamina adjoining the mid-rib so that leaves were not overlapped. A total of 110 sets of leaves on string were prepared and coded.

5.2.3.3 Placing of Strings and Bags in the Field and Fresh to Oven Dry Weight Conversion Factor

One hundred and ten of strings and litterbags were carried to the field in closed plastic bags and 100 litterbags and 100 strings were placed in the forest area randomly. They were placed flatly on the sediment and tied with flagged pegs. Ten strings and bags were put into plastic bags and brought back to the laboratory for calculating the conversion factor of fresh to oven-dry weight at 80°C to constant weight. The conversion factor was calculated as follows:

Conversion factor = Mean total oven-dry weight (g)/ Mean total fresh weight (g)

5.2.3.4 Samplings of Strings and Litterbags

Ten bags and strings were collected every five days interval for the initial first month and ten bags and strings each were collected monthly for the subsequent four months period. Each collected bag and string was placed into separate labelled airtight plastic bag and placed into ice chest and brought back to the laboratory for further processing. The collected leaf litter samples both from bags and strings were gently washed and all sediments and dirt particles were then removed by using a soft brush under the running tap water followed by final rinsing in distilled water and air-dried. Each sample was then oven-dried at 80°C to constant weight for 5 days and weighted using electric balance nearest to 0.01 g and recorded.

5.2.3.5 Loss in Dry Weight, Loss Due to Feeding Plus Mechanical Breakdown and Degradation Rate

The loss in dry weight of the samples was calculated from the original converted oven-dry weight and the percentage of loss in initial dry mass in bags and strings was calculated. The amount of leaf litter loss due to feeding plus mechanical breakdown was estimated based on the difference between mean oven-dry weight loss of leaves on

strings and mean oven-dry weight loss of leaf litter in bags. The degradation loss of leaf litter refers to wet losses due to biotic and abiotic agents and the rate (%) was calculated from the percentage of wet loss divided by the respective days of collection. The different rates (%) of leaf litter degradation and leaf litter losses were transformed to arcsin and compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test ($p < 0.05$) by using SAS (6.12). Leaf litter degradation rate in litter bags and strings at different time periods in dry and wet months were compared by Non-metric Multi-dimensional Scaling (MDS) by using Polymouth Routines in Multivariate Ecological Research (PRIMER) v5 software.

5.3 Results

5.3.1 Litter Production

During the study period of 20 months, a total weight of 1731.97 g/m² of small litter (leaves, small branches, bracts, flowers and propagules) was recovered from the traps. The annual amount of total litter production and leaf litter was 1035 g/m² and 706 g/m², respectively, which was calculated from the monthly average litter production. The percentage contributions of leaf litter, small branches, bracts, flowers, propagules were 38.05-84.59%, 3.09-12.84%, 3.79-13.42%, 0.38-9.29% and 1.24-53.58% of the total litter fall, respectively (Figure 5.1). The rate of leaf litter, small branches, bracts, flowers, propagules and total litter varied from 1.63-3.07 g/m²/day, 0.08-0.38 g/m²/day, 0.13-0.39 g/m²/day, 0.01-0.23 g/m²/day, 0.03-2.29 g/m²/day and 2.31-4.46 g/m²/day, respectively (Figure 5.2). Comparatively higher rate of total litter fall was observed during the drier months (July 02, August 02 and July 03) (Figure 5.2) (ANOVA, DMRT, $p < 0.05$), where propagules constituted about 31-52% of total litter fall during those drier months (Figure 5.1). Total litter fall showed similar pattern in inter annual fluctuation during the month of December, January, April, May, June and July (Figure 5.3). A relatively higher rate (3.08 g/m²/day) of leaf litter production was observed during February 02 followed by March 03 (2.49 g/m²/day) (intermediate seasons) (Figure 5.2) (ANOVA, DMRT, $p < 0.05$) and showed similar pattern of inter annual fluctuation during the month of December, January, April, June and July (Figure 5.4). Flowers and propagules showed seasonality in their production, and they were mature and tent to fall off during the intermediate and dry seasons, respectively. Comparatively higher rate (0.23 g/m²/day) of flowers and propagules (2.29 g/m²/day) production was observed during April 02 and July 03, respectively (Figure 5.2) (ANOVA, DMRT, $p < 0.05$). Stepwise multiple regression analysis showed a significant negative relationship (Total litter production = 3.40 - 0.004 x Rainfall; $r = -0.46$, $p < 0.05$) between rainfall and total litter production and relative humidity showed significant negative relationship (Leaf fall = 6.17 - 0.061 x Relative humidity; $r = -0.66$, $p < 0.05$) with leaf fall.

5.3.2 Litter Standing Crop

A total amount of 587.81 g/m² of small litter (intact leaves, broken leaves, small branches, bracts and propagules) were collected as standing crop from the permanent plots during the study period of 20 months. The annual amount of litter standing crop was 337.72 g/m², which was calculated from the monthly average litter standing crop. The percentage contributions of intact leaves, broken leaves, small branches, bracts and propagules were 25.35-44.35%, 28.47-53.80%, 9.35-23.65%, 1.98-13.80% and 5.35-28.55% of total litter standing crop, respectively (Figure 5.5). The rate of total leaves, small branches, bracts, propagules and total litter standing crop varied from 0.32-1.29 g/m²/day, 0.10-0.25 g/m²/day, 0.02-0.08 g/m²/day, 0.04-0.49 g/m²/day and 0.49-1.72 g/m²/day, respectively (Figure 5.6). Comparatively higher rate of total litter standing crop was observed in the month of July 02, July 03 and February 02 at 1.72, 1.61 and 1.55 g/m²/day, respectively, where propagules constituted about 26-27% of total litter standing crop during the month of July (Figures 5.5-5.6) (ANOVA, DMRT, $p < 0.05$). Total litter standing crop showed similar pattern in inter annual fluctuation during the month of December, January, June and July, (Figure 5.7). A relatively higher rate (1.29 g/m²/day) of total leaf litter was observed during February 02 followed by July 02 (1.03 g/m²/day) and lower rate of 0.32 g/m²/day was found in the month of April 03 (Figure 5.6) (ANOVA, DMRT, $p < 0.05$). Total leaf litter (intact and broken leaves) showed similar pattern in inter annual fluctuation during the month of December, January and July, (Figure 5.8). A significant negative relationship ($r = -0.82$, $p < 0.05$) was observed between the number of spring high tides that flooded the forest areas and monthly amount of total litter standing crop (Figure 5.9).

5.3.3 Leaf Litter Loss

5.3.3.1 Fresh Weight to Oven Dry Weight Conversion Factor

Fresh weight to oven-dry weight conversion ratios of leaf litter was calculated and two different conversion factors during the dry and wet months were used. Leaf area, fresh weight, oven dry weight of leaf litter varied from 10.36 to 29.31 cm², 0.23 to 0.71 g and 0.11 to 0.33 g respectively (Table 5.1).

5.3.3.2 General Observations on Progressive Changes of the Leaf Litter

Leaf litter on strings showed physical changes in colour from 10 days during the initial period of dry and wet months. The higher grazing evidence was observed from 10 to 30 days and 10 to 15 days during the initial period of dry and wet months, respectively. Crabs not only grazed the freshly fallen leaves but also grazed the aged leaves. Leaves on strings, being freely suspended, showed little evidence of sediment settlement and resuspension. Leaves in bags showed physical changes in colour from 10 days during the initial period of dry and wet months. Leaves in bag showed physical changes in structure from 60 and 15 days during dry and wet months, respectively. There were some evidences of leaf grazing inside the bag by crabs. Moreover, partial burial of litter

bags started from 20 and 5 days during the dry and wet months, respectively (Table 5.2).

5.3.3.3 Leaf Litter Loss and Degradation Rate

Comparatively higher percentage of dry weight loss occurred in bags and strings during the wet months. In bags, 63% and 86% of the dry weight loss were observed for 150 days during dry and wet months, respectively (Figure 5.10). All leaves on strings disappeared from 60 and 20 days during dry and wet months (Figure 5.11). The degradation loss of leaf litter refers to weight losses due to biotic and abiotic agents and comparatively higher rate of leaf litter degradation was observed during the wet months (ANOVA, DMRT, $p < 0.05$). A relatively higher rate of leaf litter degradation in bags occurred in 5 days and 10 days during the initial period of wet and dry months, respectively, followed by lower rates at different collection time (Figure 5.12) (ANOVA, DMRT, $p < 0.05$). Comparatively lower rate of leaf litter loss on strings was observed in 5 days and relatively higher rate was observed in 10 days during the initial period of dry and wet months (Figure 5.13) (ANOVA, DMRT, $p < 0.05$). Leaf litter degradation rate in bags was compared in relation to days and seasons. Similar degradation rate was observed during 5, 10, 15, 20, 25 and 30 days of wet months, but dry months experiment showed similar degradation rates during 60, 90, 120 and 150 days (Figure 5.14). However, the rate of leaf litter loss on strings did not show any distinct pattern among the wet and dry months experiments (Figure 5.15).

5.3.3.4 Contribution of Macro-feeders and Micro-organisms to Leaf Litter Degradation

The percentage of dry weight loss due to feeding plus mechanical breakdown by crabs was lower (4.83-11.31%) for 5 days but similar percentage (55.18%-52.61%) of weight loss was observed for 20 days during the initial period of dry and wet months. Leaf litter grazed and mechanically broken down by crabs amounted to 52.61 to 69.33% after 20 and 60 days in the wet and dry months, respectively, but the contribution of microbial degradation amounted to 47.39% and 30.67% (Table 5.3 and Figure 5.10 and 5.11). In general, leaf litter loss due to feeding plus mechanical breakdown did not vary in dry and wet months but microbial degradation was varied in dry and wet months.

5.4 Discussion

5.4.1. Litter Production

Comparatively higher rate of total litter production was observed during the dry months (June, July and August) (Figure 5.2). *Bruguiera parviflora* showed distinct seasonality in flowering and fruiting. Drier months coincide with fruiting season and propagules contributed to 10.94 to 55.58% of the total litter fall (Figure 5.1). Apart from flowering and fruiting season, environmental parameters (rainfall, temperature and relative humidity) and stand characteristics (density and species composition) have significant

influence on litter production (Sasekumar and Loi, 1983; Aksornkoae and Khemnark, 1984; Saenger and Snedaker, 1993; Day *et al.*, 1996). Peak fall of leaf litter of *Avicennia germinans* and *A. marina* was observed during the months of higher temperature associated with lower rainfall (Lopez-Portillo and Ezcurra, 1985; Hegazy, 1998). In the present study, *B. parviflora* leaf litter and total litter production showed negative correlations with rainfall and relative humidity. The combined effect of environmental parameters (rainfall, temperature and relative humidity) may be important for determining the litter fall pattern rather than individual factor. Moreover, wind speed and soil salinity have shown significant influence on litter fall rate (Sasekumar and Loi, 1983; Lopez-Portillo and Ezcurra, 1985).

Litter production studies at different places of mangrove forest in the world are shown in Figure 5.16. The most studied species are *A. marina*, *A. officinalis*, *A. corniculatum*, *A. germinans*, *B. gymnorhiza*, *B. sexangula*, *Ceriops tagal*, *Laguncularia* sp., *Kandelia candel*, *Rhizophora apiculata*, *R. mucronata*, *R. stylosa*, *Sonneratia alba* and *S. caseolaris*, but only one study was conducted for *B. parviflora* (Table 5.4). *Bruguiera parviflora* in this study showed comparatively higher rate of total litter production than *B. parviflora*, *B. gymnorhiza*, *C. tagal*, *Avicennia* sp. and *S. alba* in Hinchinbrook Island, Australia at 33°55'S latitude (Duke *et al.*, 1981), mixed mangroves (*R. apiculata*, *R. mucronata* and *B. gymnorhiza*) in Sungai Merbok, Malaysia at 5°40'N latitude (Ong *et al.*, 1980). Present study showed comparatively lower litter production than mixed mangrove (*Avicennia* spp., *Sonneratia* spp., *Rhizophora* spp.) in Sungai Buloh, Kuala Selangor, Malaysia at 3°15'N latitude (Table 5.4). This variation of litter production in mangroves may be related to the species as well as different geographical locations. However, a significant negative correlation ($r=-0.34$, $p<0.05$) was observed when the available published values of total litter production in mangroves (Table 5.4) were plotted against the latitude (Figure 5.17). This relationship explains that highest litter production was observed at the lower latitude (tropical region) and it decreased linearly with increasing latitude (sub-tropical region) (Saenger and Snedaker, 1993).

In the present study, *B. parviflora* showed comparatively higher mean percentage of leaf fall and stipules than *B. parviflora* in Hinchinbrook Island, Australia (Duke *et al.*, 1981). Different mangrove species showed different percentage range of litter components. The percentage range of leaf litter production in *Avicennia* spp., *Bruguiera* spp., *Ceriops* spp., *Rhizophora* spp. and *Sonneratia* spp. were 34.00-83.00%, 40.30-49.20%, 58.10-71.00%, 57.40-88.80% and 47.00-61.00%, respectively (Table 5.5). It has been reported that total litter production and litter components in mangroves vary from place to place, species to species (Amarasinghe and Balasubramaniam, 1992a; Bunt, 1995), and it also vary from the same species (*R. apiculata*) at different age (Gong *et al.*, 1984; and Clough *et al.*, 2000).

5.4.2 Litter Standing Crop

The difference between annual amount of litter production (1035 g/m²/yr) and litter standing crop (337.72 g/m²/yr) was 697.28 g/m²/yr, and it suggested that 67.37% of annual total litter production was disappeared from this mangrove forest. This disappearance of litter is the combined effect of tidal export, burial, microbial degradation and loss due to feeding plus mechanical breakdown by litter consuming fauna (such as crabs) (Twilley *et al.*, 1986; Japar Sidik, 1989; Dick and Osunkoya, 2000; Ashton, 2002). Similarly, a significant negative correlation ($r=-0.82$, $p<0.05$) was observed between the number of spring high tides that flooded the forest area and monthly amount of total litter standing crop (Figure 5.9). This relationship explains that frequency of tidal inundation determines the amount of litter standing crop which remains on the mangroves forest floor.

5.4.3 Leaf Litter Loss

Bruguiera parviflora leaf litter showed comparatively higher rate of weight loss both in litter bags and strings during the initial 10 and 5 days of dry and wet months, respectively (Figures 5.12-5.13). Leaching process may be responsible for the initial rapid loss of leaf litter dry mass during the dry and wet months. Leaching is the first phase of litter decomposition and significant amount of soluble compounds is lost during this process (Valiela *et al.*, 1985; Steinke *et al.*, 1993a). Van der Valk and Attiwill (1984) reported that 13% reduction in weight was caused by leaching process after 3 days, when *A. marina* leaf litter was submerged in seawater. Robertson (1988) reported that initial rapid loss of leaf litter (*R. stylosa*, *A. marina* and *C. tagal*) mass both in subtidal and submerged condition is the result of rapid leaching of dissolved organic matter, including organic carbon, nitrogen, tannins and inorganic salts. Similarly, Cundell *et al.* (1979) reported that readily leachable carbohydrate and tannin were lost from the submerged *R. mangal* leaf litter by 14 to 28 days and microbial population are slowly growing up on the leaf surface and start degradation of structural material. The structural organic matter is decomposed slowly and highly dependent on the action of bacteria and fungal communities (Robertson *et al.*, 1992).

In this study, *B. parviflora* leaf litter showed comparatively rapid change in leaf litter structure and higher degradation rate was observed during the wet months. Moisture is an important factor that can accelerate the degradation process, when drying followed by rewetting of soil (Hesse, 1961). Moreover, it enhances the activity of microbial decomposers (Swift *et al.*, 1979). Steinke and Ward (1987) reported that leaf litter degradation rate varied with *A. marina* and *B. gymnorhiza* in different exposure condition (continuous submergence, exposed only at low spring tides and inundated only at high spring) and seasons (cool and warm). *Avicennia marina* leaf litter showed higher degradation rate than *B. gymnorhiza*. Constantly submerged leaves degraded at a faster rate than those exposed for longer time and the degradation rate was consistently lower in the cool season. Higher rate of *R. apiculata* leaf litter degradation

was reported during heavy rainfall (Japar Sidik, 1989). Lu and Lin (1990) have shown higher rates of leaf litter (*A. marina* and *K. candel*) degradation during the summer at Fujian, China. Mackey and Smail (1996) studied the leaf litter degradation of *A. marina* during the winter and summer seasons at two different tidal exposure conditions in Brisbane River estuary, Queensland, Australia. They observed significantly higher degradation rate during the summer season at low tidal level. They concluded that the summer months are comparatively wetter and more humid, accelerating the activity of microbial decomposers.

Microbial degradation rate of *B. parviflora* leaf litter varied in dry and wet months. But, leaf litter loss due to feeding plus mechanical breakdown by macro-feeders did not vary in dry and wet months. Japar Sidik (1989) studied the leaf litter (*R. apiculata*) degradation in Matang Mangrove Forest Reserve, Malaysia under different Watson's (1928) tidal inundation classes. He reported that microbial degradation was 22.80% to 58.60% and 26.90% to 76.7% for 90 days during the dry and wet months, respectively. Leaf litter loss due to feeding plus mechanical breakdown by crabs was 12.60% to 49% and 7.30% to 29.80% for 90 days during the dry and wet months, respectively. Similarly, Ashton (2002) studied the grazing and consumption of leaf litter (*A. officinalis*, *B. gymnorhiza*, *B. parviflora* and *R. apiculata*) by sesarmid crab in Merbok estuary mangrove forest, Kedah, Peninsular Malaysia. He reported that 79% of the initial dry weight of the leaf litter was grazed in 24 hours at *Bruguiera* zone and *Rhizophora* zone at high and low intertidal positions of upstream (Sungai Pasir) and downstream (Lower Merbok). Van der Valk and Attiwill (1984) reported that 61% of *A. marina* leaf litter was lost due to feeding plus mechanical breakdown by crabs in Westernport Bay Mangrove forest, Australia at 1.50 to 2.30 m tidal height during the wet months. It is documented that sesarmid crab consumes mangrove detritus as food. Leh and Sasekumar (1985) reported that food of five common species of sesarminae crabs (*Chiromantes onychophorum*, *Chiromantes eumolpe*, *Clistocoeloma merguiensis*, *Sesarma versicolor* and *Sesarmoides kraussi*) at Kapar Mangrove Forest Reserve, Malaysia consisted of 83% to 97% mangrove plant matter. Comparative results of leaf litter degradation with different mangrove species at various geographical locations are presented in Table 5.6. Leaf litter of different mangrove species and even the same species showed different degradation rates in relation to geographical locations, exposure condition and seasons. Thus, the rate of mangrove leaf litter degradation depends on species, sites, exposure conditions and abundance of micro- and macro-organisms.

Table 5.1: Leaf area, fresh weight, oven dry weight and conversion factor of fresh weight to oven dry weight at different sampling time and standard error of means are given in parenthesis

Sampling time	Leaf area (cm ²)	Fresh weight (g)	Oven dry weight (g)	Conversion ratio
July 2002	10.84 to 28.72	0.23 to 0.62	0.13 to 0.33	0.54 (0.01)
November 2002	10.36 to 29.31	0.26 to 0.71	0.11 to 0.31	0.43 (0.01)

Table 5.2: Observation on progressive changes of the leaf litter under different exposure condition

Days	Leaf on strings	Days	Leaf in bags
Dry months			
5	Leaves remained yellowish and intact on strings. Some leaves were grazed along the margin. Leaves were dragged into crab holes.	5 to 15	Leaves remained yellowish in colour. Leaves surface covered with black spots. Some litterbags have holes and the crabs grazed inside leaves.
10 to 15	Leaves turned to light brown in colour. Leaves were grazed up to the mid rib. Some leaves disappeared and some dragged into crab holes.	20 to 30	Leaves turned to brown and veins were visible with small round shaped. Leaves inside the bags partially covered by thin sediment layers.
20 to 30	Leaves turned to brown and heavily grazed and small parts were attached with strings Some leaves disappeared and thin layers of sediment smothered the leaves surface.	60 to 90	Leaves turned to dark brown and soft. Leaves veins were cleared with more surface areas and leaves areas were lost along the margin. Leaves were partially covered by thick sediment layers.
60	All leaves were lost	120 to 150	Leaves remained dark brown and fragmented into bigger pieces Leaves remained partially covered by thick sediment layers.

Table 5.2 (Cont'd)

Days Wet month	Leaf on strings	Days	Leaf in bags
5	Leaves remained yellowish and intact on strings. Some leaves were grazed along the margin. Leaves were dragged into crab holes. Thin layers of sediment smothered the leaves surface	5	Leaves remained yellowish and leaves surface covered with black spots. Some bags have holes and the crabs grazed inside leaves. Leaves partially covered by thin sediment layers.
10	Leaves turned to brown and grazed up to the mid rib. Some leaves disappeared and some dragged into crab holes. Thin layers of sediment smothered the leaves surface	10	Leaves turned to light brown and became soft and veins cleared in round shaped areas. Some bags have holes and the crabs grazed inside leaves. Leaves partially covered by thin sediment layers.
15	Leaves turned to dark brown and heavily grazed. Small parts of leaves were attached with strings. Thin layers of sediment smothered the leaves surface	15 to 20	Leaves turned to brown and became soft and fragile. Leaves areas were lost a long the margin up to the mid rib. Leaves were partially covered by thick sediment layers
20	All leaves were lost	25 to 60	Leaves turned to dark brown and fragmented into bigger pieces. Leaves remained partially covered by thick sediment layers.
		90 to 150	Leaves remained dark brown and fragmented into smaller pieces. Leaves remained partially covered by thick sediment layers.

Table 5.3: The estimates of contribution of macro-feeders and micro-organisms to leaf litter degradation

Days	Mean percentage of weight loss on string	Mean percentage of weight loss in bags	Percentage of weight loss by feeding plus mechanical breakdown
Dry months			
5	15.02±5.48	3.72±0.57	11.31
10	53.53±11.85	10.92±1.41	42.61
15	65.69±6.82	14.38±1.02	51.31
20	70.76±8.91	15.58±1.11	55.18
25	80.03±5.34	16.69±1.08	63.34
30	82.99±5.69	20.17±2.47	62.82
60	100	30.67±1.41	69.33
Wet months			
5	16.7±2.6	11.87±1.16	4.83
10	57.96±9.46	20.1±1.32	37.86
15	91.98±4.45	31.2±0.9	60.78
20	100	47.39±1.61	52.61

Table 5.4: Litter production of different mangrove species in different places

Geographical location	Species	Dry weight (g/m ² /day)	Sources
Middle Harbour, Sydney, Australia (33°55' S, 151°10' E)	<i>Avicennia marina</i>	1.59	Goulter and Allaway (1979)
Hinchinbrook Island, Australia (18°15' S, 146°15' E)	<i>Rhizophora</i> spp. <i>Ceriops tagal</i> <i>Bruguiera</i> <i>gymnorhiza</i> <i>B. parviflora</i> <i>Avicennia</i> spp. <i>Sonneratia alba</i>	2.99 1.97 2.19 2.74 2.19 2.16	Duke <i>et al.</i> (1981)
Sungai Merbok, Malaysia (5°40' N, 100°25' E)	<i>Rhizophora</i> <i>apiculata</i> <i>R. mucronata</i> <i>B. gymnorhiza</i>	2.76	Ong <i>et al.</i> (1980)
Western Port Bay, Australia (38°25' S, 145°12' E)	<i>Avicennia</i> spp.	0.55	Clough and Attiwill (1982)
Kuala Selangor, Malaysia (3°15' N and 101°18' E)	<i>Avicennia</i> spp. <i>Sonneratia</i> spp. <i>Rhizophora</i> spp.	4.22 3.84 4.32	Sasekumar and Loi (1983)
Matang Mangrove, Malaysia (4°50' N, 100° 36' E)	<i>R. apiculata</i> (Planted) <i>R. apiculata</i> <i>R. mucronata</i> <i>Bruguiera</i> spp.	1.91-3.12 2.09	Gong <i>et al.</i> (1984)
Tuvalu (7°28' S, 178°42' E)	<i>R. stylosa</i>	5.39	Woodroffe (1984)
Motupore Island, Papua New Guinea (9°31' S, 147°17' E)	<i>R. stylosa</i>	3.92	Leach and Burgin (1985)
Tabasco, Mexico (18°25' N, 93°10' W)	<i>A. germinans</i>	1.68	Lopez-Portillo and Ezcurra (1985)
Mgeni estuary, South Africa (29°48' S, 31°03' E)	<i>A. marina</i>	1.91	Steinke and Charles (1986)
Southwest Florida (26°02' N, 81°45' W; 25°02' N, 81°34' W)	<i>Avicennia</i> spp. <i>Rhizophora</i> spp.	1.22 2.22	Twilley <i>et al.</i> (1986)

Table 5.4 (Cont'd)

Geographical location	Species	Dry weight (g/m ² /day)	Sources
Queensland and Port Clinton, Australia (18°05' S, 146°01' E; 22°35' S, 150°45' E)	<i>S. alba</i> <i>S. caseolaris</i>	2.48 2.56	Duke (1988)
St. Lucia and Richards Bay, South Africa (27°58' N, 32°24' E)	<i>A. marina</i> <i>B. gymnorrhiza</i> <i>R. mucronata</i>	2.78-2.89 2.00 2.66	Steinke and Ward (1988)
Darwin Harbour, Northern Australia (12°26' S, 130°52' E)	<i>C. tagal</i>	1.88-2.04	Woodroffe <i>et al.</i> (1988)
Mai Po Marshes, Hong Kong (22°31' N, 114°05' E)	<i>Kandelia candel</i>	2.18-3.44	Lee (1989)
Ohura Bay, Okinawa, Japan	Mixed mangrove	2.11-2.94	Hardiwinoto <i>et al.</i> (1989)
Ras Hatiba, Saudi Arabia (21°36' N, 39°9' E)	<i>Avicennia</i> spp.	2.16	Saifullah <i>et al.</i> (1989)
Hainan Island, China (19°51' N, 110°24' E)	<i>B. sexangula</i>	3.02-3.44	Lu and Lin (1990)
Transkei estuaries, South Africa	Mixed mangrove	1.24	Steinke and Ward (1990)
Bonny estuary, Nigeria (4°22' N, 7°12' E)	<i>Rhizophora</i> spp. <i>Avicennia</i> spp. <i>Laguncularia</i> spp.	2.32 1.76 2.24	Abbey Kalio (1992)
Dutch bay, Kala Oya and Erumathivu, Sri Lanka (8°15' N, 79°50' E)	<i>R. mucronata</i> <i>A. marina</i> zone	1.71 1.02-1.51	Amarasinghe and Balasubramaniam (1992a)
Tritih, Java, Indonesia (7°58' S, 108°44' E)	<i>R. mucronata</i> (Planted)	2.26	Sukardjo and Yamada (1992)
Queensland, Australia (27°24' S, 153°8' E)	<i>A. marina</i>	2.40	Mackey and Smail (1995)
Onverwagt, Guyana (6°27' N, 57°38' W)	<i>A. germinans</i>	4.85	Chale (1996)
Northeastern Gulf of Carpentaria, Australia	<i>R. stylosa</i>	2.70-3.35	Conacher <i>et al.</i> (1996)
Gazi Bay, Kenya. (4°25' S, 39°30' E)	<i>R. mucronata</i>	1.15-2.51	Slim <i>et al.</i> (1996)
Churute estuary, Ecuador (2°35' S, 79°40' W)	<i>Rhizophora</i> spp.	1.77-2.92	Twilley <i>et al.</i> (1997)

Table 5.4 (Cont'd)

Geographical location	Species	Dry weight (g/m ² /day)	Sources
Mandovi-Zuari Estuaries, India	<i>R. apiculata</i> <i>R. mucronata</i> <i>S. alba</i> <i>A. officinalis</i>	3.21 3.23 4.66 2.79	Wafar <i>et al.</i> (1997)
Al Khor, Qatar (25°40' N, 51°35'E)	<i>A. marina</i>	4.65	Hegazy (1998)
Futian, China (22°31' N, 114°05' E)	<i>A. corniculatum</i> and <i>K. candel</i>	3.20	Tam <i>et al.</i> (1998)
Mekong Delta, Vietnam (8°47' N, 104°27' E)	<i>R. apiculata</i> (Planted)	2.58-4.76	Clough <i>et al.</i> (2000)
Kuala Selangor, Malaysia (3°19' N, 101°14'E)	<i>B. parviflora</i>	2.89 (2.31-4.46)	This study

Table 5.5: Percentage contribution of litter production components of different mangrove species in different places

Geographical location	Species	Components (%)					Sources
		Leaves	Stipules	Twigs/ wood	Reproductive parts	Others	
Hinchinbrook Island, Australia (18°15'S, 146°15' E)	<i>Rhizophora</i> spp.	57.40	8.70	9.90	16.30	7.20	Duke <i>et al.</i> (1981)
	<i>Ceriops tagal</i>	58.10	2.00	7.90	7.60	24.40	
	<i>Bruguiera gymnorhiza</i>	49.20	3.50	12.50	26.60	7.80	
	<i>B. parviflora</i>	40.30	6.20	9.70	30.00	13.40	
	<i>Avicennia</i> spp.	74.90		8.40	1.60	14.80	
	<i>Sonneratia alba</i>	48.80		14.70	21.20	15.20	
Kuala Selangor, Malaysia (3°15' N, 101°18' E)	<i>Avicennia alba</i>	40.00		17.20	28.50	14.30	Sasekumar and Loi (1983)
Matang Mangrove, Malaysia (4°50' N, 100° 38' E)	<i>R. apiculata</i> (Planted)	74.03- 88.80		9.91-17.83	0.20-16.22		Gong <i>et al.</i> (1984)
	<i>R. apiculata</i>	75.49		8.26	16.25		
	<i>R. mucronata</i>						
	<i>Bruguiera</i> spp.						
Tuvalu (7°28' S, 178°42' E)	<i>R. stylosa</i>	84.00	13.00	1.00	2.00		Woodroffe (1984)
Tabasco, Mexico (18°25' N, 93°10' W)	<i>A. germinans</i>	83.00		9.00	8.00		Lopez-Portillo and Ezcurra (1985)
Queensland and Port Clinton, Australia (18°05' S, 146°01' E; 22°35' S, 150°45' E)	<i>S. alba</i>	47.00		12.00	41.00		Duke (1988)
	<i>S. caseolaris</i>	61.00		14.00	25.00		

Table 5.5 (Cont'd)

Geographical location	Species	Components (%)					Sources
		Leaves	Stipules	Twigs/wood	Reproductive parts	Others	
Darwin Harbour, Northern Australia (12°26' S, 130°52' E)	<i>C. tagal</i>	71.00	3.00	8.00	18.00		Woodroffe <i>et al.</i> (1988)
Mai Po Marshes, Hong Kong (22°31' N, 114°05' E)	<i>Kandelia candel</i>	53.94		6.15	39.91		Lee (1989)
Ras Hatiba, Saudi Arabia (22°13' N, 38°58' E)	<i>Avicennia</i> spp.	49.7-99			0.60-56.6	1.20-50.30	Saifullah <i>et al.</i> (1989)
Bonny estuary, Nigeria (4°22' N, 7°12' E)	<i>Rhizophora</i> spp.	79.13		7.48	14.11		Abbey Kalio (1992)
	<i>Avicennia</i> spp.	72.80	9.02		18.73		
	<i>Laguncularia</i> spp.	75.12	8.85		15.05		
Tritih, Java, Indonesia (7°58' S, 108°44' E)	<i>R. mucronata</i> (Planted)	80.00	13.49		6.51		Sukardjo and Yamada (1992)
Queensland, Australia (27°24' S, 153°8' E)	<i>A. marina</i>	47.00		23.00	30.00		Mackey and Smail (1995)
Onverwagt, Guyana (6°27' N, 37°38' W)	<i>A. germinans</i>	61.41		4.87	33.72		Chale (1996)
Churute estuary, Ecuador (2°35' S, 79°40' W)	<i>Rhizophora</i> spp.	72-80	12.00-14.00	3.00-28.00	5.00-10.00	2.00-3.00	Twilley <i>et al.</i> (1997)

Table 5.5 (Cont'd)

Geographical location	Species	Components (%)					Sources
		Leaves	Stipules	Twigs/wood	Reproductive parts	Others	
Mandovi-Zuari	<i>R. apiculata</i>	68.00			22.00	10.00	Wafar <i>et al.</i> (1997)
Estuaries, India	<i>R. mucronata</i>	67.00			23.00	10.00	
	<i>S. alba</i>	58.00			17.00	25.00	
	<i>A. officinalis</i>	43.00			18.00	39.00	Hegazy (1998)
Al Khor, Qatar	<i>A. marina</i>	34.00		38.00	28.00		
(25°40' N, 51°35' E)							
Kuala Selangor,	<i>B. parviflora</i>	70.75	10.17	7.37	11.71		This study
Malaysia		(38.05-84.59)	(3.79-13.42)	(3.09-12.84)	(1.62-62.87)		
(3°19' N, 101°14' E)							

Table 5.6: Comparison of leaf litter loss and degradation rate with different mangrove species in different places

Geographical location, exposure condition and season	Species	Leaves litter loss		Sources
		% of litter loss	Days	
Matang Mangrove forest, Malaysia (4°50' N, 100° 36' E)	<i>Rhizophora</i> spp.	75-90	20	Ong <i>et al.</i> (1980)
Litter on string	<i>Bruguiera</i> spp.	80	20	
Queensland, Australia (18°05' S, 146°01' E)	<i>R. stylosa</i>	50	39	Robertson (1988)
Litter bags (Summer)	<i>Avicennia marina</i>	50	10	
	<i>Ceriops tagal</i>	50	27	
Matang Mangrove forest, Malaysia (4°50' N, 100° 36' E)	<i>R. apiculata</i>			Japar Sidik (1989)
Litter on strings		94-98	180	
Litter bags		80	180	
Arabian Gulf region (25°40' N, 51°35' E)	<i>A. marina</i>	46	150	Hegazy, (1998)
Litter bags (December)				
Shenzhen, China (22°31' N, 114°05' E)	<i>Aegiceras corniculatum</i>	68	70	Tam <i>et al.</i> (1998)
Litter bags (Summer)	<i>K. candel</i>	88	42	
Matang Mangrove forest, Malaysia (4°50' N, 100° 36' E)				Ashton <i>et al.</i> (1999)
Litter bags (Wet months)				
Cleared areas	<i>B. parviflora</i>	35	56	
Virgin Jungle Reserve		53	56	
Cleared areas	<i>R. apiculata</i>	50	56	
Virgin Jungle Reserve		58	56	
Cleared areas	<i>R. mucronata</i>	33	56	
Virgin Jungle Reserve		68	56	
Cleared areas	<i>Sonneratia alba</i>	85	56	
Virgin Jungle Reserve		93	56	
Tomago, Newcastel, Australia (32°52' S, 151°43'E)				Dick and Osunkoya (2000)
Litter bags (Summer)	<i>A. marina</i>	53	360	
Landward		95	360	
Shoreward				
Merbok estuary, Kedah, Malaysia (5°40' N, 100°25'E)	<i>A. officinalis</i>	79	1	Ashton (2002)
Litter on strings	<i>B. gymnorhiza</i>			
	<i>B. parviflora</i>			
	<i>R. apiculata</i>			

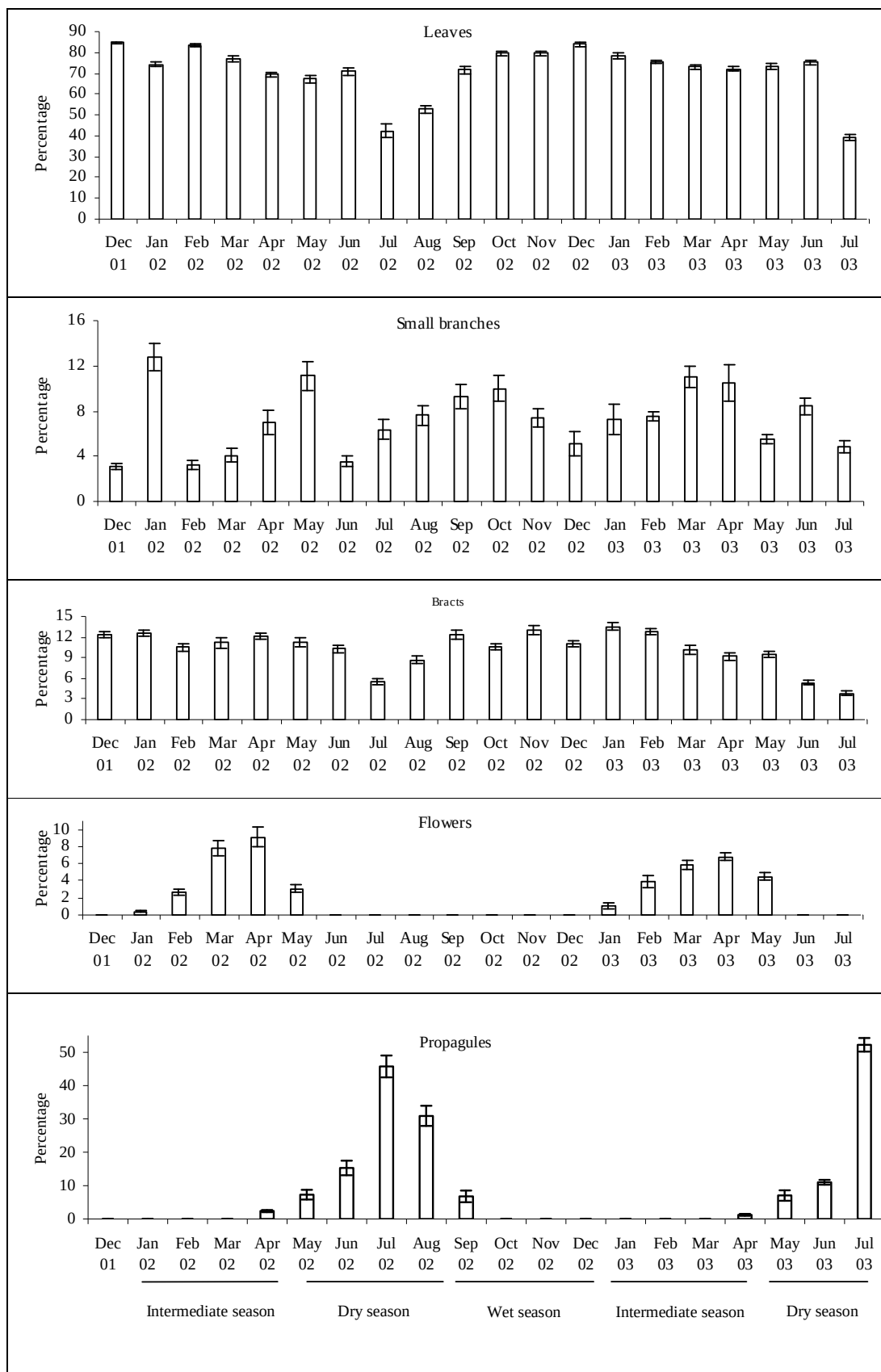


Figure 5.1: Pattern of litter production components at different months/seasons

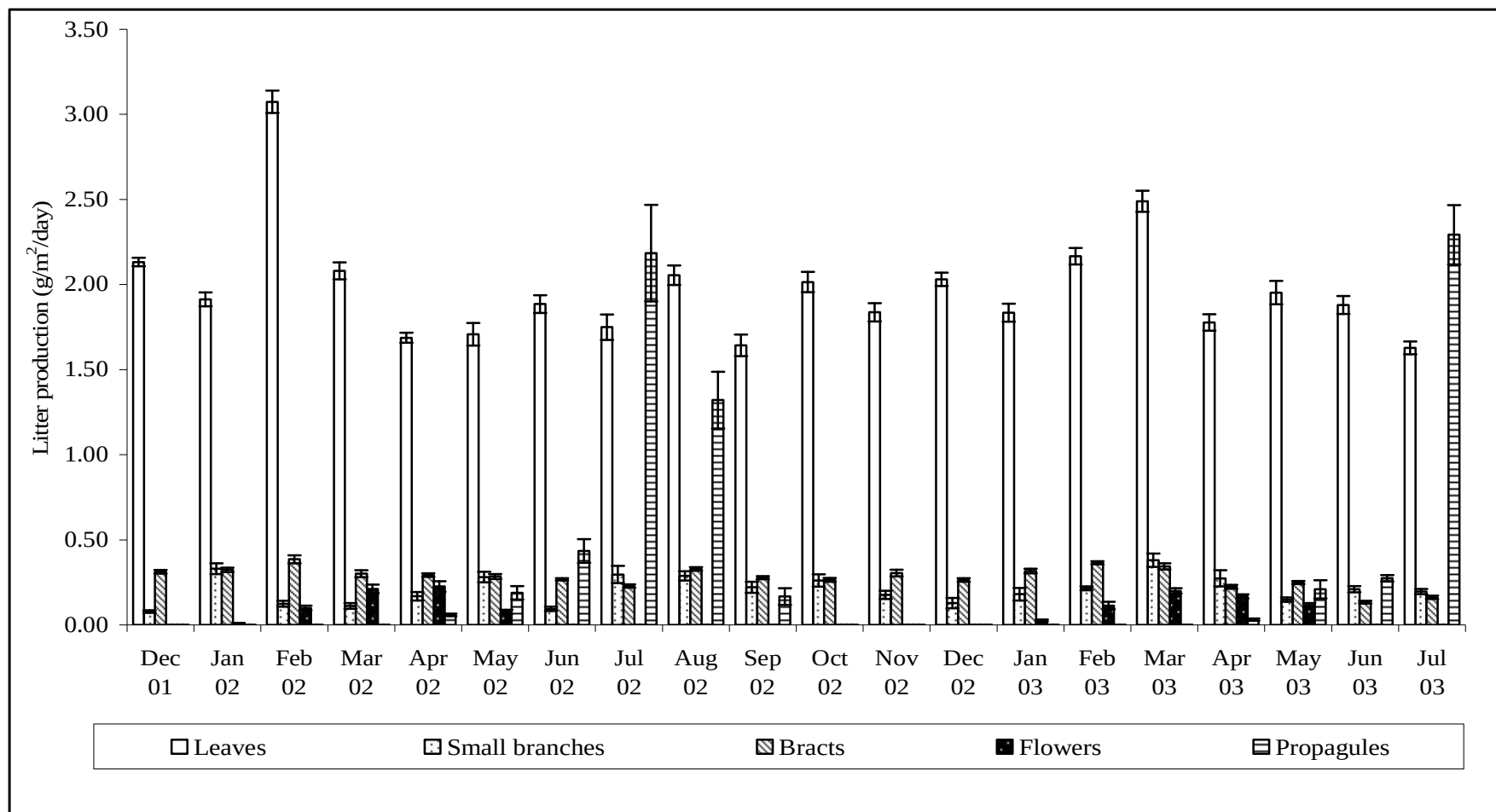


Figure 5.2: Variation in litter production (g/m²/day) by components at different months

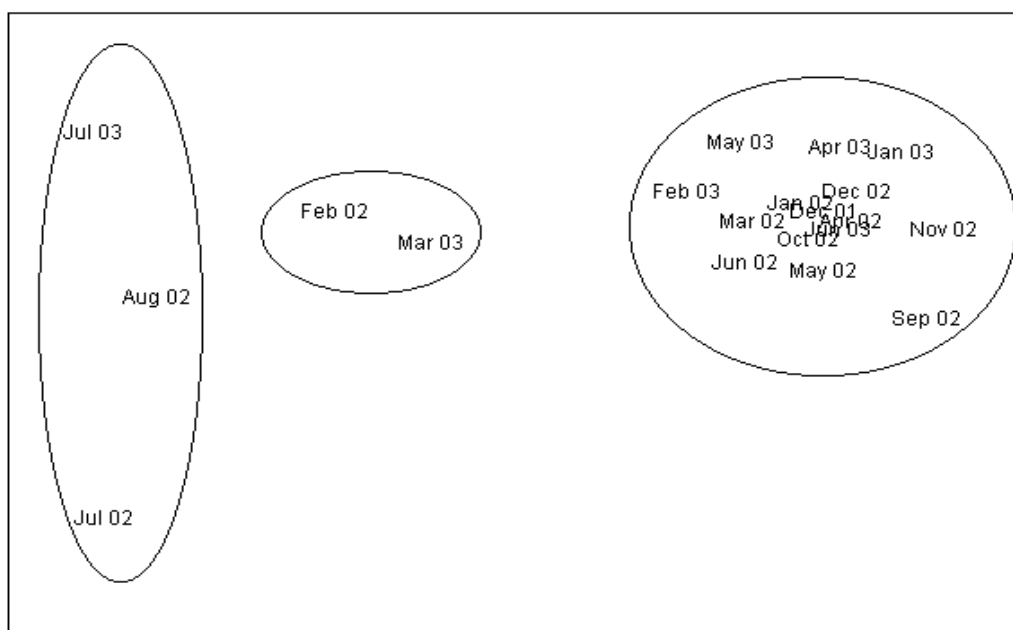


Figure 5.3: Total litter fall fluctuation pattern. Months within circles are not significantly (DMRT, $p>0.05$) different

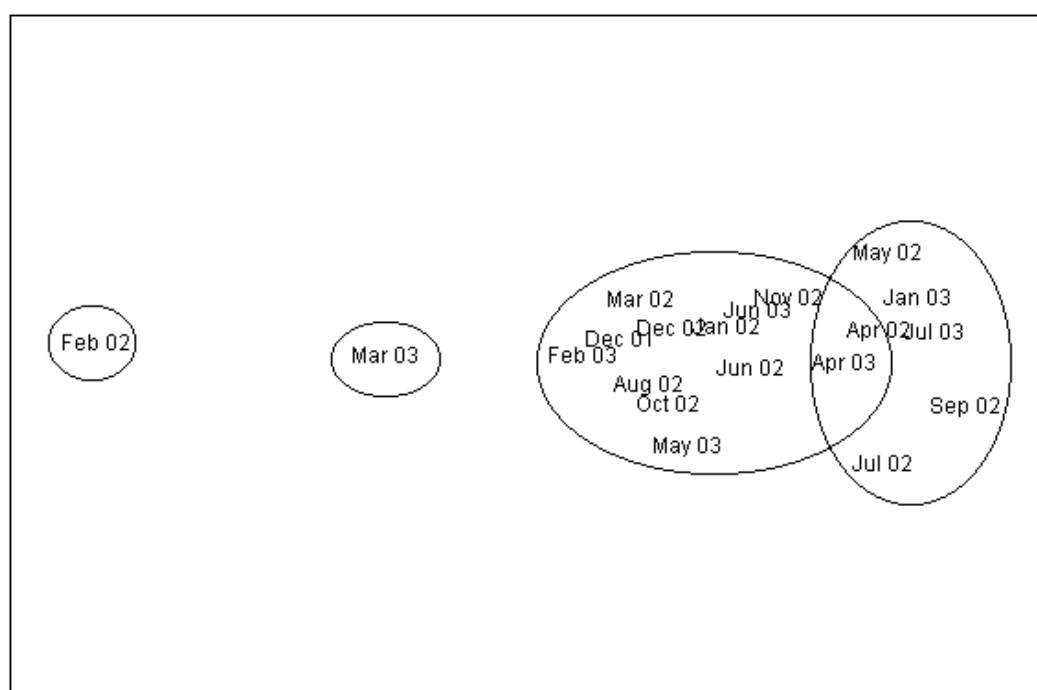


Figure 5.4: Leaf fall fluctuation pattern. Months within circles are not significantly (DMRT, $p>0.05$) different

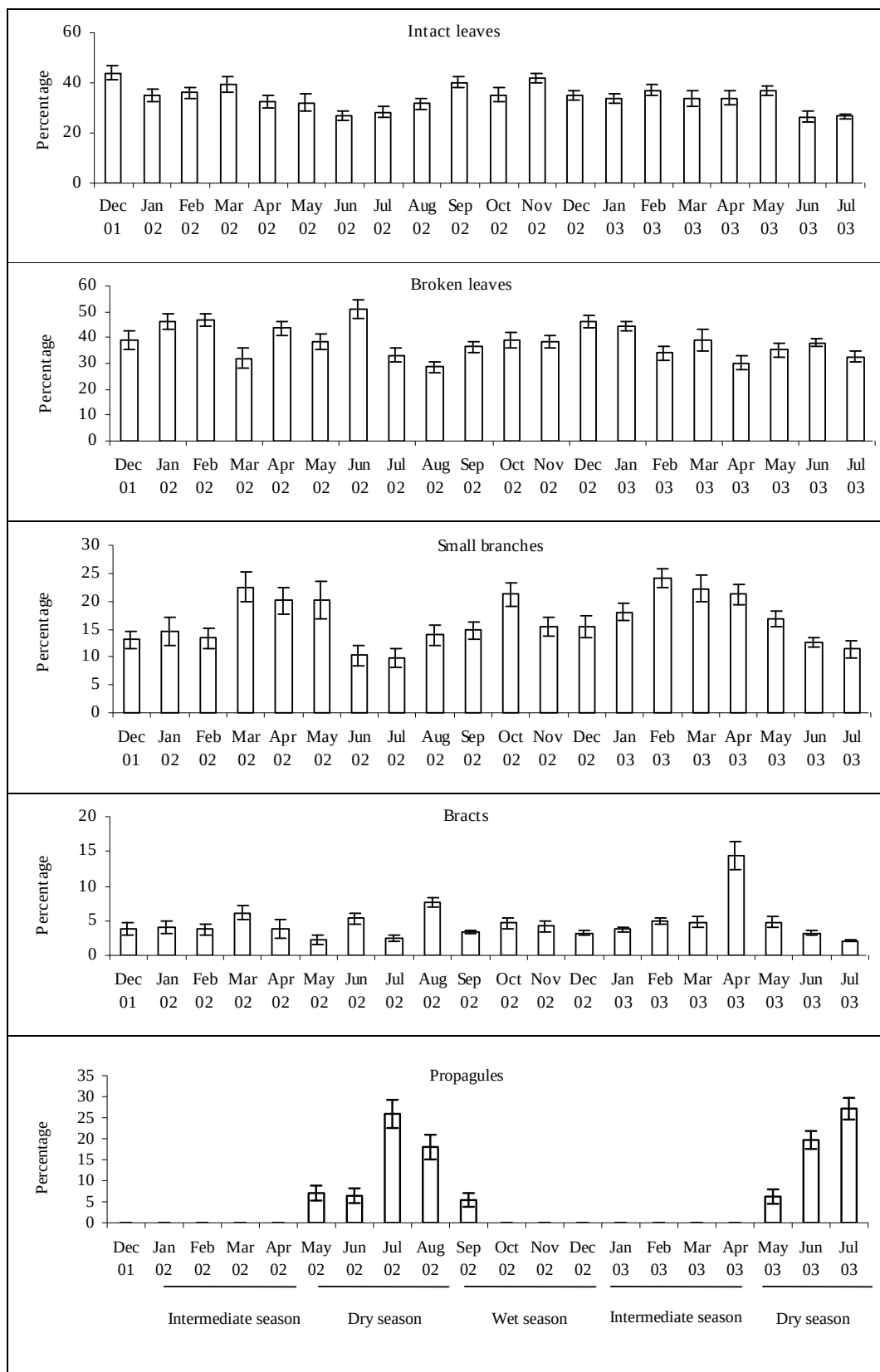


Figure 5.5: Pattern of litter standing crop components at different sampling months/seasons

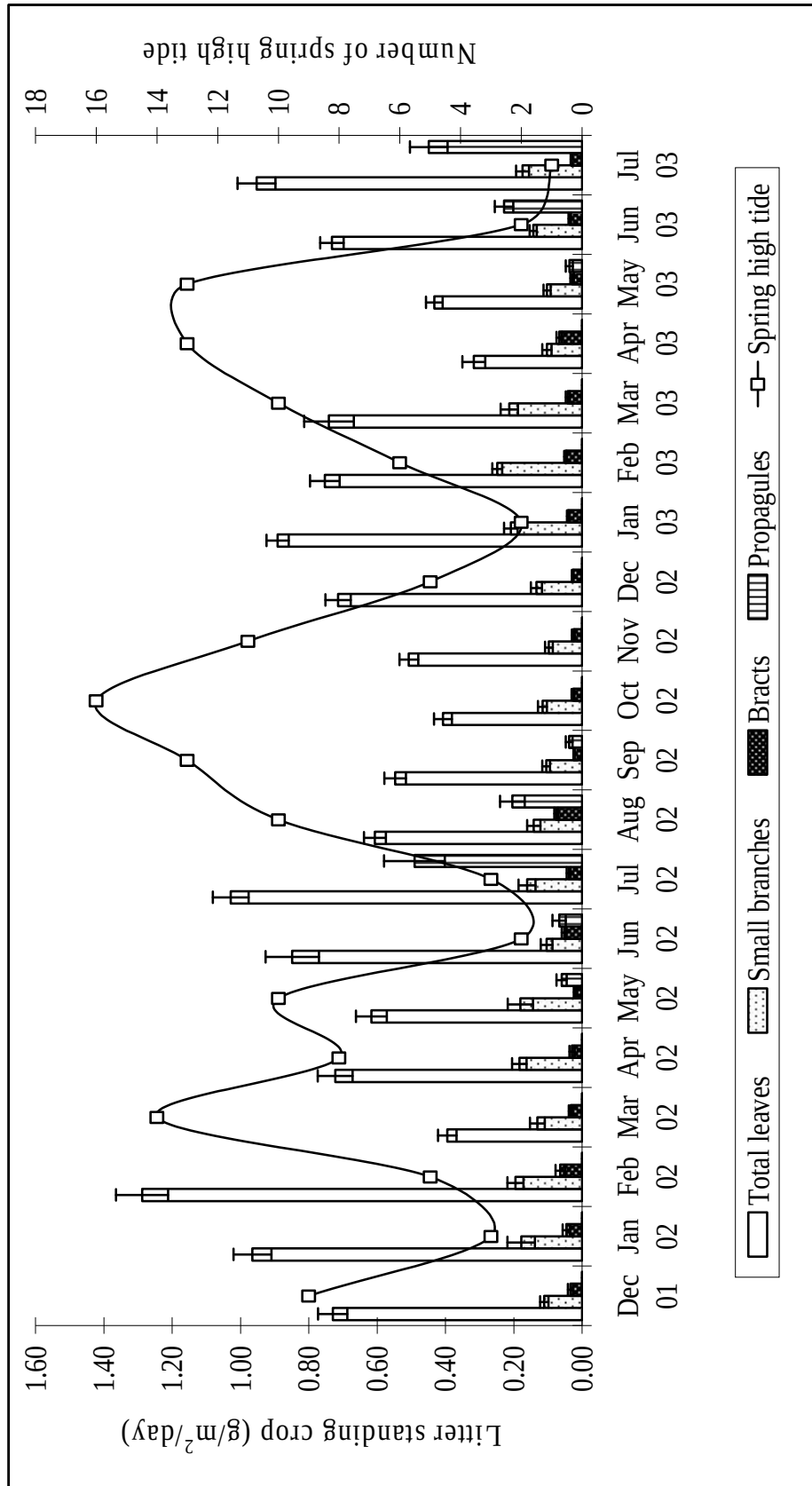


Figure 5.6: Variation in litter standing crop ($\text{g/m}^2/\text{day}$) by components at different months associated with number of spring high tide flooded the forest area

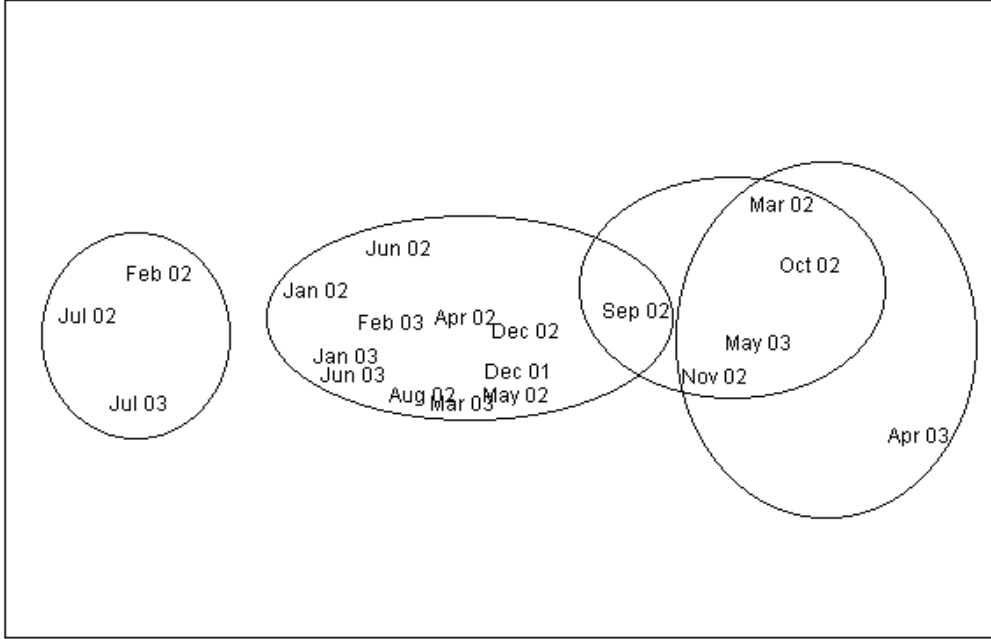


Figure 5.7: Fluctuation pattern of total litter standing crop. Months within circles are not significantly (DMRT, $p > 0.05$) different

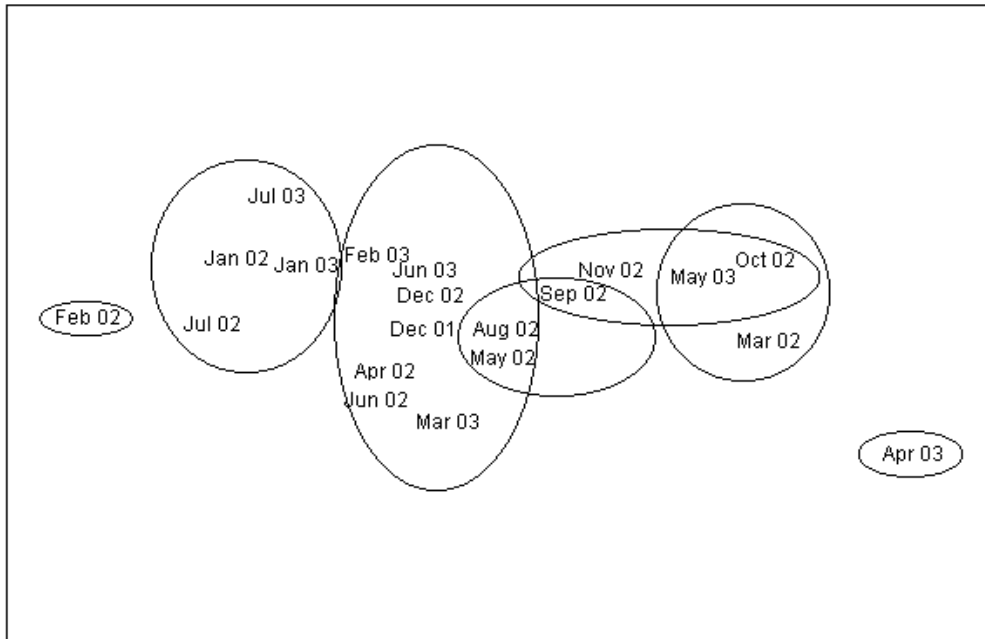


Figure 5.8: Fluctuation pattern of total leaf litter (intact and broken leaves) standing crop. Months within circles are not significantly (DMRT, $p > 0.05$) different

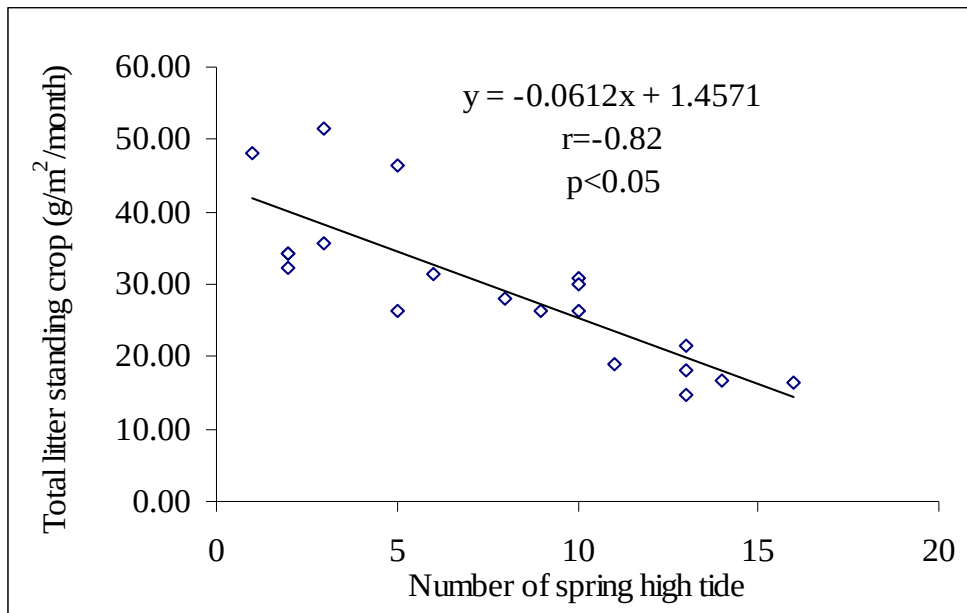


Figure 5.9: Relationship between number of spring high tide that flooded the forest area and monthly amount (g/m²/month) of total litter standing crop

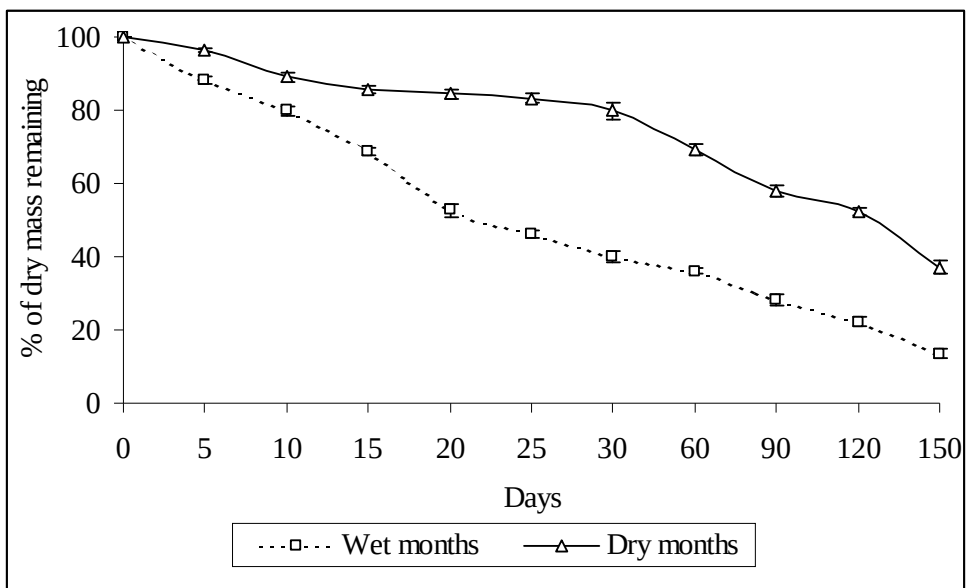


Figure 5.10: Mean percentage of dry mass remaining in litterbags at different time interval during dry and wet months

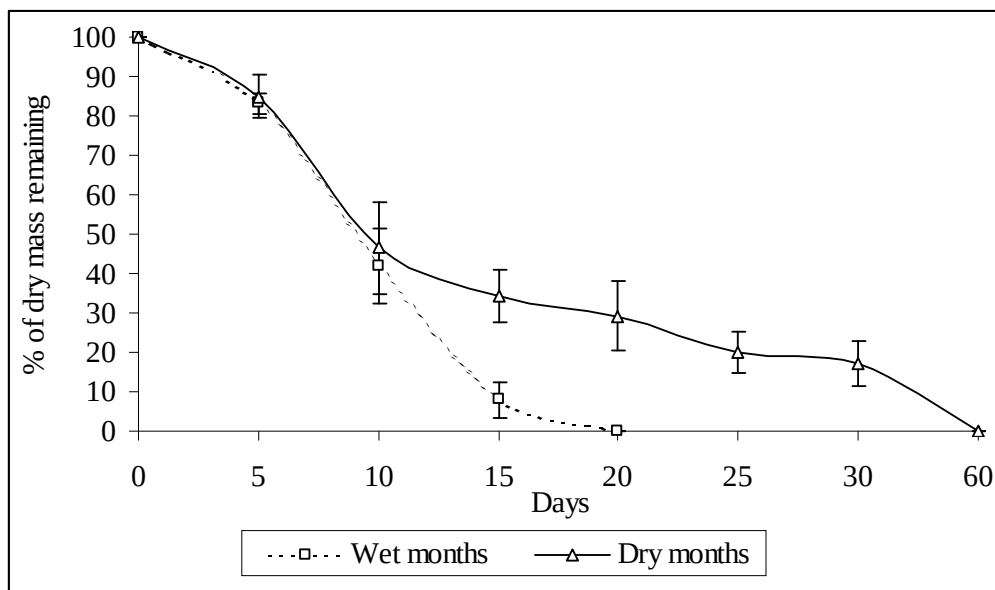


Figure 5.11: Mean percentage of dry mass remaining in litter strings at different time interval during dry and wet months

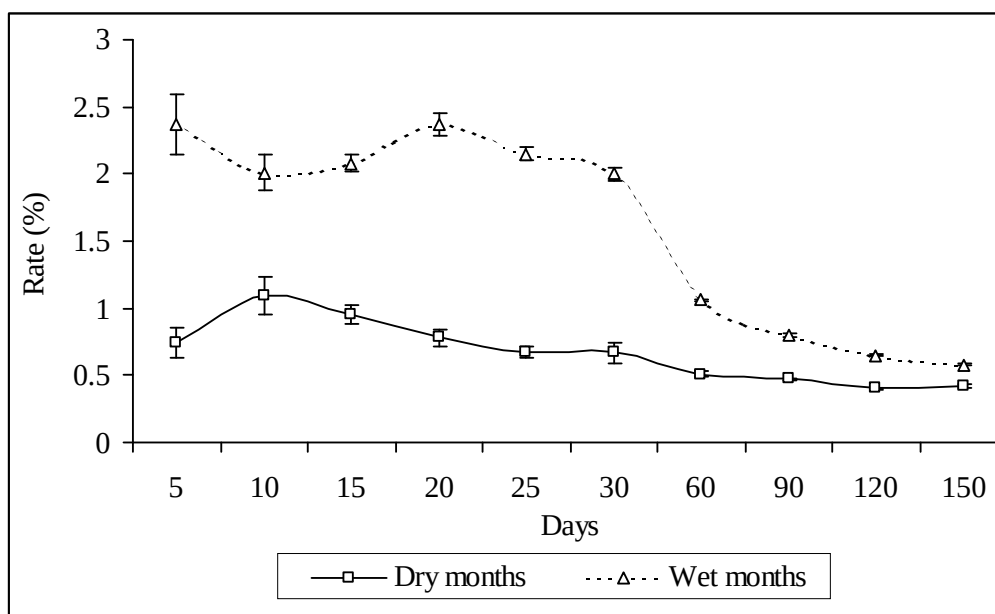


Figure 5.12: Degradation rate (%) of leaf litter in bags at different time interval during dry and wet months

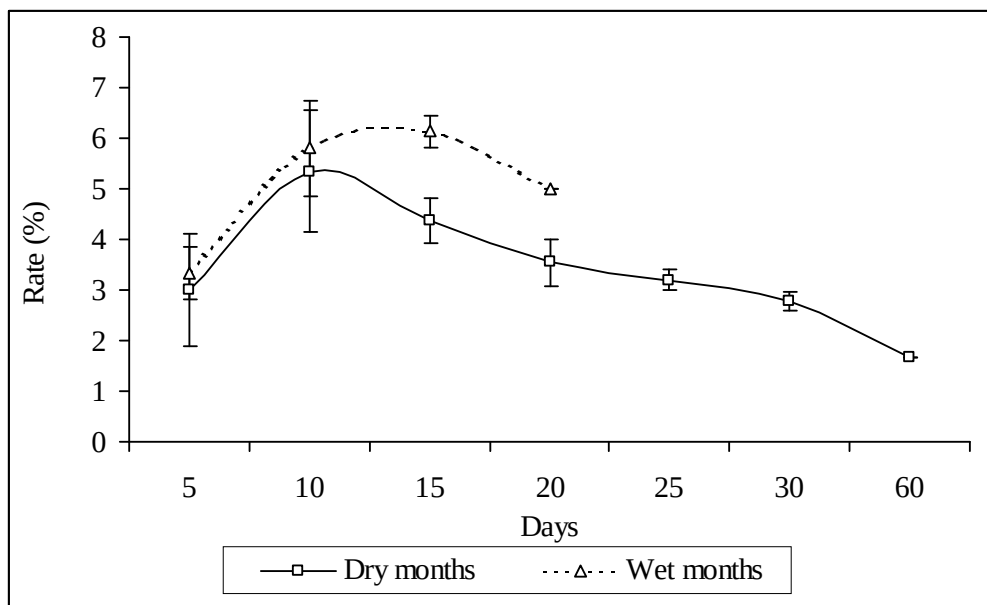
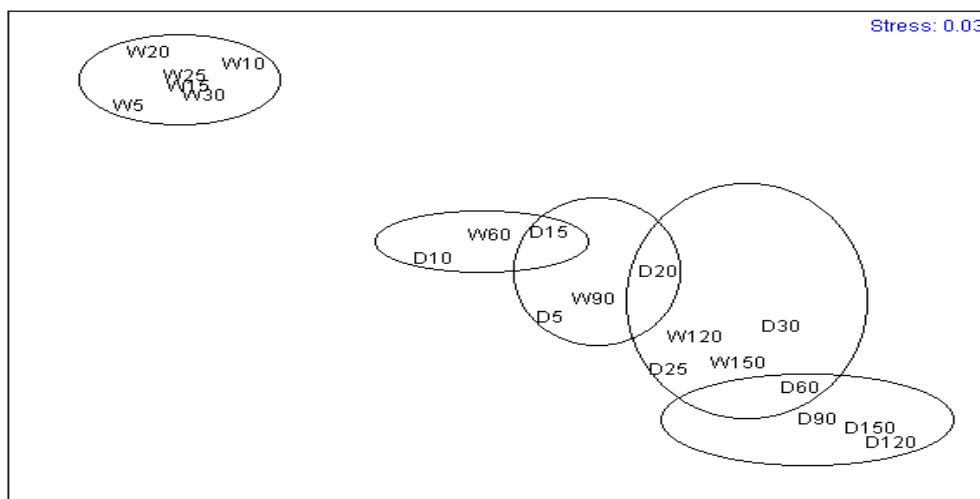
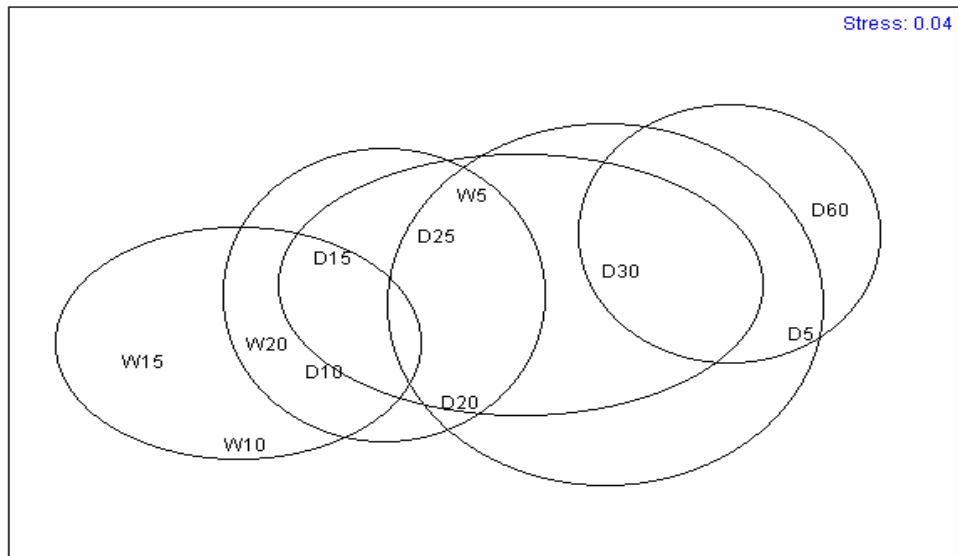


Figure 5.13: Degradation rate (%) of leaf litter on strings at different time interval during dry and wet months



D5. ...D150 and W5...W150 are different days during dry and wet months

Figure 5.14: Pattern of microbial degradation rates of leaves litter during dry and wet months. Days within circles are not significantly (DMRT, $p > 0.05$) different



D5. J60 and W5...W20 are different days during dry and wet months

Figure 5.15: Pattern of leaves litter loss due to microbial and feeding plus mechanical breakdown rates during dry and wet months. Days within circles are not significantly (DMRT, $p > 0.05$) different

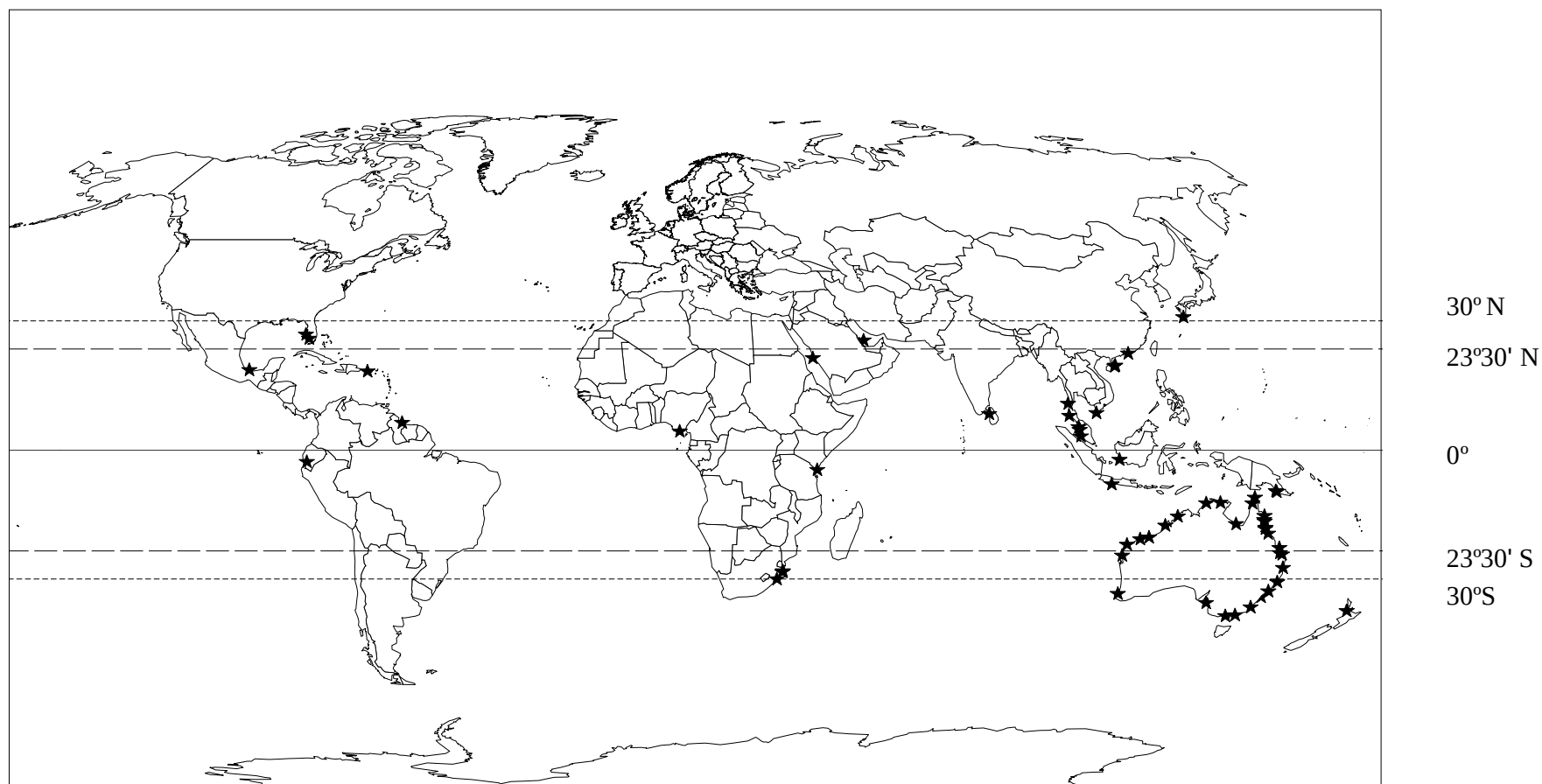


Figure 5.16: World map showing mangrove litter production studies (*)

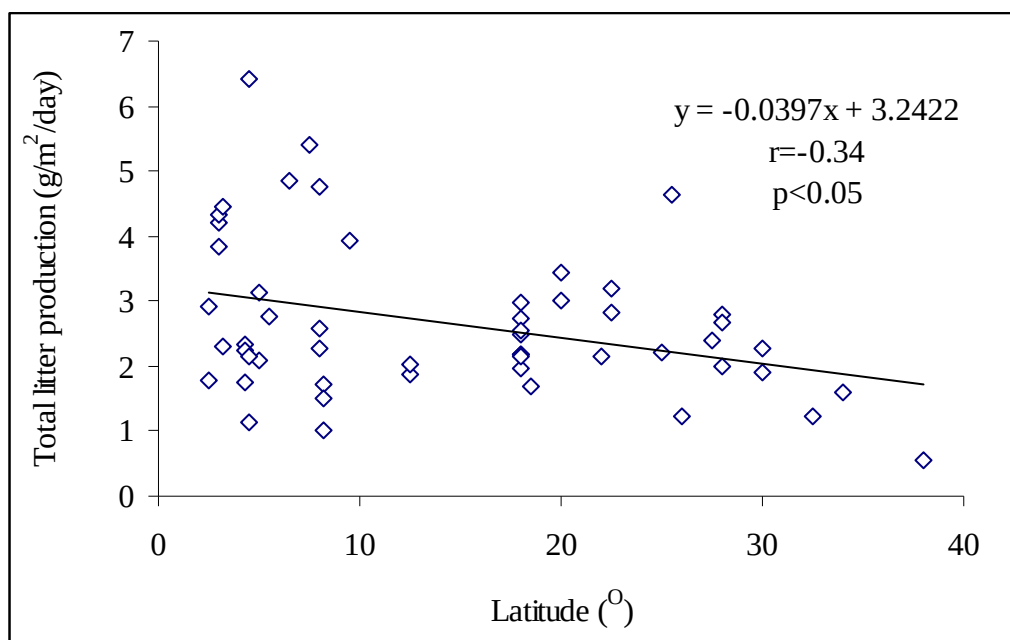


Figure 5.17: Relationship between latitude and total litter production

CHAPTER 6

NUTRIENTS IN PLANT

6.1 Introduction

Sixteen elements (C, H, O, Ca, Mg, N, P, K, S, B, Cl, Cu, Fe, Mn, Mo and Zn) are considered essential for plant growth and development (Jones, 1998). Carbon, hydrogen and oxygen are major elements and abundant as carbon dioxide and water (Binkley, 1986; Jones *et al.*, 1991). The remaining 13 essential elements have the unique pattern of sources, transformation and availability to plants under various environmental conditions (Mengel and Kirkby, 1982; Binkley, 1986; Marschner, 1995). A considerable amount of atmospheric nitrogen is fixed in the roots of leguminous plants by the nitrogen-fixing bacteria living in the root surface symbiotically (Jones *et al.*, 1991).

Plants uptake available form of nutrients from soil and are translocated to their different components. The nutrients are essential for different physiological function (such as respiration, transpiration and photosynthesis) and normal growth or metabolism of plants or to complete life cycle (Jones *et al.*, 1991; Marschner, 1995). Thus, forest productivity is directly related to nutrient availability and uptake (Boto and Wellington, 1983; Binkley, 1986). The nutrients, absorbed by plants tend to be immobilised in plant tissues and some portions of these nutrients returned as plant litter (Golley *et al.*, 1975; Clough *et al.*, 1983; Jordan, 1985; Heal and Harrison, 1990; Jiao *et al.*, 1997; Li, 1997). In the mangrove forest, some portions of the plant litter are exported by tidal flushing and result in nutrients loss from the system (Boto and Bunt, 1981; Boto, 1982; Lee, 1995). Nutrients are released from the plant litter by leaching process (Steinke *et al.*, 1993a) and decomposed by micro-organisms (JaparSidik, 1989; Tam *et al.*, 1998; Mackey and Smail 1996; Ashton *et al.*, 1999).

A number of studies have been carried out on nutrient contents in different components of mangrove species (mainly trees) (Clough and Attiwill, 1975; Aksornkoae and Khemnark, 1984; Onget *et al.*, 1985a; Lacerdaet *et al.*, 1985; Gong and Ong, 1990; Sadiq and Zaidi, 1994; Tam *et al.*, 1995a; Lianet *et al.*, 1999; Lin and Wang, 2001), litter production (Aksornkoae and Khemnark, 1984; Gong *et al.*, 1984; Onget *et al.*, 1985a; Woodroffe *et al.*, 1988; Day *et al.*, 1996; Jiao *et al.*, 1997; Li, 1997), litter standing crop (Gong *et al.*, 1984; Onget *et al.*, 1985a; Gong and Ong, 1990; Day *et al.*, 1996) and nutrients at the different stages of leaf litter decomposition (Valk and Attiwill, 1984; Robertson, 1988; Tam *et al.*, 1990; Tam *et al.*, 1998; Dick and Osunkoya, 2000; Davis *et al.*, 2003; Nielsen and Andersen, 2003). Some studies focused on nutrient fluxes in the mangroves (Aksornkoae and Khemnark, 1984; Gong and Ong, 1990; Jiao *et al.*, 1997; Li, 1997), but reports on seasonal variation of nutrient contents in plant components, litter production and litter standing crop are still lacking.

6.1.1 Objectives

The objectives of this study were

1. To measure and compare the nutrient (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) and organic matter contents in different components of *Bruguiera parviflora* seedlings, saplings and trees during the intermediate (March), dry (July) and wet (November) seasons.
2. To measure and compare the nutrient (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) and organic matter contents in different components of litter production and litter standing crop during the intermediate (March), dry (July) and wet (November) seasons.
3. To measure and compare the nutrient (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) and organic matter contents at different stages of *B. parviflora* leaf litter degradation during the dry (July 2002 – November 2002) and wet (November 2002 – March 2003) months.

6.2 Materials and Methods

6.2.1 Plant Sampling

Samples of different components of *B. parviflora* seedlings, saplings and trees were collected from the study area during the intermediate season (March 2002), dry season (July 2002), wet season (November 2002), intermediate season (March 2003) and dry season (July 2003). Six seedlings (height less than one meter) were randomly selected and uprooted. Collected seedlings were then separated into leaves, stems and roots. Sub-samples (about 100 g) of each component were taken randomly for analysing the selected nutrients.

A total of six saplings (two saplings from each DBH class of 1-2 cm, 2-3 cm, and 3->4 cm), were selected randomly (avoiding suppressed, mechanically or insect damaged or infested with disease), felled and uprooted. Sub-samples (about 100 g) of leaves, buds, branches, bark, stems and roots were collected randomly from each sapling for analysing the selected nutrients.

A total of six trees (one tree from each DBH class of 4-6 cm, 6-8 cm, 8-10 cm, 10-12 cm, 12-14 cm and 14-16 cm) were selected randomly (avoiding suppressed, mechanically or insect damaged or infested with disease). Selected nutrients were analysed from randomly collected sub-samples (about 100 g) of leaves, buds, flowers, propagules and small branches (diameter < 2 cm), bark, stems and roots (homogenous sub-sample of smaller and bigger roots of diameter < 1 cm and diameter > 1 cm, respectively). Sub-samples of leaves, buds, flowers, propagules and small branches (diameter < 2 cm) were collected randomly by using sharp knife attached with long pole, bark samples were collected by using sharp knife and stem borer was used for the collection of stem samples. One buttress root was selected randomly from each tree and

roots were excavated followed by the buttress root by using water jet and portable winch. The detail procedures of root excavation of seedlings, saplings and trees are described in Sections 4.2.1-4.2.2, Chapter 4.

6.2.2 Sampling of Litter Production and Litter Standing Crop

The detail sampling procedures of litter production and litter standing crop were described in Sections 5.2.1-5.2.2, Chapter 5. Selected nutrient contents in different components of litter production and litter standing crop were analysed during the intermediate season (March 2002), dry season (July 2002), wet season (November 2002), intermediate season (March 2003) and dry season (July 2003).

6.2.3 Sampling of Degraded Leaf Litter

The selected nutrient contents at different stages of *B. parviflora* leaf litter degradation in litter bags and leaves on strings were analysed during the dry (July 2002 to November 2002) and wet (November 2002 to March 2003) months. The detail sampling procedures were described in Section 5.2.3.4, Chapter 5.

6.2.4 Sample Processing

Collected plant samples were put into separate labelled airtight plastic bag and placed into ice chest and brought back to the laboratory for further processing. Individual plant component was then oven-dried at 80°C until constant weight for 5 days. The detail sample processing of litter production, litter standing crop and degraded leaf litter were described in Sections 5.2.1-5.2.2 and 5.2.3.4, Chapter 5. The oven-dried samples were grinded by a mechanical grinder (model A10 manufactured by 1 KA-Labortechnik) and sieved through 2 mm mesh (Allen, 1974).

6.2.5 Nutrients in Plant Samples

6.2.5.1 Determination of Total Nitrogen

Oven-dried plant sample (0.10 g) was placed into a digestion tube and digested according to Allen (1974), the detail digestion procedure was describes in Section 3.2.1.9, Chapter 3. Ammonium content in digested samples was measured according to Weatherburn (1967) and total nitrogen content in plant samples was calculated from the ammonium content as described in Section 3.2.1.9, Chapter 3.

6.2.5.2 Determination of Total Phosphorus

Same digested solution of samples for total nitrogen (Section 6.2.5.1) was used for measuring total phosphorus content in plant samples. Total phosphorus content in plant samples was measured according to Timothy *et al.* (1984) as described in Section 3.2.1.10, Chapter 3.

6.2.5.3 Determination of Total Potassium, Calcium, Magnesium, Copper, Iron and Zinc

Oven-dried plant sample (0.50 g) was placed into a digestion tube and 5 ml concentrated Nitric acid was added and heated cautiously to oxidize the organic matter and 6.50 ml of mixed acid (Perchloric acid 60%, Nitric acid and Sulphuric acid were mixed at a proportion of 2:10:1) was added to the predigested samples and digested until clear. After digestion, the extract was filtered and diluted to 50 ml with deionized water (Allen, 1974). Atomic Absorption Spectrophotometer (PERKIN ELMER 4100, USA) was used for measuring total calcium, magnesium, copper, iron and zinc content in the extract. Total potassium content in samples extract was measured by Flame photometer (PFP7, Jenway LTD, England). The detail of standard stock solution and preparation of calibration curves were described in the Section 3.2.1.11.

6.2.5.4 Determination of Total Sulphur

Oven-dried sieved plant sample (0.20 g) was placed into a digestion tube and samples were digested according to Hesse (1971) as mentioned in Section 3.2.1.12, Chapter 3. Total sulphur content in samples extraction was measured by Barium chloride turbidity method (Tandon, 1993) and the detailed procedure was described in Section 3.2.1.12, Chapter 3.

6.2.5.5 Determination of Total Carbon

Total carbon content in plant samples was measured by combustion method (Allen, 1974) by using Leco CR – 12 Carbon determinator, USA and the principle of this instrumental measurement was described in Section 3.2.1.13, Chapter 3.

6.2.5.6 Organic Matter Content

One gram of oven-dried (105°C) plant sample was taken in a crucible and placed in a furnace (Carbolite ELF 11/6, Thermal Engineering Services, England). Temperature was raised slowly up to 500°C and kept this temperature for three hours. After cooling to room temperature, the weight of the ignited sample was taken (Onget *al.*, 1985b). Percentage of organic matter content in plant samples was calculated from the following equation.

$$\text{Organic matter (\%)} = \frac{\text{Loss of weight (g)}}{\text{Oven dry weight (g)}} \times 100$$

6.2.6 Statistical Analysis

Nutrient contents in different components of *B. parviflora* seedlings, saplings, trees, litter production and litter standing crop were compared in each season and among the

seasons by two-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p < 0.05$) by using SAS (6.12) statistical software. Pearson correlation analysis was performed among nutrient contents in plant components and soil nutrients level by using SPSS (11.0) statistical software. Nutrient contents at different stages of leaf litter degradation in litter bags and leaves on strings during the dry and wet months were compared by one-way analysis of variance (ANOVA) followed by Duncan Multiple Range Test (DMRT, $p < 0.05$) by using SAS (6.12) statistical software.

6.3 Results

6.3.1 Nitrogen

In seedlings components, comparatively higher nitrogen content was observed in leaves (8.51 ± 0.27 - 10.70 ± 0.35 mg/g) followed by stems (4.59 ± 0.11 - 8.24 ± 0.13 mg/g) and roots (3.45 ± 0.06 - 5.80 ± 0.12 mg/g) (ANOVA, DMRT, $p < 0.05$). Seedlings components contained relatively higher nitrogen during the intermediate (March 02 and 03) seasons followed by wet (November 02) and dry seasons (July 02 and 03) (Tables 6.1-6.5 and Figure 6.1) (ANOVA, DMRT, $p < 0.05$). In saplings components, leaves contained relatively higher nitrogen (11.54 ± 0.09 - 12.48 ± 0.14 mg/g) followed by buds (8.09 ± 0.13 - 9.80 ± 0.11 mg/g), branches (4.72 ± 0.13 - 6.39 ± 0.15 mg/g), bark (4.27 ± 0.04 - 4.66 ± 0.03 mg/g), roots (3.52 ± 0.07 - 3.91 ± 0.08 mg/g) and stems (1.49 ± 0.14 - 1.53 ± 0.13 mg/g) (ANOVA, DMRT, $p < 0.05$). Leaves, buds and branches showed significant variation in nitrogen content among the seasons and comparatively higher nitrogen content was found during the intermediate seasons (March 02 and 03) (ANOVA, DMRT, $p < 0.05$). Nitrogen content in stems, roots and bark did not show significant (ANOVA, DMRT, $p > 0.05$) difference among the seasons (Tables 6.1-6.5 Figure 6.2). In trees components, relatively higher nitrogen content was observed in leaves (11.58 ± 0.19 - 14.05 ± 0.30 mg/g) followed by buds (8.66 ± 0.17 - 10.98 ± 0.19 mg/g) and branches (3.48 ± 0.10 - 5.00 ± 0.10 mg/g) (ANOVA, DMRT, $p < 0.05$). Comparatively higher nitrogen content was found in leaves, buds and branches during the intermediate seasons (March 02 and 03) followed by wet (November 02) and dry seasons (July 02 and 03), but bark, stems and roots showed almost similar nitrogen content among the seasons (Tables 6.1-6.5 and Figure 6.3) (ANOVA, DMRT, $p < 0.05$). Nitrogen content in all the components of seedlings, saplings and trees (except the stems of saplings and trees) showed positive correlation with the total nitrogen content in soil (Table 6.6).

In litter production components, leaves contained comparatively higher nitrogen (5.47 ± 0.18 - 6.31 ± 0.11 mg/g) followed by bracts (4.28 ± 0.13 - 5.57 ± 0.17 mg/g) and branches (2.81 ± 0.12 - 3.48 ± 0.12 mg/g) and their contents varied significantly (ANOVA, DMRT, $p < 0.05$) among the seasons. However, comparatively higher nitrogen content was observed in leaves, branches and bracts during the intermediate season (March 03), dry season (July 03) and intermediate season (March 02), respectively (Table 6.7 and Figure 6.4) (ANOVA, DMRT, $p < 0.05$). In litter standing crop, broken leaves contained

relatively higher nitrogen (7.13 ± 0.18 - 10.62 ± 0.29 mg/g) compared to other components (ANOVA, DMRT, $p < 0.05$). Intact leaves, broken leaves and bracts contained relatively higher nitrogen during the intermediate seasons (March 02 and 03), but branches contained comparatively higher nitrogen during the intermediate seasons (March 02 and 03) and dry season (July 03) (Tables 6.7-6.11 and Figure 6.5) (ANOVA, DMRT, $p < 0.05$). In leaf litter degradation, nitrogen in degraded leaf litter significantly (ANOVA, DMRT, $p < 0.05$) increased from the initial content (4.24 ± 0.14 mg/g) up to 9.34 ± 0.03 mg/g at the end of 150 days during the dry months (July 02-November 02). During the wet months (November 02-March 03), initial nitrogen content (4.60 ± 0.03 mg/g) in leaf litter significantly (ANOVA, DMRT, $p < 0.05$) increased up to 10.68 ± 0.04 mg/g at 60 days and sharply decreased at 3.88 ± 0.03 mg/g after 150 days (Table 6.12 and Figure 6.6).

6.3.2 Phosphorus

In seedlings components, leaves contained relatively higher phosphorus (1.34 ± 0.02 - 1.80 ± 0.04 mg/g) and the ranges of phosphorus in stem and roots were 0.39 ± 0.01 - 0.93 ± 0.03 mg/g and 0.68 ± 0.01 - 0.90 ± 0.02 mg/g, respectively (ANOVA, DMRT, $p < 0.05$). Seedlings leaves and stems contained comparatively higher phosphorus 1.34 ± 0.02 mg/g and 0.93 ± 0.03 mg/g, respectively, during the intermediate season (March 02) and lower content was observed in the wet season (November 02) (Tables 6.1-6.5 and Figure 6.7) (ANOVA, DMRT, $p < 0.05$). In saplings components, comparatively higher phosphorus content was observed in buds (1.19 ± 0.03 - 1.50 ± 0.03 mg/g) followed by leaves (0.86 ± 0.02 - 1.24 ± 0.03 mg/g) and lower content was observed in stems (0.29 ± 0.01 - 0.81 ± 0.01 mg/g) (ANOVA, DMRT, $p < 0.05$). Phosphorus in saplings components showed significant (ANOVA, DMRT, $p < 0.05$) seasonal variation and relatively lower content was observed during the wet season (November 02) (Tables 6.1-6.5 and Figure 6.8). In trees, buds contained relatively higher phosphorus (1.30 ± 0.03 - 1.59 ± 0.03 mg/g) followed by bark (1.22 ± 0.03 - 1.43 ± 0.03 mg/g) and leaves (0.97 ± 0.02 - 1.33 ± 0.02 mg/g) and lowest content (0.28 ± 0.01 - 0.42 ± 0.01 mg/g) was found in the stems (ANOVA, DMRT, $p < 0.05$). Different components of trees contained comparatively lower phosphorus during the wet season (November 02) (Tables 6.1-6.5 and Figure 6.9) (ANOVA, DMRT, $p < 0.05$). Phosphorus content in all the components of seedlings, saplings and trees, except the roots of seedlings showed positive correlation with the total phosphorus content in soil (Table 6.6).

In litter production components, comparatively higher phosphorus content was found in flowers (1.56 ± 0.05 - 1.64 ± 0.05 mg/g) followed by leaves (0.69 ± 0.01 - 1.21 ± 0.02 mg/g), bracts (0.65 ± 0.02 - 1.13 ± 0.02 mg/g) and branches (0.51 ± 0.01 - 0.92 ± 0.01 mg/g) (ANOVA, DMRT, $p < 0.05$). Litter production components showed significantly (ANOVA, DMRT, $p < 0.05$) lower phosphorus content during the wet season

(November 02) (Tables 6.7-6.11 and Figure 6.10). In litter standing crop, intact leaves contained relatively higher phosphorus (0.60 ± 0.02 - 1.13 ± 0.02 mg/g) followed by broken leaves (0.41 ± 0.01 - 1.12 ± 0.02 mg/g) and in some cases bracts (0.38 ± 0.01 - 1.00 ± 0.03 mg/g) and lowest content (0.34 ± 0.01 - 0.75 ± 0.02 mg/g) was found in branches (ANOVA, DMRT, $p<0.05$). However, different components of litter standing crops showed relatively lower content during the wet season (November 02) (Tables 6.7-6.11 and Figure 6.11) (ANOVA, DMRT, $p<0.05$). In leaf litter degradation, initial phosphorus content (1.11 ± 0.03 mg/g) in degraded leaf litter significantly (ANOVA, DMRT, $p<0.05$) increased (1.19 ± 0.04 - 1.24 ± 0.01 mg/g) after 5 to 10 days and decreased up to 0.16 ± 0.01 mg/g at the end of 150 days during the dry months (July 02-November 02). During the wet months (November 02-March 03), phosphorus in degraded leaf litter significantly (ANOVA, DMRT, $p<0.05$) decreased from initial content (0.60 ± 0.01 mg/g) up to 0.050 ± 0.01 mg/g after 150 days (Table 6.12 and Figure 6.12).

6.3.3 Potassium

In seedlings components, comparatively higher potassium content (5.83 ± 0.12 - 7.62 ± 0.16 mg/g) was observed in leaves followed by roots (2.43 ± 0.06 - 6.31 ± 0.11 mg/g) and stems (2.27 ± 0.10 - 5.39 ± 0.11 mg/g) (ANOVA, DMRT, $p<0.05$). Seedlings components contained relatively higher potassium during the intermediate seasons (March 02 and 03) followed by dry seasons (July 02 and 03) (Tables 6.1-6.5 and Figure 6.13) (ANOVA, DMRT, $p<0.05$). In saplings components, leaves contained comparatively higher potassium (4.17 ± 0.13 - 12.62 ± 0.22 mg/g) followed by buds (4.01 ± 0.09 - 8.66 ± 0.17 mg/g), but stems contained relatively lower potassium (0.91 ± 0.04 - 1.02 ± 0.01 mg/g) (ANOVA, DMRT, $p<0.05$). Leaves, buds, branches and roots of saplings contained relatively higher potassium during the intermediate seasons (March 02 and 03) and lower in wet season (November 02) (ANOVA, DMRT, $p<0.05$). However, potassium in leaves, buds and roots was not significantly (ANOVA, DMRT, $p>0.05$) different during the wet season (November 02) (Tables 6.1-6.5 and Figure 6.14). In tree components, leaves contained relatively higher potassium (5.50 ± 0.10 - 11.89 ± 0.07 mg/g) followed by buds (4.80 ± 0.09 - 8.39 ± 0.09 mg/g), roots (3.18 ± 0.08 - 6.08 ± 0.13 mg/g) and branches (1.08 ± 0.03 - 2.60 ± 0.04 mg/g) (ANOVA, DMRT, $p<0.05$). Leaves, buds, branches and roots showed comparatively higher potassium content during the intermediate seasons (March 02 and 03), but stems and bark showed almost similar potassium content in different seasons (Tables 6.1-6.5 and Figure 6.15) (ANOVA, DMRT, $p<0.05$). Potassium content in leaves, stems and roots of seedlings, leaves, buds, branches and roots of saplings and leaves, stems and roots of trees showed significant ($p<0.05$) positive correlation with the total potassium content in soil (Table 6.6).

In litter production components, flowers (4.12 ± 0.09 - 4.54 ± 0.15 mg/g) and propagules (4.21 ± 0.12 - 4.37 ± 0.13 mg/g) contained relatively higher potassium followed by leaves (2.03 ± 0.05 - 2.41 ± 0.04 mg/g), bracts (0.80 ± 0.03 - 1.50 ± 0.03 mg/g) and branches (0.52 ± 0.02 - 0.74 ± 0.02 mg/g) (ANOVA, DMRT, $p<0.05$). Potassium content in leaves, branches and bracts did not show any consistent pattern in seasonal fluctuation (Tables 6.7-6.11 and Figure 6.16). In litter standing crops, propagules contained comparatively higher potassium (3.41 ± 0.14 - 3.49 ± 0.10 mg/g) and the lower content (0.97 ± 0.03 - 1.12 ± 0.04 mg/g) was observed in branches (except intermediate season, March 02) (ANOVA, DMRT, $p<0.05$). However, relatively higher potassium content in intact leaves, broken leaves and bracts was found during the dry seasons (July 02 and 03) (Tables 6.7-6.11 and Figure 6.17) (ANOVA, DMRT, $p<0.05$). In leaf litter degradation, initial potassium content (2.36 ± 0.03 mg/g) in degraded leaf litter significantly (ANOVA, DMRT, $p<0.05$) decreased down to 0.92 ± 0.02 mg/g (leaf on strings) and 0.73 ± 0.02 mg/g (litter bags) after 15 days and remained almost similar content (0.79 ± 0.02 mg/g) at the end of 150 days during the dry months (July 02-November 02). During the wet months (November 02-March 03), potassium content in degraded leaf litter significantly (ANOVA, DMRT, $p<0.05$) decreased from the initial content (3.03 ± 0.02 mg/g) down to 0.66 ± 0.01 mg/g (leaf on strings) and 0.60 ± 0.01 mg/g (litter bags), respectively after 10 days and remained almost similar content (0.64 ± 0.01 mg/g) at the end of 150 days (Table 6.12 and Figure 6.18).

6.3.4 Calcium

In seedlings components, leaves contained relatively higher calcium (5.04 ± 0.09 - 6.70 ± 0.14 mg/g) followed by stems (3.57 ± 0.09 - 4.64 ± 0.10 mg/g) and roots (2.50 ± 0.08 - 3.57 ± 0.12 mg/g) (ANOVA, DMRT, $p<0.05$). Comparatively higher calcium content in seedlings components was observed during the intermediate seasons (March 02 and 03) and lower in the dry seasons (July 02 and 03) (Tables 6.1-6.5 and Figure 6.19) (ANOVA, DMRT, $p<0.05$). In saplings components, buds contained relatively higher calcium (8.55 ± 0.15 - 11.63 ± 0.21 mg/g) and stems contained comparatively lower calcium (1.53 ± 0.03 - 1.56 ± 0.02 mg/g) (ANOVA, DMRT, $p<0.05$). Similar content of calcium in leaves and buds; leaves, buds and bark; buds and bark was observed during the intermediate seasons (March 02 and 03), intermediate season (March 03) and dry season (July 03), respectively. Comparatively higher calcium content in leaves, buds, branches and roots were observed during the intermediate seasons (March 02 and 03) (ANOVA, DMRT, $p<0.05$), but stem showed similar calcium content ($1.53\pm$ - $1.56\pm$ mg/g) in different seasons (Tables 6.1-6.5 and Figure 6.20). In trees components, relatively higher calcium content (11.10 ± 0.05 - 17.70 ± 0.13 mg/g) was found in bark followed by buds (8.87 ± 0.15 - 11.67 ± 0.18 mg/g), leaves (7.28 ± 0.10 - 11.40 ± 0.13 mg/g), branches (5.62 ± 0.11 - 7.98 ± 0.13 mg/g), roots (3.19 ± 0.05 - 6.00 ± 0.08 mg/g) and stems (1.07 ± 0.02 - 1.12 ± 0.02 mg/g) (ANOVA, DMRT, $p<0.05$). Comparatively higher calcium content in leaves, buds, bark and roots was observed during the intermediate

seasons (March 02 and 03) (ANOVA, DMRT, $p < 0.05$) and calcium content in stems remained similar in different seasons (Tables 6.1-6.5 and Figure 6.21). Calcium content in roots of seedlings, bark and roots of saplings and leaves, buds, bark and roots of trees showed significant ($p < 0.05$) positive correlation with the total calcium content in soil (Table 6.6).

In litter production components, the ranges of calcium content in leaves, branches, bracts, flowers and propaguls in different seasons were 10.03 ± 0.16 - 17.06 ± 0.12 mg/g, 8.27 ± 0.07 - 12.73 ± 0.10 mg/g, 11.26 ± 0.10 - 14.63 ± 0.12 mg/g, 11.04 ± 0.04 - 17.30 ± 0.09 and 1.55 ± 0.07 - 1.80 ± 0.03 mg/g, respectively and leaves and branches showed similar trend of calcium content in different seasons. Comparatively higher calcium content in leaves, branches and bracts was observed during the intermediate season (March 03) and relatively lower calcium content in leaves and branches were found during the dry seasons (July 02 and 03) (Tables 6.7-6.11 and Figure 6.22) (ANOVA, DMRT, $p < 0.05$). In litter standing crop, relatively higher calcium (11.48 ± 0.19 - 16.08 ± 0.26 mg/g) was found in bracts and lower in broken leaves (6.71 ± 0.10 - 9.11 ± 0.17 mg/g) (ANOVA, DMRT, $p < 0.05$). Intact leaves, broken leaves and bracts showed similar trend of calcium content in different seasons and comparatively higher calcium content was observed during the intermediate season (March 03) (Tables 6.7-6.11 and Figure 6.23) (ANOVA, DMRT, $p < 0.05$). In leaf litter degradation, calcium content in degraded leaf litter showed similar decreasing trend during the dry (July 02-November 02) and wet (November 02-March 03) months. Initial calcium content (8.72 ± 0.02 mg/g) in degraded leaf litter significantly (ANOVA, DMRT, $p < 0.05$) decreased up to 4.08 ± 0.06 mg/g during the dry months after 150 days and initial calcium content (15.12 ± 0.11 mg/g) during the wet months significantly (ANOVA, DMRT, $p < 0.05$) decreased up to 7.70 ± 0.06 mg/g after 150 days (Table 6.12 and Figure 6.24).

6.3.5 Magnesium

In seedlings components, leaves contained comparatively higher magnesium (8.12 ± 0.13 - 10.93 ± 0.24 mg/g) followed by roots (4.29 ± 0.13 - 5.42 ± 0.15 mg/g) and stems (2.19 ± 0.08 - 3.00 ± 0.07 mg/g) (ANOVA, DMRT, $p < 0.05$). Seedlings components showed significant (ANOVA, DMRT, $p < 0.05$) variation in magnesium content in different seasons and relatively higher magnesium content in leaves and roots was observed during the intermediate seasons (March 02 and 03) (Tables 6.1-6.5 and Figure 6.25) (ANOVA, DMRT, $p < 0.05$). In saplings components, comparatively higher magnesium content (6.01 ± 0.09 - 11.46 ± 0.11 mg/g) was found in leaves followed by buds (4.67 ± 0.10 - 7.35 ± 0.11 mg/g), roots (3.74 ± 0.14 - 5.18 ± 0.20 mg/g), branches (1.20 ± 0.06 - 1.86 ± 0.06 mg/g), barks (1.05 ± 0.03 - 1.26 ± 0.04 mg/g) and stems (0.58 ± 0.01 - 0.61 ± 0.01 mg/g) (ANOVA, DMRT, $p < 0.05$). Magnesium content in stems remained similar in different seasons, but other components (leaves, buds and roots) showed relatively higher content during the intermediate seasons (March 02 and 03) followed by wet (November 02) and dry seasons (July 02 and 03) (Tables 6.1-6.5 and Figure

6.26) (ANOVA, DMRT, $p < 0.05$). In trees components, leaves contained comparatively higher magnesium (6.63 ± 0.16 - 11.08 ± 0.12 mg/g) and relatively lower magnesium (0.39 ± 0.01 - 0.41 ± 0.01 mg/g) was observed in stems (ANOVA, DMRT, $p < 0.05$). Magnesium content in bark and stems remained similar in different seasons, but other components showed comparatively higher magnesium content during the intermediate seasons (March 02 and 03) (Tables 6.1-6.5 and Figure 6.27) (ANOVA, DMRT, $p < 0.05$). Magnesium content in leaves and roots of seedlings, leaves, buds, branches, bark and roots of saplings and leaves, buds, branches, and roots of trees showed significant ($p < 0.05$) positive correlation with the total magnesium content in soil (Table 6.6).

In litter production components, leaves (2.93 ± 0.06 - 4.00 ± 0.05 mg/g) and bracts (2.99 ± 0.04 - 3.90 ± 0.05 mg/g) contained relatively higher magnesium followed by branches (0.49 ± 0.04 - 0.81 ± 0.04 mg/g) (ANOVA, DMRT, $p < 0.05$). Comparatively higher magnesium content in leaves and bracts was observed during the intermediate seasons (March 02 and 03) and relatively lower magnesium was found during the dry seasons (July 02 and 03) (Table 6.7-6.11 and Figure 6.28) (ANOVA, DMRT, $p < 0.05$). In litter standing crop, broken leaves (3.40 ± 0.12 - 4.69 ± 0.12 mg/g) and bracts (3.87 ± 0.15 - 4.68 ± 0.11 mg/g) contained comparatively higher magnesium followed by intact leaves (2.78 ± 0.05 - 3.85 ± 0.07 mg/g) and branches (1.00 ± 0.04 - 1.29 ± 0.04 mg/g). Broken leaves contained relatively higher magnesium during the wet season (November 02) and remained similar in the intermediate season (March 03) and dry season (July 03) (ANOVA, DMRT, $p < 0.05$). Comparatively higher magnesium content in bracts was observed during the intermediate season (March 03), but intact leaves and branches showed relatively higher magnesium content during the intermediate season (March 02) (Tables 6.7-6.11 and Figure 6.29) (ANOVA, DMRT, $p < 0.05$). In leaf litter degradation, initial magnesium content (5.03 ± 0.02 mg/g) in degraded leaf litter remained similar up to 10 days during the dry months (July 02-November 02) and significantly (ANOVA, DMRT, $p < 0.05$) increased up to 8.93 ± 0.09 mg/g after 150 days. During the wet months (November 02-March 03), initial magnesium content (5.27 ± 0.07 mg/g) significantly (ANOVA, DMRT, $p < 0.05$) decreased up to 3.32 ± 0.04 mg/g after 15 days and thereafter significantly (ANOVA, DMRT, $p < 0.05$) increased up to 9.16 ± 0.08 mg/g at the end of 150 days (Table 6.12 and Figure 6.30).

6.3.6 Sulphur

In seedlings components, roots contained comparatively higher sulphur (5.06 ± 0.11 - 7.93 ± 0.19 mg/g) followed by leaves (4.06 ± 0.08 - 7.69 ± 0.17 mg/g) and stems (3.38 ± 0.06 - 7.30 ± 0.14 mg/g) (ANOVA, DMRT, $p < 0.05$). Seedlings components contained relatively higher sulphur during the dry seasons (July 02 and 03) followed by intermediate seasons (March 02 and 03) and wet season (November 02) (Tables 6.1-6.5 and Figure 6.31) (ANOVA, DMRT, $p < 0.05$). In saplings components, relatively higher sulphur content (6.90 ± 0.17 - 18.31 ± 0.20 mg/g) was observed in roots and lowest content

(1.13 ± 0.02 - 3.70 ± 0.05 mg/g) was found in stems (ANOVA, DMRT, $p < 0.05$). The ranges of sulphur content in leaves, buds, branches and bark were 2.01 ± 0.06 - 8.17 ± 0.10 mg/g, 1.72 ± 0.05 - 6.42 ± 0.11 mg/g, 1.63 ± 0.04 - 5.44 ± 0.09 mg/g and 3.28 ± 0.04 - 6.73 ± 0.11 mg/g, respectively at different seasons. Saplings components contained comparatively higher sulphur during the dry seasons (July 02 and 03) followed by intermediate seasons (March 02 and 03) and wet season (November 02) (Tables 6.1-6.5 and Figure 6.32) (ANOVA, DMRT, $p < 0.05$). In trees components, leaves contained relatively higher sulphur (11.49 ± 0.12 - 18.89 ± 0.26 mg/g) and lowest content (1.14 ± 0.04 - 2.79 ± 0.07 mg/g) was found in stems (ANOVA, DMRT, $p < 0.05$). The ranges of sulphur content in buds, flowers, propagules, branches, bark and roots were 7.13 ± 0.15 - 11.01 ± 0.17 mg/g, 13.91 ± 0.15 - 14.76 ± 0.12 mg/g, 16.73 ± 0.11 - 18.70 ± 0.12 mg/g, 3.14 ± 0.06 - 4.98 ± 0.10 mg/g, 3.28 ± 0.06 - 8.53 ± 0.12 mg/g and 6.38 ± 0.12 - 17.91 ± 0.20 mg/g respectively at different seasons. Trees components showed comparatively higher sulphur content during the dry seasons (July 02 and 03) followed by intermediate seasons (March 02 and 03) and wet season (November 02) (Tables 6.1-6.5 and Figures 6.33) (ANOVA, DMRT, $p < 0.05$). Sulphur content in all the components of seedlings, saplings and trees showed significant ($p < 0.05$) positive correlation with the total sulphur content in soil (Table 6.6).

In litter production components, comparatively higher sulphur content (8.21 ± 0.12 - 8.87 ± 0.16 mg/g) was observed in propagules and followed by leaves (4.53 ± 0.14 - 5.93 ± 0.14 mg/g) and branches contained the lowest sulphur (2.49 ± 0.06 - 3.06 ± 0.03 mg/g) except for the wet season (November 02) (ANOVA, DMRT, $p < 0.05$). Leaves and bracts contained relatively higher sulphur content during the dry seasons (July 02 and 03) followed by intermediate seasons (March 02 and 03) and wet season (November 02) (Tables 5.7-5.11 and Figure 6.34) (ANOVA, DMRT, $p < 0.05$). In litter standing crops, relatively higher sulphur content (6.51 ± 0.09 - 11.72 ± 0.10 mg/g) was observed in broken leaves and lowest content (2.81 ± 0.04 - 5.44 ± 0.11 mg/g) was found in bracts (ANOVA, DMRT, $p < 0.05$). The ranges of sulphur content in intact leaves and branches were 5.34 ± 0.17 - 8.39 ± 0.18 mg/g and 5.56 ± 0.13 - 10.30 ± 0.17 mg/g, respectively, at different seasons. All the components of litter standing crop showed comparatively higher sulphur content during the dry season (July 02) and lowest in wet season (November 02) (Tables 6.7-6.11 and Figure 6.35) (ANOVA, DMRT, $p < 0.05$). In leaf litter degradation, initial sulphur content (6.88 ± 0.08 mg/g) in degraded leaf litter significantly (ANOVA, DMRT, $p < 0.05$) decreased up to 5.06 ± 0.03 mg/g (leaf on strings) and 5.31 ± 0.04 mg/g (litter bags) after 15 days during the dry months (July 02-November 02) and final content significantly (ANOVA, DMRT, $p < 0.05$) increased up to 7.73 ± 0.04 mg/g after 150 days. During the wet months (November 02-March 03), initial sulphur content (5.78 ± 0.02 mg/g) significantly (ANOVA, DMRT, $p < 0.05$) decreased up to 2.77 ± 0.03 mg/g after 15 days and final sulphur content was 6.16 ± 0.07 mg/g at the end of 150 days (Table 6.12 and Figure 6.36).

6.3.7 Carbon

In seedlings components, the ranges of carbon content in leaves, stems and roots were 43.04 ± 0.02 - $54.32\pm0.01\%$, 48.64 ± 0.08 - $57.32\pm0.02\%$ and 37.74 ± 0.08 - $50.34\pm0.05\%$, respectively. Seedlings stems contained relatively higher carbon followed by leaves and roots during the intermediate (March 02 and 03) and dry seasons (July 02 and 03), but leaves contained comparatively lower carbon during the wet season (November 02) (ANOVA, DMRT, $p<0.05$). Leaves and stems contained relatively higher carbon during the dry season (July 02) followed by intermediate season (March 03) (Tables 6.1-6.5 and Figure 6.37) (ANOVA, DMRT, $p<0.05$). In saplings components, stem (46.53 ± 0.06 - $52.40\pm0.08\%$) and branches (48.05 ± 0.03 - $50.28\pm0.06\%$) showed relatively higher carbon content at different seasons and lower carbon content (37.63 ± 0.02 - $42.26\pm0.07\%$) was observed in leaves (ANOVA, DMRT, $p<0.05$). The ranges of carbon content in buds, bark and roots were 43.62 ± 0.02 - $45.44\pm0.02\%$, 44.28 ± 0.04 - $46.94\pm0.04\%$ and 45.04 ± 0.05 - $47.04\pm0.02\%$, respectively. Saplings components showed different trends of carbon distribution in each season and relatively higher carbon content in leaves, buds, branches, bark and stems was found during the dry season (July 03) (Tables 6.1-6.5 and Figure 6.38) (ANOVA, DMRT, $p<0.05$). In trees components, stems (45.26 ± 0.01 - $57.52\pm0.02\%$) and roots (46.06 ± 0.01 - $53.68\pm0.03\%$) contained comparatively higher carbon at different seasons (ANOVA, DMRT, $p<0.05$). The ranges of carbon content in leaves, buds, flowers, propagules, branches and bark were 37.86 ± 0.03 - $44.14\pm0.09\%$, 41.72 ± 0.04 - $46.99\pm0.05\%$, 46.16 ± 0.03 - $47.30\pm0.04\%$, 47.76 ± 0.03 - $48.57\pm0.02\%$, 42.03 ± 0.04 - $49.68\pm0.02\%$ and 41.32 ± 0.05 - $46.51\pm0.04\%$, respectively. All the components showed different trends of carbon distribution in each season and relatively higher carbon in leaves, buds, branches, bark and stems was observed during the dry season (July 02) (Tables 6.1-6.5 and Figure 6.39) (ANOVA, DMRT, $p<0.05$).

In litter production components, comparatively higher carbon content was found in leaves (48.77 ± 0.07 - $54.92\pm0.02\%$) and the ranges of carbon in braches and bracts were 43.42 ± 0.01 - $52.20\pm0.03\%$ and 41.44 ± 0.02 - $50.37\pm0.05\%$, respectively (ANOVA, DMRT, $p<0.05$). Relatively higher carbon in leaves and branches were observed during the dry seasons (July 02 and 03) (Tables 6.7-6.11 and Figure 6.40) (ANOVA, DMRT, $p<0.05$). In litter standing crop, the ranges of carbon content in intact leaves, broken leaves, branches, bracts and propagules were 46.00 ± 0.01 - $52.61\pm0.02\%$, 45.94 ± 0.05 - $52.31\pm0.03\%$, 42.45 ± 0.02 - $51.41\pm0.03\%$, 40.10 ± 0.01 - $48.67\pm0.02\%$ and 49.42 ± 0.03 - $51.38\pm0.02\%$, respectively. All the components showed different trends of carbon distribution in each season and showed different pattern of carbon fluctuation among the seasons (Tables 6.7-6.11 and Figure 6.41). In leaf litter degradation, initial carbon content ($57.55\pm0.15\%$) in degraded leaf litter of strings and litter bags significantly (ANOVA, DMRT, $p<0.05$) decreased up to $51.41\pm0.13\%$ and $46.52\pm0.16\%$ after 10 days during the dry months (July 02-November 02), respectively. Carbon content in degraded leaf litter significantly (ANOVA, DMRT, $p<0.05$) increased up to

61.39±0.03% after 25 days and final content was 59.64±0.04% at the end of 150 days. During the wet months (November 02-March 03), initial carbon content (45.11±0.05%) in degraded leaf litter of strings and litter bags significantly (ANOVA, DMRT, $p<0.05$) increased up to 60.35±0.04% and 63.24±0.02% after 15 and 10 days, respectively and final content was 61.25±0.18% at the end of 150 days (Table 6.12 and Figure 6.42).

6.3.8 Organic Matter

In seedlings components, stems contained comparatively higher organic matter (89.00±0.24-93.22±0.20%) and the ranges of organic matter in leaves and roots were 80.11±0.20-87.33±0.17% and 79.56±0.34-86.11±0.26%, respectively (ANOVA, DMRT, $p<0.05$). Seedlings components showed different trend of organic matter in each seasons and relatively lower organic matter was observed during the intermediate season (March 02) (Tables 6.1-6.5 and Figure 6.43) (ANOVA, DMRT, $p<0.05$). In saplings components, stems contained comparatively higher organic matter (98.22±0.15-98.67±0.17%) and lowest content (79.33-87.56) was observed in roots (ANOVA, DMRT, $p<0.05$). Stems and bark showed similar content of organic matter in different seasons, but comparatively higher organic matter content in branches and roots was observed during the wet season (November 02) (Tables 6.1-6.5 and Figure 6.44) (ANOVA, DMRT, $p<0.05$). In trees components, comparatively higher organic matter content (98.44±0.18-98.56±0.18%) was observed in stems and lowest content of organic matter (82.44±0.41-87.00±0.24%) was found in roots (ANOVA, DMRT, $p<0.05$). However, tree components showed different trends of organic matter content in each season and different fluctuation patterns among the seasons (Tables 6.1-6.5 and Figure 6.45).

In litter production components, branches contained comparatively higher organic matter (95.33±0.17-96.78±0.15%) and the ranges of organic matter content in leaves and bracts were 89.67±0.17-93.67±0.17% and 91.56±0.18-92.67±0.17%, respectively, (ANOVA, DMRT, $p<0.05$). Relatively higher organic matter content in branches was found during the intermediate season (March 03) and remained similar in the dry season (July 03), but leaves and bracts contained comparatively higher organic matter during the intermediate season (March 02) and intermediate season (March 03), respectively (Tables 6.7-6.11 and Figure 6.46) (ANOVA, DMRT, $p<0.05$). In litter standing crop components, comparatively higher organic matter content (91.44±0.18-95.44±0.18%) was found in bracts (ANOVA, DMRT, $p<0.05$). Different components of litter standing crop showed different patterns in organic matter content among the seasons (Tables 6.7-6.11 and Figure 6.47). In leaf litter degradation, initial content of organic matter (88.89±0.26%) in degraded leaf litter significantly (ANOVA, DMRT, $p<0.05$) increased up to 92.56±0.18% after 15 days during the dry months (July 02-November 02) and final content was 86.89±0.20% at the end of 150 days. During the wet months (November 02-March 03), initial organic matter content (88.56±0.18%) in

degraded leaf litter significant (ANOVA, DMRT, $p < 0.05$) increased up to $97.89 \pm 0.11\%$ at the end of 150 days (Table 6.12 and Figure 6.48).

6.3.9 Copper

In seedling components, stems contained relatively lower copper (3.17 ± 0.12 - 7.87 ± 0.01 $\mu\text{g/g}$) and the ranges of copper in leaves and roots were 3.67 ± 0.17 - 11.73 ± 0.35 $\mu\text{g/g}$ and 5.22 ± 0.17 - 10.93 ± 0.11 $\mu\text{g/g}$, respectively (ANOVA, DMRT, $p < 0.05$). Comparatively higher copper content in seedlings components was observed during the intermediate season (March 02) and lower content was found in the intermediate season (March 03) (Table 6.1-6.5, Figure 6.49) (ANOVA, DMRT, $p < 0.05$). In saplings components, the ranges of copper content in leaves, buds, branches, stems, bark and roots were 4.06 ± 0.10 - 10.93 ± 0.13 $\mu\text{g/g}$, 4.67 ± 0.17 - 12.53 ± 0.35 $\mu\text{g/g}$, 4.00 ± 0.12 - 17.33 ± 0.27 $\mu\text{g/g}$, 3.33 ± 0.17 - 6.87 ± 0.03 $\mu\text{g/g}$, 4.33 ± 0.17 - 9.33 ± 0.12 $\mu\text{g/g}$ and 4.33 ± 0.33 - 10.47 ± 0.12 $\mu\text{g/g}$, respectively in different seasons (Table 6.1-6.5, Figure 6.50). In trees components, the ranges of copper content in leaves, buds, flowers, propagules, branches, stems, bark, and roots of trees were 4.67 ± 0.17 - 10.14 ± 0.14 $\mu\text{g/g}$, 5.67 ± 0.17 - 11.74 ± 0.21 $\mu\text{g/g}$, 8.67 ± 0.17 - 12.27 ± 0.16 $\mu\text{g/g}$, 4.67 ± 0.17 - 6.11 ± 0.11 $\mu\text{g/g}$, 5.67 ± 0.17 - 11.00 ± 0.29 $\mu\text{g/g}$, 3.33 ± 0.17 - 9.94 ± 0.17 $\mu\text{g/g}$, 3.33 ± 0.17 - 8.02 ± 0.06 $\mu\text{g/g}$ and 6.56 ± 0.18 - 10.48 ± 0.17 $\mu\text{g/g}$, respectively in different seasons (Table 6.1-6.5, Figure 6.51). All components of saplings and trees contained comparatively higher copper during the intermediate season (March 02) and showed different trends in copper content in each season (Tables 6.1-6.5 and Figures 6.50-6.51) (ANOVA, DMRT, $p < 0.05$). Copper content in leaves, stems and roots of seedlings, leaves, buds, branches, bark and roots of saplings and roots of trees showed significant ($p < 0.05$) positive correlations with the total copper content in soil (Table 6.6).

In litter production, the ranges of copper content in leaves, branches, bracts, flowers and propagules were 3.33 ± 0.18 - 10.66 ± 0.15 $\mu\text{g/g}$, 5.67 ± 0.22 - 17.70 ± 0.17 $\mu\text{g/g}$, 4.67 ± 0.18 - 10.43 ± 0.11 $\mu\text{g/g}$, 7.25 ± 0.23 - 10.68 ± 0.23 $\mu\text{g/g}$ and 8.67 ± 0.22 - 9.67 ± 0.22 $\mu\text{g/g}$, respectively. Leaves, branches and bracts contained comparatively higher copper during the intermediate season (March 02) and showed different trend of copper content in each season (Table 6.7-6.11, Figure 6.52) (ANOVA, DMRT, $p < 0.05$). In litter standing crop, higher copper content in branches (8.17 ± 0.18 - 16.22 ± 0.20 $\mu\text{g/g}$) and bracts (4.33 ± 0.22 - 11.33 ± 0.18 $\mu\text{g/g}$) was observed in different seasons (ANOVA, DMRT, $p < 0.05$) compared to other components. Different components of litter standing crop showed different trend of copper content in each season. Intact leaves, broken leaves and bracts contained relatively lower copper during the wet season (November 02) (Table 6.7-6.11, Figure 6.53) (ANOVA, DMRT, $p < 0.05$). In leaf litter degradation, copper content at different stages in leaf litter degradation during the dry (July 02-November 02) and wet months (November 02-March 03) showed reverse trends. Initial copper content ($10.00 \pm 0.50 \mu\text{g/g}$) in degraded leaf litter significantly (ANOVA, DMRT, $p < 0.05$) decreased up to $2.67 \pm 0.17 \mu\text{g/g}$ after 60 days during the dry

months. During the wet months, initial copper content ($2.00 \pm 0.08 \mu\text{g/g}$) significantly (ANOVA, DMRT, $p < 0.05$) increased up to $10.67 \pm 0.17 \mu\text{g/g}$ after 150 days (Table 6.12 and Figure 6.54).

6.3.10 Iron

In seedlings components, roots contained comparatively higher iron (2988.33 ± 46.40 - $5258.82 \pm 86.84 \mu\text{g/g}$) followed by leaves (308.67 ± 6.98 - $561.29 \pm 10.08 \mu\text{g/g}$) and stems (276.33 ± 5.09 - $510.67 \pm 14.87 \mu\text{g/g}$) (ANOVA, DMRT, $p < 0.05$). Seedlings components contained relatively higher iron during the intermediate seasons (March 02 and 03) followed by wet season (November 02) and dry seasons (July 02 and 03) (Tables 6.1-6.5 and Figures 6.55 and 6.58). In saplings components, relatively (ANOVA, DMRT, $p < 0.05$) higher iron content was observed in roots (4088.44 ± 77.34 - $6313.44 \pm 130.70 \mu\text{g/g}$) and lower content was found in stems (38.78 ± 1.41 - $68.00 \pm 2.66 \mu\text{g/g}$) and buds (42.22 ± 0.97 - $83.33 \pm 1.86 \mu\text{g/g}$) (Tables 6.1-6.5 and Figures 6.56 and 6.58) (ANOVA, DMRT, $p < 0.05$). In trees components, roots contained relatively higher iron (2803.56 ± 102.96 - $5409.56 \pm 115.20 \mu\text{g/g}$) and lower content was observed in stems (53.89 ± 1.87 - $66.33 \pm 2.22 \mu\text{g/g}$) and buds (38.67 ± 1.17 - $100.22 \pm 2.17 \mu\text{g/g}$) (Tables 6.1-6.5 and Figures 6.57 and 6.58) (ANOVA, DMRT, $p < 0.05$). Saplings and trees components contained comparatively higher iron during the intermediate seasons (March 02 and 03) and lower in the dry seasons (July 02 and 03) (Tables 6.1-6.5 and Figures 6.56-6.58) (ANOVA, DMRT, $p < 0.05$). Iron content in leaves and roots of seedlings, leaves, braches and roots of saplings and leaves and roots of trees showed significant ($p < 0.05$) positive correlations with the total iron content in soil (Table 6.6). In litter production, the ranges of iron content in leaves, branches, bracts, flowers and propagules were 69.67 ± 2.47 - $97.83 \pm 4.20 \mu\text{g/g}$, 55.17 ± 1.88 - $93.27 \pm 2.50 \mu\text{g/g}$, 43.17 ± 1.53 - $110.07 \pm 4.31 \mu\text{g/g}$, 107.83 ± 3.82 - $120.17 \pm 3.56 \mu\text{g/g}$ and 27.67 ± 1.20 - $30.67 \pm 1.28 \mu\text{g/g}$, respectively, and showed different trend of iron content in each season. Comparatively higher iron content in litter production components was found during the intermediate seasons (March 02 and 03) followed by wet season (November 02) and dry seasons (July 02 and 03) (Tables 6.7-6.11 and Figure 6.59) (ANOVA, DMRT, $p < 0.05$). In litter standing crop, broken leaves contained comparatively higher iron (453.67 ± 11.50 - $939.80 \pm 15.16 \mu\text{g/g}$) and followed by bracts (306.07 ± 9.68 - $454.67 \pm 10.32 \mu\text{g/g}$), branches (110.00 ± 3.83 - $268.67 \pm 8.64 \mu\text{g/g}$) and intact leaves (77.83 ± 1.60 - $123.67 \pm 2.32 \mu\text{g/g}$) (Tables 6.7-6.11 and Figure 6.60) (ANOVA, DMRT, $p < 0.05$). In leaf litter degradation, iron content at different stages of leaf litter degradation during the dry (July 02-November 02) and wet (November 02-March 03) months showed similar trend. Initial iron content ($81.67 \pm 0.67 \mu\text{g/g}$) in degraded leaf litter significantly (ANOVA, DMRT, $p < 0.05$) increased up to $2550.00 \pm 3.73 \mu\text{g/g}$ after 150 days during the dry months and initial iron content ($210.00 \pm 0.76 \mu\text{g/g}$) during the wet months significantly (ANOVA, DMRT, $p < 0.05$) increased up to $4211.67 \pm 1.67 \mu\text{g/g}$ after 150 days (Table 6.12 and Figure 6.61).

6.3.11 Zinc

In seedlings components, the ranges of zinc content in leaves, stems and roots were 6.67 ± 0.17 - 25.00 ± 0.29 $\mu\text{g/g}$, 6.67 ± 0.17 - 16.18 ± 0.26 $\mu\text{g/g}$ and 11.33 ± 0.29 - 22.67 ± 0.53 $\mu\text{g/g}$, respectively in different seasons. Comparatively higher zinc content in leaves and stems was observed during the intermediate season (March 02) and lower content was found in the dry season (July 02), but roots contained relatively higher zinc during the wet season (November 02) and lower in the dry season (July 02) (Tables 6.1-6.5, Figure 6.62) (ANOVA, DMRT, $p < 0.05$). In saplings components, the ranges of zinc content in leaves, buds, branches, stem, bark and roots were 7.33 ± 0.17 - 14.93 ± 0.67 $\mu\text{g/g}$, 8.33 ± 0.17 - 17.07 ± 0.27 $\mu\text{g/g}$, 5.33 ± 0.17 - 14.00 ± 0.29 $\mu\text{g/g}$, 4.67 ± 0.17 - 12.00 ± 0.17 $\mu\text{g/g}$, 8.00 ± 0.29 - 20.56 ± 0.18 $\mu\text{g/g}$ and 5.67 ± 0.17 - 29.60 ± 0.46 $\mu\text{g/g}$, respectively, in different seasons. Saplings components showed different trends of zinc content in each season. Relatively higher zinc content in leaves, buds, bark and roots was observed during the intermediate season (March 02) and lower zinc content was observed in the dry season (July 02) (Tables 6.1-6.5, Figure 6.63) (ANOVA, DMRT, $p < 0.05$). In trees components, the ranges of zinc content in leaves, buds, flowers, propagules, branches, stems, bark and roots were 7.22 ± 0.15 - 25.22 ± 0.22 $\mu\text{g/g}$, 11.22 ± 0.15 - 28.07 ± 0.37 $\mu\text{g/g}$, 18.00 ± 0.29 - 25.60 ± 0.23 $\mu\text{g/g}$, 3.33 ± 0.17 - 4.89 ± 0.11 $\mu\text{g/g}$, 8.44 ± 0.18 - 14.44 ± 0.24 $\mu\text{g/g}$, 5.67 ± 0.17 - 21.00 ± 0.29 $\mu\text{g/g}$, 3.33 ± 0.17 - 17.11 ± 0.11 $\mu\text{g/g}$ and 7.33 ± 0.17 - 24.89 ± 0.11 $\mu\text{g/g}$, respectively, in different seasons. Tree components showed different trends of zinc content in each season. Leaves, buds, bark and roots contained comparatively higher zinc during the intermediate season (March 02) (Tables 6.1-6.5 and Figure 6.64) (ANOVA, DMRT, $p < 0.05$). Zinc content in leaves and stems of seedlings, buds and roots of saplings and leaves, buds, bark and roots of trees showed significant ($p < 0.05$) positive correlations with the total zinc content in soil (Table 6.6).

In litter production, the ranges of zinc content in leaves, branches, bracts, flowers and propagules were 10.00 ± 0.18 - 27.33 ± 0.34 $\mu\text{g/g}$, 6.17 ± 0.18 - 16.17 ± 0.18 $\mu\text{g/g}$, 8.67 ± 0.22 - 24.33 ± 0.18 $\mu\text{g/g}$, 22.83 ± 0.41 - 26.33 ± 0.22 $\mu\text{g/g}$ and 3.67 ± 0.22 - 6.50 ± 0.22 $\mu\text{g/g}$, respectively. In litter standing crop, the ranges of zinc content in intact leaves, broken leaves, branches, bracts and propagules were 12.33 ± 0.22 - 20.33 ± 0.22 $\mu\text{g/g}$, 8.67 ± 0.18 - 18.33 ± 0.37 $\mu\text{g/g}$, 4.67 ± 0.18 - 19.00 ± 0.29 $\mu\text{g/g}$, 10.67 ± 0.18 - 23.50 ± 0.37 $\mu\text{g/g}$, 4.67 ± 0.18 - 6.17 ± 0.18 $\mu\text{g/g}$, respectively. Different components of litter production and litter standing crop contained comparatively lower zinc during the dry season (July 02) (Tables 6.7-6.11 and Figures 6.65-6.66) (ANOVA, DMRT, $p < 0.05$). In leaf litter degradation, initial zinc content (16.67 ± 0.53 $\mu\text{g/g}$) in degraded leaf litter of strings and litter bags significantly (ANOVA, DMRT, $p < 0.05$) decreased up to 10.67 ± 0.44 $\mu\text{g/g}$ and 8.00 ± 0.29 $\mu\text{g/g}$, respectively after 20 days during the dry months (July 02-November 02) and zinc content significantly (ANOVA, DMRT, $p < 0.05$) increased up to 77.33 ± 0.93 $\mu\text{g/g}$ at the end of 150 days. During the wet months (November 02-March

03), initial zinc content ($22.00 \pm 0.29 \mu\text{g/g}$) significantly (ANOVA, DMRT, $p < 0.05$) increased up to $85.11 \pm 0.26 \mu\text{g/g}$ at the end of 150 days (Table 6.12 and Figure 6.67).

6.4 Discussion

6.4.1 Nutrients in Different Components of Seedlings, Saplings and Trees

Bruguiera parviflora contained comparatively higher percentage of nitrogen (17-824%), phosphorus (10-543%) and potassium (67-1272%) in the leaves of seedlings, leaves and buds of saplings and trees and reproductive components (flowers and propagules) of trees than the woody components (branches and stems) of saplings and trees. Nitrogen is the major component of amino acid, enzymes, nucleic acid, chlorophyll and alkaloid and consequently higher content is observed in photosynthetic tissue (Jones *et al.*, 1991). Phosphorus is most abundant in meristematic tissue and accumulated in the reproductive components (seeds and fruits) (Meyer *et al.*, 1973). But, potassium is highly mobile in plants and accumulated in physiologically active tissue (leaves, buds and roots) (Marschner, 1995). The above physiological function and mobility nature of N, P and K in plant components could result in higher content of N, P and K in leaves and buds compared to branches and stems of *B. parviflora*. Irrespective to *B. parviflora*, *Rhizophora apiculata* trees in Matang mangroves showed higher percentage of nitrogen (198-410%), phosphorus (22-450%) and potassium (172-767%) in leaves than branches and stems (Onget *et al.*, 1985a; Gong and Ong, 1990). In a similar study, Aksornkoae and Khemnark (1984) reported that leaves of *Avicennia* spp., *Bruguiera* spp. and *Ceriops* spp. contained higher percentage of nitrogen (30-193%), phosphorus (17-133%) and potassium (19-2057%) than their branches and stems.

Bruguiera parviflora showed relatively higher percentage of calcium in leaves (41-44%) of seedlings, leaves (337-628%), buds (459-646%) and bark (463-758%) of saplings and leaves (580-917%), buds (729-942%), and bark (937-1480%) of trees than the stems of seedlings, saplings and trees. Calcium is necessary for the continued growth of apical meristems, accumulated in the leaves and permanently fixed in the cell wall as calcium salt (Meyer *et al.*, 1973; Jones *et al.*, 1991) and this could be the reason for observing comparatively higher calcium in leaves and buds. Irrespectively, leaves of *R. apiculata* at Matang mangrove forest (Onget *et al.*, 1985a; Gong and Ong, 1990), *Avicennia* spp., *Bruguiera* spp. and *Ceriops* spp. at Amphoe Khung mangrove, Thailand (Aksornkoae and Khemnark, 1984) contained 52-233%, 79-127%, 43-150% and 55-170% of higher calcium compared to their branches and stems, respectively.

Magnesium is a mineral constituent of chlorophyll and large proportion of magnesium is found in leaves (Jones *et al.*, 1991). Similarly, *B. parviflora* showed higher percentage of magnesium (171-399%) in the leaves of seedlings, saplings (885-1876%) and trees (1517-2741%); buds of saplings (666-1167%) and trees (898-1393%) than stems of seedlings, saplings and trees. Irrespective to *B. parviflora*, higher percentage (370%) of magnesium was observed in leaves of *R. mangle* in Panama (Golley *et al.*,

1975), *A. marina* (840%) in Westernport Bay, Australia (Clough and Attiwill, 1975) and *R. apiculata* (285%) in Matang mangrove forest (Gond and Ong, 1990) compared to their stems.

Sulphur plays an important role in the formation of amino acid and protein synthesis (Jones *et al.*, 1991). This process largely operates in the leaves and results in higher sulphur content in leaves (Binkley, 1986). Sulphur is absorbed by root as SO_4^- and sulphur salts of Ca, Fe and Al. These sulphate salts are fairly soluble and more available for plant uptake. During the process of uptake, sulphur precipitate as CaSO_4 at the root surface (Jungk, 1991). The precipitation of CaSO_4 on root surface and accumulation of sulphur in leaves during the formation of amino acid and protein synthesis might lead to higher sulphur accumulation in roots of *B. parviflora* seedlings, saplings and trees and leaves of trees.

Bruguiera parviflora showed comparatively higher percentage (6-11%) of organic matter and total carbon (8-25%) in woody components (branches and stems) compared to green components (leaves and buds) and reproductive components (flowers and propagules). Organic matter content indirectly shows a rough estimation of mineral nutrients in plant components. Therefore, higher organic matter vice versa lower ash content in woody components (branches and stems) represents lower nutrients level (Meyer *et al.*, 1973) and this statement is well supported by the result of present study (branches and stems contained relatively lower N, P, K, Ca, Mg, S, Cu, Fe and Zn). According to Westlake (1963), carbon content in each plant component maintains a constant ratio to organic matter and this could be the reason for observing similar trend of carbon with the organic matter in different components of *B. parviflora* seedlings, saplings and trees.

Copper and zinc are distributed more uniformly throughout the plant components (Kabata-Pendias and Pendias, 1984) and this statement is supported by the narrow range (3.17-17.33 $\mu\text{g/g}$) of copper and zinc (3.33-29.60 $\mu\text{g/g}$) in different components of *B. parviflora* seedlings, saplings and trees. In the present study, *B. parviflora* showed comparatively higher percentage (400-5433%) of iron in roots than leaves of seedlings, saplings and trees. Similarly, roots of *R. mangle* in Panama (Golley *et al.*, 1975) and Sepetiba Bay, Brazil (Silva *et al.*, 1990) contained 11196% and 2618% of higher iron compared to leaves, respectively. It has been reported that iron involves in chlorophyll formation, protein synthesis and root tip meristem growth (Meyer *et al.*, 1973; Jones *et al.*, 1998), hence, higher iron content is expected in plant leaves and roots. On the other hand, roots of mangrove plant release oxygen and an oxidant geochemical micro-environment is created (Silva *et al.* 1990), and helps to oxidize soluble Fe^{2+} and Mn^{2+} to insoluble $\text{Fe}(\text{OH})_3$ and MnO_2 . After oxidization, these oxide-hydroxides of Fe and Mn strongly co-precipitate with other metals (Barlett, 1961) and the formation of iron plaques on root surfaces is common in the mangrove environment (Lacerda, 1998). This oxidant geochemical reaction in the mangrove soil could be the reason for observing higher iron in roots.

Nutrients (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) and organic matter content in different components of *B. parviflora* seedlings, saplings and trees showed seasonal fluctuation (with the exception of N, K, Ca, Mg, and organic matter content in stems of saplings and trees, K and Mg content in bark of saplings and trees). Comparatively higher N, P, K, Ca, Mg and Fe were observed in plant components during the intermediate seasons (March 02 and 03) and relatively higher sulphur and carbon content were found during the dry seasons (July 02 and 03). During the process of photosynthesis, atmospheric carbon dioxide is transformed to carbohydrate and accumulated in plant biomass. The rate of photosynthesis is accelerated with higher temperature and higher light intensity (Meyer *et al.*, 1973). Dry season is characterised by comparatively higher temperature with higher light intensity, which results in higher rate of photosynthesis. This higher rate of photosynthesis leads to accumulation of higher amount of carbon in plant biomass and this could be the reason for observing higher carbon content in different component of *B. parviflora* seedlings, saplings and trees in dry seasons (July 02 and 03). It has been reported that fluctuation in climatic condition (rainfall and temperature), soil edaphic factors, available nutrients in the substrate and concentration of other nutrients can affect the nutrient contents in plant components considerably (Kabata-Pendias and Pendias, 1984; Walbridge, 1991; Jones, 1998) as well as mineral metabolism and uptake of nutrients by the roots (Barber, 1984; Jones *et al.*, 1991; Marschner, 1995; Jones, 1998). The fluctuation in environmental parameters and soil physiochemical characteristics may affect the uptake of nutrients and their contents in different components of *B. parviflora* seedlings, saplings and trees. However, each element characteristics, plant species, types of plant components, physiological age of the tissue and seasons (dry and wet) may influence the nutrient contents in plant components (Jones *et al.*, 1991; Walbridge, 1991).

According to Kabata-Pendias and Pendias (1984) and MacFarlane and Burchett (2002), the rate of nutrients uptake by plants is positively related to the nutrients level in soil. Similarly, nutrient (N, P, K, Ca, Mg, S, Cu, Fe and Zn) contents in different components of seedlings, saplings and trees of *B. parviflora* (with the exception of N in stems of saplings and trees, P in seedlings roots) showed positive correlation with the soil nutrient levels. Thomas and Fernandez (1997) observed positive correlation between Fe, Mn and Cu content in leaves of *Acanthus officinalis* and their respective content in soil and the correlation coefficients values were 0.73, 0.36 and 0.46, respectively. On the contrary, Cai (1987) reported that nitrogen, phosphorus and potassium content in leaves of *Aegicerasspp.* showed negative correlation coefficients of -0.33, -0.55 and -0.43 with the respective nutrient levels in soil. Similarly, Fe, Mn, Cu, Zn, Pb and Co content in leaves of *A. ilicifolius*, *B. gymnorrhiza*, *Sonneratiacaseolaris* and *B. racemosa* showed negative correlation with their respective content in soil (Thomas and Fernandez, 1997). In another study, Srivastava *et al.* (1978) failed to obtain significant correlations among the nutrient (N, P, K, Ca, Mg, Na and Fe) contents in leaves of *R. apiculata* and their respective content in soil. However, the studies of Srivastava *et al.* (1978), Cai, (1987) and Thomas and Fernandez

(1997) were performed with one time sampling but they did not consider the seasonal fluctuation of nutrient contents both in soil and plant components.

In the present study, nitrogen, phosphorus, potassium, calcium and magnesium contents in above ground components of *B. parviflora* saplings and trees showed similar trend (leaves>branches>stems) with *R. apiculata* in Matang mangrove forest reserve, Malaysia (Onget *et al.*, 1985a), *Avicennia* spp., *Bruguiera* spp. and *Ceriops* spp. in AmphoeKhlung mangrove forest, Thailand, (Aksornkoae and Khemnark, 1984). Considering the above and below-ground components, saplings and trees of *B. parviflora* showed different trends for phosphorus (leaves>branches>roots>stems), calcium (leaves >branches >roots >stems) and magnesium (leaves >roots >branches >stems) compared to *R. apiculata* in Matang mangrove forest reserve (Gong and Ong, 1990). *Aegiceras corniculatum* and *Kandelia candel* at Futian mangrove, South China, have shown different trends of nitrogen, phosphorus and potassium distribution in different plant components (Li, 1997) (Table 6.13). Copper and zinc have shown different trends of distribution in different components of *B. parviflora* seedlings, saplings and trees in different seasons. Irrespectively, *R. mucronata* seedlings showed higher copper in the roots followed by leaves and stems (Mahmood *et al.*, 2001), but higher zinc content was observed in the roots followed by the stem and leaves in SepangLukut Mangrove forest, Malaysia (Mahmood and Saberi, 2000). Moreover, *R. stylosa* in Shankou Mangrove reserve showed higher copper content in stems followed by roots and leaves, but higher zinc content was observed in stems followed by leaves and roots (Jiao *et al.*, 1997). In the present study, seedlings, saplings and trees of *B. parviflora* showed similar distributional trend of iron (roots>leaves>stems or branches) with *R. mangle* in Panama (Golley *et al.*, 1975) and Sepetiba Bay, Brazil (Silva *et al.*, 1990) (Table 6.13). From this comparison, it reveals that different mangrove species have different rates of nutrient uptake and distributional patterns in their components, which vary with the geomorphology of mangroves. It has been reported that comparatively higher demand of nutrients is observed during the initial stage of growth (production of new leaves and biomass) and cropping season (flowering and fruiting), and it is documented in agricultural and horticultural crops (Jones, 1998). Similarly, the different ranges of nutrient contents in plant components and their distributional trends in seedling, sapling and tree stages of *B. parviflora* at different seasons suggested that different levels of nutrients are required at various stages of plant growth and development.

6.4.2 Nutrients in Litter

Green leaves of *B. parviflora* saplings and trees contained higher percentage of N (53-55%), P (9-20%) and K (61-81%) than the leaves of litter production, but 50% higher calcium was observed in leaves of litter production compared to the green leaves of saplings and trees. The retranslocation mechanism of N, P and K from senescence leaves and less mobile nature of Ca compared to N, P and K (Jones, 1998) could result in lower content of N, P and K and higher content of Ca in leaves of litter production.

Similar to *B. parviflora*, *B. gymnorrhiza* showed 80% N, 60% P and 30% K retranslocation from senescence leaves (Lin and Wang, 2001).

Nitrogen, calcium, magnesium, sulphur and iron content in leaves of litter production and litter standing crop showed similar pattern of seasonal fluctuation with the green leaves of *B. parviflora*. Leaf litter contained comparatively higher N, P, K, S, C and Zn than the other components of litter production and litter standing crops. Leaves and branches of litter standing crop contained higher percentage of N (18-147%), Mg (16-104%), S (18-314%) and Fe (12-861%) compared to leaves and branches of litter production. Comparatively lower percentage of P (8-41%), K (9-60%), Ca (33-38%) and C (5-6%) in leaves and branches of litter standing crop was observed than leaves and branches of litter production. Litter standing crop is subjected to leaching loss and microbial degradation (Swift *et al.*, 1979; Steinke *et al.*, 1993a). The considerable lower P, K, Ca and C in litter standing crop compared to litter production may be due to the leaching and microbial effect. On the contrary, microbial immobilization of N, Mg, S and Fe could result in higher content of the respective nutrients in litter standing crop.

Leaf litter decomposition in mangroves plays an important role in within stand nutrient cycling and supply of organic matter to the estuarine detritus food webs (Twilley *et al.*, 1986). At the decomposition stage, nutrients are released into the soil solution largely as byproducts of microbial scavenging for energy (Binkley, 1986). The nutrients bound in the decomposing litter are released by leaching or by mineralization (Swift *et al.*, 1979). Potassium is not a structural component of plant litter and subjects to leaching loss (Blair, 1988; Salamanca *et al.*, 1998). The degraded leaf litter of *B. parviflora* made loss of 65-80% of initial potassium after 10 to 15 days. Irrespective to *B. parviflora*, *A. corniculatum*, *A. marina* and *K. candel* made loss of about 80-85% of initial potassium content from the degraded leaf litter after 25 days at SaiKeng, Hong Kong (Tam *et al.*, 1990). The pattern of potassium, which is released during the early stage, varies from the later stage of leaf litter degradation (Tam *et al.*, 1998) and leaching is responsible for the initial rapid loss of potassium from the degraded leaf litter (Davis *et al.*, 2003).

In the present study, 86-92% of phosphorus and 49-53% of calcium were lost from the degraded leaf litter of *B. parviflora* after 150 days and showed slower rate of loss during the early stages of degradation. The rate of phosphorus loss from the leaf litter is comparable with leaf litter loss (63-86%) of dry mass loss after 150 days (Figure 5.10, Chapter 5), but loss of calcium from the degraded leaf litter was much slower than the litter loss. Phosphorus and calcium are the structural components of plant cell (Junes *et al.*, 1991) resulting in minimal leaching loss, which is principally associated with the cellular loss (O'Connell, 1989; Salamanca *et al.*, 1998).

Initial nitrogen content in degraded leaf litter of *B. parviflora* gradually increased by 120% and 130% after 150 and 60 days during the dry and wet months, respectively. Apart from nitrogen, degraded leaf litter gained 74-78%, 7-12%, 1906-3022% and 287-364% of Mg, S, Fe and Zn, respectively, from the initial content after 150 days during

the dry and wet months. The initial carbon content in degraded leaf litter increased by 3-36% after 150 days during the dry and wet months. From the field observation, it was found that leaf structure (leaf veins) started to be visible at 20-30 days and 10 days during the dry and wet months (Table 5.2, Chapter 5). Plant structural components mostly consist of carbon compound (Jones, 1998) and this could be the reason for observing comparatively higher carbon content at the later stage of leaf litter degradation. Copper content in degraded leaf litter increased by 434% from the initial content during the wet season and vice versa 53% decreased during the dry season after 150 days. It is reported that considerable amount of nutrients is accumulated with the increasing microbial biomass in the degraded litter (Robetson, 1988; Tam *et al.*, 1990; Davis *et al.*, 2003). Very higher iron content in degraded litter could be the result of contamination from soil or tidal born iron compound in the mangroves. The patterns of nutrients released and gained are influenced by the seasonal variation in environmental parameters (rainfall, temperature and humidity), initial nutrient contents in litter, the structural characteristics of the nutrient in the litter matrix, microbial demand for the nutrient, rate of litter degradation and availability of exogenous nutrients (Seasted, 1984; O'Connel, 1989).

In a comparison, initial nitrogen content in degraded leaf litter of *A. marina* increased by 23% after 120 days, but 35% phosphorus was lost after 120 days. Degraded leaf litter of *A. corniculatum* gained about 52% N, 40% P, 360% Ca and 220% Mg after 120 days at SaiKeng, Hong Kong (Tam *et al.*, 1990). It has been reported that the degraded leaf litter of *Rhizophoraspp.* gained considerable amount of N, P and Fe with time (Silva *et al.*, 1998; Davis *et al.*, 2003; Nielsen and Andersen, 2003). On the contrary, Van de Valk and Attiwill (1984) reported that about 60-80% N, 85-90% P, 89-99% K, 90-95% Mg and 70-80% Ca of initial content were lost from the degraded leaf litter of *A. marina* after 230-270 days at Westernport Bay mangrove forest at Victoria, Australia. This comparison reveals that nutrients, which gained in degraded leaf litter of mangroves, and is released from degraded leaf litter, vary from species to species and with the locations.

Table 6.1. The mean with standard error and range of different nutrients content in plant components during the intermediate season (March 2002).
Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper (µg/g)	Iron (µg/g)	Zinc (µg/g)
Seedlings												
Leaves	6	10.37±0.21 ^D (8.97-11.98)	1.80±0.04 ^A (1.65-2.00)	7.62±0.16 ^E (6.56-8.20)	6.70±0.14 ^G (6.23-7.45)	10.93±0.24 ^B (10.02-11.88)	4.90±0.10 ^G (4.23-5.23)	45.64±0.13 ^I (45.12-46.35)	80.11±0.20 ^I (79.00-81.00)	11.73±0.35 ^C (10.40-12.80)	561.29±10.08 ^D (512.00-598.00)	25.00±0.29 ^C (24.00-26.00)
Stems	6	7.74±0.18 ^F (7.00-9.00)	0.93±0.03 ^I (0.80-1.06)	5.39±0.11 ^G (5.00-6.00)	4.46±0.10 ^I (4.00-4.89)	3.00±0.07 ^H (2.68-3.45)	4.31±0.12 ^H (3.88-4.84)	48.64±0.08 ^C (48.26-49.12)	89.00±0.24 ^F (88.00-90.00)	7.87±0.01 ^G (7.80-7.91)	510.67±14.87 ^{DE} (451.20-540.80)	16.18±0.26 ^G (15.00-17.00)
Roots	6	5.80±0.12 ^H (5.12-6.78)	0.83±0.03 ^{JK} (0.63-0.98)	6.31±0.11 ^F (5.89-6.90)	3.26±0.10 ^K (2.98-3.89)	5.42±0.15 ^{EF} (4.89-6.14)	6.56±0.11 ^E (6.12-6.98)	37.74±0.08 ^L (37.28-38.12)	79.56±0.34 ^I (78.00-81.00)	10.93±0.11 ^D (10.40-11.20)	5258.82±86.84 ^C (4958.00-5680.00)	18.89±0.45 ^E (16.00-20.00)
Saplings												
Leaves	6	12.48±0.14 ^B (11.26-13.45)	1.24±0.03 ^F (1.11-1.42)	12.62±0.22 ^A (11.23-13.56)	11.35±0.23 ^B (10.55-12.36)	11.46±0.20 ^A (10.89-12.80)	5.47±0.12 ^F (5.00-5.90)	39.59±0.07 ^K (39.24-39.88)	86.33±0.17 ^G (86.00-87.00)	10.93±0.13 ^D (10.40-11.20)	136.49±4.91 ^F (120.00-158.40)	14.93±0.67 ^H (13.60-17.60)
Buds	6	9.80±0.11 ^E (9.00-10.56)	1.50±0.03 ^C (1.32-1.65)	8.66±0.17 ^D (7.98-9.56)	11.63±0.21 ^B (10.89-12.56)	7.35±0.14 ^C (7.00-8.12)	3.90±0.09 ^I (3.44-4.26)	45.51±0.10 ^I (44.98-45.89)	88.44±0.18 ^F (88.00-89.00)	12.53±0.35 ^B (11.20-13.60)	83.33±1.86 ^F (76.00-88.00)	17.07±0.27 ^{FG} (16.00-17.60)
Branches	6	6.39±0.15 ^G (5.12-7.56)	1.00±0.01 ^H (0.98-1.03)	5.47±0.12 ^G (5.00-6.02)	7.56±0.11 ^F (7.23-8.12)	1.86±0.06 ^I (1.56-2.03)	3.94±0.09 ^I (3.45-4.33)	48.05±0.03 ^D (47.88-48.25)	92.33±0.17 ^D (92.00-93.00)	17.33±0.27 ^A (16.80-18.40)	111.67±2.90 ^F (100.00-126.00)	10.22±0.15 ^I (10.00-11.00)
Stems	6	1.53±0.03 ^L (1.32-1.76)	0.81±0.02 ^K (0.75-0.89)	0.96±0.04 ^I (0.80-1.09)	1.56±0.02 ^L (1.47-1.62)	0.61±0.02 ^{KL} (0.52-0.71)	2.07±0.05 ^K (1.89-2.36)	46.53±0.06 ^F (46.22-46.78)	98.44±0.18 ^A (98.00-99.00)	6.87±0.03 ^H (6.70-7.00)	68.00±2.66 ^F (60.80-78.40)	8.78±0.15 ^K (8.00-9.00)
Bark	6	4.66±0.08 ^{IJ} (4.16-5.26)	0.85±0.01 ^{JK} (0.81-0.89)	1.32±0.03 ^I (1.21-1.45)	9.37±0.16 ^E (8.78-10.12)	1.26±0.04 ^J (1.10-1.49)	4.33±0.11 ^H (4.00-4.89)	44.28±0.04 ^I (44.12-44.56)	93.33±0.17 ^C (93.00-94.00)	9.33±0.12 ^F (8.80-9.66)	121.62±2.22 ^F (111.20-135.20)	20.56±0.18 ^D (20.00-21.00)
Roots	6	3.91±0.08 ^K (3.26-4.56)	0.93±0.02 ^I (0.80-1.00)	5.23±0.13 ^G (4.87-6.12)	4.04±0.08 ^J (3.68-4.56)	5.18±0.11 ^F (4.78-5.86)	10.94±0.22 ^C (10.23-11.90)	45.51±0.10 ^I (44.98-45.88)	79.33±0.17 ^I (79.00-80.00)	10.47±0.12 ^{DE} (10.02-11.10)	6313.44±130.70 ^A (5689.00-6745.00)	29.60±0.46 ^A (28.00-31.20)
Trees												
Leaves	6	13.54±0.13 ^A (12.55-14.26)	1.32±0.03 ^E (1.20-1.50)	11.89±0.07 ^B (11.60-12.20)	10.74±0.17 ^D (10.23-11.89)	11.08±0.12 ^B (10.80-12.03)	12.94±0.18 ^B (12.00-14.00)	37.86±0.09 ^L (37.55-38.45)	88.78±0.28 ^F (88.00-90.00)	10.14±0.14 ^E (9.56-10.90)	374.40±7.07 ^F (348.80-397.60)	25.22±0.22 ^C (24.00-26.00)
Buds	6	10.98±0.19 ^C (10.02-12.36)	1.59±0.03 ^B (1.45-1.75)	8.39±0.09 ^D (8.12-9.00)	11.01±0.23 ^D (10.00-12.00)	6.12±0.12 ^D (5.78-6.99)	8.78±0.17 ^D (8.00-9.45)	45.56±0.08 ^I (45.26-45.88)	89.78±0.22 ^E (89.00-91.00)	11.74±0.21 ^C (10.64-12.50)	73.87±3.47 ^F (61.60-85.60)	28.07±0.37 ^B (26.40-28.80)
Flowers	6	7.98±0.03 ^F (7.68-8.12)	1.42±0.02 ^D (1.32-1.56)	10.29±0.11 ^C (10.00-11.07)	11.19±0.12 ^C (10.87-11.78)	5.63±0.09 ^E (5.13-5.95)	14.76±0.12 ^A (14.23-15.26)	46.16±0.03 ^H (46.03-46.30)	90.00±0.24 ^E (89.00-91.00)	12.27±0.16 ^{BC} (11.20-12.80)	116.80±4.77 ^F (98.40-130.40)	25.60±0.23 ^C (24.80-26.40)
Branches	6	5.00±0.10 ^I (4.36-5.89)	1.11±0.03 ^G (0.98-1.29)	2.60±0.04 ^H (2.33-2.79)	6.73±0.13 ^G (6.23-7.26)	1.25±0.04 ^J (1.11-1.45)	3.39±0.10 ^J (3.00-3.89)	47.68±0.04 ^E (47.55-47.89)	93.56±0.18 ^{BC} (93.00-94.00)	10.87±0.04 ^D (10.68-11.00)	112.22±2.50 ^F (100.00-129.00)	12.22±0.15 ^I (12.00-13.00)
Stems	6	1.55±0.04 ^L (1.25-1.79)	0.41±0.01 ^L (0.40-0.45)	1.05±0.02 ^J (1.01-1.15)	1.12±0.02 ^M (1.03-1.19)	0.41±0.01 ^L (0.34-0.46)	1.92±0.07 ^K (1.55-2.15)	50.52±0.04 ^B (50.26-50.64)	98.44±0.18 ^A (98.00-99.00)	9.94±0.17 ^E (9.12-11.00)	64.00±1.83 ^F (59.20-71.20)	16.33±0.24 ^{FG} (15.00-17.00)
Bark	6	4.53±0.11 ^J (3.89-5.34)	1.39±0.03 ^D (1.25-1.56)	1.29±0.04 ^I (1.15-1.41)	14.14±0.09 ^A (13.67-14.56)	0.81±0.01 ^K (0.77-0.85)	5.43±0.09 ^F (5.00-5.78)	46.27±0.04 ^G (46.00-46.37)	94.11±0.20 ^B (93.00-95.00)	8.02±0.06 ^G (7.80-8.50)	202.89±3.51 ^F (188.00-222.00)	17.11±0.11 ^F (17.00-18.00)
Roots	6	4.48±0.06 ^J (4.10-5.00)	0.90±0.02 ^{IJ} (0.80-0.98)	6.08±0.13 ^F (5.84-7.12)	5.14±0.08 ^H (4.89-5.56)	4.83±0.19 ^G (4.03-5.65)	10.81±0.14 ^C (10.00-11.50)	52.56±0.05 ^A (52.36-52.88)	82.44±0.41 ^H (81.00-85.00)	10.48±0.17 ^{DE} (10.00-11.00)	5409.56±115.20 ^B (5026.00-5912.00)	24.89±0.11 ^C (24.00-25.00)

Table 6.2: The mean with standard error and range of different nutrients content in plant components during the dry season (July 2002).

Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper (µg/g)	Iron (µg/g)	Zinc (µg/g)
Seedlings												
Leaves	6	8.51±0.27 ^D (6.26-9.89)	1.60±0.04 ^A (1.40-1.88)	6.13±0.13 ^A (5.77-7.12)	4.34±0.06 ^G (4.00-4.65)	8.50±0.17 ^A (8.00-9.30)	7.69±0.17 ^{GH} (7.23-8.45)	54.32±0.01 ^D (54.28-54.36)	83.78±0.40 ^K (82.00-85.00)	6.00±0.29 ^{CD} (5.00-7.00)	308.67±6.98 ^D (289.00-360.00)	6.67±0.17 ^D (6.00-7.00)
Stems	6	5.00±0.10 ^H (4.26-5.89)	0.74±0.02 ^I (0.68-0.83)	2.54±0.09 ^H (2.00-3.00)	4.00±0.06 ^H (3.78-4.36)	2.47±0.08 ^H (2.11-2.78)	7.30±0.14 ^H (6.90-8.00)	57.32±0.02 ^B (57.25-57.37)	93.22±0.15 ^D (93.00-94.00)	4.67±0.17 ^E (4.00-5.00)	276.33±5.09 ^D (256.00-287.00)	6.67±0.17 ^D (6.00-7.00)
Roots	6	3.63±0.06 ^K (3.12-4.12)	0.90±0.02 ^F (0.86-0.98)	3.64±0.09 ^F (3.22-4.23)	2.50±0.08 ^K (2.01-2.89)	4.29±0.13 ^E (3.89-4.97)	7.93±0.19 ^{FG} (7.23-8.78)	48.74±0.01 ^I (48.71-48.79)	86.11±0.31 ^I (85.00-87.00)	6.00±0.29 ^{CD} (5.00-7.00)	2988.33±46.40 ^B (2856.00-3156.00)	11.33±0.29 ^A (10.00-12.00)
Saplings												
Leaves	6	12.00±0.14 ^A (11.00-13.12)	1.15±0.03 ^E (1.00-1.28)	5.25±0.11 ^C (4.89-6.00)	6.68±0.11 ^E (6.12-7.12)	6.49±0.14 ^C (6.02-7.23)	8.17±0.10 ^{EF} (7.88-8.80)	41.11±0.02 ^N (41.02-41.19)	90.00±0.29 ^G (89.00-91.00)	6.28±0.15 ^{BC} (6.00-7.00)	116.22±4.29 ^{FG} (100.00-134.00)	7.33±0.17 ^C (7.00-8.00)
Buds	6	8.09±0.13 ^E (7.44-9.12)	1.30±0.02 ^C (1.20-1.45)	4.50±0.13 ^D (4.00-5.12)	10.01±0.14 ^B (9.45-10.56)	5.13±0.12 ^D (4.68-5.89)	6.42±0.11 ^I (6.05-6.89)	44.41±0.01 ^M (44.38-44.44)	88.22±0.15 ^H (88.00-89.00)	6.67±0.17 ^B (6.00-7.00)	51.44±1.19 ^G (47.00-59.00)	8.33±0.17 ^B (8.00-9.00)
Branches	6	6.10±0.15 ^G (5.26-7.02)	0.93±0.03 ^F (0.80-1.09)	2.91±0.06 ^G (2.55-3.20)	5.70±0.15 ^F (5.02-6.12)	1.27±0.07 ^I (1.03-1.68)	5.44±0.09 ^J (5.12-5.78)	49.67±0.01 ^I (49.65-49.69)	94.22±0.15 ^C (94.00-95.00)	6.33±0.17 ^{BC} (6.00-7.00)	43.67±1.09 ^G (41.00-48.00)	5.33±0.17 ^E (5.00-6.00)
Stems	6	1.53±0.04 ^L (1.29-1.81)	0.72±0.01 ^I (0.69-0.75)	0.93±0.03 ^K (0.77-1.09)	1.53±0.03 ^M (1.45-1.68)	0.60±0.02 ^{KL} (0.50-0.72)	3.70±0.05 ^L (3.45-3.89)	50.59±0.01 ^H (50.56-50.62)	98.67±0.17 ^A (98.00-99.00)	5.67±0.17 ^D (5.00-6.00)	38.78±1.41 ^G (34.00-48.00)	4.67±0.17 ^F (4.00-5.00)
Bark	6	4.44±0.10 ^I (3.90-5.06)	0.85±0.01 ^G (0.82-0.87)	1.24±0.04 ^J (1.10-1.50)	8.95±0.15 ^C (8.45-9.78)	1.05±0.03 ^J (0.93-1.23)	6.73±0.11 ^I (6.12-7.16)	47.41±0.01 ^L (47.39-47.44)	93.67±0.17 ^{CD} (93.00-94.00)	4.33±0.17 ^E (4.00-5.00)	82.11±1.99 ^{FG} (70.00-92.00)	8.00±0.29 ^B (7.00-9.00)
Roots	6	3.62±0.08 ^K (3.15-4.15)	0.84±0.01 ^H (0.79-0.89)	4.71±0.09 ^D (4.23-5.12)	3.50±0.10 ^I (3.10-3.89)	3.74±0.10 ^F (3.12-4.00)	18.31±0.20 ^{BC} (17.68-19.56)	48.72±0.01 ^J (48.69-48.76)	85.67±0.17 ^J (85.00-86.00)	6.56±0.24 ^{BC} (5.00-7.00)	4088.44±77.34 ^A (3789.00-4412.00)	5.67±0.17 ^E (5.00-6.00)
Trees												
Leaves	6	11.58±0.19 ^B (10.56-13.00)	1.24±0.03 ^D (1.10-1.40)	5.72±0.09 ^B (5.30-6.20)	7.28±0.10 ^D (6.89-7.89)	6.85±0.18 ^B (6.23-7.56)	18.89±0.26 ^A (18.01-19.90)	48.71±0.02 ^J (48.65-48.77)	91.22±0.28 ^F (90.00-92.00)	4.67±0.17 ^E (4.00-5.00)	165.78±3.91 ^E (145.00-185.00)	7.22±0.15 ^C (7.00-8.00)
Buds	6	9.38±0.18 ^C (8.45-11.25)	1.44±0.03 ^B (1.28-1.62)	5.31±0.07 ^C (4.98-5.61)	8.87±0.15 ^C (8.26-9.45)	4.92±0.10 ^D (4.55-5.47)	11.01±0.17 ^D (10.26-11.89)	51.83±0.02 ^F (51.76-51.87)	89.33±0.29 ^G (88.00-91.00)	5.67±0.17 ^D (5.00-6.00)	38.67±1.17 ^G (35.00-43.00)	11.22±0.15 ^A (11.00-12.00)
Propagules	6	7.49±0.14 ^F (6.45-8.00)	1.40±0.02 ^B (1.33-1.48)	4.57±0.09 ^D (4.20-5.00)	1.97±0.03 ^L (1.88-2.13)	1.06±0.04 ^J (0.89-1.20)	18.70±0.12 ^{AB} (18.23-19.25)	47.76±0.02 ^K (47.68-47.82)	95.44±0.18 ^B (95.00-96.00)	4.67±0.17 ^E (4.00-5.00)	26.00±0.97 ^G (23.00-31.00)	3.33±0.17 ^G (3.00-4.00)
Branches	6	4.93±0.13 ^H (4.23-6.00)	0.91±0.02 ^F (0.85-0.98)	1.08±0.03 ^K (0.95-1.28)	5.62±0.11 ^F (5.12-6.12)	0.77±0.03 ^{JK} (0.65-0.89)	4.98±0.10 ^K (4.68-5.09)	54.99±0.03 ^C (54.89-55.09)	94.22±0.15 ^C (94.00-95.00)	5.67±0.17 ^D (5.00-6.00)	94.56±1.74 ^{FG} (85.00-98.00)	8.44±0.18 ^B (8.00-9.00)
Stems	6	1.52±0.05 ^L (1.26-1.76)	0.42±0.01 ^J (0.40-0.46)	0.98±0.03 ^K (0.87-1.09)	1.10±0.02 ^N (1.03-1.20)	0.39±0.01 ^L (0.35-0.45)	2.79±0.07 ^M (2.50-3.00)	57.92±0.02 ^A (57.87-57.99)	98.56±0.18 ^A (98.00-99.00)	8.33±0.17 ^A (8.00-9.00)	55.22±1.96 ^G (45.00-65.00)	5.67±0.17 ^E (5.00-6.00)
Bark	6	4.35±0.10 ^J (3.78-5.00)	1.34±0.02 ^C (1.25-1.45)	1.33±0.03 ^I (1.19-1.40)	11.23±0.09 ^A (10.83-11.50)	0.78±0.01 ^{JK} (0.73-0.83)	8.53±0.12 ^E (8.00-8.90)	52.20±0.05 ^E (52.09-52.38)	92.56±0.18 ^E (92.00-93.00)	6.67±0.17 ^B (6.00-7.00)	155.33±4.99 ^{EF} (137.00-178.00)	3.33±0.17 ^G (3.00-4.00)
Roots	6	4.01±0.07 ^J (3.58-4.68)	0.83±0.02 ^H (0.75-0.96)	3.91±0.08 ^E (3.33-4.22)	3.19±0.05 ^J (3.00-3.56)	3.18±0.11 ^G (2.89-3.89)	17.91±0.20 ^C (17.12-18.88)	51.52±0.02 ^G (51.48-51.58)	87.00±0.24 ^I (86.00-88.00)	6.56±0.18 ^{BC} (6.00-7.00)	2803.56±102.96 ^C (2456.00-3264.00)	7.33±0.17 ^C (7.00-8.00)

Table 6.3: The mean with standard error and range of different nutrients content in plant components during the wet season (November 2002). Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper ($\mu\text{g/g}$)	Iron ($\mu\text{g/g}$)	Zinc ($\mu\text{g/g}$)
Seedlings												
Leaves	6	9.00 $\pm$ 0.21 ^D (7.89-10.33)	1.34 $\pm$ 0.02 ^A (1.27-1.45)	5.83 $\pm$ 0.12 ^A (5.23-6.56)	5.04 $\pm$ 0.09 ^F (4.70-5.35)	8.74 $\pm$ 0.14 ^A (8.02-9.16)	4.06 $\pm$ 0.08 ^E (3.78-4.60)	43.04 $\pm$ 0.02 ^J (42.98-43.12)	83.33 $\pm$ 0.17 ^J (83.00-84.00)	6.22 $\pm$ 0.12 ^H (6.00-7.00)	363.00 $\pm$ 9.50 ^D (302.00-400.00)	15.00 $\pm$ 0.24 ^E (14.00-16.00)
Stems	6	6.39 $\pm$ 0.14 ^E (5.55-7.56)	0.39 $\pm$ 0.01 ^H (0.35-0.40)	2.27 $\pm$ 0.10 ^F (2.00-3.00)	4.64 $\pm$ 0.10 ^G (4.23-5.12)	2.72 $\pm$ 0.09 ^F (2.15-3.00)	3.38 $\pm$ 0.06 ^F (3.12-3.67)	50.72 $\pm$ 0.01 ^B (50.68-50.77)	93.11 $\pm$ 0.20 ^D (92.00-94.00)	5.33 $\pm$ 0.17 ^J (5.00-6.00)	328.56 $\pm$ 8.76 ^{DE} (298.00-389.00)	11.67 $\pm$ 0.17 ^H (11.00-12.00)
Roots	6	4.14 $\pm$ 0.09 ^G (3.26-4.89)	0.85 $\pm$ 0.02 ^D (0.76-0.95)	2.43 $\pm$ 0.06 ^F (2.20-2.75)	2.83 $\pm$ 0.08 ^I (2.60-3.20)	4.69 $\pm$ 0.13 ^D (4.06-5.12)	5.06 $\pm$ 0.11 ^D (4.66-5.60)	46.44 $\pm$ 0.02 ^E (46.38-46.49)	85.33 $\pm$ 0.17 ^I (85.00-86.00)	6.33 $\pm$ 0.17 ^H (6.00-7.00)	4035.11 $\pm$ 51.46 ^B (3845.00-4256.00)	22.67 $\pm$ 0.53 ^A (20.00-25.00)
Saplings												
Leaves	6	11.54 $\pm$ 0.09 ^B (11.02-12.56)	0.86 $\pm$ 0.02 ^D (0.74-1.00)	4.17 $\pm$ 0.13 ^D (3.66-5.00)	9.59 $\pm$ 0.17 ^C (9.12-10.56)	7.16 $\pm$ 0.08 ^C (6.95-7.56)	2.01 $\pm$ 0.06 ^G (1.75-2.25)	37.63 $\pm$ 0.01 ^N (37.59-37.65)	90.56 $\pm$ 0.18 ^F (90.00-91.00)	7.67 $\pm$ 0.17 ^F (7.00-8.00)	123.56 $\pm$ 4.30 ^{FG} (100.00-145.00)	10.67 $\pm$ 0.17 ^I (10.00-11.00)
Buds	6	9.18 $\pm$ 0.17 ^D (8.12-10.26)	1.19 $\pm$ 0.03 ^B (1.00-1.32)	4.01 $\pm$ 0.09 ^D (3.56-4.60)	10.12 $\pm$ 0.15 ^B (9.45-10.89)	4.67 $\pm$ 0.10 ^D (4.23-5.03)	1.72 $\pm$ 0.05 ^H (1.50-1.88)	43.62 $\pm$ 0.02 ^I (43.55-43.68)	88.56 $\pm$ 0.18 ^G (88.00-89.00)	8.22 $\pm$ 0.17 ^{DE} (7.50-9.00)	61.87 $\pm$ 1.96 ^G (56.80-69.60)	16.33 $\pm$ 0.17 ^D (16.00-17.00)
Branches	6	4.72 $\pm$ 0.13 ^F (3.89-5.94)	0.55 $\pm$ 0.01 ^G (0.50-0.59)	2.39 $\pm$ 0.04 ^F (2.22-2.68)	6.54 $\pm$ 0.13 ^E (6.00-7.12)	1.45 $\pm$ 0.06 ^G (1.23-1.85)	1.63 $\pm$ 0.04 ^H (1.50-1.81)	48.06 $\pm$ 0.02 ^C (47.97-48.13)	94.89 $\pm$ 0.11 ^B (94.00-95.00)	7.00 $\pm$ 0.14 ^G (6.50-7.50)	83.00 $\pm$ 1.99 ^{FG} (70.00-88.00)	14.00 $\pm$ 0.29 ^{FG} (13.00-15.00)
Stems	6	1.53 $\pm$ 0.04 ^J (1.25-1.87)	0.29 $\pm$ 0.01 ^I (0.28-0.33)	0.91 $\pm$ 0.04 ^I (0.75-1.10)	1.56 $\pm$ 0.03 ^J (1.45-1.71)	0.58 $\pm$ 0.01 ^{IJ} (0.55-0.60)	1.13 $\pm$ 0.02 ^I (1.06-1.19)	50.92 $\pm$ 0.01 ^A (50.87-50.96)	98.33 $\pm$ 0.17 ^A (98.00-99.00)	6.33 $\pm$ 0.17 ^H (6.00-7.00)	70.67 $\pm$ 1.35 ^G (65.00-76.00)	12.00 $\pm$ 0.17 ^H (11.00-13.00)
Bark	6	4.31 $\pm$ 0.10 ^G (3.88-5.01)	0.58 $\pm$ 0.01 ^G (0.52-0.61)	1.21 $\pm$ 0.04 ^H (1.06-1.51)	9.69 $\pm$ 0.18 ^C (9.01-10.56)	1.14 $\pm$ 0.04 ^H (1.02-1.35)	3.28 $\pm$ 0.04 ^F (3.00-3.40)	47.15 $\pm$ 0.01 ^D (47.10-47.19)	93.89 $\pm$ 0.11 ^C (93.00-94.00)	7.78 $\pm$ 0.15 ^{EF} (7.00-8.00)	125.00 $\pm$ 2.88 ^{FG} (115.00-142.00)	16.67 $\pm$ 0.33 ^D (16.00-19.00)
Roots	6	3.60 $\pm$ 0.07 ^I (3.15-4.05)	0.76 $\pm$ 0.01 ^E (0.70-0.80)	4.16 $\pm$ 0.06 ^D (3.94-4.44)	3.52 $\pm$ 0.08 ^H (3.25-3.89)	4.11 $\pm$ 0.09 ^E (3.87-4.61)	6.90 $\pm$ 0.17 ^B (6.13-7.80)	45.04 $\pm$ 0.02 ^H (44.98-45.10)	87.56 $\pm$ 0.18 ^H (87.00-88.00)	6.33 $\pm$ 0.17 ^H (6.00-7.00)	5438.56 $\pm$ 83.79 ^A (5166.00-5878.00)	18.89 $\pm$ 0.31 ^C (18.00-20.00)
Trees												
Leaves	6	12.58 $\pm$ 0.18 ^A (11.11-14.03)	0.97 $\pm$ 0.02 ^C (0.88-1.06)	5.50 $\pm$ 0.10 ^B (5.00-5.96)	9.61 $\pm$ 0.15 ^C (9.02-10.23)	7.80 $\pm$ 0.15 ^B (7.26-8.45)	11.49 $\pm$ 0.12 ^A (11.00-12.00)	42.36 $\pm$ 0.02 ^K (42.31-42.42)	90.56 $\pm$ 0.29 ^F (90.00-92.00)	9.67 $\pm$ 0.17 ^B (9.00-10.00)	222.22 $\pm$ 5.86 ^{EF} (200.00-256.00)	14.22 $\pm$ 0.22 ^F (13.00-15.00)
Buds	6	10.65 $\pm$ 0.20 ^C (9.23-12.15)	1.30 $\pm$ 0.03 ^A (1.15-1.45)	4.80 $\pm$ 0.09 ^C (4.35-5.23)	10.42 $\pm$ 0.14 ^B (10.10-11.45)	4.59 $\pm$ 0.11 ^D (4.15-5.16)	7.13 $\pm$ 0.15 ^B (6.48-7.89)	41.72 $\pm$ 0.01 ^M (41.68-41.77)	90.67 $\pm$ 0.17 ^F (90.00-91.00)	11.33 $\pm$ 0.17 ^A (11.00-12.00)	100.22 $\pm$ 2.17 ^{FG} (86.00-108.00)	19.00 $\pm$ 0.29 ^C (18.00-20.00)
Branches	6	4.44 $\pm$ 0.10 ^{FG} (3.89-5.12)	0.64 $\pm$ 0.01 ^F (0.60-0.69)	1.84 $\pm$ 0.04 ^G (1.66-1.97)	7.58 $\pm$ 0.13 ^D (7.12-8.11)	0.83 $\pm$ 0.02 ^I (0.68-0.91)	3.14 $\pm$ 0.06 ^F (2.94-3.50)	42.03 $\pm$ 0.03 ^L (41.92-42.12)	94.33 $\pm$ 0.17 ^C (94.00-95.00)	9.00 $\pm$ 0.24 ^C (8.00-10.00)	90.22 $\pm$ 2.16 ^{FG} (81.00-98.00)	13.33 $\pm$ 0.17 ^G (13.00-14.00)
Stems	6	1.49 $\pm$ 0.04 ^J (1.25-1.78)	0.28 $\pm$ 0.01 ^I (0.25-0.32)	0.91 $\pm$ 0.03 ^I (0.83-1.07)	1.11 $\pm$ 0.02 ^K (1.00-1.20)	0.41 $\pm$ 0.01 ^J (0.36-0.45)	1.14 $\pm$ 0.04 ^I (1.06-1.45)	45.26 $\pm$ 0.01 ^G (45.21-45.31)	98.44 $\pm$ 0.18 ^A (98.00-99.00)	5.67 $\pm$ 0.17 ^{IJ} (5.00-6.00)	53.89 $\pm$ 1.87 ^G (49.00-66.00)	21.00 $\pm$ 0.29 ^B (20.00-22.00)
Bark	6	4.11 $\pm$ 0.05 ^H (3.78-4.67)	1.22 $\pm$ 0.03 ^B (1.02-1.38)	1.19 $\pm$ 0.03 ^H (1.00-1.30)	11.10 $\pm$ 0.05 ^A (11.00-11.30)	0.80 $\pm$ 0.02 ^I (0.68-0.91)	3.28 $\pm$ 0.06 ^F (3.06-3.50)	41.32 $\pm$ 0.01 ^N (41.29-41.35)	91.78 $\pm$ 0.28 ^E (91.00-93.00)	6.11 $\pm$ 0.16 ^{HI} (5.50-7.00)	122.22 $\pm$ 4.40 ^{FG} (103.00-144.00)	10.00 $\pm$ 0.29 ^I (9.00-11.00)
Roots	6	3.93 $\pm$ 0.04 ^H (3.68-4.45)	0.69 $\pm$ 0.01 ^F (0.63-0.75)	3.18 $\pm$ 0.09 ^E (2.89-3.68)	3.34 $\pm$ 0.09 ^H (3.00-3.80)	4.09 $\pm$ 0.11 ^E (3.58-4.65)	6.38 $\pm$ 0.12 ^C (6.00-7.00)	46.06 $\pm$ 0.02 ^F (45.97-46.12)	85.67 $\pm$ 0.24 ^I (85.00-87.00)	8.33 $\pm$ 0.17 ^D (8.00-9.00)	3357.56 $\pm$ 141.15 ^C (2689.00-3894.00)	21.56 $\pm$ 0.29 ^B (20.00-23.00)

Table 6.4. The mean with standard error and range of different nutrients contents in plant components during the intermediate season (March 2003).
Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper ($\mu\text{g/g}$)	Iron ($\mu\text{g/g}$)	Zinc ($\mu\text{g/g}$)
Seedlings												
Leaves	6	10.70 $\pm$ 0.35 ^C (8.12-12.56)	1.48 $\pm$ 0.04 ^{BC} (1.33-1.76)	7.07 $\pm$ 0.11 ^D (6.44-7.56)	5.52 $\pm$ 0.08 ^G (5.20-5.80)	9.23 $\pm$ 0.12 ^A (8.75-9.80)	4.42 $\pm$ 0.12 ^{HI} (3.78-4.89)	52.46 $\pm$ 0.05 ^C (52.23-52.69)	87.33 $\pm$ 0.17 ^G (87.00-88.00)	3.67 $\pm$ 0.17 ^{GH} (3.00-4.00)	465.44 $\pm$ 11.36 ^C (400.00-513.00)	17.33 $\pm$ 0.44 ^{DE} (16.00-19.00)
Stems	6	8.24 $\pm$ 0.13 ^E (7.56-9.12)	0.71 $\pm$ 0.02 ^{FG} (0.60-0.80)	4.03 $\pm$ 0.07 ^I (3.66-4.45)	4.38 $\pm$ 0.09 ^H (4.12-4.91)	2.19 $\pm$ 0.08 ^F (1.90-2.55)	4.12 $\pm$ 0.09 ^I (3.88-4.60)	56.24 $\pm$ 0.03 ^A (56.12-56.34)	92.44 $\pm$ 0.18 ^D (92.00-93.00)	3.17 $\pm$ 0.12 ^H (3.00-4.00)	346.56 $\pm$ 7.26 ^D (323.00-389.00)	9.11 $\pm$ 0.20 ^J (8.00-10.00)
Roots	6	4.94 $\pm$ 0.09 ^F (4.26-5.66)	0.68 $\pm$ 0.01 ^G (0.63-0.75)	5.04 $\pm$ 0.14 ^G (4.55-6.00)	3.57 $\pm$ 0.12 ^I (2.89-3.89)	4.99 $\pm$ 0.16 ^D (4.23-5.78)	6.16 $\pm$ 0.10 ^F (5.67-6.58)	50.34 $\pm$ 0.05 ^E (50.14-50.63)	85.33 $\pm$ 0.17 ^H (85.00-86.00)	5.22 $\pm$ 0.17 ^D (5.00-6.50)	4836.44 $\pm$ 58.66 ^B (4560.00-5164.00)	21.78 $\pm$ 0.28 ^B (20.00-23.00)
Saplings												
Leaves	6	12.33 $\pm$ 0.16 ^B (11.11-13.56)	1.22 $\pm$ 0.02 ^D (1.15-1.28)	8.95 $\pm$ 0.18 ^B (8.00-9.89)	10.39 $\pm$ 0.18 ^C (9.78-11.23)	9.03 $\pm$ 0.10 ^A (8.69-9.65)	4.79 $\pm$ 0.14 ^G (4.20-5.45)	40.36 $\pm$ 0.05 ^K (40.16-40.63)	88.44 $\pm$ 0.18 ^F (88.00-89.00)	4.06 $\pm$ 0.10 ^{FG} (3.50-4.50)	137.11 $\pm$ 6.40 ^E (103.00-158.00)	12.78 $\pm$ 0.28 ^I (12.00-14.00)
Buds	6	9.47 $\pm$ 0.18 ^D (8.45-10.66)	1.45 $\pm$ 0.03 ^{BC} (1.30-1.60)	6.61 $\pm$ 0.12 ^E (6.00-7.12)	10.64 $\pm$ 0.13 ^C (10.12-11.23)	5.81 $\pm$ 0.11 ^B (5.23-6.15)	2.43 $\pm$ 0.08 ^K (2.12-2.78)	46.25 $\pm$ 0.06 ^H (46.00-46.58)	89.00 $\pm$ 0.24 ^F (88.00-90.00)	4.67 $\pm$ 0.17 ^F (4.00-5.00)	61.67 $\pm$ 1.17 ^E (58.00-66.00)	13.67 $\pm$ 0.37 ^H (12.00-15.00)
Branches	6	5.09 $\pm$ 0.14 ^F (4.55-6.25)	0.76 $\pm$ 0.01 ^F (0.73-0.79)	4.51 $\pm$ 0.10 ^H (4.12-5.00)	7.54 $\pm$ 0.12 ^E (7.12-8.12)	1.53 $\pm$ 0.04 ^G (1.45-1.78)	2.12 $\pm$ 0.05 ^L (2.00-2.38)	47.41 $\pm$ 0.06 ^G (47.25-47.65)	93.78 $\pm$ 0.15 ^C (93.00-94.00)	4.00 $\pm$ 0.12 ^{FG} (3.50-4.50)	93.33 $\pm$ 1.01 ^E (90.00-97.00)	9.00 $\pm$ 0.17 ^J (8.00-10.00)
Stems	6	1.49 $\pm$ 0.04 ^I (1.28-1.76)	0.50 $\pm$ 0.01 ^H (0.45-0.55)	1.02 $\pm$ 0.01 ^K (0.99-1.10)	1.55 $\pm$ 0.03 ^J (1.45-1.70)	0.58 $\pm$ 0.01 ^{IJ} (0.55-0.60)	1.47 $\pm$ 0.06 ^M (1.25-1.75)	51.40 $\pm$ 0.05 ^D (51.26-51.66)	98.33 $\pm$ 0.17 ^A (98.00-99.00)	3.33 $\pm$ 0.17 ^H (3.00-4.00)	52.67 $\pm$ 1.01 ^E (49.00-56.00)	7.67 $\pm$ 0.24 ^K (7.00-9.00)
Bark	6	4.44 $\pm$ 0.11 ^{GH} (3.88-5.12)	0.86 $\pm$ 0.01 ^E (0.82-0.90)	1.25 $\pm$ 0.03 ^K (1.15-1.45)	10.70 $\pm$ 0.21 ^C (10.12-11.68)	1.18 $\pm$ 0.04 ^H (1.05-1.36)	4.44 $\pm$ 0.12 ^H (3.88-4.90)	45.56 $\pm$ 0.07 ^I (45.26-45.89)	93.44 $\pm$ 0.18 ^C (93.00-94.00)	4.33 $\pm$ 0.17 ^{EF} (4.00-5.00)	129.33 $\pm$ 2.91 ^E (114.00-139.00)	15.00 $\pm$ 0.29 ^G (14.00-16.00)
Roots	6	3.68 $\pm$ 0.08 ^I (3.14-4.12)	0.83 $\pm$ 0.01 ^F (0.80-0.90)	5.00 $\pm$ 0.07 ^G (4.56-5.26)	4.28 $\pm$ 0.06 ^H (4.12-4.77)	4.58 $\pm$ 0.12 ^E (4.03-5.00)	9.73 $\pm$ 0.13 ^D (9.12-10.26)	48.37 $\pm$ 0.05 ^F (48.25-48.56)	84.44 $\pm$ 0.18 ^I (84.00-85.00)	4.33 $\pm$ 0.33 ^{EF} (3.00-5.00)	5934.78 $\pm$ 106.25 ^A (5456.00-6258.00)	23.33 $\pm$ 0.17 ^A (23.00-24.00)
Trees												
Leaves	6	14.05 $\pm$ 0.30 ^A (12.25-16.00)	1.20 $\pm$ 0.03 ^D (1.02-1.30)	9.41 $\pm$ 0.12 ^A (9.00-10.03)	11.40 $\pm$ 0.13 ^B (11.03-12.02)	9.29 $\pm$ 0.13 ^A (8.78-10.03)	12.83 $\pm$ 0.15 ^B (12.00-13.60)	45.40 $\pm$ 0.05 ^J (45.26-45.69)	90.67 $\pm$ 0.24 ^E (90.00-92.00)	5.33 $\pm$ 0.17 ^D (5.00-6.00)	293.33 $\pm$ 6.39 ^D (268.00-326.00)	12.56 $\pm$ 0.29 ^I (12.00-14.00)
Buds	6	10.72 $\pm$ 0.17 ^C (9.56-11.88)	1.54 $\pm$ 0.02 ^A (1.40-1.67)	6.01 $\pm$ 0.10 ^F (5.23-6.23)	11.67 $\pm$ 0.18 ^B (11.03-12.68)	5.42 $\pm$ 0.12 ^C (5.03-5.89)	7.95 $\pm$ 0.11 ^E (7.45-8.30)	47.46 $\pm$ 0.09 ^G (47.23-47.98)	90.44 $\pm$ 0.24 ^E (90.00-92.00)	8.17 $\pm$ 0.17 ^B (7.50-9.00)	72.33 $\pm$ 1.45 ^E (67.00-77.00)	16.44 $\pm$ 0.24 ^F (15.00-17.00)
Flowers	6	7.90 $\pm$ 0.04 ^E (7.55-8.12)	1.51 $\pm$ 0.04 ^{AB} (1.28-1.68)	7.51 $\pm$ 0.11 ^C (7.00-8.12)	11.48 $\pm$ 0.10 ^B (11.02-11.89)	5.54 $\pm$ 0.07 ^C (5.23-5.89)	13.91 $\pm$ 0.15 ^A (13.06-14.75)	48.44 $\pm$ 0.08 ^F (48.12-48.95)	90.00 $\pm$ 0.29 ^E (89.00-91.00)	8.67 $\pm$ 0.17 ^B (8.00-9.00)	97.78 $\pm$ 2.23 ^E (89.00-110.00)	18.00 $\pm$ 0.29 ^D (17.00-19.00)
Branches	6	4.73 $\pm$ 0.11 ^{FG} (4.05-5.68)	0.70 $\pm$ 0.01 ^{FG} (0.65-0.74)	2.00 $\pm$ 0.04 ^J (1.77-2.20)	7.98 $\pm$ 0.13 ^D (7.68-8.89)	1.11 $\pm$ 0.03 ^H (1.01-1.23)	3.24 $\pm$ 0.07 ^J (3.00-3.68)	50.35 $\pm$ 0.04 ^E (50.23-50.56)	95.56 $\pm$ 0.18 ^B (95.00-96.00)	11.00 $\pm$ 0.29 ^A (10.00-12.00)	131.67 $\pm$ 1.20 ^E (127.00-135.00)	8.67 $\pm$ 0.17 ^J (8.00-9.00)
Stems	6	1.55 $\pm$ 0.04 ^J (1.26-1.75)	0.37 $\pm$ 0.01 ^I (0.35-0.40)	1.00 $\pm$ 0.01 ^K (0.96-1.05)	1.12 $\pm$ 0.02 ^K (1.03-1.23)	0.40 $\pm$ 0.01 ^J (0.35-0.45)	1.64 $\pm$ 0.07 ^M (1.19-1.87)	52.30 $\pm$ 0.05 ^C (52.12-52.45)	98.56 $\pm$ 0.18 ^A (98.00-99.00)	3.33 $\pm$ 0.17 ^H (3.00-4.00)	66.33 $\pm$ 2.22 ^E (52.00-73.00)	17.00 $\pm$ 0.29 ^{EF} (16.00-18.00)
Bark	6	4.48 $\pm$ 0.08 ^G (3.98-5.03)	1.43 $\pm$ 0.03 ^C (1.25-1.61)	1.25 $\pm$ 0.03 ^K (1.10-1.40)	17.70 $\pm$ 0.13 ^A (17.25-18.15)	0.82 $\pm$ 0.02 ^I (0.75-0.90)	4.47 $\pm$ 0.08 ^H (4.13-4.81)	47.38 $\pm$ 0.08 ^G (47.12-47.89)	92.11 $\pm$ 0.20 ^D (91.00-93.00)	3.33 $\pm$ 0.17 ^H (3.00-4.00)	171.78 $\pm$ 4.10 ^E (145.00-184.00)	9.33 $\pm$ 0.33 ^J (8.00-10.00)
Roots	6	4.01 $\pm$ 0.05 ^{HI} (3.57-4.68)	0.82 $\pm$ 0.01 ^E (0.79-0.88)	5.20 $\pm$ 0.09 ^G (5.00-5.89)	6.00 $\pm$ 0.08 ^F (5.68-6.45)	4.35 $\pm$ 0.12 ^E (4.03-4.98)	10.72 $\pm$ 0.14 ^C (10.23-11.45)	53.68 $\pm$ 0.06 ^B (53.43-53.84)	85.67 $\pm$ 0.24 ^H (85.00-87.00)	7.33 $\pm$ 0.17 ^C (7.00-8.00)	4808.78 $\pm$ 95.84 ^B (4368.00-5236.00)	20.00 $\pm$ 0.29 ^C (19.00-21.00)

Table 6.5: The mean with standard error and range of different nutrients content in plant components during the dry season (July 2003). Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper ($\mu\text{g/g}$)	Iron ($\mu\text{g/g}$)	Zinc ($\mu\text{g/g}$)
Seedlings												
Leaves	6	8.60 $\pm$ 0.20 ^B (7.23-10.23)	1.63 $\pm$ 0.04 ^A (1.44-1.89)	6.61 $\pm$ 0.11 ^A (6.00-7.00)	3.88 $\pm$ 0.07 ^F (3.56-4.23)	8.12 $\pm$ 0.13 ^A (7.56-8.88)	5.70 $\pm$ 0.10 ^G (5.25-6.12)	50.45 $\pm$ 0.11 ^E (50.12-51.12)	85.89 $\pm$ 0.26 ^I (85.00-87.00)	5.22 $\pm$ 0.15 ^{FG} (5.00-6.00)	354.44 $\pm$ 12.15 ^D (315.00-425.00)	16.22 $\pm$ 0.15 ^C (16.00-17.00)
Stems	6	4.59 $\pm$ 0.11 ^D (3.89-5.33)	0.83 $\pm$ 0.02 ^F (0.70-0.95)	3.17 $\pm$ 0.09 ^G (2.89-3.60)	3.57 $\pm$ 0.09 ^G (3.23-3.94)	2.31 $\pm$ 0.07 ^H (2.01-2.70)	4.84 $\pm$ 0.09 ^{HI} (4.54-5.36)	51.23 $\pm$ 0.15 ^D (50.23-51.89)	92.89 $\pm$ 0.31 ^D (92.00-94.00)	5.17 $\pm$ 0.12 ^{FG} (5.00-6.00)	297.44 $\pm$ 9.73 ^D (256.00-330.00)	9.22 $\pm$ 0.15 ^G (9.00-10.00)
Roots	6	3.45 $\pm$ 0.08 ^{HI} (3.00-4.11)	0.83 $\pm$ 0.02 ^F (0.73-0.95)	4.44 $\pm$ 0.10 ^E (4.00-5.00)	2.60 $\pm$ 0.07 ^I (2.14-2.90)	4.41 $\pm$ 0.14 ^E (3.89-5.03)	7.50 $\pm$ 0.03 ^E (7.40-7.60)	48.39 $\pm$ 0.13 ^G (47.46-48.69)	86.11 $\pm$ 0.26 ^I (85.00-87.00)	8.22 $\pm$ 0.15 ^C (8.00-9.00)	3274.78 $\pm$ 78.39 ^B (2987.00-3564.00)	20.22 $\pm$ 0.15 ^A (20.00-21.00)
Saplings												
Leaves	6	12.01 $\pm$ 0.15 ^A (11.02-13.26)	1.22 $\pm$ 0.03 ^D (1.00-1.35)	6.39 $\pm$ 0.09 ^A (6.00-7.00)	6.90 $\pm$ 0.10 ^D (6.35-7.26)	6.01 $\pm$ 0.13 ^C (5.60-6.89)	6.71 $\pm$ 0.14 ^F (6.00-7.30)	42.26 $\pm$ 0.07 ^K (42.03-42.56)	90.44 $\pm$ 0.18 ^F (90.00-91.00)	8.22 $\pm$ 0.15 ^C (8.00-9.00)	114.11 $\pm$ 3.47 ^E (103.00-132.00)	11.33 $\pm$ 0.24 ^E (11.00-13.00)
Buds	6	8.93 $\pm$ 0.17 ^B (7.99-10.23)	1.44 $\pm$ 0.02 ^B (1.32-1.56)	5.20 $\pm$ 0.08 ^C (4.78-5.60)	8.55 $\pm$ 0.15 ^C (7.89-9.12)	5.27 $\pm$ 0.12 ^D (4.97-5.89)	4.25 $\pm$ 0.09 ^J (4.03-4.78)	47.43 $\pm$ 0.05 ^H (47.23-47.66)	88.33 $\pm$ 0.17 ^H (88.00-89.00)	9.00 $\pm$ 0.17 ^A (8.00-10.00)	42.22 $\pm$ 0.97 ^E (38.00-46.00)	14.22 $\pm$ 0.15 ^D (14.00-15.00)
Branches	6	4.83 $\pm$ 0.12 ^D (3.89-5.55)	0.94 $\pm$ 0.01 ^E (0.90-1.00)	3.12 $\pm$ 0.07 ^G (2.89-3.56)	7.09 $\pm$ 0.14 ^D (6.77-7.98)	1.20 $\pm$ 0.06 ^I (1.00-1.56)	4.62 $\pm$ 0.04 ^I (4.36-4.78)	50.28 $\pm$ 0.06 ^E (50.12-50.61)	94.44 $\pm$ 0.18 ^C (94.00-95.00)	8.11 $\pm$ 0.11 ^{CD} (8.00-9.00)	49.56 $\pm$ 1.17 ^E (45.00-56.00)	8.11 $\pm$ 0.11 ^H (8.00-9.00)
Stems	6	1.50 $\pm$ 0.04 ^I (1.25-1.78)	0.64 $\pm$ 0.01 ^G (0.60-0.68)	0.92 $\pm$ 0.02 ^J (0.80-1.00)	1.56 $\pm$ 0.03 ^K (1.42-1.71)	0.61 $\pm$ 0.01 ^{JK} (0.55-0.65)	3.05 $\pm$ 0.08 ^K (2.71-3.50)	52.40 $\pm$ 0.08 ^C (52.04-52.68)	98.22 $\pm$ 0.15 ^A (98.00-99.00)	4.89 $\pm$ 0.11 ^G (4.00-5.00)	43.89 $\pm$ 1.20 ^E (40.00-52.00)	7.44 $\pm$ 0.24 ^I (7.00-9.00)
Bark	6	4.27 $\pm$ 0.09 ^{EF} (3.89-5.06)	0.83 $\pm$ 0.01 ^F (0.80-0.90)	1.21 $\pm$ 0.04 ^I (1.00-1.40)	8.61 $\pm$ 0.14 ^C (8.15-9.15)	1.07 $\pm$ 0.03 ^I (0.98-1.20)	5.03 $\pm$ 0.12 ^H (4.56-5.66)	50.29 $\pm$ 0.06 ^E (50.08-50.66)	93.44 $\pm$ 0.18 ^D (93.00-94.00)	6.44 $\pm$ 0.18 ^E (6.00-7.00)	93.33 $\pm$ 1.83 ^E (84.00-100.00)	18.11 $\pm$ 0.11 ^B (18.00-19.00)
Roots	6	3.52 $\pm$ 0.07 ^{HI} (3.12-4.01)	0.80 $\pm$ 0.01 ^F (0.77-0.85)	4.60 $\pm$ 0.10 ^{DE} (4.25-5.25)	3.19 $\pm$ 0.07 ^{HI} (3.00-3.74)	4.10 $\pm$ 0.09 ^F (3.78-4.56)	16.86 $\pm$ 0.20 ^A (15.66-17.84)	47.55 $\pm$ 0.04 ^H (47.25-47.68)	84.78 $\pm$ 0.15 ^J (84.00-85.00)	7.67 $\pm$ 0.24 ^D (7.00-9.00)	4630.78 $\pm$ 102.39 ^A (4265.00-5147.00)	16.22 $\pm$ 0.15 ^C (16.00-17.00)
Trees												
Leaves	6	12.02 $\pm$ 0.20 ^A (10.26-13.26)	1.33 $\pm$ 0.02 ^C (1.22-1.43)	6.41 $\pm$ 0.12 ^A (5.89-7.00)	8.59 $\pm$ 0.14 ^C (8.03-9.15)	6.63 $\pm$ 0.16 ^B (6.00-7.23)	15.55 $\pm$ 0.20 ^C (15.00-16.45)	46.35 $\pm$ 0.05 ^I (46.15-46.57)	89.78 $\pm$ 0.15 ^{FG} (89.00-90.00)	8.44 $\pm$ 0.18 ^{BC} (8.00-9.00)	132.56 $\pm$ 5.03 ^E (106.00-156.00)	16.44 $\pm$ 0.29 ^C (16.00-18.00)
Buds	6	8.66 $\pm$ 0.17 ^B (7.12-9.66)	1.50 $\pm$ 0.04 ^B (1.35-1.75)	5.79 $\pm$ 0.08 ^B (5.40-6.03)	9.38 $\pm$ 0.18 ^B (8.89-10.23)	4.43 $\pm$ 0.11 ^E (4.00-4.98)	9.58 $\pm$ 0.12 ^D (9.00-10.02)	48.36 $\pm$ 0.06 ^G (48.12-48.56)	89.56 $\pm$ 0.41 ^G (88.00-92.00)	8.44 $\pm$ 0.18 ^{BC} (8.00-9.00)	55.33 $\pm$ 1.26 ^E (48.00-61.00)	20.56 $\pm$ 0.24 ^A (20.00-22.00)
Propagules	6	6.75 $\pm$ 0.11 ^C (6.02-7.77)	1.22 $\pm$ 0.02 ^D (1.10-1.36)	4.71 $\pm$ 0.09 ^D (4.50-5.26)	2.04 $\pm$ 0.05 ^J (1.89-2.33)	1.13 $\pm$ 0.03 ^I (1.03-1.26)	16.73 $\pm$ 0.11 ^{AB} (16.40-17.45)	49.37 $\pm$ 0.07 ^F (49.12-49.62)	94.56 $\pm$ 0.24 ^C (94.00-96.00)	6.11 $\pm$ 0.11 ^E (6.00-7.00)	32.22 $\pm$ 1.01 ^E (26.00-36.00)	4.89 $\pm$ 0.11 ^J (4.00-5.00)
Branches	6	3.48 $\pm$ 0.10 ^{HI} (2.56-4.02)	0.80 $\pm$ 0.01 ^F (0.75-0.85)	1.61 $\pm$ 0.04 ^H (1.50-1.75)	6.10 $\pm$ 0.11 ^E (5.77-6.78)	0.77 $\pm$ 0.02 ^J (0.64-0.89)	4.09 $\pm$ 0.11 ^J (3.87-4.68)	53.33 $\pm$ 0.06 ^B (53.12-53.64)	95.56 $\pm$ 0.18 ^B (95.00-96.00)	8.89 $\pm$ 0.11 ^{AB} (8.00-9.00)	84.44 $\pm$ 1.45 ^E (78.00-91.00)	14.44 $\pm$ 0.24 ^D (14.00-16.00)
Stems	6	1.52 $\pm$ 0.04 ^I (1.26-1.78)	0.42 $\pm$ 0.01 ^{HI} (0.40-0.45)	0.92 $\pm$ 0.04 ^J (0.75-1.00)	1.07 $\pm$ 0.02 ^C (1.00-1.16)	0.40 $\pm$ 0.01 ^K (0.35-0.45)	2.10 $\pm$ 0.07 ^L (1.88-2.46)	55.41 $\pm$ 0.09 ^A (55.12-55.89)	98.44 $\pm$ 0.18 ^A (98.00-99.00)	5.44 $\pm$ 0.18 ^F (5.00-6.00)	60.22 $\pm$ 2.43 ^E (46.00-68.00)	14.11 $\pm$ 0.11 ^D (14.00-15.00)
Bark	6	4.06 $\pm$ 0.04 ^{FG} (3.68-4.44)	1.37 $\pm$ 0.04 ^C (1.22-1.58)	1.33 $\pm$ 0.04 ^I (1.25-1.50)	11.38 $\pm$ 0.03 ^A (11.30-11.50)	0.78 $\pm$ 0.01 ^I (0.75-0.80)	7.24 $\pm$ 0.09 ^E (6.88-7.83)	45.41 $\pm$ 0.08 ^J (45.14-45.88)	91.44 $\pm$ 0.24 ^E (90.00-92.00)	4.33 $\pm$ 0.17 ^{HI} (4.00-5.00)	131.67 $\pm$ 3.30 ^E (120.00-150.00)	10.33 $\pm$ 0.17 ^F (10.00-11.00)
Roots	6	3.76 $\pm$ 0.05 ^{GH} (3.24-4.12)	0.91 $\pm$ 0.01 ^E (0.85-0.98)	4.21 $\pm$ 0.10 ^F (3.88-4.80)	3.40 $\pm$ 0.03 ^G (3.30-3.50)	3.59 $\pm$ 0.12 ^G (3.06-4.03)	16.48 $\pm$ 0.10 ^B (16.24-17.12)	49.59 $\pm$ 0.07 ^F (49.26-49.87)	85.33 $\pm$ 0.29 ^{IF} (84.00-87.00)	8.00 $\pm$ 0.24 ^{CD} (7.00-9.00)	3153.67 $\pm$ 106.83 ^C (2678.00-3589.00)	18.00 $\pm$ 0.24 ^B (17.00-19.00)

Table 6.6: Pearson correlation coefficient (r) between soil nutrient and nutrient content in different components of seedlings, saplings and trees

Nutrients	Seedling components			Sapling components					Tree components						
	Leaves	Stems	Roots	Leaves	Buds	Branches	Stems	Bark	Roots	Leaves	Buds	Branches	Stems	Bark	Roots
N	0.73	0.46	0.66	0.91*	0.56	0.37	-0.33	0.52	0.56	0.64	0.63	0.20	-0.28	0.57	0.39
P	0.45	0.53	-0.20	0.51	0.83*	0.47	0.47	0.22	0.70	0.24	0.82*	0.28	0.37	0.60	0.36
K	0.94*	0.91*	0.91*	0.92*	0.92*	0.96*	0.76	0.73	0.92*	0.93*	0.76	0.55	0.82*	0.15	0.96*
Ca	0.66	0.53	0.95*	0.78	0.64	0.42	0.08	0.89*	0.96*	0.85*	0.91*	0.70	0.79	0.89*	0.91*
Mg	0.97*	0.21	0.96*	0.99*	0.87*	0.96*	0.26	0.95*	0.94*	0.99*	0.94*	0.97*	0.24	0.73	0.88*
S	0.92*	0.89*	0.99*	0.99*	0.95*	0.94*	0.97*	0.95*	0.97*	0.94*	0.99*	0.90*	0.98*	0.99*	0.97*
Cu	0.94*	0.93*	0.91*	0.86*	0.91*	0.98*	0.58	0.86*	0.87*	0.67	0.65	0.46	0.57	0.59	0.96*
Fe	0.96*	0.79	0.95*	0.95*	0.76	0.88*	0.48	0.62	0.89*	0.93*	0.34	0.78	0.77	0.78	0.99*
Zn	0.85*	0.97*	0.20	0.77	0.84*	0.57	0.54	0.73	0.86*	0.83*	0.84*	0.40	0.56	0.90*	0.86*

* Significant at $p < 0.05$

Table 6.7. The mean with standard error and range of different nutrients content in different components of litter production and litter standing crop during the intermediate season (March 2002). Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper (µg/g)	Iron (µg/g)	Zinc (µg/g)
Litter production												
Leaves	18	5.93±0.11 ^{DE} (5.44-6.23)	1.12±0.04 ^B (0.98-1.25)	2.18±0.06 ^B (2.00-2.36)	13.21±0.10 ^A (13.00-13.63)	4.00±0.05 ^{AB} (3.80-4.10)	5.17±0.14 ^D (4.78-5.60)	48.77±0.07 ^D (48.36-49.02)	93.67±0.17 ^B (93.00-94.00)	10.66±0.15 ^D (10.23-11.25)	97.83±4.20 ^{DE} (86.00-111.00)	25.00±0.29 ^B (24.00-26.00)
Branches	18	3.37±0.19 ^F (2.88-3.87)	0.92±0.01 ^C (0.87-0.98)	0.62±0.02 ^E (0.56-0.68)	12.15±0.10 ^B (11.68-12.89)	0.77±0.04 ^E (0.62-0.86)	2.61±0.09 ^H (2.40-3.00)	48.27±0.05 ^E (48.06-48.56)	95.33±0.17 ^A (95.00-96.00)	17.70±0.17 ^A (17.00-18.00)	93.27±2.50 ^E (85.00-101.60)	15.00±0.41 ^G (14.00-16.00)
Bracts	18	5.57±0.17 ^E (5.23-6.23)	0.95±0.02 ^C (0.85-1.00)	1.19±0.02 ^C (1.15-1.28)	11.26±0.13 ^C (10.89-11.89)	3.90±0.05 ^B (3.67-4.00)	3.08±0.10 ^G (2.78-3.40)	45.36±0.12 ^F (45.06-46.28)	91.89±0.39 ^C (90.00-94.00)	10.43±0.11 ^D (10.00-11.20)	110.07±4.31 ^{DE} (98.00-120.00)	22.17±0.18 ^D (22.00-23.00)
Flowers	18	6.87±0.20 ^C (6.38-7.56)	1.56±0.05 ^A (1.35-1.75)	4.12±0.09 ^A (3.98-4.50)	11.04±0.04 ^C (10.88-11.22)	3.57±0.03 ^C (3.42-3.66)	4.28±0.12 ^E (4.00-4.60)	49.72±0.16 ^C (48.56-50.14)	92.56±0.18 ^C (92.00-93.00)	10.68±0.23 ^D (10.00-11.20)	120.17±3.56 ^D (108.00-132.00)	26.33±0.22 ^A (26.00-27.00)
Litter standing crop												
Intact leaves	18	7.56±0.20 ^B (7.00-8.44)	1.00±0.03 ^C (0.91-1.06)	1.20±0.05 ^C (1.10-1.40)	9.31±0.14 ^D (9.02-9.89)	3.85±0.07 ^B (3.58-4.00)	6.30±0.20 ^C (5.68-6.89)	52.61±0.09 ^A (52.15-52.98)	92.11±0.11 ^C (92.00-93.00)	6.93±0.18 ^F (6.40-7.20)	118.33±2.55 ^D (110.00-126.00)	20.33±0.22 ^E (20.00-21.00)
Broken leaves	18	10.62±0.29 ^A (9.45-11.45)	0.82±0.01 ^D (0.80-0.85)	0.97±0.02 ^D (0.86-1.00)	8.01±0.13 ^F (7.77-8.59)	4.28±0.11 ^A (4.03-4.66)	8.49±0.17 ^A (8.03-9.00)	50.43±0.09 ^B (50.04-50.89)	88.78±0.28 ^D (88.00-90.00)	11.25±0.11 ^C (11.00-11.60)	939.80±15.16 ^A (894.00-998.00)	13.17±0.18 ^H (13.00-14.00)
Branches	18	6.40±0.19 ^{CD} (5.68-7.00)	0.54±0.02 ^E (0.50-0.60)	1.12±0.04 ^C (1.00-1.28)	8.86±0.16 ^E (8.35-9.56)	1.29±0.04 ^D (1.22-1.45)	7.59±0.05 ^B (7.12-7.80)	42.45±0.04 ^H (42.25-42.64)	88.78±0.15 ^D (88.00-89.00)	16.22±0.20 ^B (15.50-16.80)	177.33±6.48 ^C (156.00-195.00)	18.33±0.22 ^F (18.00-19.00)
Bracts	18	7.65±0.21 ^B (7.00-8.36)	0.93±0.03 ^C (0.82-1.00)	1.22±0.03 ^C (1.10-1.35)	11.85±0.17 ^B (11.03-12.56)	4.07±0.16 ^{AB} (3.26-4.66)	3.47±0.07 ^F (3.20-3.60)	42.83±0.10 ^G (42.35-43.20)	95.44±0.18 ^A (95.00-96.00)	8.30±0.24 ^E (7.50-9.00)	306.07±9.68 ^B (275.00-334.40)	23.50±0.37 ^C (23.00-25.00)

Table 6.8: The mean with standard error and range of different nutrients content in different components of litter production and litter standing crop during the dry season (July 2002). Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper (µg/g)	Iron (µg/g)	Zinc (µg/g)
Litter production												
Leaves	18	5.73±0.13 ^{CD} (5.33-6.23)	1.20±0.02 ^A (1.14-1.28)	2.41±0.04 ^C (2.31-2.55)	10.03±0.16 ^B (9.56-10.83)	2.96±0.03 ^C (2.88-3.08)	5.93±0.14 ^E (5.60-6.35)	54.92±0.02 ^A (54.87-54.98)	89.67±0.17 ^E (89.00-90.00)	10.33±0.27 ^B (9.50-11.50)	69.67±2.47 ^C (61.00-76.00)	10.00±0.18 ^C (9.00-11.00)
Branches	18	2.87±0.10 ^G (2.55-3.23)	0.90±0.03 ^D (0.80-1.00)	0.52±0.02 ^H (0.45-0.55)	9.58±0.20 ^{BC} (9.06-10.28)	0.49±0.04 ^F (0.35-0.65)	3.05±0.08 ^H (2.78-3.33)	52.20±0.03 ^B (52.13-52.31)	95.78±0.15 ^B (95.00-96.00)	10.17±0.18 ^{BC} (10.00-11.00)	61.33±1.40 ^C (58.00-66.00)	6.17±0.18 ^E (6.00-7.00)
Bracts	18	4.85±0.15 ^F (4.35-5.26)	1.10±0.02 ^B (1.00-1.25)	1.32±0.05 ^F (1.19-1.51)	11.67±0.16 ^A (11.03-12.56)	2.99±0.04 ^C (2.85-3.10)	4.74±0.05 ^G (4.56-4.94)	50.02±0.02 ^D (49.98-50.09)	91.56±0.18 ^D (91.00-92.00)	4.67±0.18 ^E (4.00-5.00)	43.17±1.53 ^D (38.00-46.00)	8.67±0.22 ^D (8.00-9.00)
Flowers	18	7.54±0.18 ^B (7.00-8.12)	1.09±0.04 ^{BC} (0.95-1.16)	4.37±0.13 ^A (4.00-4.89)	1.55±0.07 ^F (1.35-1.85)	0.92±0.02 ^E (0.84-0.98)	8.87±0.16 ^C (8.45-9.48)	49.67±0.03 ^F (49.57-49.79)	96.22±0.15 ^A (96.00-97.00)	9.67±0.22 ^C (9.00-10.00)	27.67±1.20 ^D (25.00-32.00)	3.67±0.22 ^G (3.00-4.00)
Litter standing crop												
Intact leaves	18	6.16±0.19 ^C (5.68-7.00)	1.13±0.02 ^{AB} (1.05-1.18)	1.92±0.04 ^D (1.83-2.04)	8.43±0.17 ^D (8.00-8.89)	2.86±0.06 ^C (2.56-3.05)	8.39±0.18 ^D (7.89-9.15)	46.00±0.02 ^I (45.92-46.08)	88.33±0.29 ^F (87.00-89.00)	10.83±0.18 ^{AB} (10.00-11.00)	123.67±2.32 ^B (115.00-135.00)	13.00±0.18 ^A (12.00-14.00)
Broken leaves	18	8.32±0.27 ^A (7.26-9.00)	0.91±0.03 ^D (0.86-1.03)	1.47±0.04 ^E (1.40-1.60)	6.71±0.10 ^E (6.38-7.12)	3.40±0.12 ^B (3.06-3.77)	11.72±0.10 ^A (11.23-12.06)	49.74±0.02 ^E (49.68-49.82)	87.89±0.31 ^G (86.00-89.00)	10.33±0.22 ^B (10.00-11.00)	459.17±11.50 ^A (412.00-489.00)	10.67±0.22 ^B (10.00-11.00)
Branches	18	5.52±0.15 ^{BE} (4.88-5.89)	0.56±0.02 ^E (0.52-0.63)	1.08±0.03 ^G (1.00-1.19)	9.17±0.17 ^C (8.68-9.78)	1.00±0.04 ^E (0.86-1.10)	10.30±0.17 ^B (10.00-11.00)	50.44±0.03 ^C (50.34-50.53)	88.78±0.15 ^{FG} (88.00-89.00)	10.67±0.18 ^B (10.00-11.00)	110.00±3.83 ^B (100.00-126.00)	4.67±0.18 ^F (4.00-5.00)
Bracts	18	5.05±0.12 ^{EF} (4.66-5.44)	0.88±0.03 ^D (0.82-0.98)	1.62±0.05 ^E (1.45-1.76)	11.48±0.19 ^A (11.00-12.03)	4.25±0.10 ^A (3.89-4.55)	5.44±0.11 ^F (5.13-5.78)	48.67±0.02 ^H (48.62-48.73)	91.44±0.18 ^D (91.00-92.00)	11.33±0.18 ^A (11.00-12.00)	447.00±11.32 ^A (410.00-489.00)	10.67±0.18 ^B (10.00-11.00)
Propagules	18	7.21±0.19 ^B (6.55-8.00)	1.04±0.02 ^C (0.95-1.15)	3.49±0.10 ^B (3.21-3.89)	1.77±0.07 ^F (1.53-1.90)	1.46±0.05 ^D (1.30-1.61)	4.62±0.08 ^G (4.30-4.80)	49.42±0.02 ^G (49.35-49.49)	93.56±0.18 ^C (93.00-94.00)	8.17±0.18 ^D (8.00-9.00)	76.33±1.97 ^C (71.00-83.00)	4.67±0.18 ^F (4.00-5.00)

Table 6.9: The mean with standard error and range of different nutrients content in different components of litter production and litter standing crop during the wet season (November 2002). Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper ($\mu\text{g/g}$)	Iron ($\mu\text{g/g}$)	Zinc ($\mu\text{g/g}$)
Litter production												
Leaves	18	6.02 $\pm$ 0.10 ^B (5.66-6.23)	0.69 $\pm$ 0.01 ^A (0.66-0.72)	2.10 $\pm$ 0.06 ^A (1.89-2.33)	13.60 $\pm$ 0.08 ^A (13.40-13.80)	3.18 $\pm$ 0.06 ^C (3.00-3.40)	4.53 $\pm$ 0.14 ^C (4.23-5.00)	49.71 $\pm$ 0.02 ^B (49.65-49.78)	91.22 $\pm$ 0.15 ^C (91.00-92.00)	5.83 $\pm$ 0.18 ^B (5.00-6.00)	84.83 $\pm$ 2.98 ^D (76.00-94.00)	21.00 $\pm$ 0.29 ^B (20.00-22.00)
Branches	18	3.06 $\pm$ 0.14 ^F (2.77-3.55)	0.51 $\pm$ 0.01 ^D (0.49-0.55)	0.54 $\pm$ 0.02 ^F (0.48-0.63)	12.42 $\pm$ 0.13 ^C (12.03-12.89)	0.76 $\pm$ 0.03 ^E (0.69-0.89)	2.49 $\pm$ 0.06 ^E (2.25-2.69)	43.42 $\pm$ 0.01 ^E (43.37-43.47)	95.56 $\pm$ 0.18 ^A (95.00-96.00)	5.67 $\pm$ 0.22 ^B (5.00-6.00)	75.00 $\pm$ 3.43 ^D (65.00-86.00)	16.17 $\pm$ 0.18 ^F (16.00-17.00)
Bracts	18	4.28 $\pm$ 0.13 ^D (3.98-4.89)	0.65 $\pm$ 0.01 ^B (0.63-0.67)	0.80 $\pm$ 0.03 ^E (0.75-0.90)	13.15 $\pm$ 0.11 ^B (12.68-13.89)	3.17 $\pm$ 0.04 ^C (3.03-3.26)	1.93 $\pm$ 0.03 ^F (1.81-2.03)	41.44 $\pm$ 0.02 ^F (41.36-41.49)	92.22 $\pm$ 0.15 ^B (92.00-93.00)	5.33 $\pm$ 0.18 ^B (5.00-6.00)	97.00 $\pm$ 2.38 ^D (91.00-105.00)	24.33 $\pm$ 0.18 ^A (24.00-25.00)
Litter standing crop												
Intact leaves	18	3.71 $\pm$ 0.14 ^E (3.26-4.08)	0.60 $\pm$ 0.02 ^C (0.53-0.68)	1.56 $\pm$ 0.03 ^B (1.47-1.63)	11.22 $\pm$ 0.10 ^D (10.80-11.40)	3.07 $\pm$ 0.07 ^C (2.88-3.33)	5.34 $\pm$ 0.17 ^B (4.89-5.89)	50.71 $\pm$ 0.02 ^A (50.64-50.78)	89.78 $\pm$ 0.15 ^D (89.00-90.00)	2.33 $\pm$ 0.22 ^E (2.00-3.00)	77.83 $\pm$ 1.60 ^D (75.00-85.00)	17.00 $\pm$ 0.18 ^E (16.00-18.00)
Broken leaves	18	7.22 $\pm$ 0.18 ^B (6.88-8.00)	0.41 $\pm$ 0.01 ^E (0.39-0.45)	1.13 $\pm$ 0.03 ^C (1.00-1.20)	8.25 $\pm$ 0.10 ^E (8.01-8.64)	4.65 $\pm$ 0.12 ^A (4.23-4.98)	6.51 $\pm$ 0.09 ^A (6.31-6.81)	45.94 $\pm$ 0.02 ^D (45.88-46.01)	85.56 $\pm$ 0.18 ^E (85.00-86.00)	3.67 $\pm$ 0.18 ^D (3.00-4.00)	835.17 $\pm$ 11.88 ^A (800.00-900.00)	15.00 $\pm$ 0.29 ^G (14.00-16.00)
Branches	18	5.22 $\pm$ 0.15 ^C (4.90-5.88)	0.34 $\pm$ 0.01 ^F (0.30-0.36)	1.03 $\pm$ 0.02 ^D (0.94-1.15)	8.48 $\pm$ 0.17 ^E (8.06-9.02)	1.03 $\pm$ 0.05 ^D (0.89-1.23)	5.56 $\pm$ 0.13 ^B (5.20-6.12)	47.36 $\pm$ 0.02 ^C (47.31-47.42)	89.67 $\pm$ 0.17 ^D (89.00-90.00)	13.00 $\pm$ 0.29 ^A (12.00-14.00)	239.67 $\pm$ 10.06 ^C (215.00-268.00)	19.00 $\pm$ 0.29 ^D (18.00-20.00)
Bracts	18	3.48 $\pm$ 0.13 ^E (3.12-3.88)	0.38 $\pm$ 0.01 ^E (0.35-0.42)	1.57 $\pm$ 0.06 ^B (1.36-1.70)	13.07 $\pm$ 0.20 ^B (12.29-13.56)	3.87 $\pm$ 0.15 ^B (3.23-4.12)	2.81 $\pm$ 0.04 ^D (2.66-2.89)	40.10 $\pm$ 0.02 ^G (40.01-40.18)	92.22 $\pm$ 0.15 ^B (92.00-93.00)	4.33 $\pm$ 0.22 ^C (4.00-5.00)	454.67 $\pm$ 10.32 ^B (412.00-478.00)	20.00 $\pm$ 0.29 ^C (19.00-21.00)

Table 6.10. The mean with standard error and range of different nutrients contents in different components of litter production and litter standing crop during the intermediate season (March 2003). Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper (µg/g)	Iron (µg/g)	Zinc (µg/g)
Litter production												
Leaves	18	6.31±0.11 ^C (6.00-6.78)	1.21±0.02 ^B (1.11-1.38)	2.03±0.05 ^B (1.89-2.16)	17.06±0.12 ^A (16.89-17.56)	3.54±0.06 ^B (3.26-3.78)	5.02±0.07 ^D (4.78-5.23)	50.35±0.06 ^C (50.12-50.69)	92.22±0.15 ^C (92.00-93.00)	3.33±0.18 ^F (3.00-4.00)	95.67±1.43 ^{DE} (92.00-99.00)	15.00±0.29 ^D (14.00-16.00)
Branches	18	2.81±0.12 ^E (2.33-3.12)	0.74±0.01 ^F (0.72-0.78)	0.60±0.02 ^E (0.50-0.70)	12.73±0.10 ^D (12.30-12.90)	0.81±0.04 ^E (0.66-0.95)	2.50±0.09 ^H (2.20-2.80)	49.44±0.07 ^D (49.15-49.68)	96.78±0.15 ^A (96.00-97.00)	7.33±0.22 ^C (7.00-8.00)	76.00±1.31 ^E (72.00-79.00)	11.00±0.29 ^F (10.00-12.00)
Bracts	18	5.01±0.20 ^D (4.33-5.77)	1.13±0.03 ^B ^C (1.00-1.23)	1.50±0.03 ^C (1.40-1.60)	14.63±0.14 ^C (14.16-15.46)	3.42±0.07 ^B (3.26-3.64)	2.85±0.05 ^G (2.70-3.00)	50.37±0.05 ^C (50.12-50.58)	92.67±0.17 ^C (92.00-93.00)	5.67±0.22 ^D (5.00-6.00)	107.50±2.13 ^D (100.00-126.00)	23.17±0.34 ^A (22.00-24.00)
Flowers	18	6.70±0.10 ^B ^C (6.47-7.03)	1.64±0.05 ^A (1.45-1.75)	4.54±0.15 ^A (4.00-4.89)	17.30±0.09 ^A (17.10-17.55)	3.15±0.08 ^C (2.98-3.45)	4.00±0.04 ^F (3.80-4.56)	52.47±0.06 ^A (52.12-52.69)	93.44±0.18 ^B (93.00-94.00)	7.25±0.23 ^C (6.50-8.00)	107.83±3.82 ^D (100.00-123.00)	22.83±0.41 ^A (22.00-24.00)
Litter standing crop												
Intact leaves	18	5.32±0.15 ^D (4.88-6.00)	1.08±0.02 ^{CD} (1.00-1.16)	1.64±0.03 ^C (1.50-1.78)	12.33±0.16 ^D (11.89-12.89)	3.13±0.04 ^C (3.00-3.26)	6.32±0.15 ^B (6.00-6.89)	52.35±0.06 ^A (52.12-52.68)	88.33±0.17 ^E (88.00-89.00)	4.33±0.22 ^E (4.00-5.00)	108.17±2.13 ^D (100.00-116.00)	12.33±0.22 ^E (12.00-13.00)
Broken leaves	18	9.32±0.24 ^A (8.89-10.44)	0.96±0.02 ^E (0.90-1.00)	1.07±0.03 ^D (1.00-1.15)	9.11±0.17 ^F (8.68-9.58)	4.51±0.13 ^A (4.16-4.88)	8.36±0.16 ^A (8.00-8.89)	48.44±0.06 ^E (48.23-48.72)	85.67±0.17 ^F (85.00-86.00)	5.42±0.14 ^D (5.00-6.00)	661.50±13.36 ^A (612.00-694.00)	18.33±0.37 ^B (17.00-19.00)
Branches	18	6.95±0.24 ^B (5.89-7.56)	0.74±0.01 ^F (0.70-0.78)	0.98±0.03 ^D (0.87-1.05)	11.74±0.19 ^E (11.22-12.36)	1.08±0.02 ^D (1.03-1.11)	5.94±0.11 ^C (5.60-6.20)	51.41±0.06 ^B (51.23-51.69)	89.00±0.27 ^D (88.00-90.00)	11.33±0.22 ^A (11.00-12.00)	226.67±8.98 ^C (203.00-255.00)	15.00±0.29 ^D (14.00-16.00)
Bracts	18	5.06±0.17 ^D (4.55-5.78)	1.00±0.03 ^{DE} (0.85-1.18)	1.59±0.06 ^C (1.35-1.70)	16.08±0.26 ^B (15.45-16.89)	4.67±0.11 ^A (4.23-5.00)	3.18±0.06 ^F (3.00-3.31)	44.48±0.08 ^F (44.12-44.89)	92.44±0.18 ^C (92.00-93.00)	9.00±0.25 ^B (8.00-9.50)	401.50±14.30 ^B (368.00-456.00)	17.00±0.29 ^C (16.00-18.00)

Table 6.11: The mean with standard error and range of different nutrients content in different components of litter production and litter standing crop during the dry season (July 2003). Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Plant components	Sample no	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper ($\mu\text{g/g}$)	Iron ($\mu\text{g/g}$)	Zinc ($\mu\text{g/g}$)
Litter production												
Leaves	18	5.47 $\pm$ 0.18 ^C (5.03-6.12)	1.20 $\pm$ 0.02 ^A (1.11-1.33)	215 $\pm$ 0.03 ^C (2.00-2.22)	11.26 $\pm$ 0.04 ^C (11.00-11.89)	2.93 $\pm$ 0.06 ^D (2.75-3.12)	5.38 $\pm$ 0.08 ^C (5.00-6.00)	52.45 $\pm$ 0.06 ^A (52.15-52.68)	91.33 $\pm$ 0.29 ^E (90.00-92.00)	6.67 $\pm$ 0.18 ^E (6.00-7.00)	73.67 $\pm$ 3.95 ^E (64.00-89.00)	27.33 $\pm$ 0.34 ^A (26.00-28.00)
Branches	18	3.48 $\pm$ 0.12 ^E (3.12-4.00)	0.62 $\pm$ 0.01 ^E (0.60-0.65)	0.74 $\pm$ 0.02 ^G (0.65-0.80)	8.27 $\pm$ 0.07 ^F (8.03-8.89)	0.53 $\pm$ 0.03 ^G (0.46-0.61)	3.06 $\pm$ 0.03 ^E (2.98-3.15)	50.35 $\pm$ 0.03 ^C (50.26-50.47)	96.78 $\pm$ 0.15 ^A (96.00-97.00)	10.67 $\pm$ 0.18 ^A (10.00-11.00)	55.17 $\pm$ 1.88 ^F (48.00-60.00)	13.00 $\pm$ 0.29 ^C (12.00-14.00)
Bracts	18	4.85 $\pm$ 0.15 ^D (4.33-5.23)	1.13 $\pm$ 0.02 ^{AB} (1.00-1.31)	1.13 $\pm$ 0.02 ^E (1.00-1.20)	12.15 $\pm$ 0.28 ^B (11.03-12.89)	3.17 $\pm$ 0.05 ^C (3.00-3.30)	3.94 $\pm$ 0.12 ^D (3.45-4.26)	46.41 $\pm$ 0.09 ^E (45.98-46.92)	92.33 $\pm$ 0.17 ^D (92.00-93.00)	7.17 $\pm$ 0.23 ^{DE} (6.50-8.00)	46.50 $\pm$ 1.17 ^{FG} (43.00-51.00)	9.33 $\pm$ 0.22 ^D (9.00-10.00)
Propagules	18	7.03 $\pm$ 0.20 ^{AB} (6.56-7.94)	1.04 $\pm$ 0.03 ^B (0.89-1.16)	4.21 $\pm$ 0.12 ^A (3.87-4.68)	1.80 $\pm$ 0.03 ^H (1.70-1.90)	0.95 $\pm$ 0.02 ^F (0.90-1.00)	8.21 $\pm$ 0.12 ^A (7.89-8.64)	52.34 $\pm$ 0.06 ^A (52.12-52.64)	96.22 $\pm$ 0.15 ^B (96.00-97.00)	8.67 $\pm$ 0.22 ^C (8.00-9.00)	30.67 $\pm$ 1.28 ^G (27.00-35.00)	6.50 $\pm$ 0.22 ^F (6.00-7.00)
Litter standing crop												
Intact leaves	18	4.57 $\pm$ 0.18 ^D (4.02-5.10)	1.08 $\pm$ 0.02 ^B (1.00-1.23)	1.85 $\pm$ 0.05 ^D (1.66-2.00)	9.09 $\pm$ 0.10 ^E (8.68-9.45)	2.78 $\pm$ 0.05 ^D (2.65-2.89)	7.56 $\pm$ 0.15 ^B (7.14-8.12)	49.48 $\pm$ 0.06 ^D (49.23-49.68)	87.67 $\pm$ 0.17 ^G (87.00-88.00)	4.33 $\pm$ 0.22 ^F (4.00-5.00)	106.00 $\pm$ 2.43 ^D (98.00-126.00)	16.50 $\pm$ 0.22 ^B (16.00-17.00)
Broken leaves	18	7.13 $\pm$ 0.18 ^A (6.78-8.00)	1.12 $\pm$ 0.02 ^{AB} (1.00-1.26)	1.28 $\pm$ 0.03 ^E (1.25-1.40)	7.03 $\pm$ 0.15 ^G (6.15-7.68)	4.69 $\pm$ 0.12 ^A (4.23-4.89)	8.51 $\pm$ 0.08 ^A (8.23-8.75)	52.31 $\pm$ 0.05 ^A (52.06-52.48)	89.67 $\pm$ 0.24 ^F (89.00-91.00)	7.33 $\pm$ 0.22 ^D (7.00-8.00)	453.67 $\pm$ 10.10 ^A (412.00-489.00)	8.67 $\pm$ 0.18 ^E (8.00-9.00)
Branches	18	6.50 $\pm$ 0.23 ^B (5.99-7.56)	0.75 $\pm$ 0.02 ^D (0.70-0.79)	0.97 $\pm$ 0.03 ^F (0.85-1.00)	10.34 $\pm$ 0.16 ^D (9.89-11.00)	1.07 $\pm$ 0.02 ^F (1.03-1.15)	8.41 $\pm$ 0.11 ^A (8.12-8.78)	45.30 $\pm$ 0.04 ^F (45.16-45.56)	93.11 $\pm$ 0.20 ^C (92.00-94.00)	8.17 $\pm$ 0.18 ^C (8.00-9.00)	268.67 $\pm$ 8.64 ^C (234.00-285.00)	12.50 $\pm$ 0.22 ^C (12.00-13.00)
Bracts	18	4.78 $\pm$ 0.19 ^D (4.22-5.55)	0.85 $\pm$ 0.02 ^C (0.75-0.95)	1.68 $\pm$ 0.07 ^D (1.45-1.89)	12.85 $\pm$ 0.19 ^A (12.36-13.68)	4.42 $\pm$ 0.15 ^B (4.00-4.88)	4.20 $\pm$ 0.07 ^D (4.00-4.42)	46.44 $\pm$ 0.06 ^E (46.23-46.68)	92.44 $\pm$ 0.18 ^D (92.00-93.00)	9.75 $\pm$ 0.18 ^B (9.00-10.00)	351.50 $\pm$ 10.63 ^B (326.00-389.00)	16.67 $\pm$ 0.22 ^B (16.00-17.00)
Propagules	18	6.82 $\pm$ 0.23 ^{AB} (6.02-7.55)	1.04 $\pm$ 0.02 ^B (0.95-1.14)	3.41 $\pm$ 0.14 ^B (3.00-3.90)	1.88 $\pm$ 0.04 ^H (1.80-2.00)	1.50 $\pm$ 0.03 ^E (1.40-1.60)	5.25 $\pm$ 0.14 ^C (4.88-5.63)	51.38 $\pm$ 0.08 ^B (51.03-51.89)	96.56 $\pm$ 0.18 ^{AB} (96.00-97.00)	7.17 $\pm$ 0.18 ^{DE} (7.00-8.00)	83.83 $\pm$ 2.43 ^E (75.00-89.00)	6.17 $\pm$ 0.18 ^F (6.00-7.00)

Table 6.12: The mean with standard error and range of different nutrients content at different stage of leaf litter degradation. Means with similar alphabet in the same columns are not significantly (ANOVA, DMRT, $p>0.05$) different

Stage of leaf litter degradation	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper (µg/g)	Iron (µg/g)	Zinc (µg/g)
Dry months											
Litter bags											
Initial	4.24±0.14 ^S (3.61-4.78)	1.11±0.03 ^C (1.00-1.20)	2.36±0.03 ^B (2.26-2.47)	8.71±0.02 ^I (8.65-8.75)	5.03±0.02 ^{IJ} (4.95-5.10)	6.88±0.08 ^C (6.30-7.50)	57.55±0.15 ^K (56.58-58.12)	88.89±0.26 ^K (88.00-90.00)	10.00±0.50 ^{AB} (8.00-11.00)	81.67±0.67 ^T (79.00-86.00)	16.67±0.53 ^N (14.00-19.00)
5 days	4.84±0.13 ^{PQ} (4.43-5.36)	1.19±0.04 ^B (0.98-1.33)	2.33±0.03 ^B (2.26-2.47)	8.38±0.21 ^J (7.70-9.63)	5.12±0.04 ^{IJ} (4.98-5.33)	5.50±0.03 ^{IJK} (5.30-5.80)	53.39±0.23 ^P (52.12-54.12)	87.67±0.33 ^P (86.00-89.00)	7.33±0.17 ^{FGH} (7.00-8.00)	54.11±0.45 ^U (52.00-55.00)	11.00±0.50 ^{PQ} (9.00-12.00)
10 days	5.15±0.08 ^{NO} (4.82-5.40)	1.24±0.01 ^A (1.20-1.28)	1.87±0.02 ^C (1.83-1.94)	7.84±0.09 ^{LMN} (7.23-8.18)	5.04±0.09 ^{IJ} (4.63-5.50)	5.90±0.04 ^{FG} (5.60-6.20)	46.52±0.16 ^S (45.68-47.22)	89.56±0.18 ^S (89.00-90.00)	7.33±0.44 ^{FGH} (6.00-9.00)	92.44±0.67 ^T (90.00-95.00)	12.56±0.29 ^{OPQ} (12.00-14.00)
15 days	5.66±0.06 ^{JKL} (5.40-5.91)	1.11±0.04 ^C (0.95-1.30)	0.73±0.02 ^M (0.66-0.77)	8.23±0.22 ^{JK} (7.03-9.50)	4.39±0.05 ^K (4.25-4.70)	5.31±0.04 ^K (4.90-5.60)	54.49±0.06 ^O (54.23-54.82)	92.56±0.18 ^O (92.00-93.00)	8.33±0.17 ^{DE} (8.00-9.00)	175.00±0.88 ^R (170.00-180.00)	12.67±0.17 ^{OPQ} (12.00-13.00)
20 days	5.87±0.03 ^{IJ} (5.75-5.98)	0.83±0.03 ^F (0.70-0.98)	1.33±0.02 ^F (1.30-1.40)	7.14±0.21 ^{PQ} (5.90-7.78)	5.12±0.11 ^{IJ} (4.60-5.60)	6.01±0.03 ^{EF} (5.80-6.20)	59.14±0.13 ^H (58.66-59.75)	87.44±0.18 ^H (87.00-88.00)	5.67±0.33 ^{KL} (5.00-7.00)	178.78±0.80 ^R (175.00-184.00)	8.00±0.29 ^R (7.00-9.00)
25 days	6.20±0.13 ^G (5.67-6.60)	0.73±0.02 ^G (0.65-0.80)	0.80±0.02 ^L (0.77-0.87)	8.24±0.09 ^{JK} (7.88-8.68)	4.51±0.03 ^K (4.33-4.63)	6.33±0.03 ^D (6.10-6.50)	61.39±0.03 ^D (61.25-61.55)	91.67±0.17 ^D (91.00-92.00)	8.00±0.29 ^{EF} (7.00-9.00)	203.78±0.94 ^Q (200.00-207.00)	9.67±0.60 ^{QR} (8.00-12.00)
30 days	6.23±0.04 ^G (6.02-6.45)	0.73±0.02 ^G (0.63-0.85)	0.90±0.02 ^{IJ} (0.77-0.98)	7.95±0.06 ^{KLM} (7.75-8.28)	5.35±0.08 ^I (4.98-5.75)	6.71±0.05 ^C (6.10-7.00)	59.81±0.06 ^G (59.55-60.18)	90.89±0.11 ^G (90.00-91.00)	9.33±0.44 ^{BC} (8.00-11.00)	299.33±1.75 ^N (293.00-309.00)	10.00±0.29 ^{PQR} (9.00-11.00)
60 days	6.91±0.04 ^{EF} (6.76-7.07)	0.29±0.01 ^{JK} (0.27-0.31)	0.93±0.03 ^{IJ} (0.83-1.07)	5.57±0.04 ^S (5.40-5.80)	6.23±0.05 ^{FG} (6.05-6.40)	7.71±0.05 ^A (7.40-8.10)	60.87±0.03 ^E (60.68-60.99)	88.89±0.11 ^E (88.00-89.00)	2.67±0.17 ^O (2.00-3.00)	795.44±1.58 ^K (788.00-802.00)	35.67±0.60 ^I (34.00-38.00)
90 days	8.33±0.04 ^D (8.16-8.55)	0.32±0.01 ^J (0.27-0.37)	0.94±0.01 ^{HI} (0.90-1.00)	5.11±0.05 ^T (4.80-5.30)	7.02±0.08 ^D (6.85-7.35)	7.16±0.03 ^B (6.90-7.40)	58.55±0.04 ^{IJ} (58.45-58.75)	91.89±0.11 ^{IJ} (91.00-92.00)	4.33±0.44 ^N (3.00-6.00)	1501.67±2.07 ^H (1496.00-1512.00)	75.00±1.80 ^B (68.00-80.00)
120 days	8.87±0.03 ^C (8.74-8.94)	0.16±0.01 ^M (0.13-0.19)	0.84±0.04 ^{KL} (0.63-1.07)	4.49±0.05 ^U (4.30-4.80)	8.95±0.04 ^{AB} (8.80-9.05)	7.87±0.06 ^A (7.50-8.30)	58.69±0.06 ^I (58.45-58.96)	87.22±0.15 ^I (87.00-88.00)	4.33±0.33 ^N (3.00-5.00)	2036.67±3.23 ^F (2020.00-2050.00)	43.67±2.95 ^H (32.00-51.00)
150 days	9.34±0.03 ^B (9.25-9.48)	0.16±0.01 ^M (0.15-0.18)	0.79±0.02 ^L (0.73-0.87)	4.08±0.06 ^V (3.80-4.40)	8.93±0.09 ^{AB} (8.65-9.25)	7.73±0.04 ^A (7.40-8.00)	59.64±0.04 ^G (59.45-59.88)	86.89±0.20 ^G (86.00-88.00)	4.67±0.17 ^{MN} (4.00-5.00)	2550.00±3.73 ^D (2530.00-2560.00)	77.33±0.93 ^B (75.00-81.00)

Table 6.12 continues

Stage of leaf litter degradation	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper (µg/g)	Iron (µg/g)	Zinc (µg/g)
Leaves on strings											
5 days	4.64±0.25 ^{QR} (3.57-5.32)	1.16±0.01 ^B (1.13-1.23)	2.30±0.02 ^B (2.26-2.36)	7.45±0.09 ^{OP} (7.15-7.75)	4.95±0.03 ^J (4.80-5.08)	5.43±0.04 ^{JK} (5.20-5.70)	55.36±0.23 ^N (54.23-56.58)	87.78±0.28 ^N (86.00-89.00)	6.67±0.17 ^{HJ} (6.00-7.00)	56.00±0.17 ^U (55.00-57.00)	14.00±0.29 ^{NO} (13.00-15.00)
10 days	5.01±0.06 ^{OP} (4.74-5.17)	1.04±0.01 ^D (1.00-1.10)	1.72±0.03 ^D (1.62-1.83)	8.06±0.05 ^{JKL} (7.83-8.30)	5.15±0.10 ^I (4.50-5.45)	5.63±0.05 ^{HJ} (5.20-5.90)	51.41±0.13 ^Q (51.06-52.36)	89.56±0.18 ^Q (89.00-90.00)	6.67±0.17 ^{HJ} (6.00-7.00)	88.22±0.74 ^T (84.00-91.00)	13.00±0.29 ^{OP} (12.00-14.00)
15 days	5.56±0.15 ^{KL} (4.43-5.87)	1.07±0.01 ^{CD} (1.03-1.10)	0.92±0.02 ^{IJ} (0.87-0.98)	7.48±0.06 ^{OP} (7.08-7.75)	4.58±0.07 ^K (4.13-4.80)	5.06±0.03 ^L (4.80-5.20)	56.20±0.06 ^M (55.89-56.45)	92.56±0.18 ^M (92.00-93.00)	7.67±0.17 ^{EF} (7.00-8.00)	153.89±0.92 ^S (150.00-157.00)	15.00±0.29 ^{NO} (14.00-16.00)
20 days	5.45±0.07 ^{LM} (5.13-5.67)	0.98±0.03 ^E (0.85-1.15)	1.48±0.03 ^E (1.40-1.62)	7.08±0.10 ^Q (6.45-7.48)	5.71±0.07 ^H (5.40-6.00)	5.80±0.05 ^{FGH} (5.50-6.30)	55.41±0.04 ^N (55.23-55.64)	87.56±0.18 ^N (87.00-88.00)	6.67±0.33 ^{HJ} (6.00-8.00)	178.44±1.12 ^R (175.00-185.00)	10.67±0.44 ^{PQR} (9.00-12.00)
25 days	5.66±0.03 ^{JKL} (5.56-5.79)	0.83±0.02 ^F (0.73-0.90)	1.12±0.02 ^G (1.09-1.19)	6.49±0.07 ^R (6.28-6.98)	6.50±0.06 ^{EF} (6.25-6.78)	5.81±0.05 ^{FGH} (5.40-6.10)	62.13±0.08 ^B (61.79-62.55)	91.89±0.11 ^B (91.00-92.00)	6.00±0.29 ^{JKL} (5.00-7.00)	228.00±0.29 ^P (227.00-229.00)	10.00±0.58 ^{PQR} (8.00-12.00)
30 days	5.64±0.07 ^{JKL} (5.44-6.06)	0.84±0.02 ^F (0.75-0.95)	0.92±0.02 ^{IJ} (0.87-0.98)	7.56±0.06 ^{NO} (7.30-7.80)	6.70±0.03 ^E (6.60-6.80)	6.22±0.02 ^{DE} (6.00-6.40)	58.34±0.04 ^J (58.22-58.66)	90.89±0.11 ^J (90.00-91.00)	9.67±0.17 ^{BC} (9.00-10.00)	288.89±1.59 ^N (280.00-294.00)	10.44±0.38 ^{PQR} (9.00-12.00)
Wet months											
Litter bags											
Initial	4.60±0.03 ^R (4.51-4.78)	0.60±0.01 ^H (0.58-0.62)	3.03±0.02 ^A (2.93-3.13)	15.12±0.11 ^A (14.70-15.45)	5.27±0.07 ^{IJ} (5.05-5.50)	5.78±0.02 ^{FGH} (5.63-6.00)	45.11±0.05 ^T (44.89-45.41)	88.56±0.18 ^T (88.00-89.00)	2.00±0.08 ^O (1.50-2.50)	210.00±0.76 ^Q (208.00-213.00)	22.00±0.29 ^M (21.00-23.00)
5 days	5.27±0.06 ^{MN} (5.13-5.63)	0.49±0.01 ^I (0.45-0.52)	0.90±0.03 ^{IJ} (0.77-1.00)	13.43±0.04 ^C (13.30-13.60)	3.60±0.13 ^{MN} (3.10-3.95)	3.43±0.01 ^P (3.31-3.50)	49.59±0.02 ^R (49.45-49.68)	91.22±0.15 ^R (91.00-92.00)	2.33±0.17 ^O (2.00-3.00)	252.00±1.00 ^O (250.00-256.00)	33.00±2.08 ^I (25.00-39.00)
10 days	5.79±0.04 ^{JK} (5.59-5.91)	0.27±0.01 ^K (0.25-0.30)	0.60±0.01 ^N (0.57-0.67)	13.85±0.07 ^B (13.70-14.15)	3.45±0.05 ^{NO} (3.35-3.65)	2.88±0.04 ^{RS} (2.50-3.06)	63.24±0.02 ^A (63.15-3.33)	93.89±0.11 ^A (93.00-4.00)	5.33±0.17 ^{LM} (5.00-6.00)	402.56±0.93 ^M (400.00-408.00)	37.00±0.50 ^I (36.00-39.00)
15 days	6.13±0.05 ^{GH} (5.91-6.41)	0.20±0.01 ^{LM} (0.18-0.21)	0.63±0.02 ^N (0.57-0.70)	12.02±0.07 ^E (11.80-12.25)	3.32±0.04 ^{NOP} (3.20-3.45)	2.77±0.03 ^S (2.63-3.00)	61.75±0.04 ^C (61.55-1.94)	94.89±0.11 ^C (94.00-95.00)	4.67±0.17 ^{MN} (4.00-5.00)	621.78±0.89 ^L (618.00-625.00)	28.33±0.88 ^K (25.00-31.00)
20 days	6.70±0.05 ^F (6.45-6.92)	0.17±0.01 ^M (0.16-0.18)	0.82±0.01 ^L (0.77-0.83)	12.22±0.06 ^E (12.00-12.40)	3.45±0.03 ^{NO} (3.35-3.55)	3.01±0.07 ^R (2.63-3.56)	56.23±0.04 ^M (56.12-56.45)	94.89±0.11 ^M (94.00-95.00)	6.67±0.17 ^{HJ} (6.00-7.00)	945.56±1.30 ^J (940.00-950.00)	50.00±1.61 ^F (45.00-56.00)

Table 6.12 continues

Stage of leaf litter degradation	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	Magnesium (mg/g)	Sulphur (mg/g)	Carbon (%)	Organic matter (%)	Copper (µg/g)	Iron (µg/g)	Zinc (µg/g)
25 days	7.02±0.04 ^E (6.88-7.23)	0.18±0.01 ^M (0.15-0.23)	0.97±0.01 ^{HI} (0.90-1.00)	12.83±0.04 ^D (12.70-13.00)	4.10±0.04 ^L (3.95-4.20)	3.53±0.05 ^{OP} (3.25-3.88)	57.12±0.06 ^L (56.89-57.45)	94.89±0.11 ^L (94.00-95.00)	7.67±0.17 ^{EF} (7.00-8.00)	1224.44±2.42 ^I (1210.00-1230.00)	47.33±0.17 ^G (47.00-48.00)
30 days	8.41±0.08 ^D (8.00-8.78)	0.17±0.01 ^M (0.15-0.18)	1.12±0.02 ^G (1.03-1.20)	13.28±0.27 ^C (12.65-14.35)	6.05±0.38 ^G (4.80-7.40)	3.69±0.08 ^O (3.19-4.25)	58.45±0.07 ^{IJ} (58.12-58.78)	94.89±0.11 ^{IJ} (94.00-95.00)	7.00±0.29 ^{GHI} (6.00-8.00)	1606.11±1.39 ^G (1600.00-1610.00)	53.22±0.46 ^E (51.00-56.00)
60 days	10.68±0.04 ^A (10.49-10.88)	0.15±0.01 ^{MN} (0.13-0.18)	0.87±0.01 ^{JK} (0.85-0.91)	11.22±0.21 ^F (10.60-12.60)	5.97±0.04 ^{GH} (5.80-6.10)	4.19±0.06 ^N (3.50-4.44)	59.76±0.06 ^G (59.51-59.97)	96.56±0.18 ^G (96.00-97.00)	6.33±0.17 ^{UJK} (6.00-7.00)	2266.67±30.05 ^E (2150.00-2350.00)	63.89±0.31 ^D (63.00-65.00)
90 days	5.77±0.04 ^{IJK} (5.59-5.91)	0.11±0.01 ^{NO} (0.08-0.13)	0.80±0.01 ^L (0.78-0.83)	9.80±0.07 ^G (9.60-10.20)	8.28±0.05 ^C (8.00-8.50)	4.57±0.04 ^M (4.31-4.75)	60.34±0.07 ^F (60.12-60.75)	96.89±0.11 ^F (96.00-97.00)	9.00±0.24 ^{CD} (8.00-10.00)	2592.22±1.47 ^C (2585.00-2600.00)	69.78±0.36 ^C (68.00-71.00)
120 days	4.99±0.03 ^{OP} (4.78-5.05)	0.08±0.01 ^{OP} (0.05-0.10)	0.73±0.01 ^M (0.69-0.75)	9.10±0.11 ^H (8.60-9.50)	8.74±0.07 ^B (8.40-9.10)	5.69±0.05 ^{GHI} (5.38-6.13)	60.43±0.07 ^F (60.16-60.75)	97.56±0.18 ^F (97.00-98.00)	9.67±0.17 ^{BC} (9.00-10.00)	3511.11±1.62 ^B (3500.00-3515.00)	76.56±0.34 ^B (75.00-78.00)
150 days	3.88±0.03 ^T (3.81-4.00)	0.05±0.01 ^P (0.03-0.08)	0.64±0.01 ^N (0.63-0.66)	7.70±0.06 ^{MNO} (7.40-7.90)	9.16±0.08 ^A (8.80-9.50)	6.16±0.07 ^{DE} (5.69-6.88)	61.25±0.18 ^D (60.25-62.12)	97.89±0.11 ^D (97.00-98.00)	10.67±0.17 ^A (10.00-11.00)	4211.67±1.67 ^A (4200.00-4215.00)	85.11±0.26 ^A (84.00-86.00)
Leaves on strings											
5 days	5.22±0.08 ^{MNO} (4.82-5.56)	0.50±0.01 ^I (0.47-0.52)	0.99±0.04 ^H (0.67-1.10)	12.87±0.21 ^D (12.15-13.60)	3.77±0.20 ^M (3.05-4.45)	3.31±0.02 ^{PQ} (3.13-3.50)	46.57±0.06 ^S (46.25-46.88)	91.22±0.15 ^S (91.00-92.00)	2.00±0.29 ^O (1.00-3.00)	252.00±6.79 ^O (236.00-279.00)	24.00±0.87 ^{LM} (21.00-27.00)
10 days	5.81±0.04 ^{IJK} (5.59-5.98)	0.28±0.01 ^{JK} (0.25-0.30)	0.66±0.01 ^N (0.63-0.70)	12.90±0.04 ^D (12.75-13.00)	3.13±0.07 ^P (2.85-3.35)	2.91±0.04 ^{RS} (2.56-3.13)	58.48±0.19 ^{IJ} (57.46-59.51)	92.56±0.18 ^{IJ} (92.00-93.00)	4.67±0.17 ^{MN} (4.00-5.00)	409.00±0.29 ^M (408.00-410.00)	25.33±0.44 ^L (24.00-27.00)
15 days	5.95±0.02 ^{HI} (5.91-6.06)	0.24±0.01 ^{KL} (0.22-0.26)	0.64±0.01 ^N (0.57-0.70)	13.43±0.05 ^C (13.25-13.60)	3.23±0.06 ^{OP} (2.80-3.35)	3.11±0.07 ^{QR} (2.56-3.44)	60.35±0.04 ^F (60.12-60.55)	94.22±0.15 ^F (94.00-95.00)	5.33±0.17 ^{LM} (5.00-6.00)	606.67±1.36 ^L (600.00-610.00)	30.67±1.45 ^{JK} (26.00-36.00)

Table 6.13: Comparison of nutrients content in different components of different mangrove species

Species	Plant parts	Nutrients								Sources and Location
		N (mg/g)	P (mg/g)	K (mg/g)	Ca (mg/g)	Mg (mg/g)	Cu (µg/g)	Fe (µg/g)	Zn (µg/g)	
<i>Rhizophora mangle</i>	Leaves	-	0.90	8.40	12.20	4.70	6.00	82.00	11.00	Panama, Golleyet <i>al.</i> (1975)
	Stems	-	0.90	3.90	5.70	1.00	8.00	36.00	12.00	
	Roots	-	0.70	2.30	7.50	4.60	47.00	1000.00	139.00	
<i>R. apiculata</i>	Leaves	10.20	1.10	9.80	14.00	5.10				Onget <i>al.</i> (1985a)
	Branches	2.90	0.90	3.60	8.40	1.90				Matang Mangrove, Malaysia
	Stem	2.00	0.20	3.30	4.20	0.70				(4°50'N, 100°36'E)
<i>Avicennia</i> spp.	Leaves	19.60	1.40	11.00	2.50	1.40				Aksornkoae and Khemnark
	Branch	8.90	1.40	7.50	1.40	0.60				(1984)
	Stem	8.60	0.90	0.51	1.10	0.70				AmphoeKhung mangrove,
<i>Bruguiera</i> spp.	Leaves	11.70	0.70	3.70	4.30	2.40				Thailand
	Branch	9.00	0.60	3.10	3.00	1.20				(12°-13°N, 102°-103°E)
	Stem	4.00	0.30	0.80	2.80	0.70				
<i>Ceriops</i> spp.	Leaves	10.80	0.60	7.80	14.60	1.40				
	Branch	6.70	0.40	5.50	9.40	0.70				
	Stem	4.40	0.30	3.10	5.40	0.30				
<i>R. apiculata</i>	Leaves	16.40	0.20	5.20	4.40	7.70				Gong and Ong (1990)
	Branch	5.50	0.30	1.60	2.50	2.80				Matang Mangrove, Malaysia
	Stem	4.00	0.30	0.60	2.90	2.00				(4°50'N, 100°36'E)
	Root	4.50	0.30	1.70	1.10	5.40				
<i>R. mangle</i>	Leaves						ND	37.20	7.20	Silva <i>et al.</i> (1990)
	Branches						0.60	19.40	6.20	Sepetiba Bay, Rio de
	Stems						0.50	12.40	3.40	Janeiro, Brazil
	Roots						5.10	1011.00	19.90	

ND: Not detected

Table 6.13 continues

Species	Plant parts	Nutrients								Sources and Location
		N (mg/g)	P (mg/g)	K (mg/g)	Ca (mg/g)	Mg (mg/g)	Cu (µg/g)	Fe (µg/g)	Zn (µg/g)	
<i>R. stylosa</i>	Leaves						0.58		5.80	Jiao <i>et al.</i> (1997)
	Branches						1.30		6.50	ShankouMagrove, China
	Stems						0.60		3.00	(21°28'N, 119°43'E)
<i>Aegiceras corniculatum</i>	Leaves	13.70	1.20	5.00						Li (1997)
	Branches	7.50	1.90	10.30						Shenzhen, South China
	Stems	5.80	0.70	2.60						(22°32'N, 114°03'E)
	Roots	4.80	1.70	14.80						
<i>Kandelia candel</i>	Leaves	13.90	1.30	6.40						
	Branches	5.40	1.50	8.50						
	Stems	6.80	0.70	2.10						
	Roots	4.40	1.60	12.60						
<i>R. mucronata</i>	Leaves								27.71	SepangLukut, Malaysia
	Stems								29.61	(2°36'N, 101°42'E)
	Roots								39.78	Mahmood and Saberi (2000)
<i>R. mucronata</i>	Leaves						2.58			SepangLukut, Malaysia
	Stems						2.19			(2°36'N, 101°42'E)
	Roots						4.54			Mahmood <i>et al.</i> (2001)

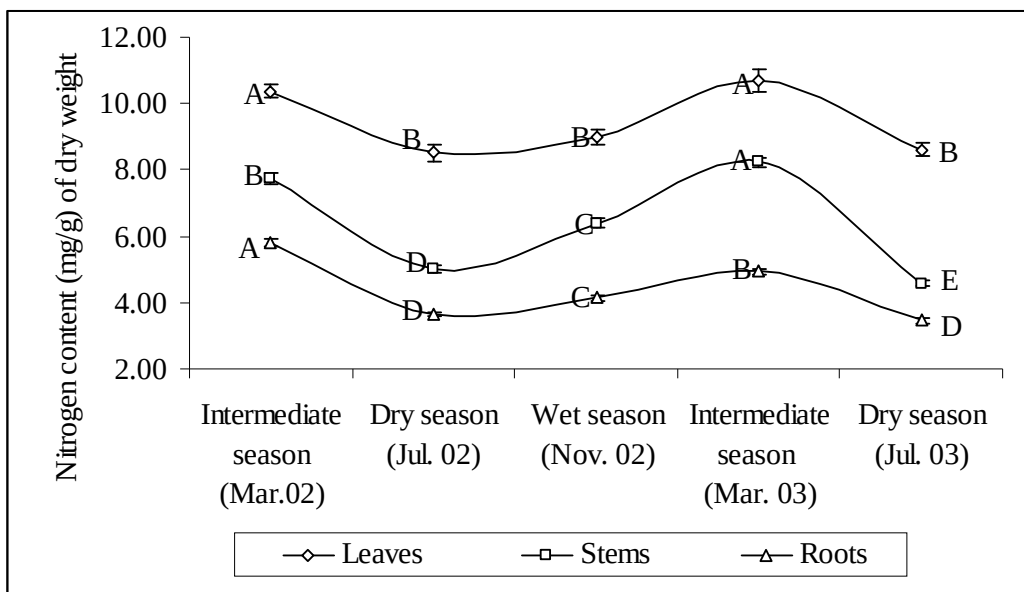


Figure 6.1: Nitrogen content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

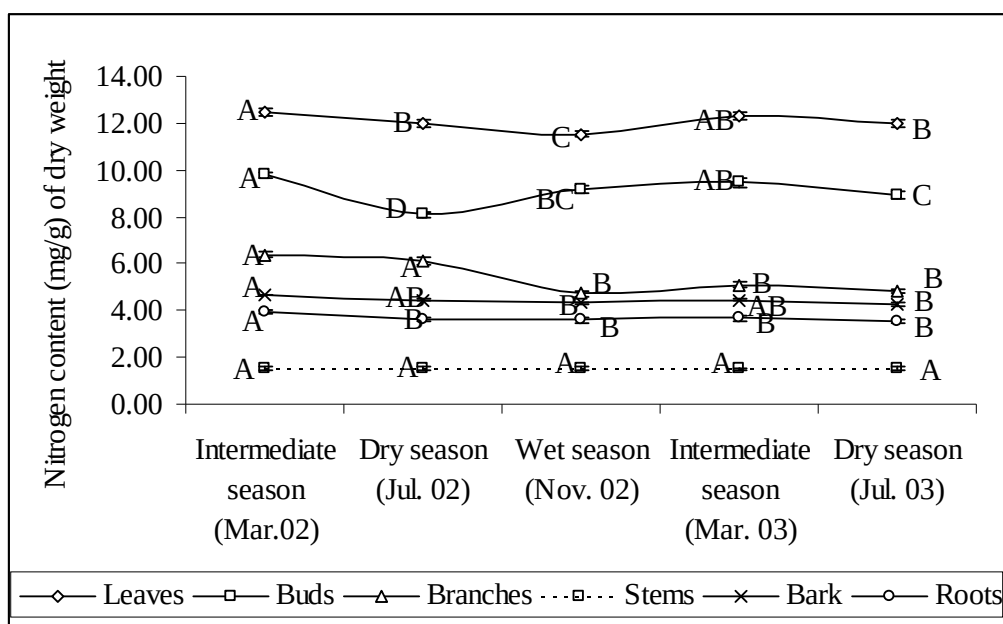


Figure 6.2: Nitrogen content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

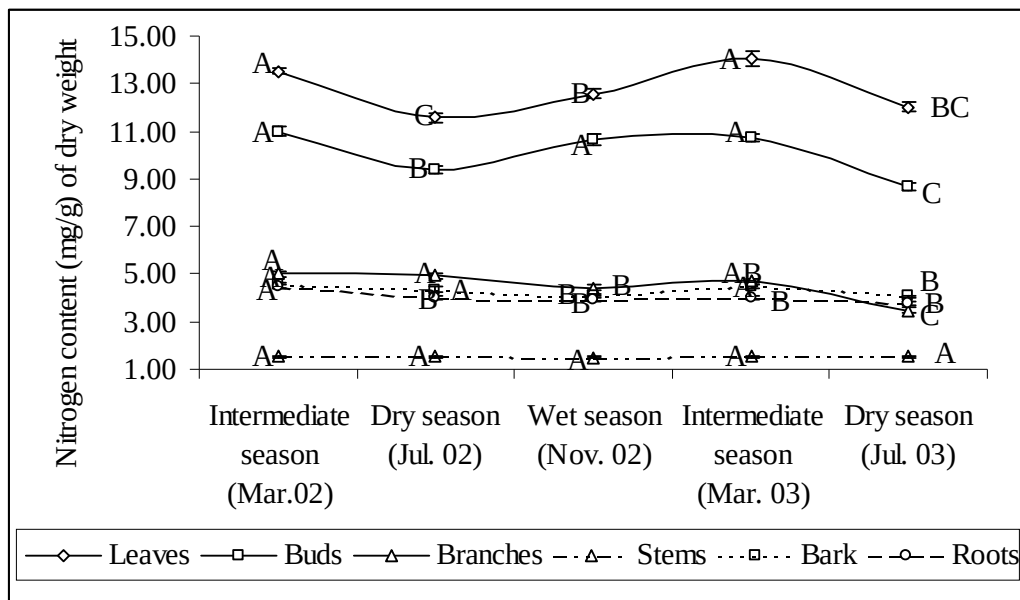


Figure 6.3: Nitrogen content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

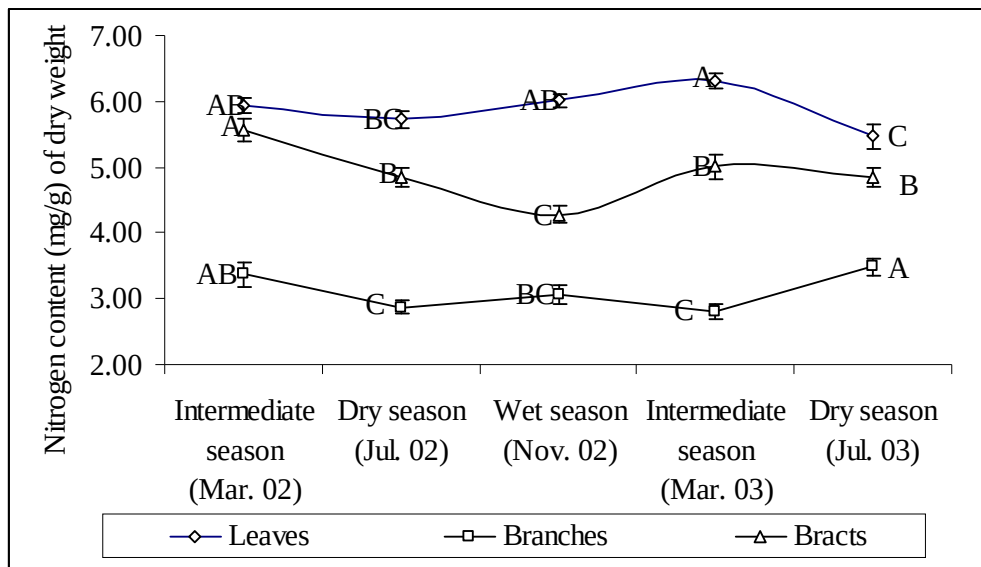


Figure 6.4: Nitrogen content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

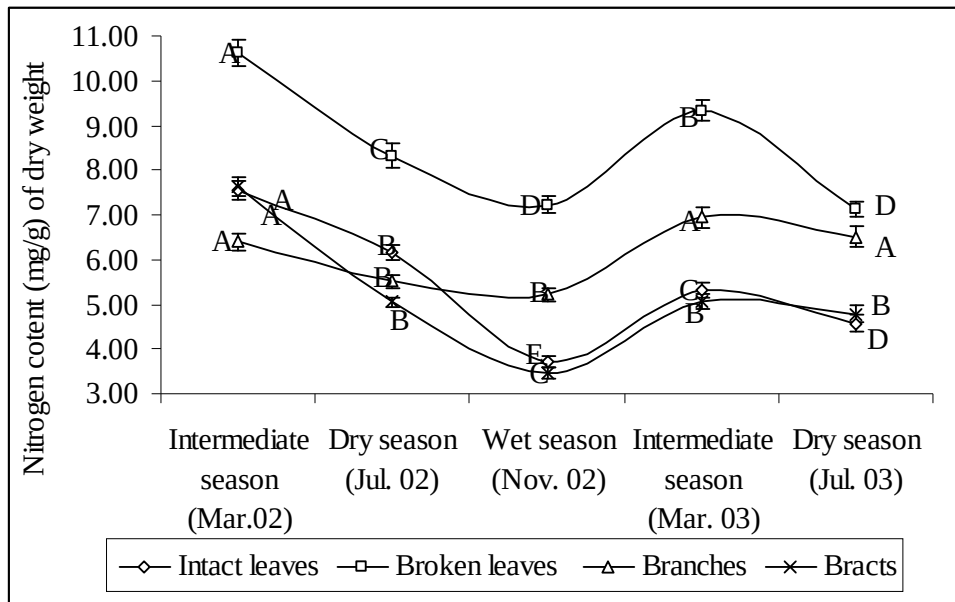


Figure 6.5: Nitrogen content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

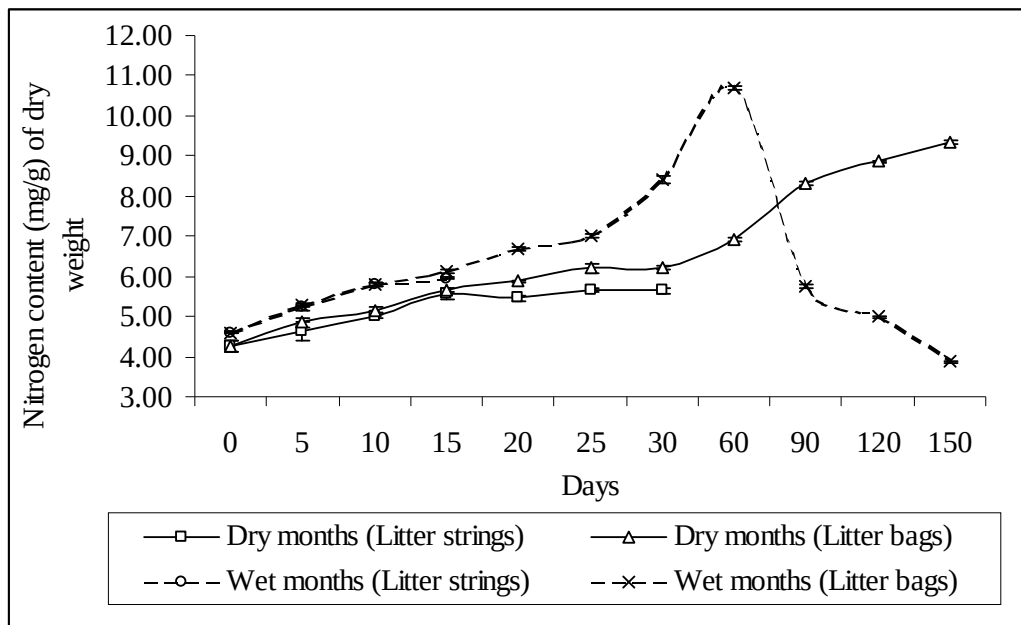


Figure 6.6: Nitrogen content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

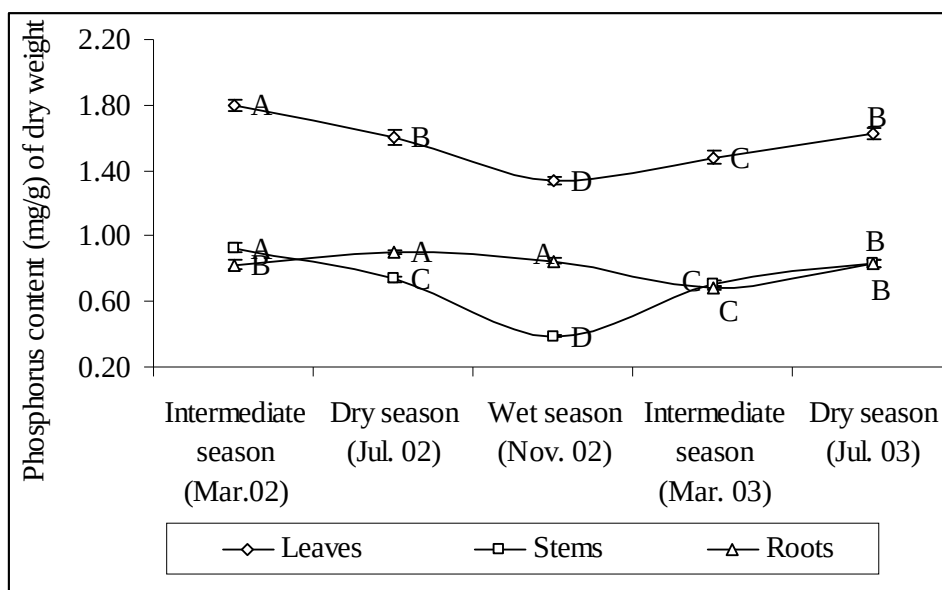


Figure 6.7: Phosphorus content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

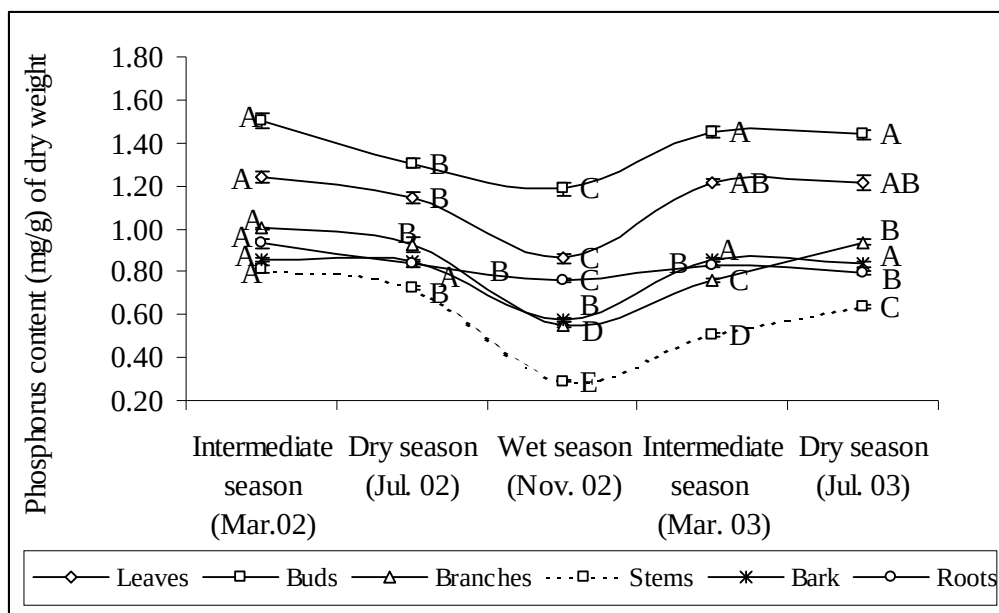


Figure 6.8: Phosphorus content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

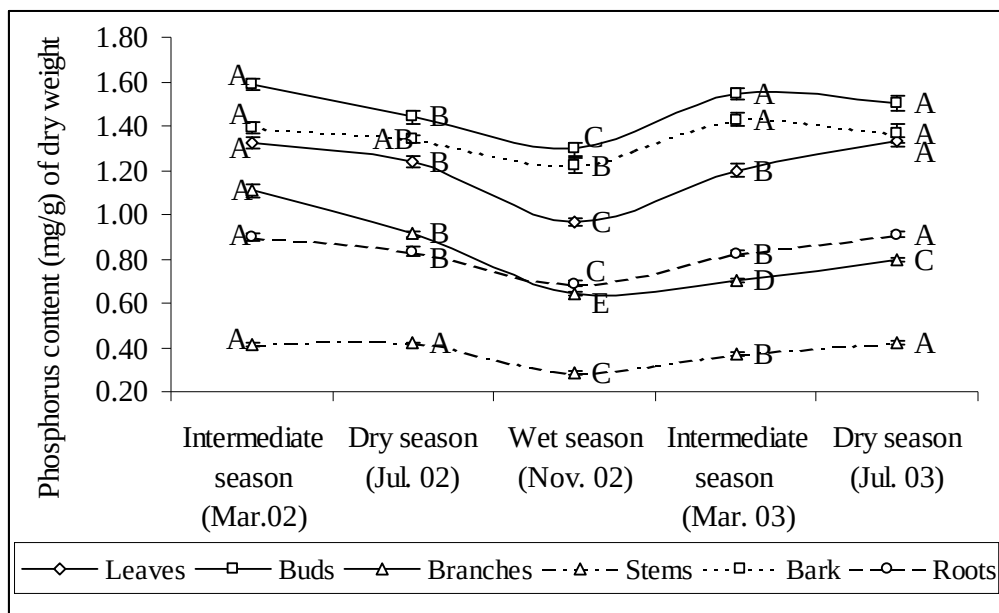


Figure 6.9: Phosphorus content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

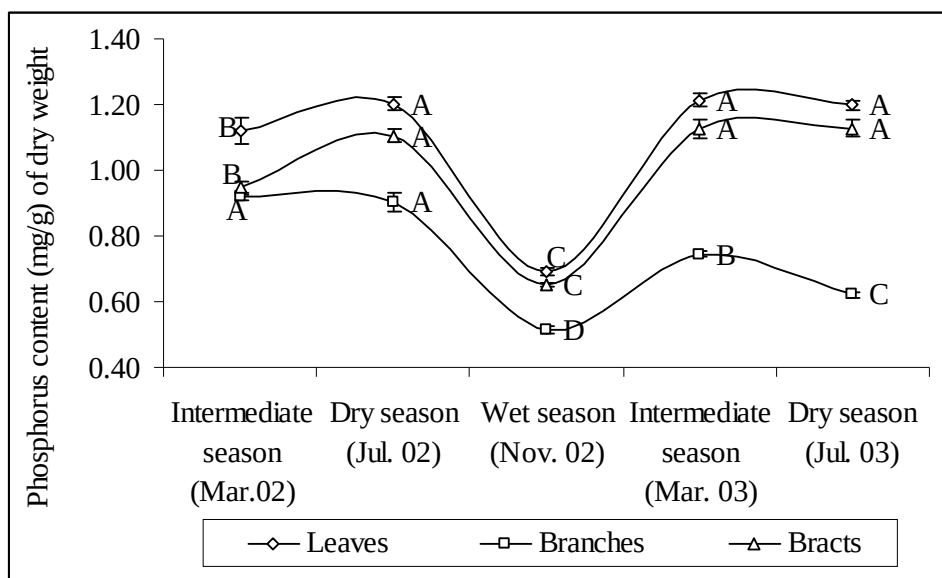


Figure 6.10: Phosphorus content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

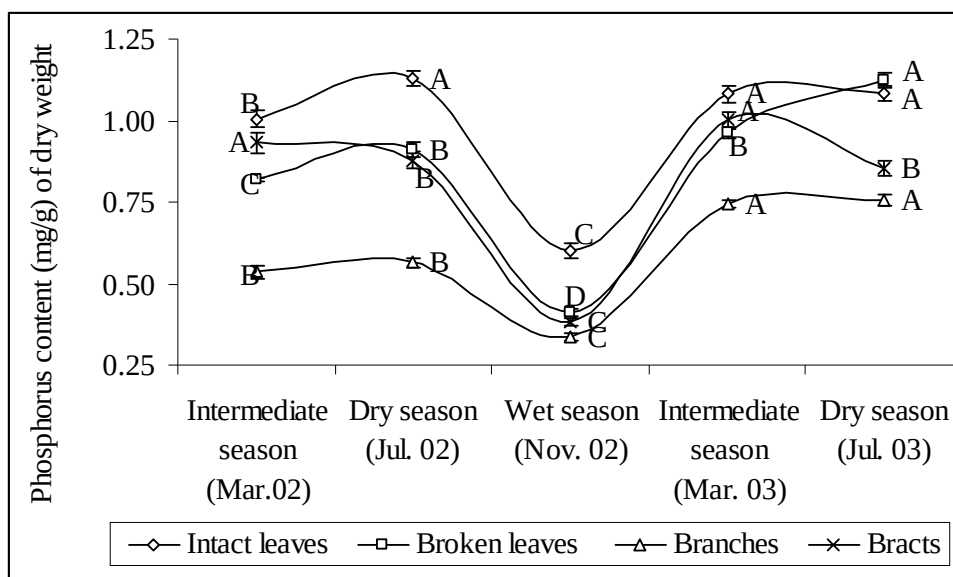


Figure 6.11: Phosphorus content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

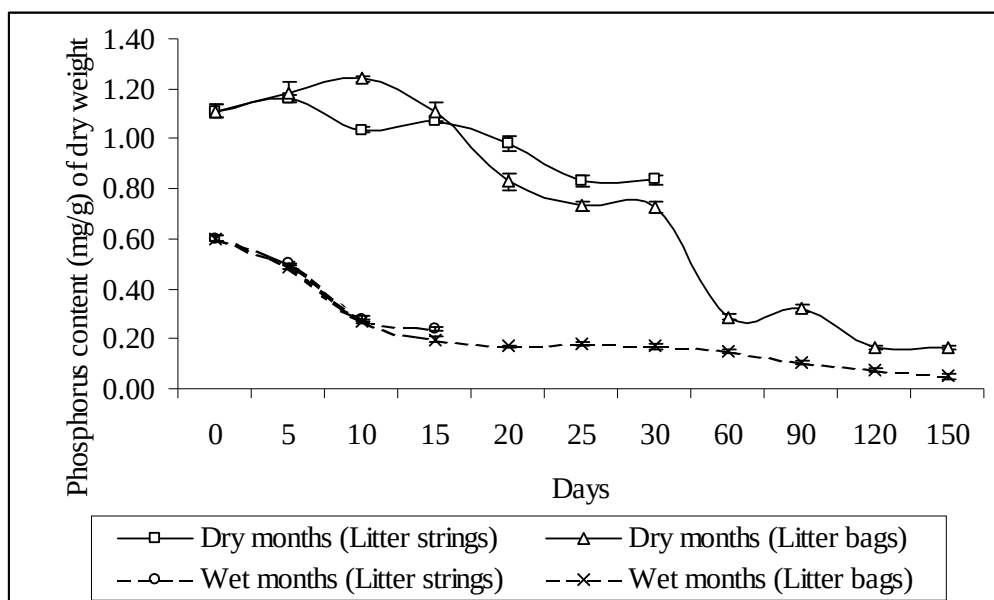


Figure 6.12: Phosphorus content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

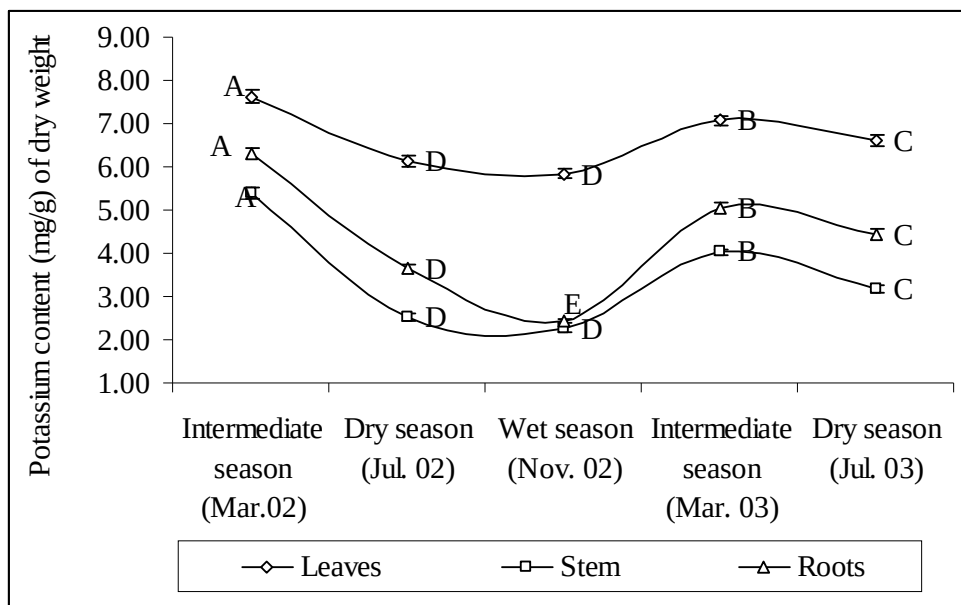


Figure 6.13: Potassium content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

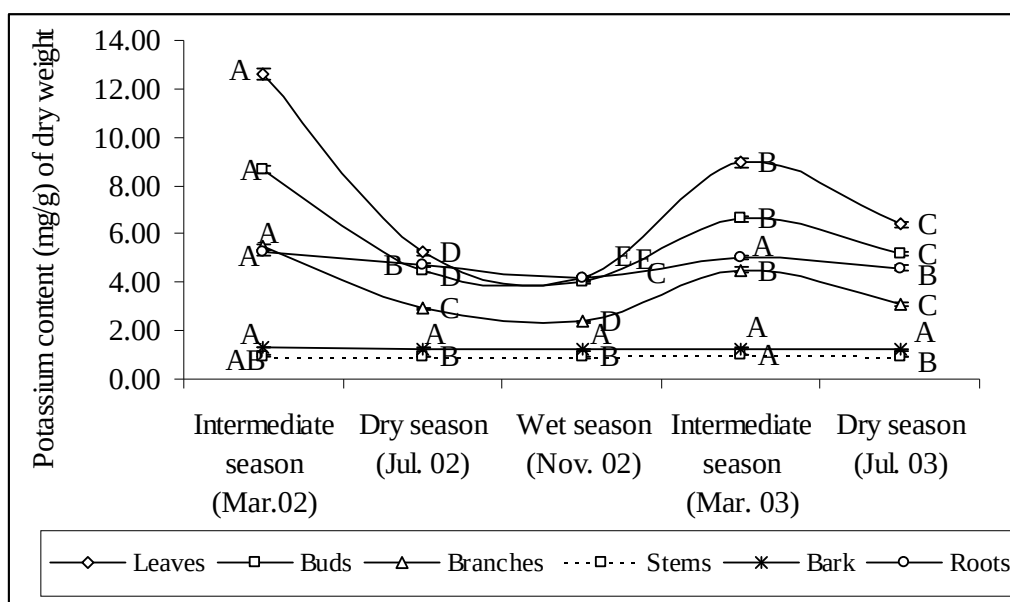


Figure 6.14: Potassium content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

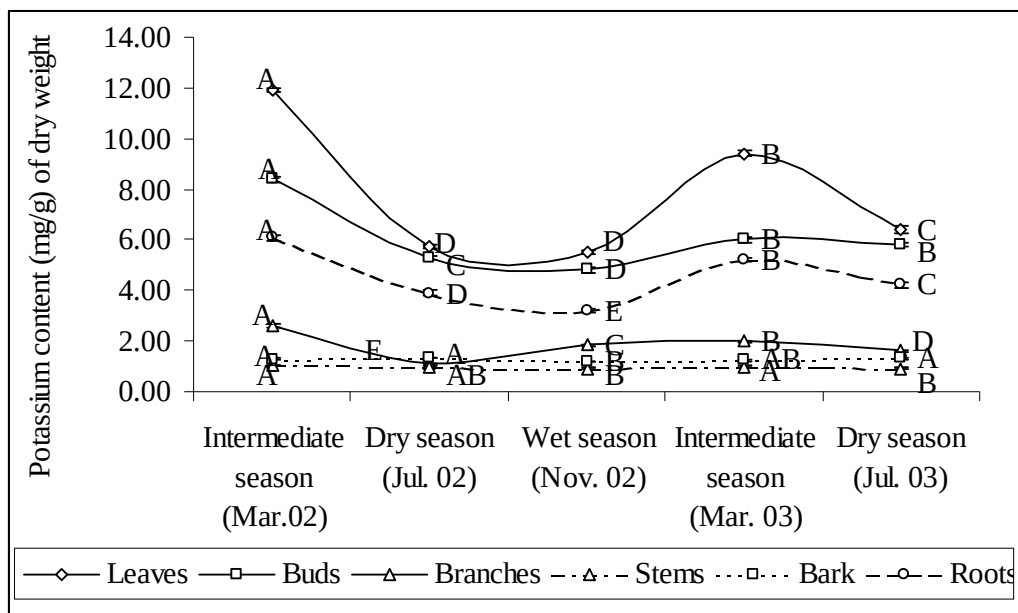


Figure 6.15: Potassium content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

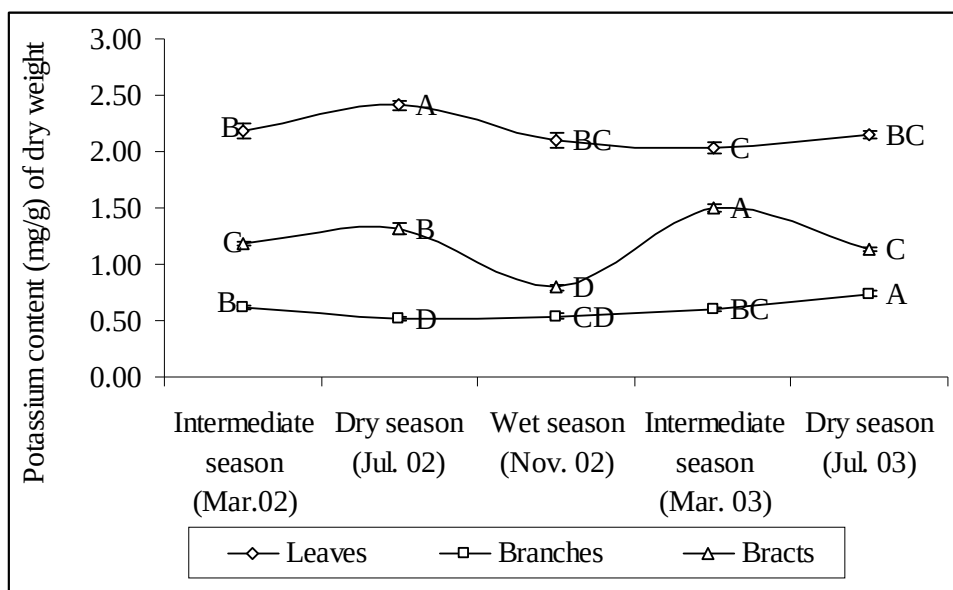


Figure 6.16: Potassium content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

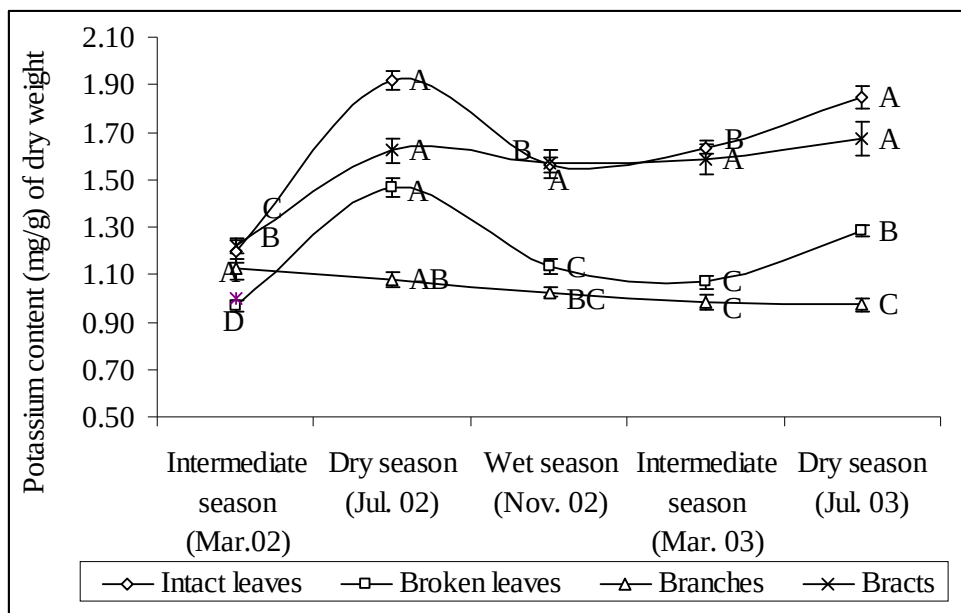


Figure 6.17: Potassium content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

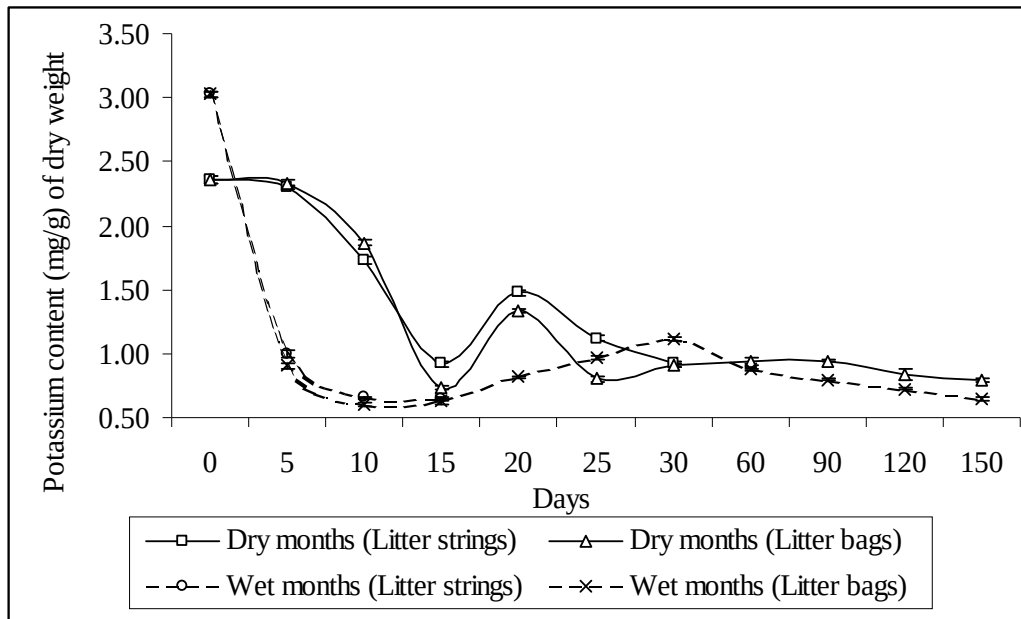


Figure 6.18: Potassium content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

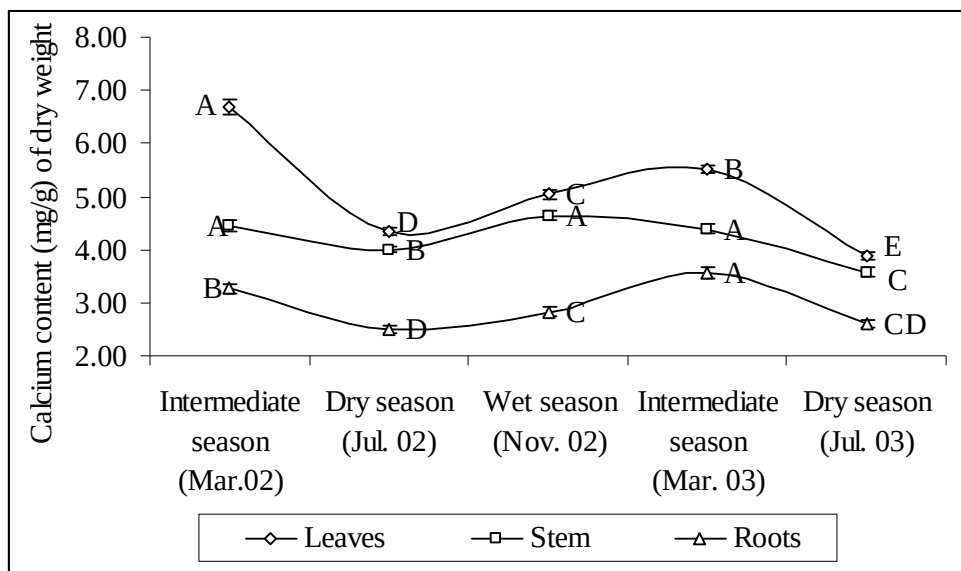


Figure 6.19: Calcium content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

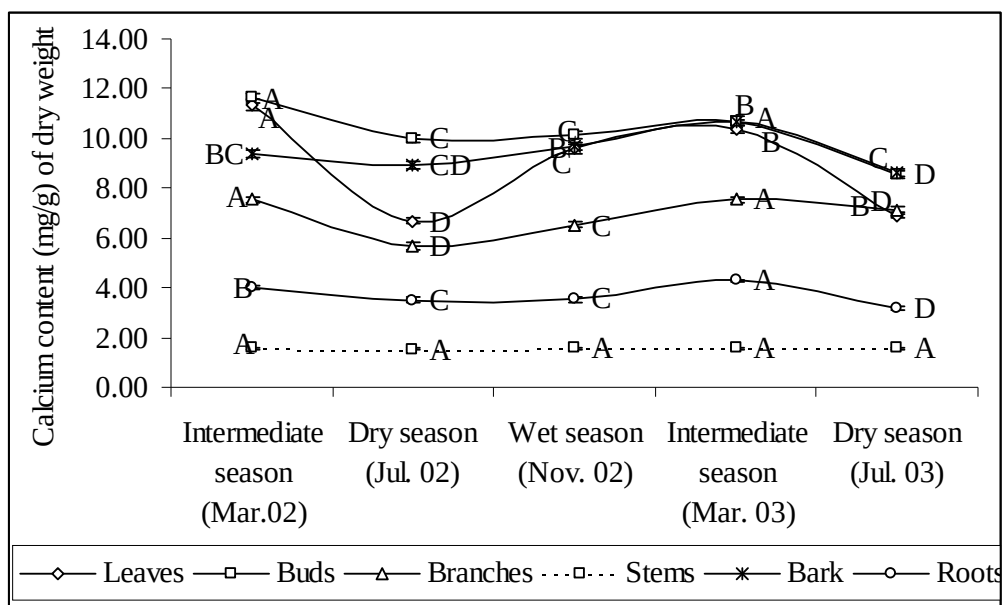


Figure 6.20: Calcium content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

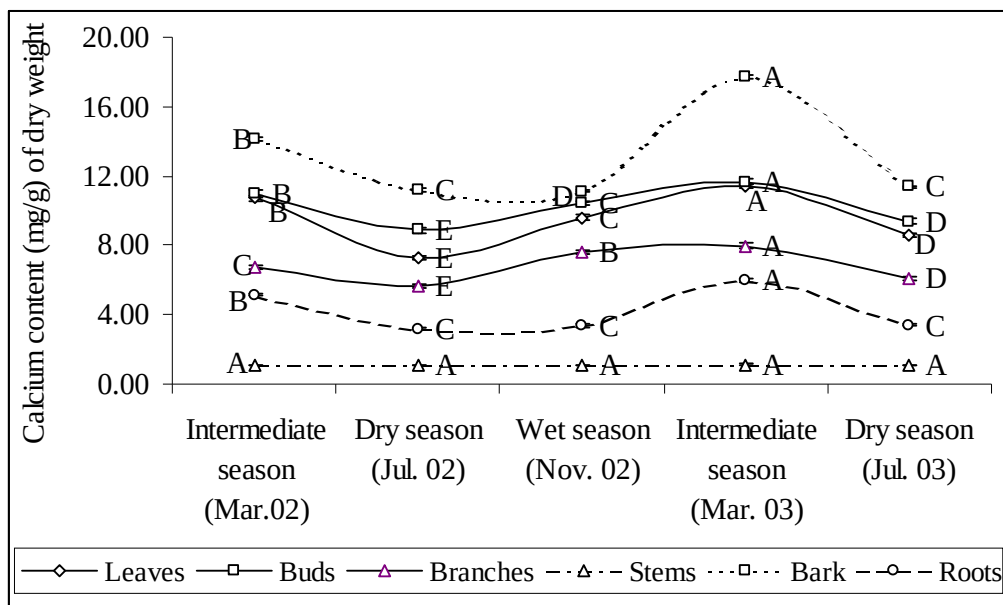


Figure 6.21: Calcium content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

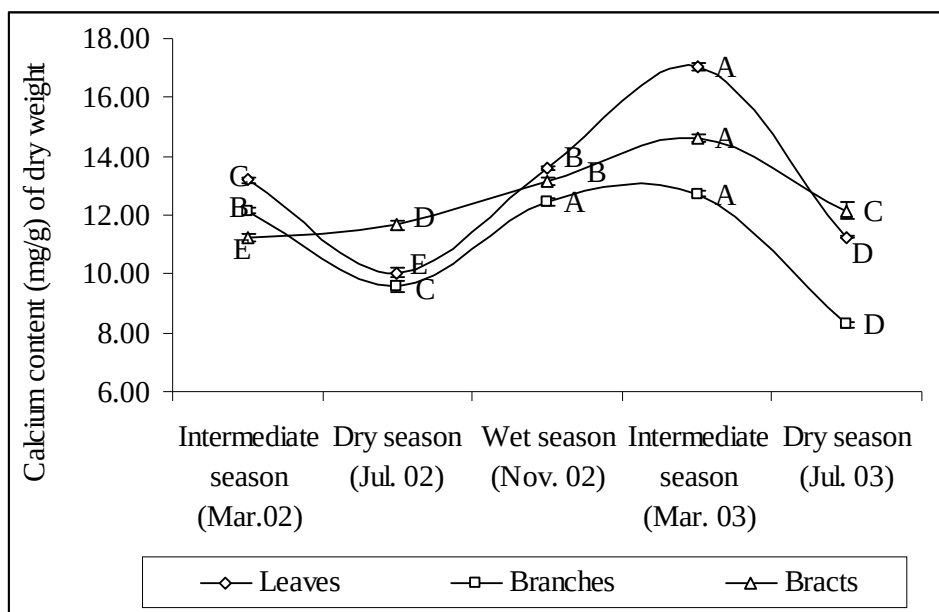


Figure 6.22: Calcium content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

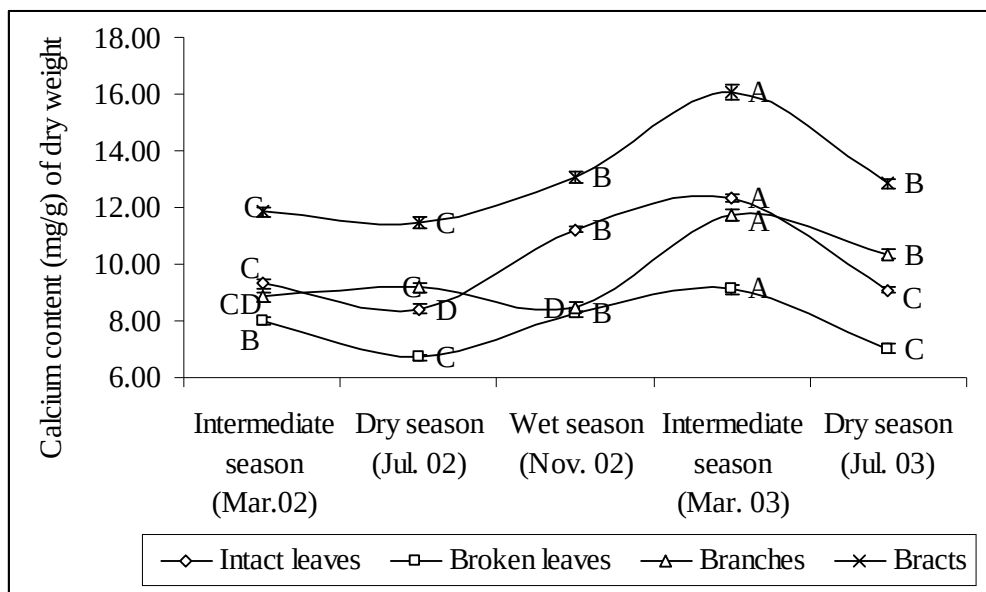


Figure 6.23: Calcium content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

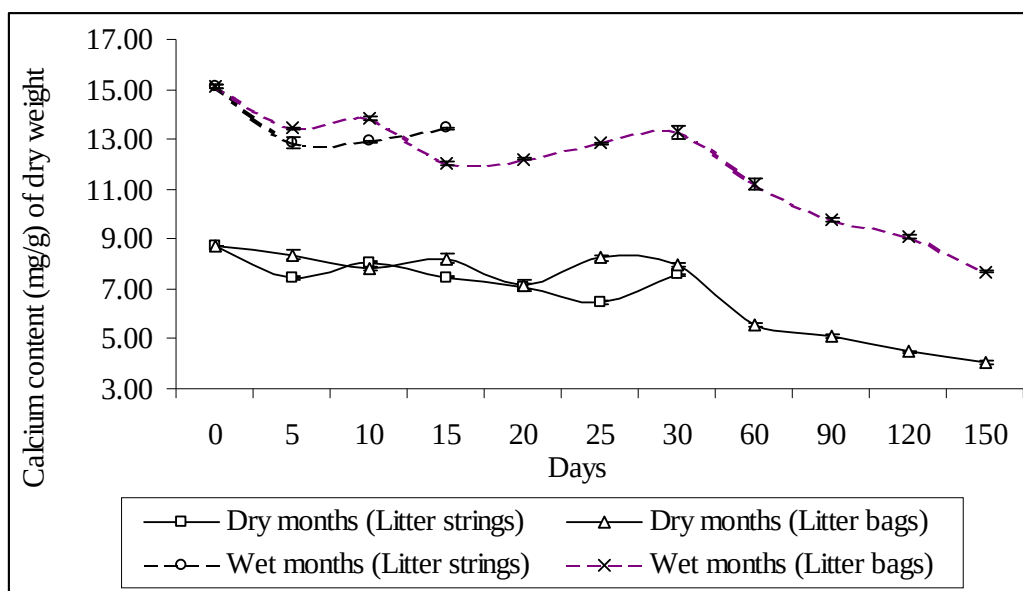


Figure 6.24: Calcium content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

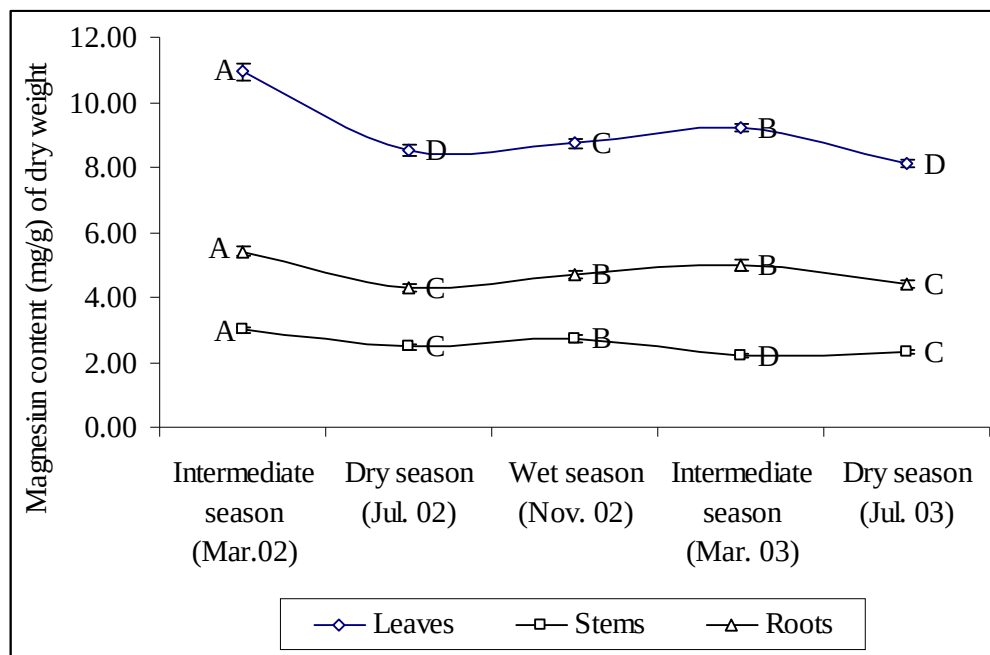


Figure 6.25: Magnesium content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

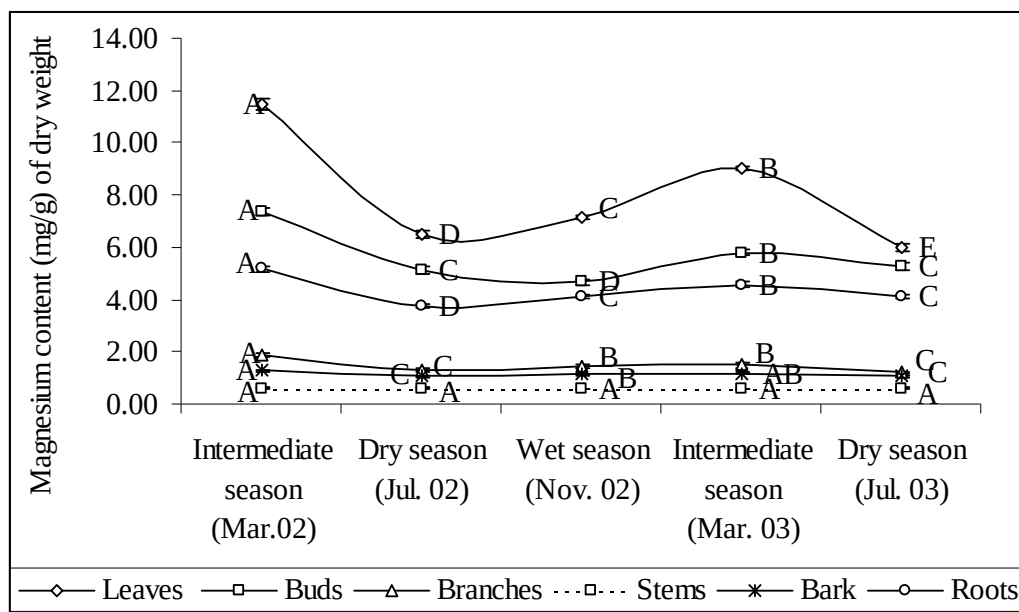


Figure 6.26: Magnesium content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

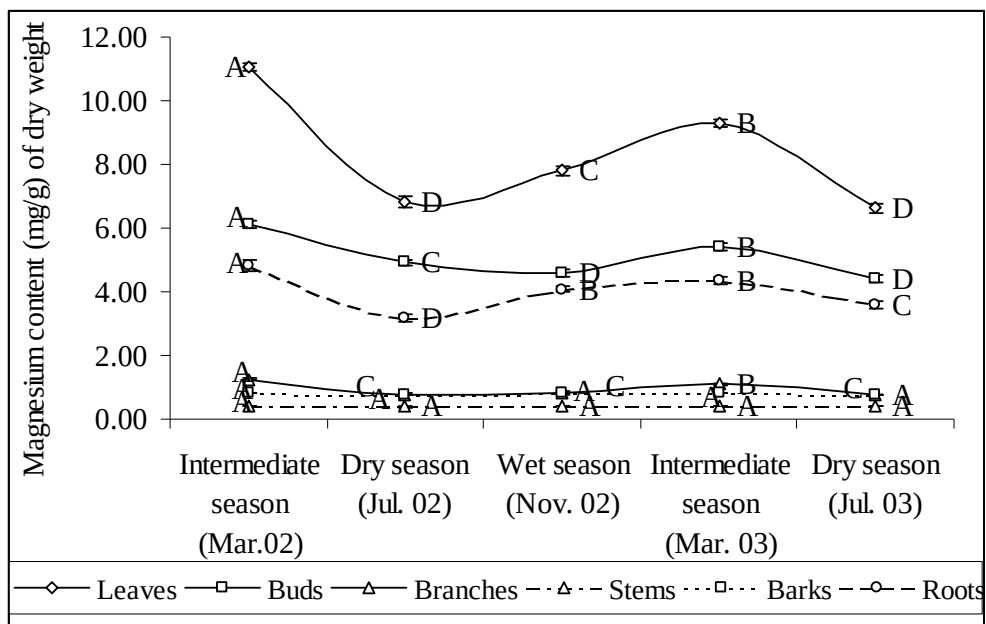


Figure 6.27: Magnesium content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

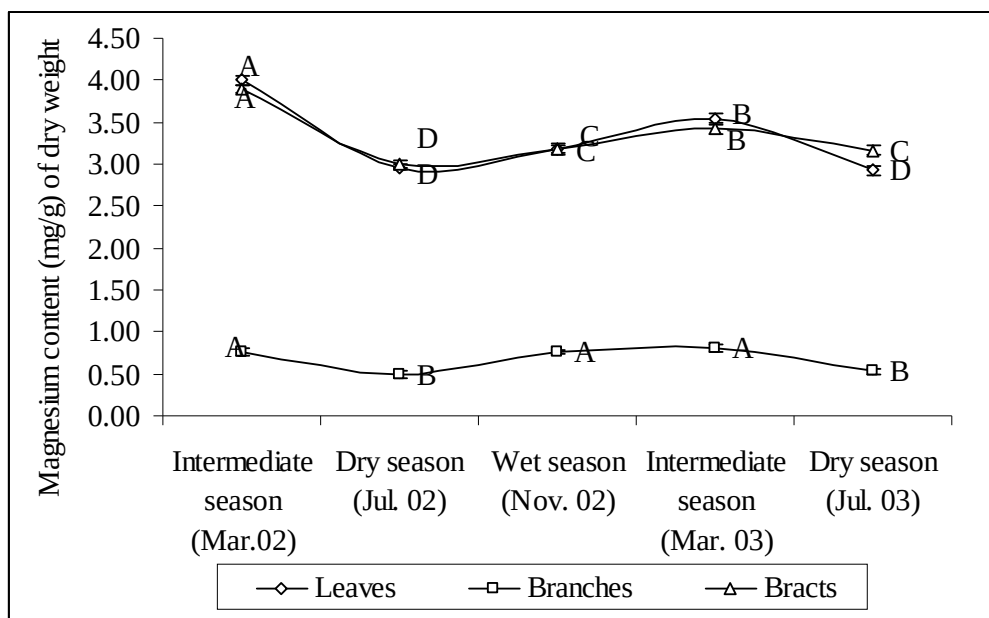


Figure 6.28: Magnesium content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

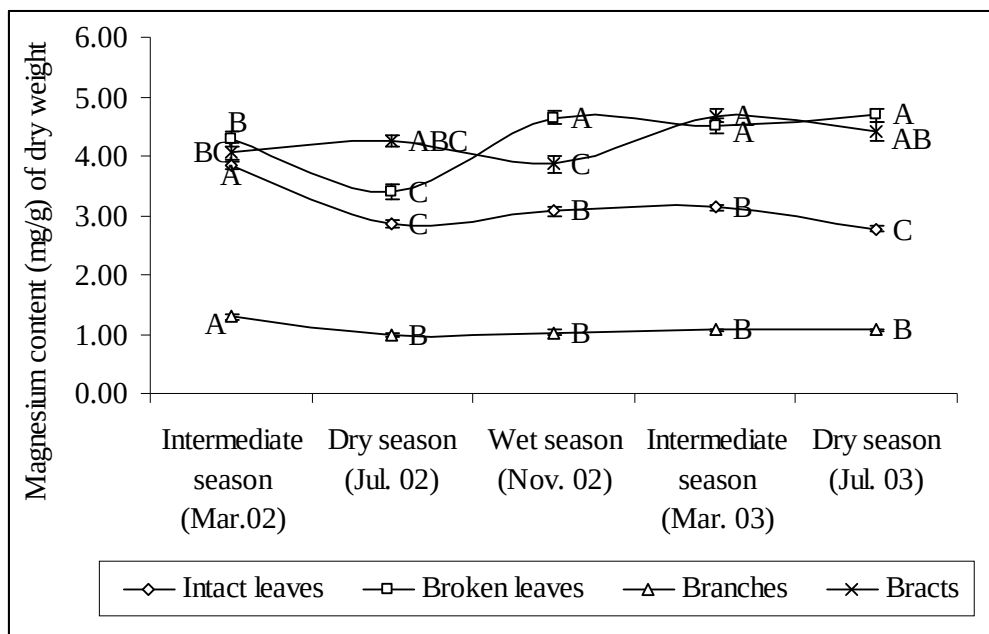


Figure 6.29: Magnesium content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

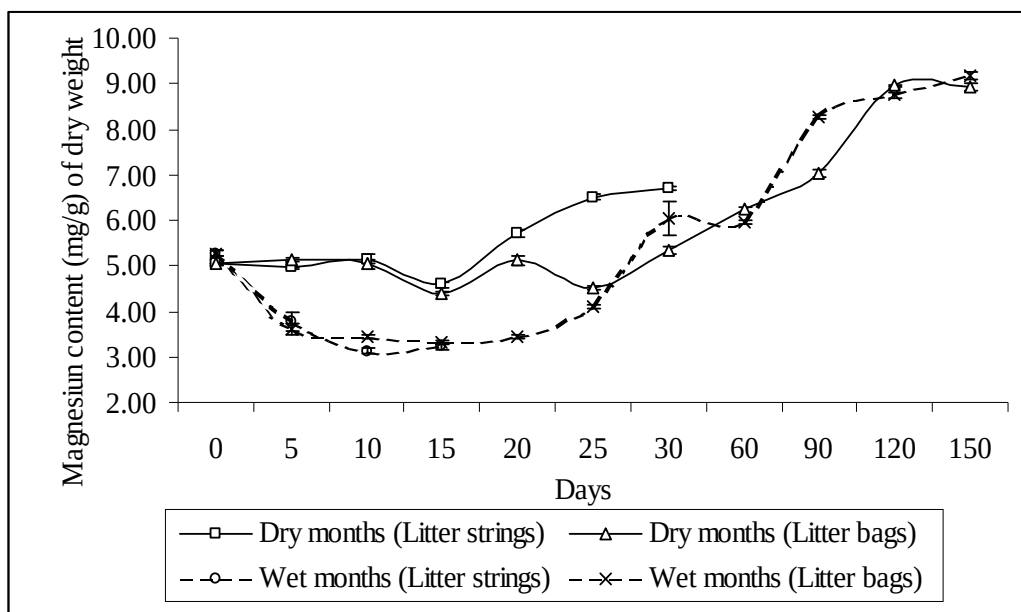


Figure 6.30: Magnesium content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

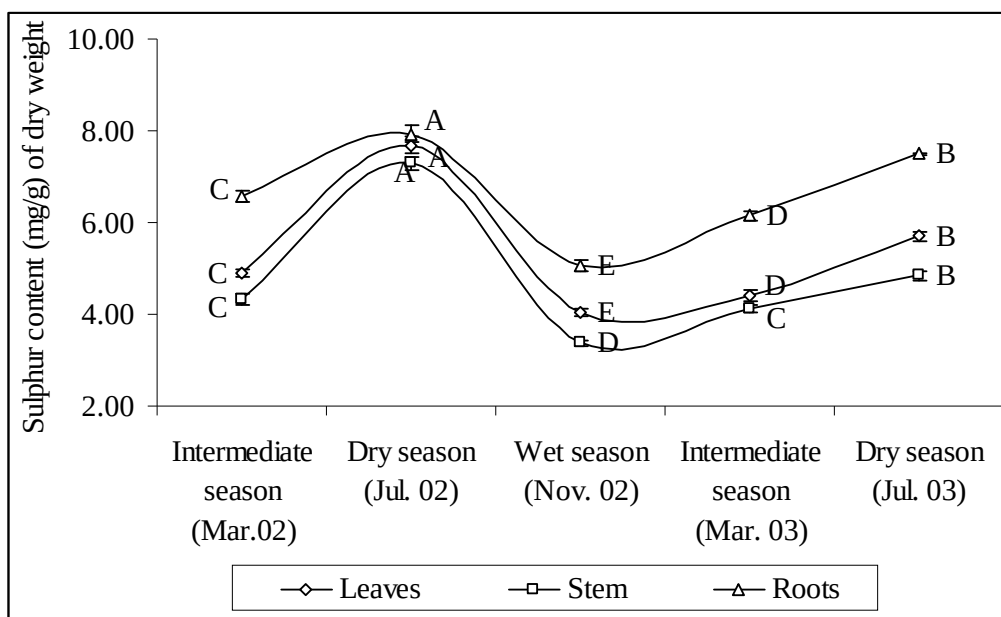


Figure 6.31: Sulphur content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

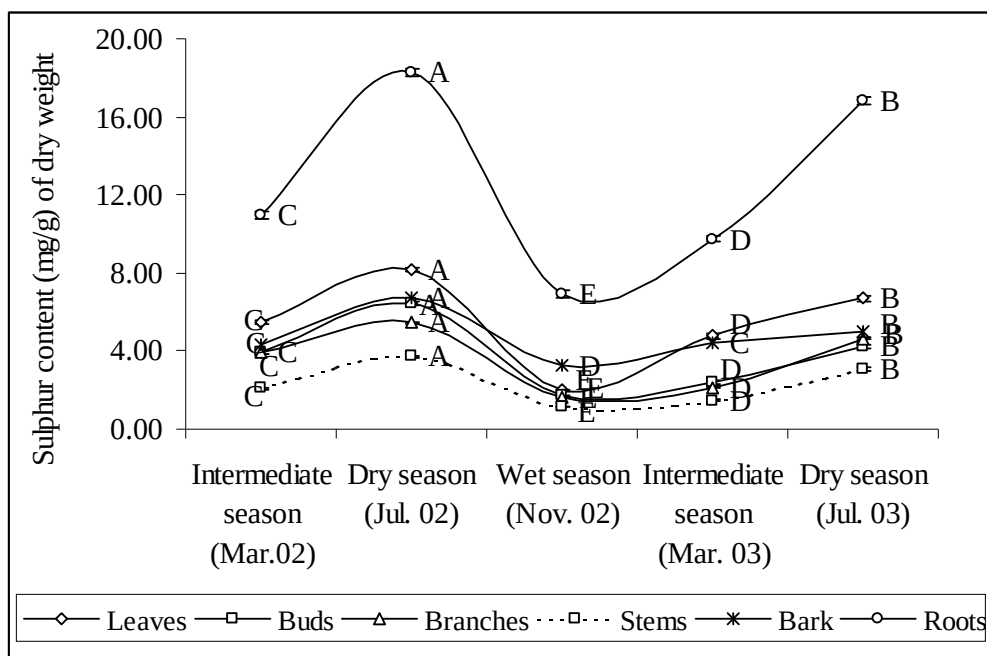


Figure 6.32: Sulphur content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

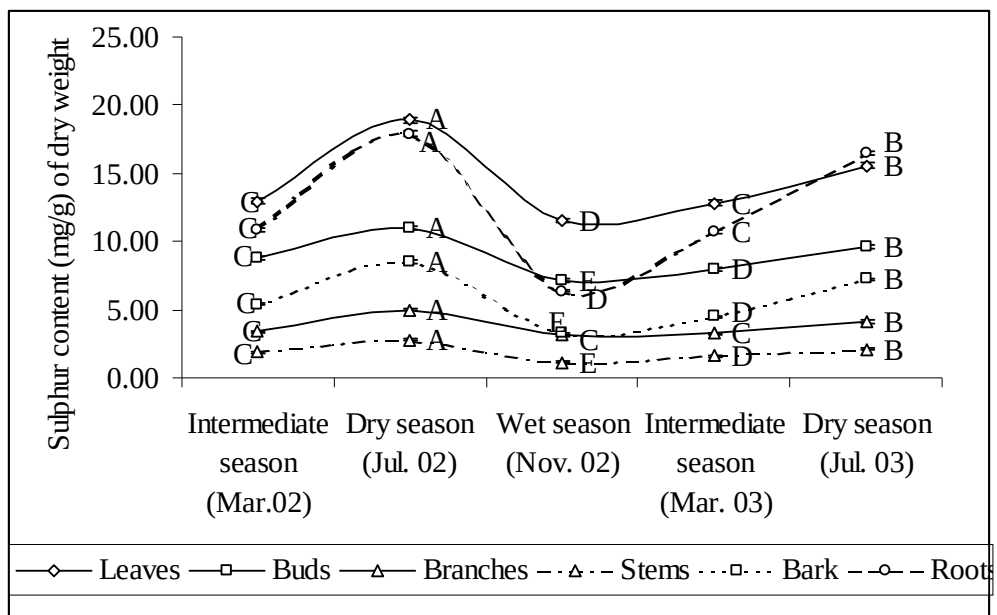


Figure 6.33: Sulphur content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

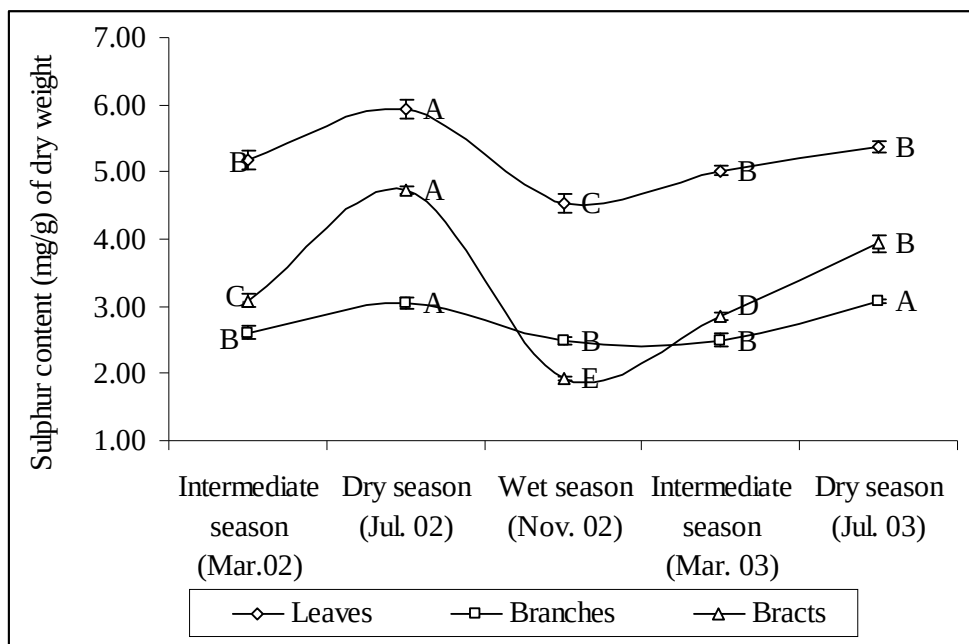


Figure 6.34: Sulphur content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

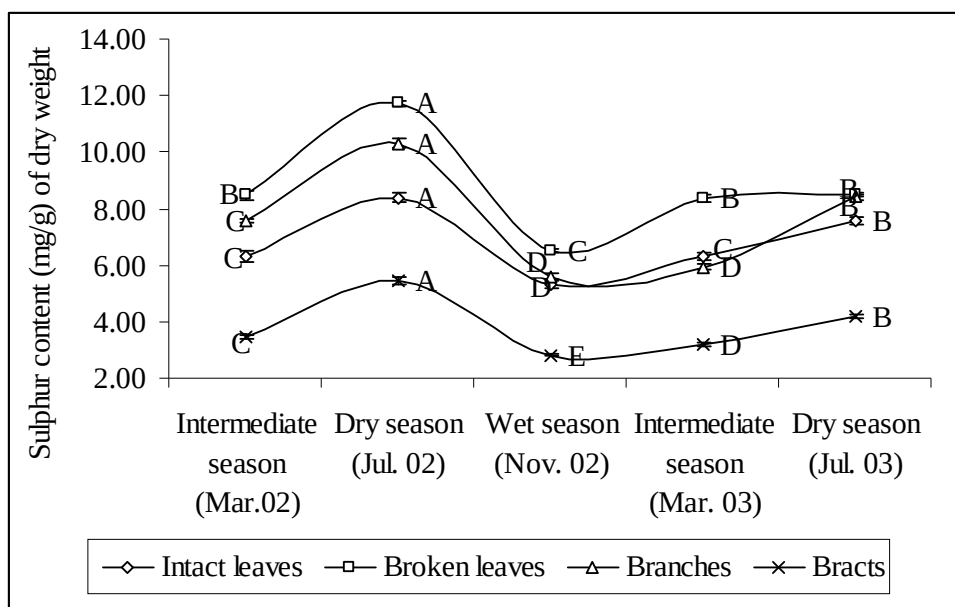


Figure 6.35: Sulphur content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

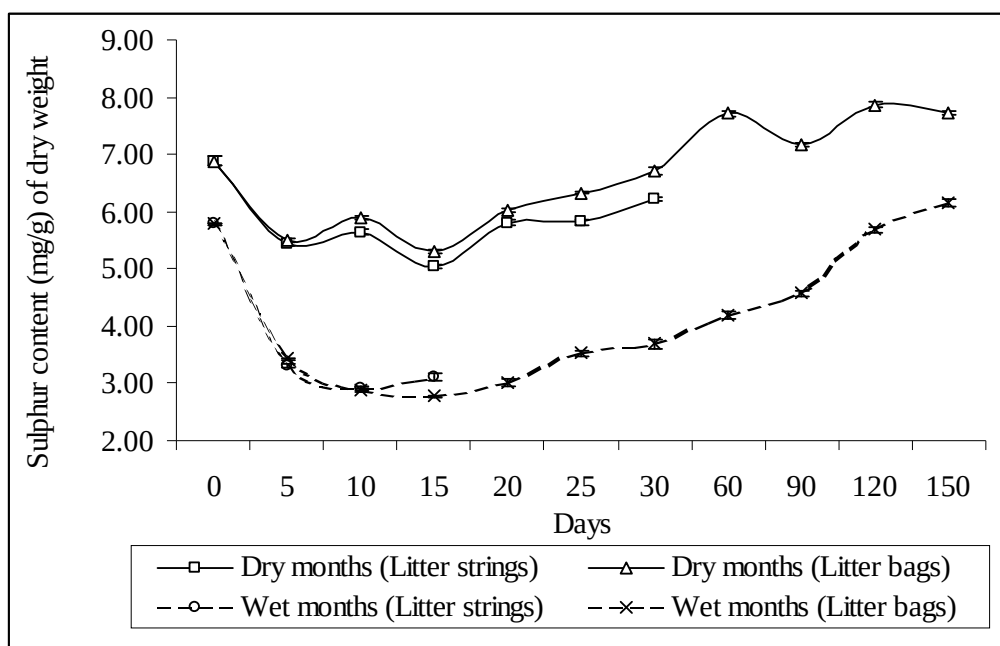


Figure 6.36: Sulphur content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

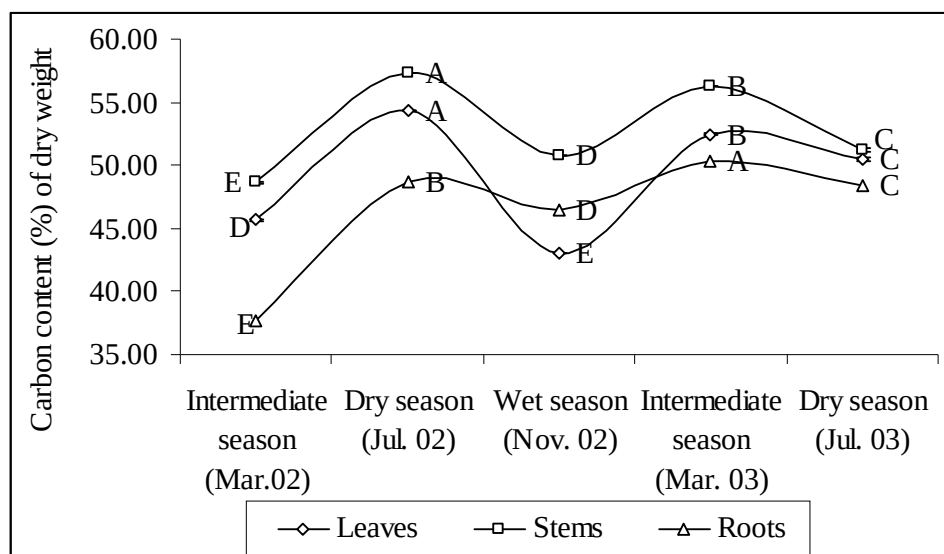


Figure 6.37: Carbon content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

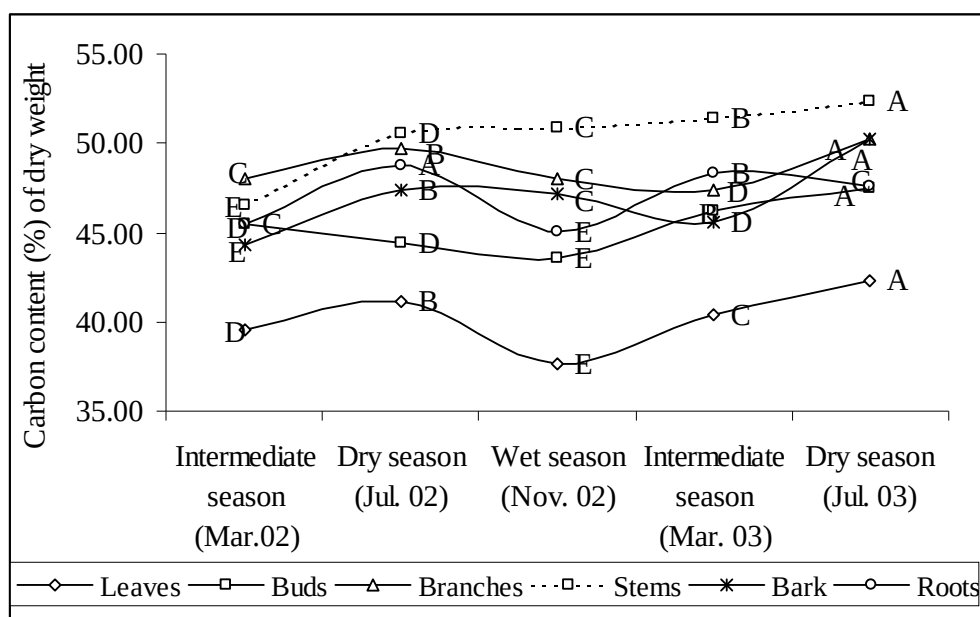


Figure 6.38: Carbon content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

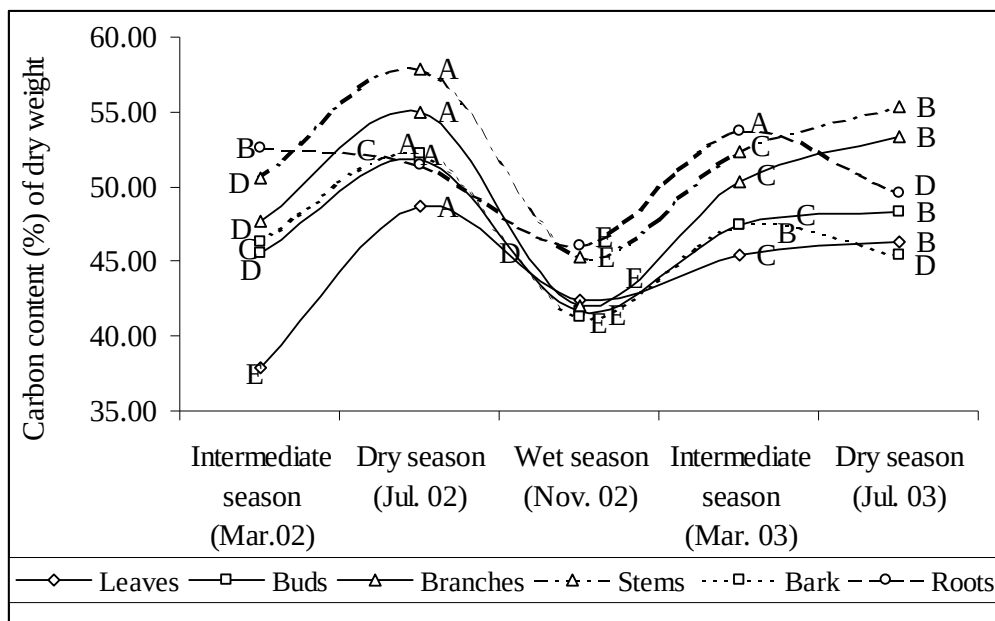


Figure 6.39: Carbon content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

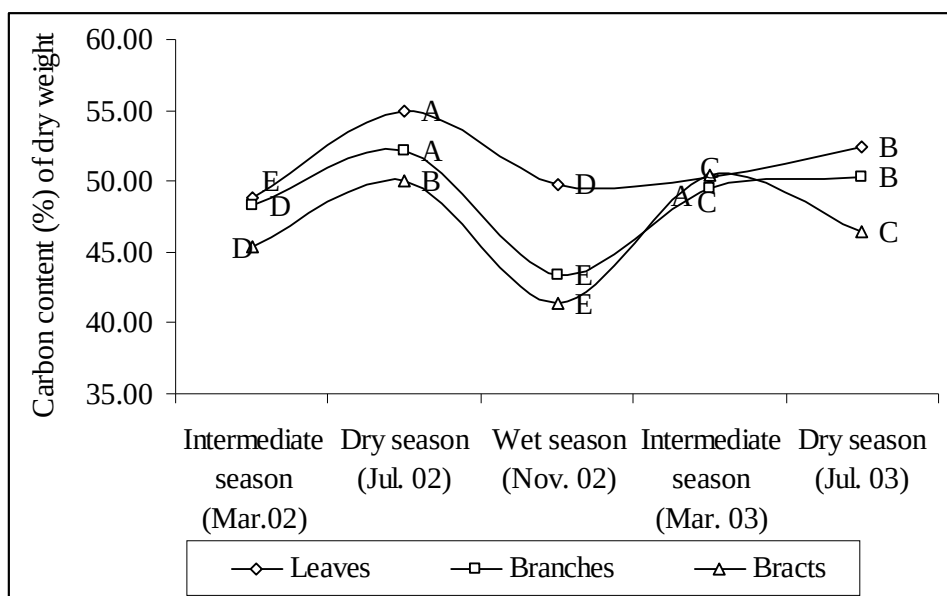


Figure 6.40: Carbon content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

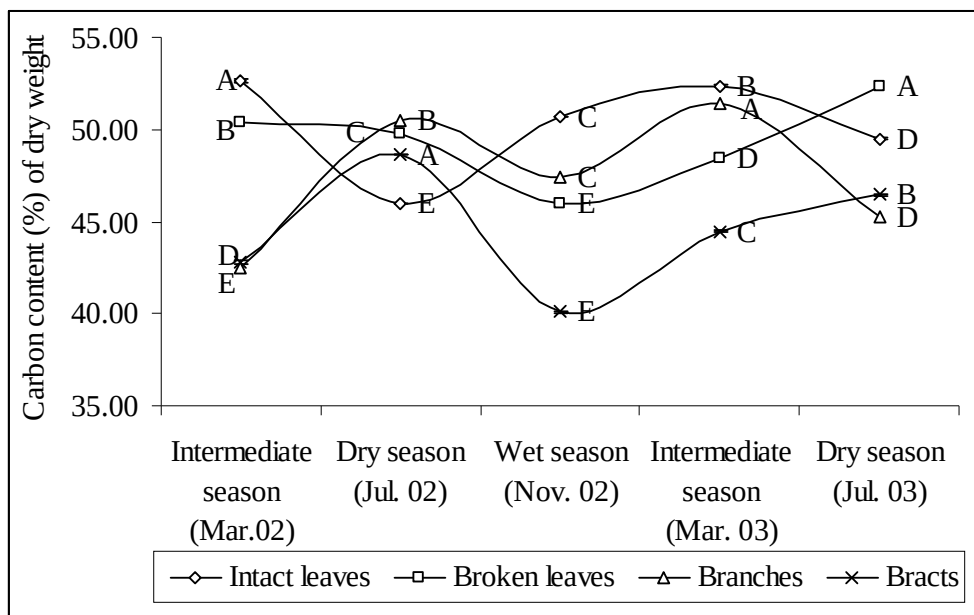


Figure 6.41: Carbon content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

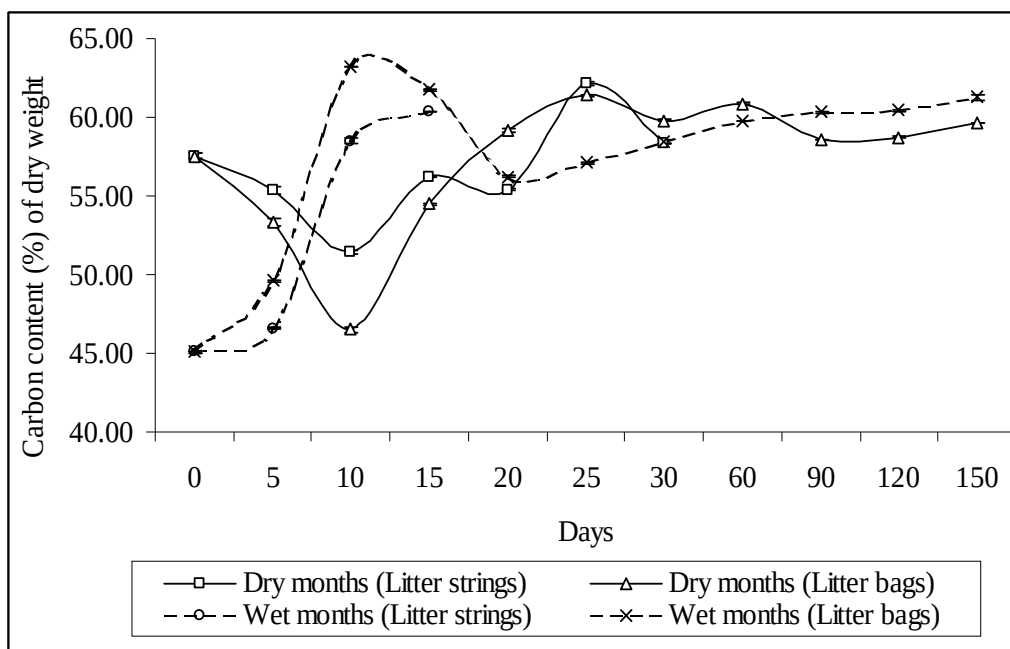


Figure 6.42: Carbon content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

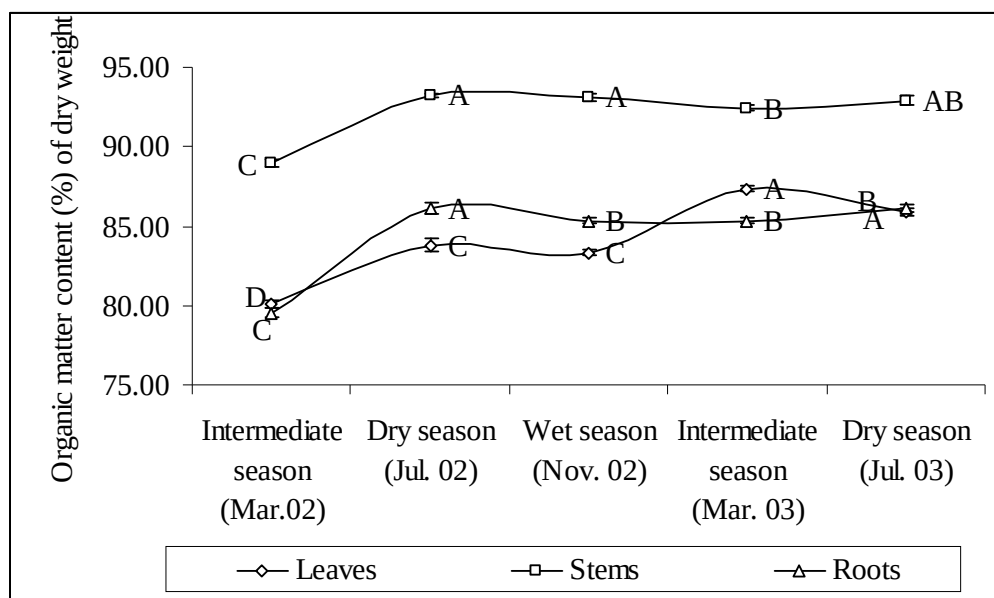


Figure 6.43: Organic matter content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

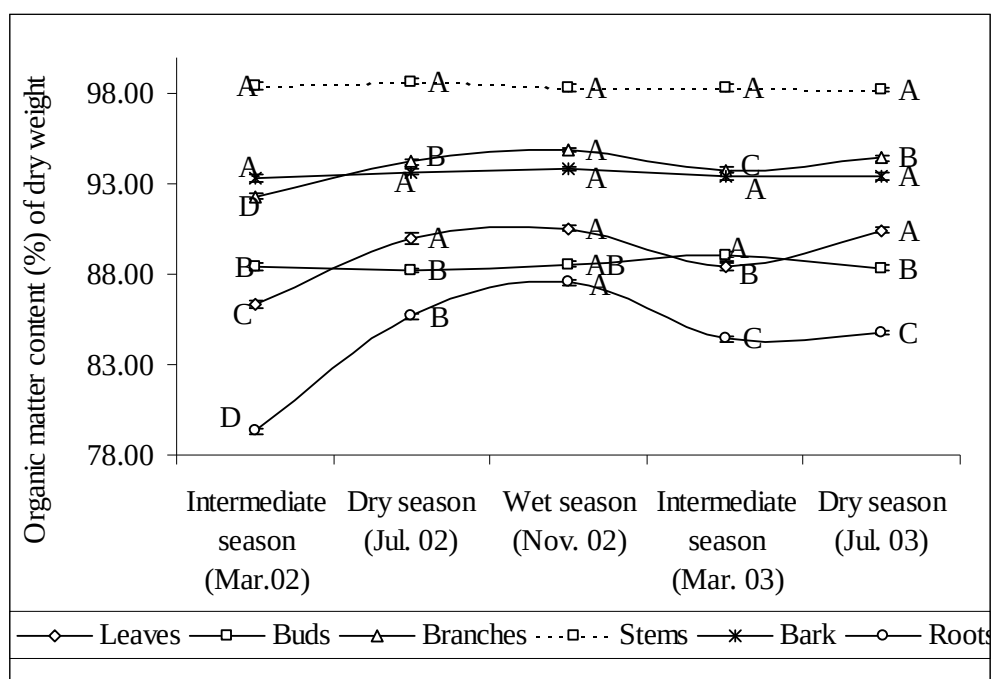


Figure 6.44: Organic matter content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

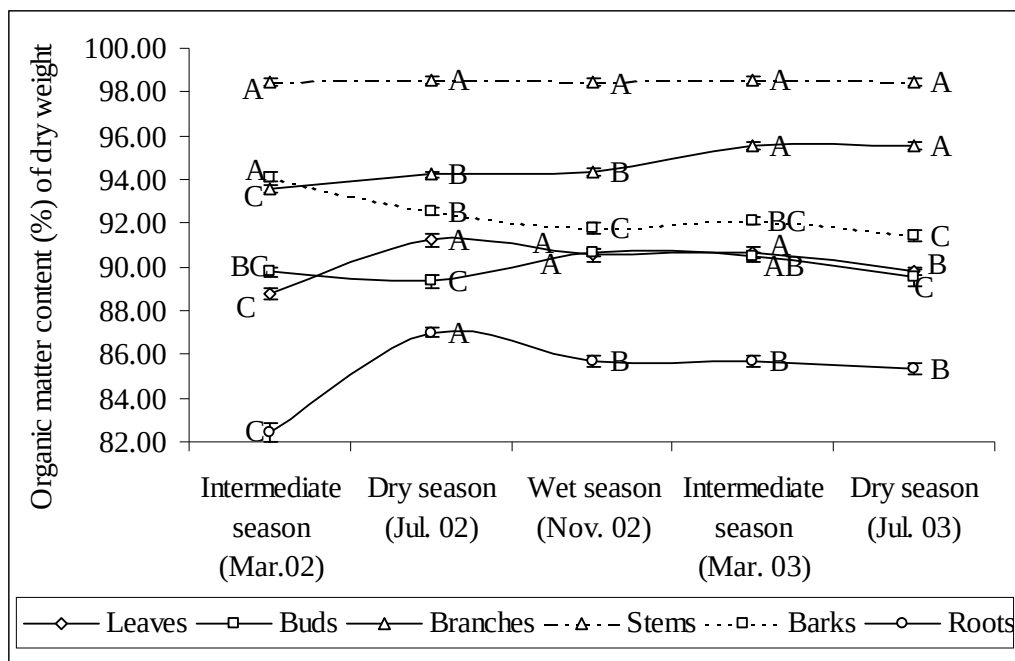


Figure 6.45: Organic matter content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

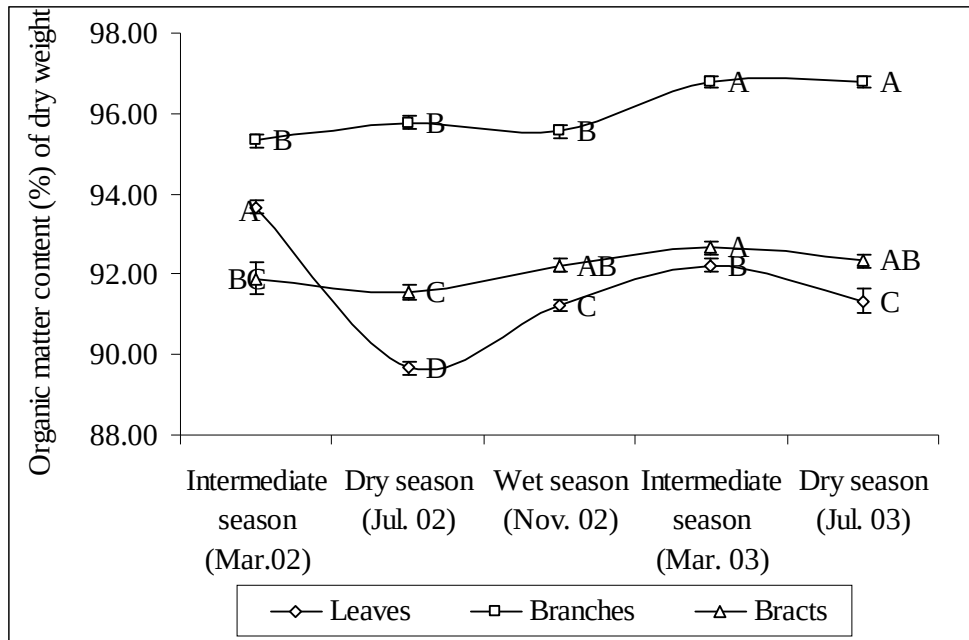


Figure 6.46: Organic matter content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

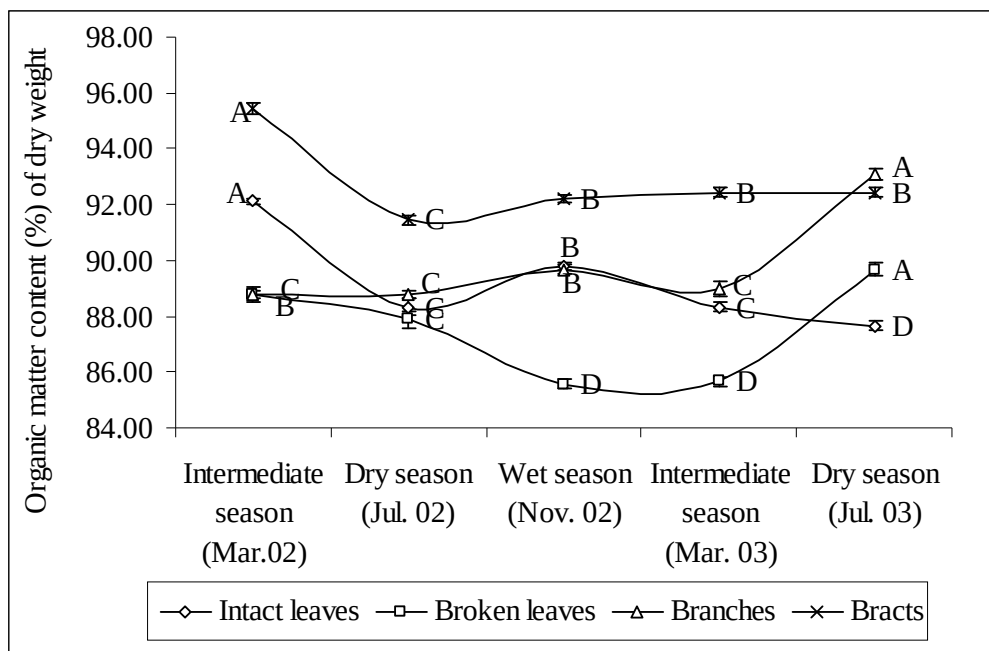


Figure 6.47: Organic matter content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

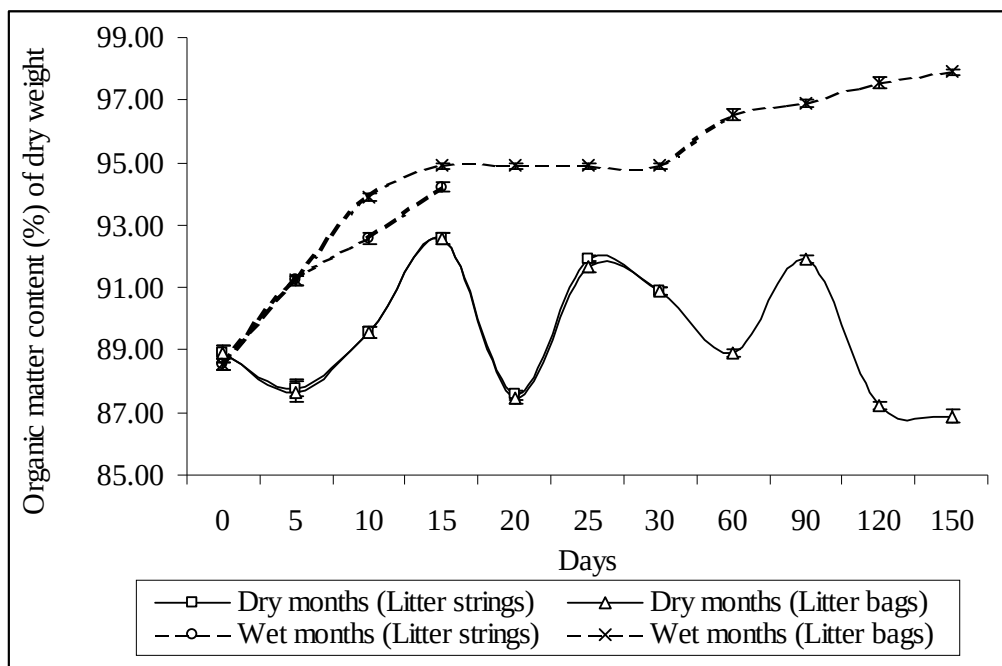


Figure 6.48: Organic matter content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

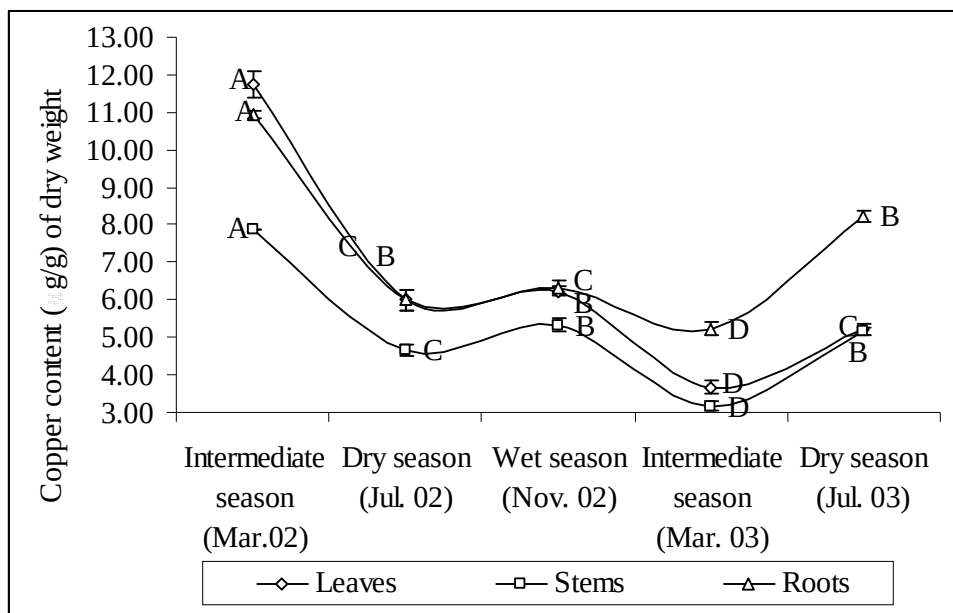


Figure 6.49: Copper content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

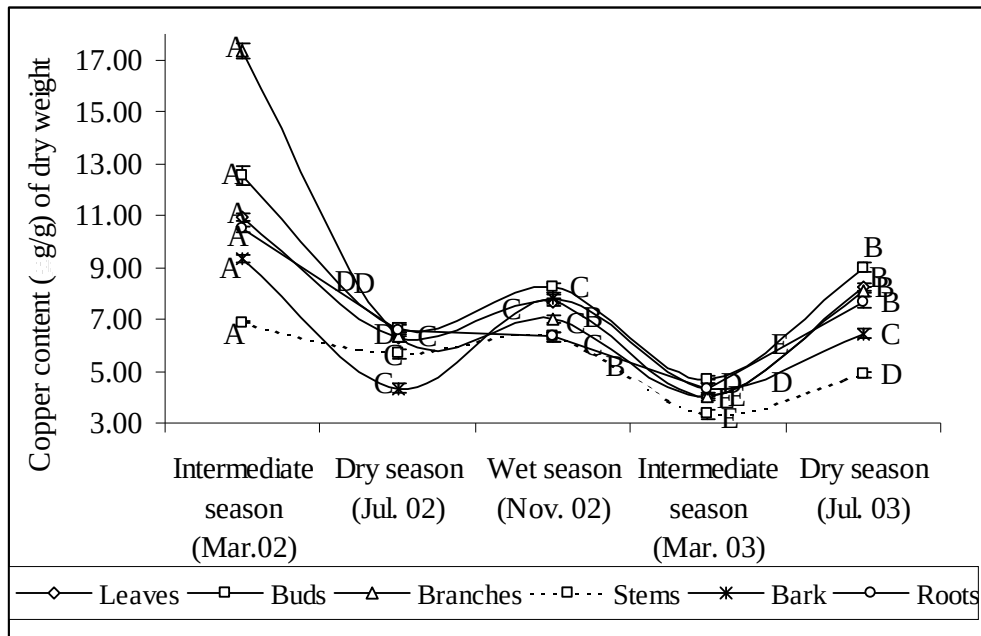


Figure 6.50: Copper content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

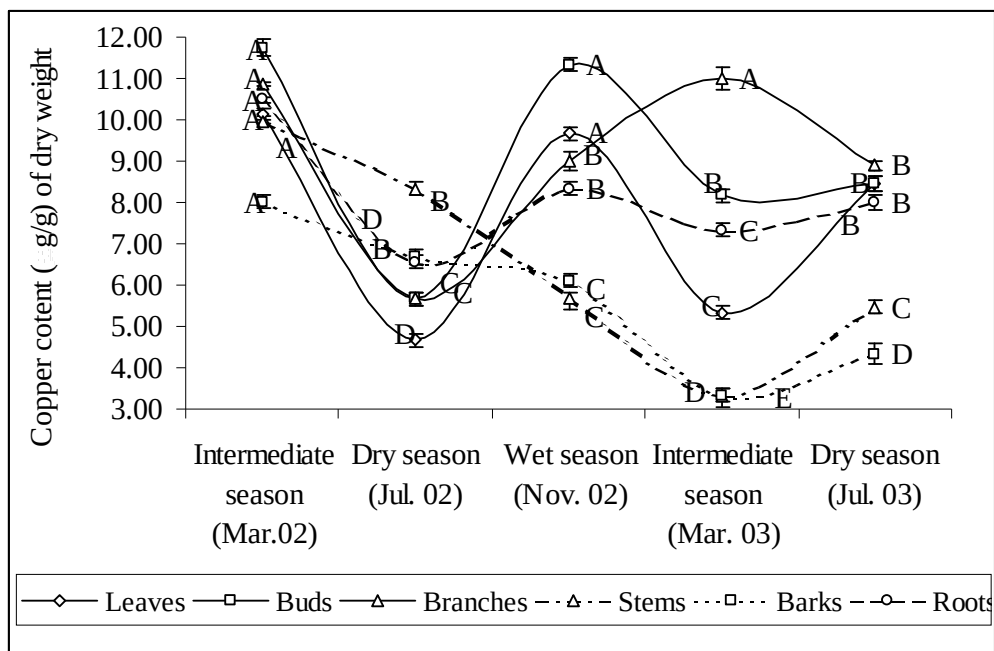


Figure 6.51: Copper content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

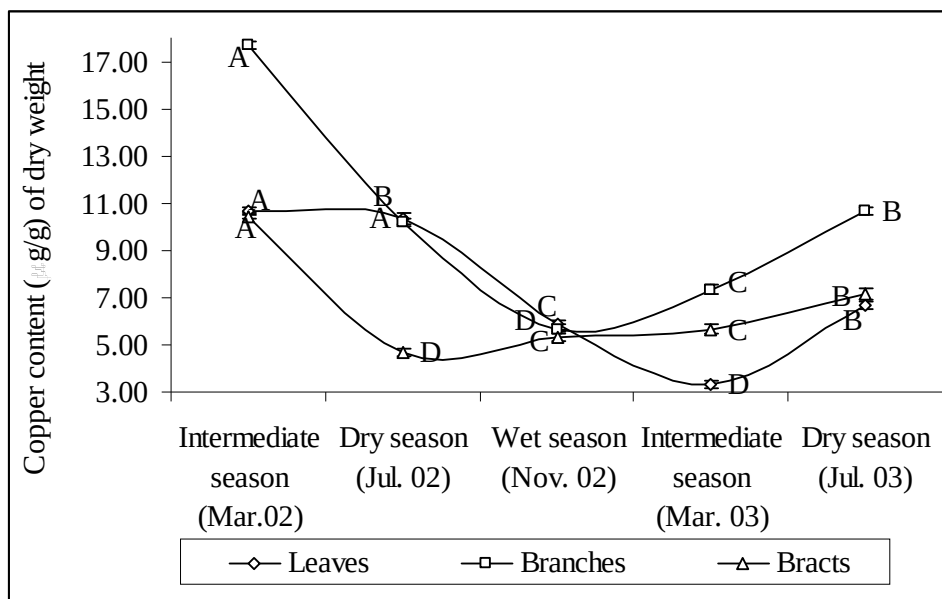


Figure 6.52: Copper content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

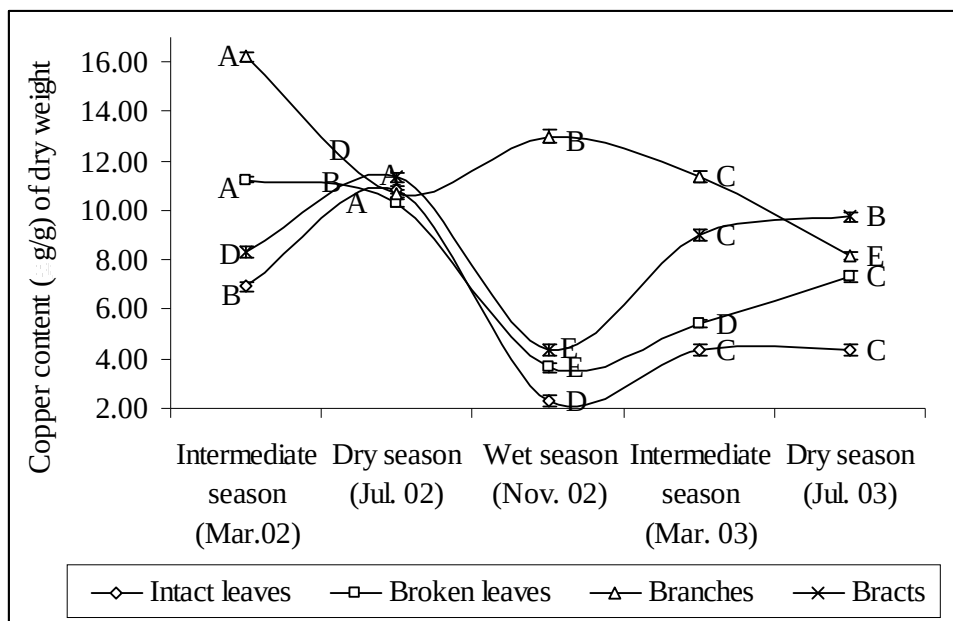


Figure 6.53: Copper content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

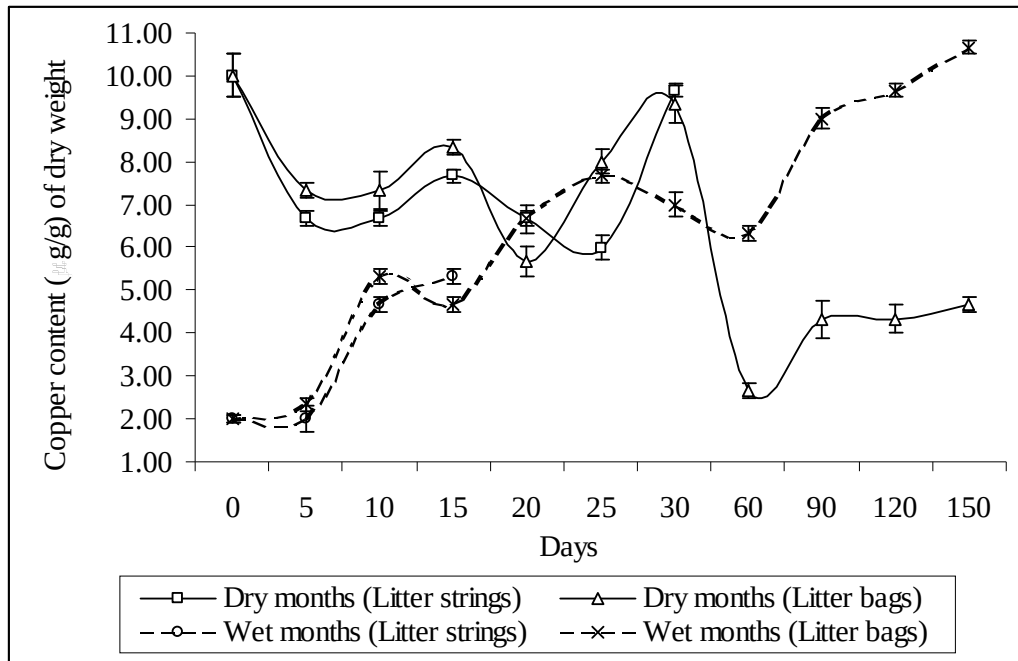


Figure 6.54: Copper content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

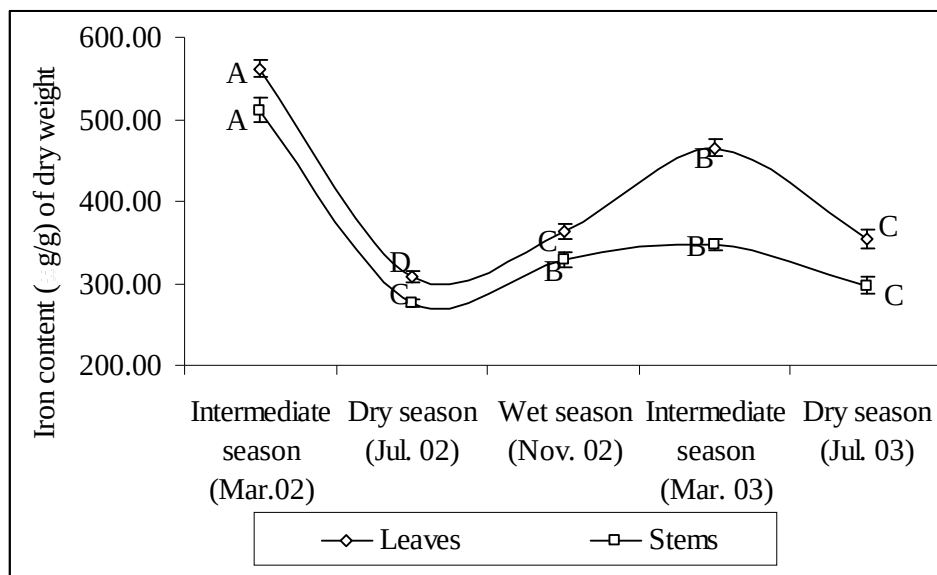


Figure 6.55: Iron content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

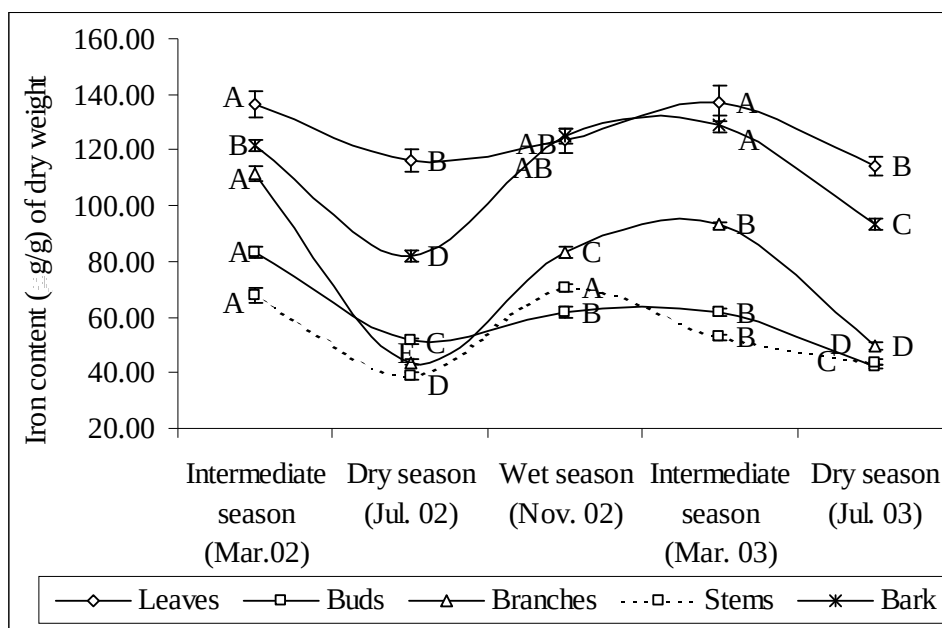


Figure 6.56: Iron content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

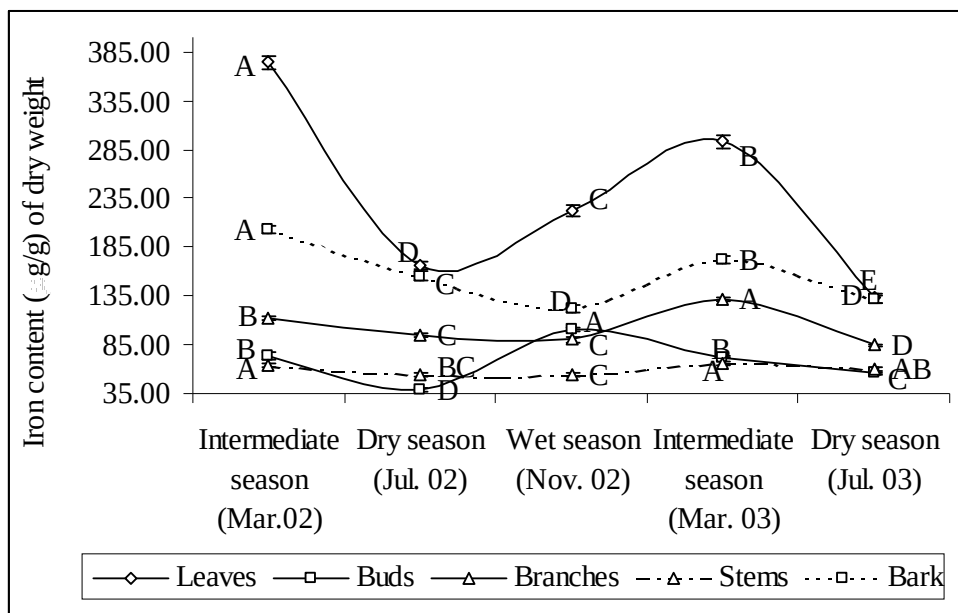


Figure 6.57: Iron content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

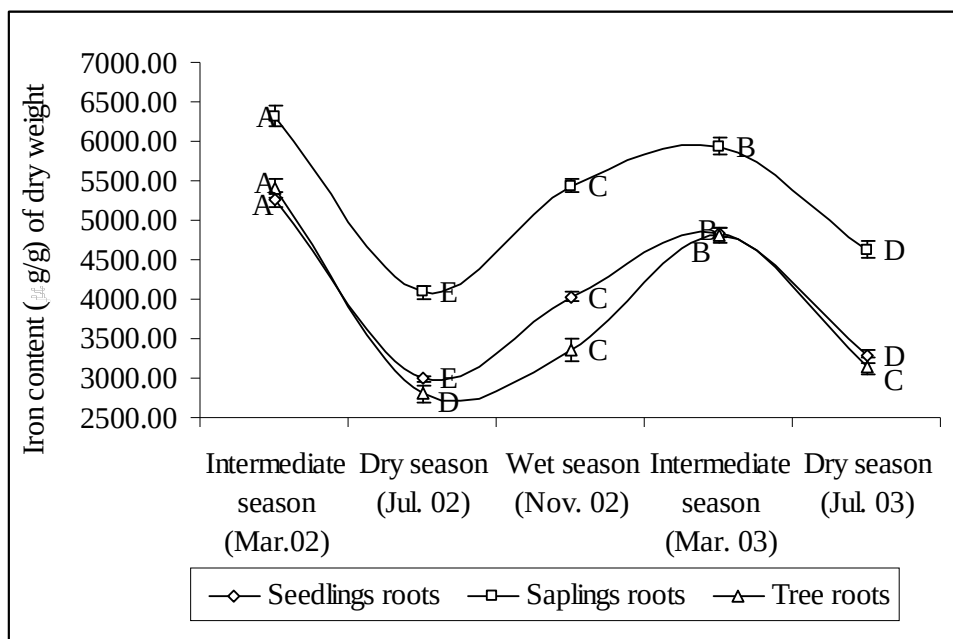


Figure 6.58: Iron content in roots of seedlings, saplings and trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

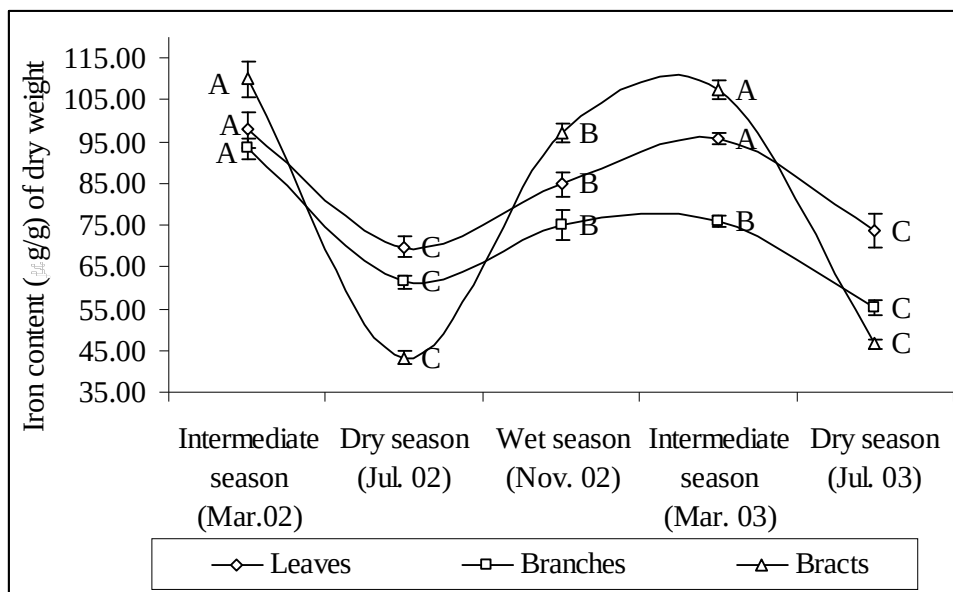


Figure 6.59: Iron content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

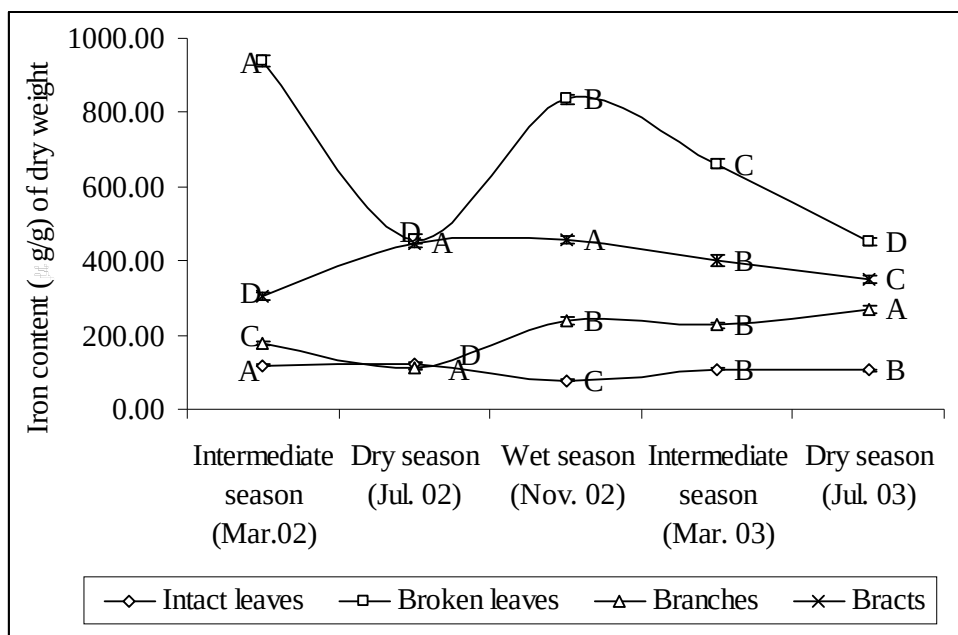


Figure 6.60: Iron content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p>0.05$) different

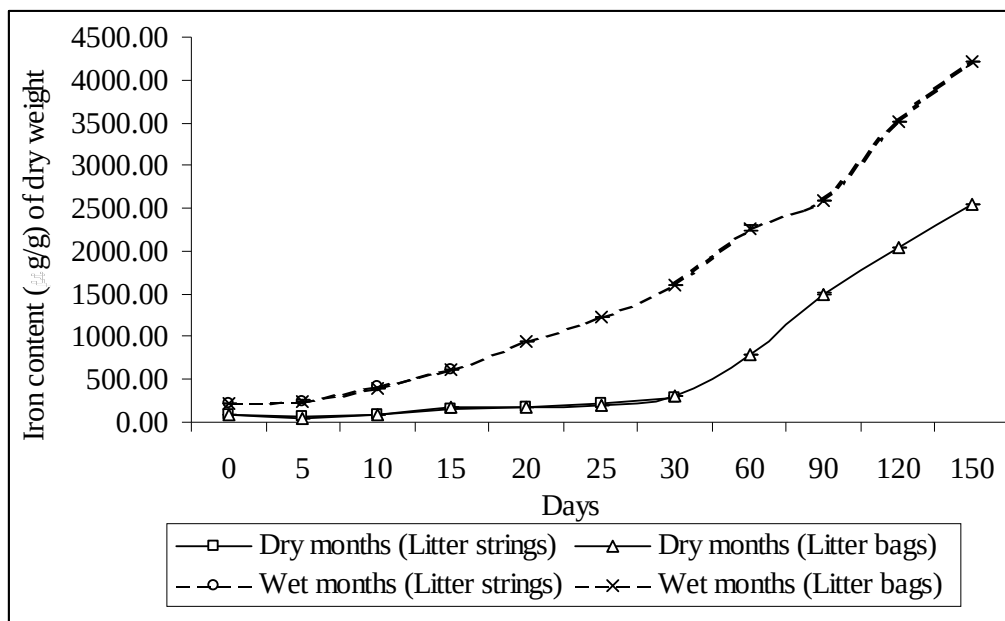


Figure 6.61: Iron content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

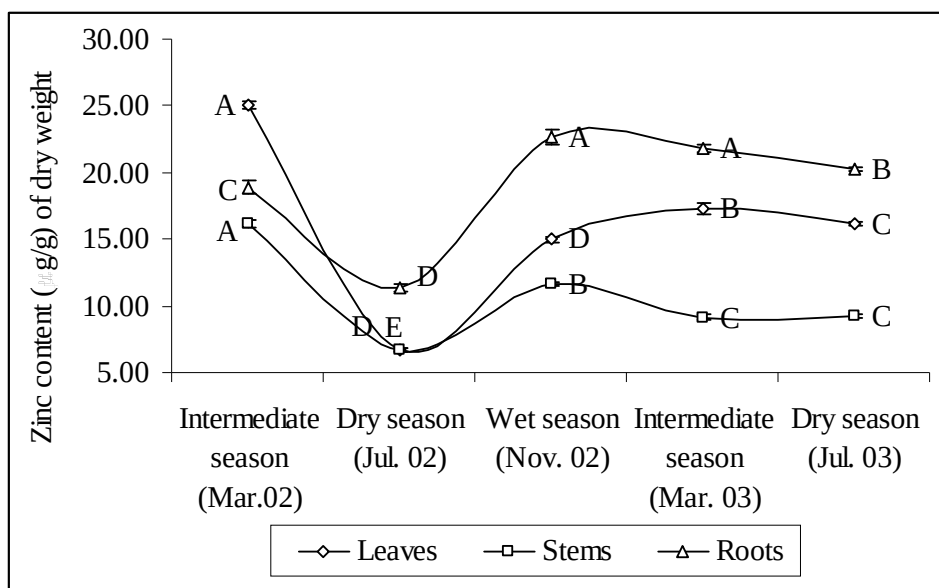


Figure 6.62: Zinc content in different components of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

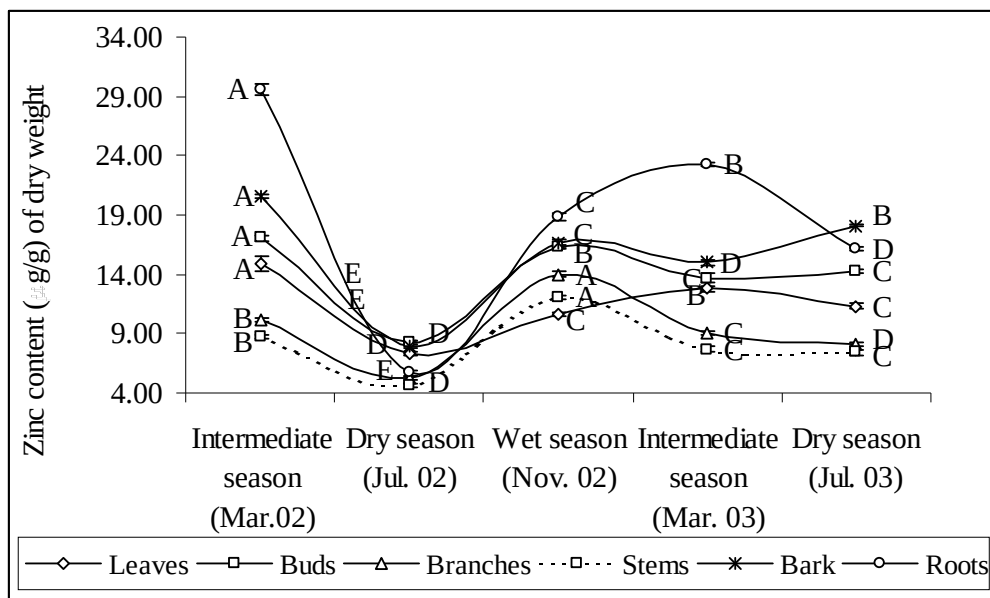


Figure 6.63: Zinc content in different components of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

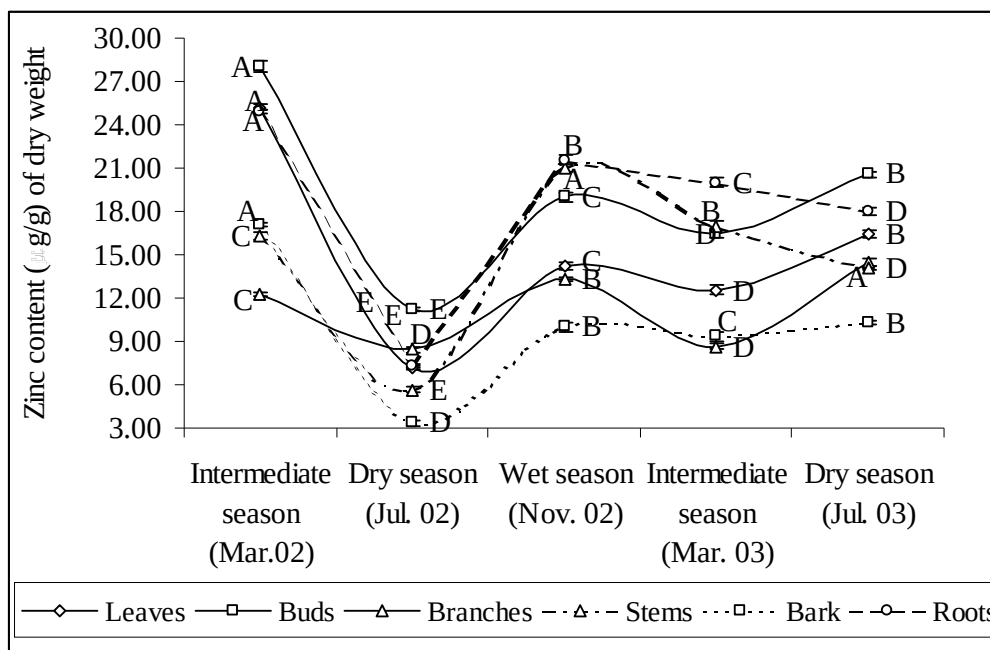


Figure 6.64: Zinc content in different components of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

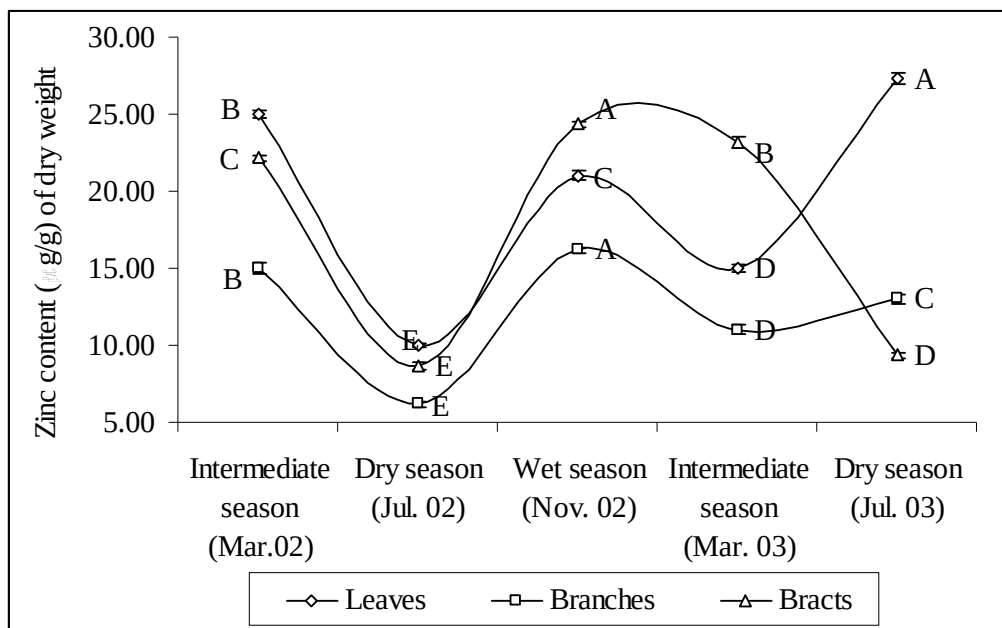


Figure 6.65: Zinc content in different components of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

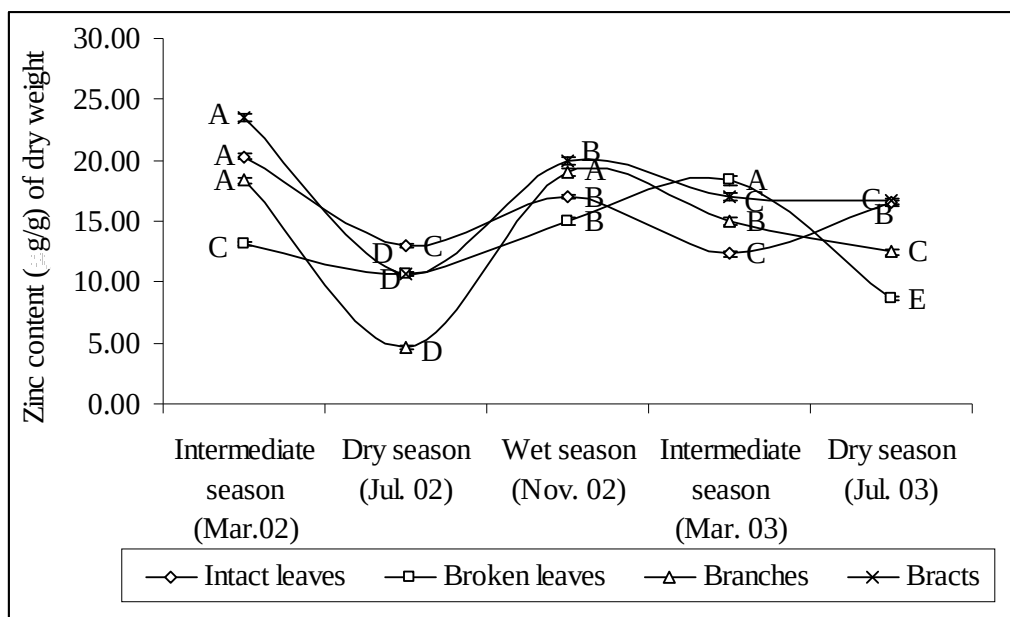


Figure 6.66: Zinc content in different components of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly (ANOVA, DMRT, $p > 0.05$) different

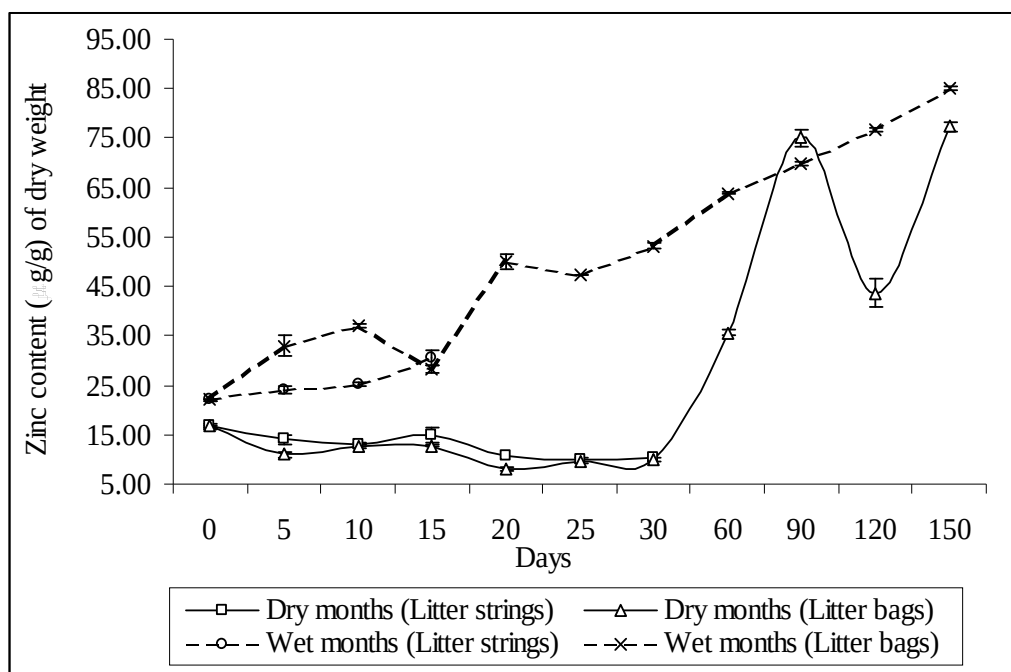


Figure 6.67: Zinc content at different stages of leaf litter degradation in litter bags and leaves on strings during dry and wet months

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSION

The studied mangrove forest in Kuala Selangor Nature Park appears as a strip with an average 200 m width and varies from 150 to 250 m from seaward to landward. This forest can be categorized under Watson's (1928) tidal inundation class 4, characterized by tidal height range from 4 to 5 m and inundated by the tidal water for 2 to 20 times per month. Five mangrove species were recorded during the field inventory and the species are *Avicennia alba*, *Bruguiera parviflora*, *Rhizophora apiculata*, *R. mucronata* and *Sonneratia caseolaris*.

Trees constitute the top stratum of 8.90 ± 0.02 to 10.27 ± 0.08 m height, 2180 ± 175 trees/ha, DBH range 4 to 26 cm and 18.90 ± 1.87 m²/ha of basal area. Saplings constitute the middle stratum of 2.55 ± 0.14 to 4.20 ± 0.02 m height, 695 ± 90 saplings/ha, and DBH range 1 to <4 cm and 0.28 ± 0.03 m²/ha of basal area (Table 2.2, Chapter 2). The lower stratum (< 1 m height) consisted of dense seedlings ($408,000 \pm 34800$ seedlings/ha). A high abundance of *B. parviflora* seedlings at densities of $380,500 \pm 28311$ seedlings/ha were found in the study site and other mangrove seedlings occurred in lesser abundance: *A. alba* ($10,500 \pm 1711$ seedlings/ha), *S. caseolaris* ($7,000 \pm 1879$ seedlings/ha), *R. apiculata* ($5,500 \pm 1599$ seedlings/ha) and *R. mucronata* ($4,500 \pm 1308$ seedlings/ha) (Table 2.3, Chapter 2). *Bruguiera parviflora* appeared as dominant species with higher density (2595 ± 194 stem/ha) and importance value was about 75% over the other species such as *A. alba*, *R. apiculata*, *R. mucronata* and *S. caseolaris* (Table 2.2, Chapter 2). *Bruguiera parviflora* generally grows in less frequently tidal inundated areas (Watson's tidal inundation class 3 and 4). According to Tomlinson (1986) *B. parviflora* is relatively short lived and occurs on the inner mangrove fringe and river banks. *Bruguiera parviflora* has small and easily dispersed propagules (Noakes, 1952). When it is fully grown, it can form a nearly complete understorey below the canopy of *Rhizophora* trees (Chapman, 1976).

Soil physical parameters and nutrients level are the major determinants of plant growth and distribution in mangroves (Aksornkoae, 1975; McKee, 1993; Ukpong, 1994). In the present study, different soil parameters (pH, redox potential, moisture, organic matter, conductivity, salinity and cation exchange capacity) are found to vary in different (intermediate, dry and wet) seasons. Comparatively higher moisture content was observed during the wet seasons (November 01 and 02), and lower in dry seasons (July 02 and 03). Relatively higher organic matter and cation exchange capacity of soil were found during the intermediate seasons (March 02 and 03). On the contrary, higher conductivity and salinity were observed during the dry seasons (July 02 and 03) and lower in wet seasons (November 01 and 02) (Table 3.1, Chapter 3). According to Lacerda *et al.* (1995), seasonal variation of soil parameters (moisture, salinity, conductivity) in mangroves is due to the combined effect of rainfall, temperature, tidal

characteristics and microtopography. Similarly, seasonal fluctuation of soil air-dry moisture content showed positive correlation with rainfall ($r=0.89$, $p<0.05$) and number of spring high tide ($r=0.72$) that flooded the forest floor, but temperature showed low negative correlation (Figures 7.1-7.3). Areas with higher fluctuation of temperature in different seasons usually showed a significant negative correlation among temperature and soil moisture content. However, narrow range of temperature fluctuation (30.4 to 31.9°C) in the study area during the different seasons could result in lower negative correlation with soil moisture. Fresh water flow from upstream and rainwater can also reduce the water and soil salinity in the mangrove forest. Negative correlation of soil salinity ($r=-0.71$) and conductivity ($r=-0.75$) with rainfall in this mangrove forest indicates the dilution phenomenon (Figures 7.4-7.5). Litter production is an obvious source of soil organic matter through the decomposition in any forest ecosystem (Binkley, 1986). In this mangrove forest, a positive relationship ($r=0.62$) was observed among the seasonal variation in soil organic matter and leaf litter production (Figure 7.6). Soil parameters showed significant relationship with soil nutrients level at different seasons (Table 3.6, Chapter 3). Soil nutrients (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) were found to fluctuate in different seasons and comparatively higher N, P, K, Ca, Mg, C, and Fe in soil were observed during the intermediated seasons (March 02 and 03) (Figures 3.1-3.10, Chapter 3). Soil nutrients (N, P, K, C and Fe) showed significant ($p<0.05$) positive relationship with soil organic matter and it may be the evidence of nutrient input to the soil through organic matter (Aksornkoae, 1993; Tam *et al.*, 1995a).

Other sources of nutrients in any forest ecosystem have been reported from rainwater (Golley *et al.*, 1975). Similarly, rainwater is expected to be one of the sources of nutrient input to the studied mangrove forest. During the rainfall, considerable amount of nutrients is leached from the foliage, branches and stems and this could be the reason for observing comparatively higher content of NH_4 , NO_3 , PO_4 , K, Ca, Mg and SO_4 in canopy drip and stem flow than rainwater in this forest (Table 3.4, Chapter 3). Macronutrients (NH_4 , PO_4 , K, Ca, Mg and SO_4) content in canopy drip and stem flow showed positive correlations with rainwater, but Cu, Fe and Zn showed negative correlations (Table 3.9, Chapter 3). Present study showed seasonal fluctuation of macronutrients (NH_4 , NO_3 , PO_4 , K, Ca, Mg and SO_4) content in rainwater, canopy drip and stem flow but, similar content of Cu (0.01 ± 0.00 ppm), Fe (0.03 ± 0.00 ppm) and Zn (0.02 ± 0.00 ppm) was observed in rainwater, canopy drip and stem flow in different seasons (Table 3.4, Chapter 3). It has been reported that nutrients in rainwater vary with time, closeness to the sea (effect of sea-borne spray) and source of local pollution (quarry dust, road dust and industrial emission) (Boto, 1982). Seasonal fluctuation of nutrients in rainwater and tree foliage could be responsible for the variation of nutrients level in canopy drip and stem flow and similar pattern was observed by Leite and Valle (1990) under the cacao ecosystem at Bahia, Brazil. Macronutrients in rainwater are augmented by canopy leaching and result in comparatively higher nutrient contents in canopy drip and stem flow (Trudgill, 1988; Leite and Valle, 1990). This leaching may

contribute to the higher conductivity of canopy drip and stem flow compared to rainfall and suggest the leaching of cation from the forest canopy. The lower pH value of canopy drip and stem flow could be the result of leaching of organic acid from canopy foliage and branches (Leite and Valle (1990).

Apart from organic matter and rainwater, nutrients input to the mangrove forest also come from tidal water. Tidal water percolated into the soil profile during the high tide and can influence the nutrient content of infiltration water. In this mangrove forest, NO₃, PO₄, Mg, SO₄, Cu and Fe showed positive correlations between river and infiltration water which could be the evidence of nutrients exchange among the river and infiltration water (Table 3.9, Chapter 3). Tidal water carry large amount of sediment during the rainy season (Milliman and Meade, 1983) and nutrients are usually dissolved and bounded to sediment particles. Present study showed 1.02 cm of sediment accretion in a year and this sedimentation constitutes the major source of nutrients input to this mangrove forest. The annual amount of nutrients input through the sedimentation (0 to 1.02 cm/yr) was calculated from the soil weight (64.26 t/ha) multiplying by the respective nutrients concentration in soil. The annual amount of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn input to this mangroves was 219.13-224.91 kg/ha/yr, 19.92-21.85 kg/ha/yr, 278.45-453.68 kg/ha/yr, 196.64-232.05 kg/ha/yr, 532.07-695.94 kg/ha/yr, 207.06-631.18 kg/ha/yr, 2881.42-4345.90 kg/ha/yr, 0.95-1.61 kg/ha/yr, 460.42-826.81 kg/ha/yr and 4.09-6.18 kg/ha/yr, respectively.

Mangrove soil receives nutrients from rainwater, canopy leaching and tidal water which can be best described by the correlation analysis of soil nutrients at different seasons and the respective nutrient contents in rainwater, canopy drip, stem flow and tidal water. In this study, positive correlations of soil nutrients with the respective nutrient contents in rainwater, canopy drip, stem flow, river and infiltration water indicate the potential sources of nutrients to the soil (Table 3.5, Chapter 3). According to Clough (1992), beside the climatic factors, soil edaphic factors (pH, redox potential and salinity) and soil nutrient levels are the prime important for mangrove growth and productivity.

Estimation of standing biomass is often used to compare the potential forest productivity (Golley *et al.*, 1975). In this study, the total biomass (above and below-ground) of seedlings, saplings and trees was 1.37 t/ha, 1.03 t/ha and 161.39 t/ha, respectively and made a total of 163.79 t/ha (Table 4.5, Chapter 4). This value is about 94% higher than the above and below-ground biomass of *B. gymnorrhiza* in Mgeni, South Africa (Steinke *et al.*, 1995). Although, Mgeni mangrove in South Africa (29°48'S, 31°03'E) and Kuala Selangor Nature Park mangrove forest (3°19'N, 101°14'E) are dominated by different species, but the species are in the same genus. The different geographical location could produce different standing biomass. According to Saenger and Snedaker (1993), mangrove biomass is higher in tropical region and decreases towards the sub-tropical region. Apart from the geographical location and climatic factors, standing biomass of mangroves depends on species

composition and stand structure (Clough, 1992). Litter on natural litter bed is a part of total standing biomass of a forest. The litter standing crop (leaves, small branches, bracts and propagules) on forest floor in different seasons varied from 0.63 ± 0.02 to 1.05 ± 0.04 t/ha and the mean was 0.84 ± 0.04 t/ha (Table 2.6, Chapter 2). The total standing biomass (164.63 t/ha) was calculated from the total biomass (163.79 t/ha) (above and below-ground) of *B. parviflora* seedlings, saplings, trees plus litter standing crop (0.84 t/ha) (Figure 7.7). Seedlings and saplings together contributes only to 1.46% of total biomass and litter standing crop constitutes 0.51% of the total standing biomass, but they can play an important role in mangrove ecosystem dynamics through the cycling of nutrients

It has been reported that average annual biomass increment is an important indicator and part of forest productivity (Hutchings and Saenger, 1987). Average annual biomass increment (leaves, bud, branches, stems, bark and root) in *B. parviflora* saplings and trees was 0.58 ± 0.01 t/ha and 16.51 ± 0.63 t/ha, respectively (Table 4.7, Chapter 4). In the present study, net primary productivity 27.44 t/ha/yr was estimated from the average annual biomass increment of 17.09 ± 0.64 t/ha/yr in saplings and trees (Table 4.7, Chapter 4) plus annual litter fall (leaves, small branches, bracts, flowers and propagules) of 10.35 t/ha/yr (Section 5.3.1, Chapter 5) and presented in Figure 7.8. The relationship between biomass and productivity is a complex function of ecosystem maturity. The maturity of any forest ecosystem can be explained by the net primary productivity and litter fall ratio. According to Etherington (1975), large proportion of net primary production is associated with the biomass increment in a juvenile forest ecosystem (succession stage) and results in higher ratio of net primary productivity and litter fall. The higher ratio (2.65:1) of the net primary productivity and litter fall suggests that this mangrove forest is sustainable at the succession stage. In a comparison, Putz and Chan (1986) obtained a lower (1.61:1) ratio of net primary productivity and litter fall in a mature unmanaged mixed mangrove forest (*R. apiculata*, *B. parviflora*, *B. gymnorhiza*) in Pulau Kecil, Matang, Malaysia. The ratio of net primary productivity and litter fall in mangroves has been reported to vary with species, forest structure, seasonality, age of stand and fluctuation in litter production (Ong *et al.*, 1985a; Aksornkoae, 1993; Day *et al.*, 1996).

Litter production is an indicator and component of net primary productivity as well as important source of organic matter to the soil. In this study, annual total litter production (leaves, small branches, bracts, flowers and propagules) was 10.35 t/ha/yr (Section 5.3.1, Chapter 5). Flowering and fruiting of *B. parviflora* showed distinct seasonality from January to May and April to September, respectively (Figures 5.1-5.2, Chapter 5). The fluctuation of total litter production in this mangrove was associated with the seasonality of flowering and fruiting time. Comparatively higher rate of total litter production was associated with the peak fruiting time during the July 02 and 03 (Figure 5.2, Chapter 5), where propagules contributed to 45.73-52.21% of the total litter production (Figure 5.1, Chapter 5). Apart from these biological factors, abiotic

factors such as rainfall, temperature, humidity, wind speed and soil salinity have been reported as important determinants in fluctuation of litter production in mangroves (Sasekumar and Loi, 1983; Lopez-Portillo and Ezcurra, 1985; Hegazy, 1998). Total litter production and leaf litter showed significant (ANOVA, $p < 0.05$) negative relationship with rainfall and relative humidity, respectively (Section 5.3.1, Chapter 5). In this mangrove forest, higher amount of total litter production was observed during the fruiting season, which was coincided with the dry season and resulted in negative correlation with rainfall. However, the influence of temperature on litter production, which was not observed, may be due to the narrow range (30.4 to 31.9°C) of temperature fluctuation throughout the year.

Litter standing crop in mangroves is the fraction of litter production that remains on the forest floor after the loss from microbial degradation, grazed by macro-organisms and tidal export. A total of 3.78 t/ha/yr of litter (leaves, small braches, bracts and propagules) was collected from litter layer of the studied mangrove forest (Section 5.3.2, Chapter 5). Comparatively higher amount of litter standing crop was observed during the dry season (July 02 and 03) (Figure 5.6, Chapter 5), where propagules contributed to 25.90-27.16% of the total litter standing crop (Figure 5.5, Chapter 5). A Significant positive relationship ($y = 0.3767x - 3.2337$, $r = 0.73$, $p < 0.05$) between total litter production and total litter standing crop (Figure 7.9) and a negative relationship ($y = 1.1571 - 0.0612x$, $r = -0.082$, $p < 0.05$) between number of spring high tide that flooded the forest floor and total litter standing crop (Figure 5.9, Chapter 5) explain that the fluctuation of litter standing crop in different months is the results of variation in litter production rate and tidal export.

According to Swift *et al.* (1979), decomposition of litter in any forest ecosystem is primly important for readily cycling of nutrients within the system. Similarly, litter in mangrove ecosystem is subjected to microbial decomposition (Robertson, 1988; Ashton *et al.*, 1999) and feedings plus mechanical breakdown by macro-organisms (Ashton, 2002). Microbial degradation contributed to $15.58 \pm 1.11\%$ and $47.39 \pm 1.61\%$ loss of *B. parviflora* leaf litter dry mass after 20 days during the dry (July 02) and wet (November 02) months, respectively, but crabs grazed 69.33% and 52.61% of leaf litter after 60 and 20 days during the dry months (July 02-August 02) and wet (November 02) months, respectively (Table 5.3, Chapter 5). The significantly higher rate of microbial degradation during the wet month (November 02) may be due to the higher soil moisture (11.20%) compared to dry month of July 02 (8.06%) (Table 3.1, Chapter 3). Similarly, Hesse (1961) observed higher degradation rates of *Rhizophora* sp. and *Avicennia* sp. leaf litter in the presence of higher soil moisture. Higher moisture content enhances the activity of microbes (Swift *et al.*, 1979) and this could be the reason for observing comparatively higher rate of microbial degradation in *B. parviflora* leaf litter during the wet month (November 02) (Figure 5.12, Chapter 5). Leaching and microbial degradation of litter result in quick release of nutrients and readily available to plants.

On the other hand, litter, assimilated to the crab biomass, is not readily available to the plants and pass through the complex food web in mangroves.

The disappearance of leaf litter from this mangrove is the combined effect of microbial degradation, feeding plus mechanical breakdown and tidal export. The amount of leaf litter export from this mangrove forest is calculated from mass balance method (Gong *et al.*, 1984). The disappearance rate (%) of leaf litter (1412 times per year) was calculated from annual leaf litter fall amount of 7060 kg/ha/yr (Section 5.3.1, Chapter 5) divided by leaf (intact and broken leaves) litter standing crop amount of 500 kg/ha (Figure 7.7) (Nye, 1961). Therefore, disappearance of leaf litter occurred by 25.83 days. The time scale of disappearance was adjusted to 20 days to match with the field experiment duration and actual degradation rate of the experiments. From the field experiment, it was observed that 100% leaves on strings were lost after 20 days during the wet months (Table 5.3 and Figure 5.11, Chapter 5). It was found that some litter strings were empty, some were dragged to the crab holes and some remained untouched as same situation of leaves in litter bags during the same period of collection. This heterogeneous rates of leaf litter degradation were minimize by using mean degradation rate (%) (litter bags and leaves on strings) of 20 days. Total leaf litter production for 20 days was calculated to be 38.60 g/m². During the 20 days, the mean degradation rates (litter bags and leaves on string) were 43.17% and 73.70% during the dry and wet months, respectively (Table 5.3, Chapter 5), which constitute 16.66-28.45 g/m² of leaf litter subjected to microbial degradation and feeding plus mechanical breakdown by crabs. Annual leaf litter fall and leaf litter standing crop were 7060 kg/ha/yr and 500 kg/ha, respectively, and resulted in leaf litter loss of 6560 kg/ha/yr. For the 20 days period, a total loss of leaf litter would be 35.95 g/m² (6560/365 x 20 kg/ha). The export of leaf litter (7.50-19.29 g/m²) was calculated from the difference between leaf litter loss (35.95 g/m²) and the amount of leaf litter degraded (16.66-28.45 g/m²) by microbial and feeding plus mechanical breakdown by crabs.

According to Japar Sidik (1989), apart from the tidal inundation, litter degradation rate has impact on the export of litter from the mangrove to the adjacent aquatic system. Irrespectively, during the dry month (July 02), lower amount (43.17%) of leaf fall was lost due to microbial degradation and feeding plus mechanical breakdown by crabs, which resulted in higher percentage (49.97%) of leaf litter export. On the contrary, microbial degradation and feeding plus mechanical breakdown together contributed to 73.70% loss of leaf litter production during the wet month (November 02) and resulted in lower amount (19.43%) of leaf litter export to the adjacent aquatic system (Figure 7.10).

Considering the above discussion, the input sources of nutrients in this mangrove forest are rainwater, canopy drip, stem flow, tidal water and decomposition of litter. Plants uptake the nutrients by roots and translocated to the different components for the physiological function (respiration, photosynthesis), growth and developments. However, nutrient contents in different components of plants vary with the plant

species, types of plant components and physiological age of the tissue (Walbridge, 1991). Meyer *et al.* (1973) and Jones (1998) found comparatively higher nutrients in physiologically active tissue (leaves and buds). Similarly, *B. parviflora* seedlings, saplings and trees showed comparatively higher N, P, K, Ca and Mg in leaves and buds than the structural components (branches and stems). On the contrary, copper and zinc were found to be varies in different components with the narrow ranges of 3.17-17.33 µg/g and 3.33-29.60 µg/g, respectively (Tables 6.1-6.5, Chapter 6).

Nutrients (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) and organic matter contents in different components of *B. parviflora* seedlings, saplings and trees showed seasonal fluctuation (with the exception of N, K, Ca, and Mg in stems of saplings and trees, K and Mg content in bark of saplings and trees). Similar to the *B. parviflora* plant components, leaves of litter production showed similar pattern of nutrients fluctuation at different seasons (Figures 6.1-6.4, 6.7-6.10, 6.13-6.16, 6.19-6.22, 6.25-6.28, 6.31-6.34, 6.37-6.40, 6.43-6.46, 6.49-6.52, 6.55-6.59, 6.62-6.65, Chapter 6). The seasonal fluctuation of nutrients in plant components can be best described by the positive correlation results of nutrient contents between different components of *B. parviflora* seedlings, saplings and trees and their contents in soil (Table 6.6, Chapter 6). Similarly, Kabata-Pendias and Pendias (1984) and MacFarlane and Burchett (2002) reported that the rate of nutrients uptake by plants and nutrient contents in plant components are positively related to the available nutrients level in soil.

The nutrients that are taken up by plants, return to the soil through the litter fall and considerable amount of nutrients are released during the period of litter decomposition (Japar Sidik, 1989; Tam *et al.*, 1990; Wafar *et al.*, 1997) and cycles within the system (Golley *et al.*, 1975; Jordan, 1985). Nutrient cycling in any forest ecosystem is explained as uptake of nutrients by plants roots from the soil and nutrients accumulate in the biomass during the process of photosynthesis and return to the soil through the decomposition of litter (Golley *et al.*, 1975; Jordan, 1985; Binkley, 1986). In closed ecosystem such as terrestrial forest, lower amount of nutrients is lost from the system compared to mangrove. In mangrove ecosystem, cycling of nutrients is determined by many factors such as exchange of nutrients, detritus and sediment accretion or erosion by tidal influences (Lugo *et al.*, 1976; Boto, 1982; Alongi *et al.*, 1992).

The relationship among nutrients input, output sources, annual accumulation in biomass, return, and uptake in the studied *B. parviflora* dominated mangrove ecosystem are summarized and presented in Figure 7.11. Seasonal fluctuation of nutrients concentration in soil, water and different components of plant and litter production was included in the calculation and presented with ranges. Nutrients are incorporated in this mangrove forest through rainwater, canopy drip, stem flow and tidal water and enrich the soil nutrient pool. On the contrary, considerable amount of litter is exported from this mangrove forest to the adjacent aquatic system and results in loss of nutrients from the mangrove forest.

Plants uptake nutrients from soil and carbon absorb from atmospheric carbon dioxide during the process of photosynthesis and accumulate them in the biomass. Annual accumulation of nutrients in different components (leaves, buds, branches, stems, bark and roots) of *B. parviflora* saplings and trees was calculated from the average annual biomass increment of respective components (Table 4.7, Chapter 4) and their respective nutrients concentrations (Tables 6.1-6.5, Chapter 6). The annual accumulation range of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn in plant biomass was 53.74-65.59 kg/ha, 9.10-13.49 kg/ha, 27.19-48.86 kg/ha, 60.94-89.47 kg/ha, 22.35-33.47 kg/ha, 53.61-115.60 kg/ha, 7.50-9.49 t/ha, 75.28-172.89 g/ha, 7346.06-13758.70 g/ha and 111.10-337.48 g/ha, respectively, which were in the order of C>S>Ca>N>K>Mg>P>Fe>Zn>Cu. Comparatively higher percentages of Fe (85.22-87.22%) were accumulated in the root biomass and other nutrients were accumulated in the above-ground biomass (Table 7.1).

Annual return of nutrients in the form of litter fall was calculated from annual amount of litter fall (leaves, small branches, bracts, flowers and propagules) (Figure 7.8) and their respective nutrients concentrations (Table 6.7-6.11, Chapter 6). Annual return range of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn in the form of litter fall was 55.60-64.08 kg/ha, 7.60-12.16 kg/ha, 12.50-17.85 kg/ha, 92.90-150.94 kg/ha, 25.95-34.80 kg/ha, 47.32-61.45 kg/ha, 4.94-5.58 t/ha, 45.33-114.25 g/ha, 635.25-938.59 g/ha and 93.39-243.93 g/ha, respectively, with the order of C>Ca>N>S>Mg>K>P>Fe>Zn>Cu. Leaf fall is the main and quick source of nutrients return to the soil and contributed to 69.46-69.52%, 64.21-70.39%, 40.16-51.43%, 76.22-79.79%, 79.73-81.15%, 67.58-68.14%, 69.53-69.64%, 51.86-65.88%, 73.59-77.43% and 75.60-79.11% of the total annual return of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn, respectively (Table 7.2).

Annual uptake of nutrients was calculated by adding the annual accumulation and annual return of nutrients. The annual uptake range of N, P, K, Ca, Mg, S, Cu, Fe and Zn was 109.34-129.67 kg/ha, 16.70-25.65 kg/ha, 39.69-66.71 kg/ha, 153.84-240.41 kg/ha, 48.30-68.27 kg/ha, 100.93-177.05 kg/ha, 120.61-287.14 g/ha, 7981.31-14697.29 g/ha and 204.49-581.41 g/ha, respectively, with the order of Ca>S>N>Mg>K>P>Fe>Zn>Cu. The return/accumulation ratios of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn were 0.98-1.03, 0.84-0.90, 0.37-0.46, 1.52-1.69, 1.04-1.16, 0.53-0.88, 0.59-0.66, 0.60-0.66, 0.07-0.09 and 0.72-0.84, respectively, and resulted in accumulation = return for N, return > accumulation for Ca and Mg, accumulation > return for P, K, S, C, Cu, Fe and Zn (Table 7.4).

Estimation of nutrients stock in different components of *B. parviflora* seedlings, saplings and trees is important to calculate nutrients turnover rate and utilization coefficients. Nutrients stock and allocation in different components of seedlings, saplings and trees were calculated from the biomass of respective components (Table 4.5, Chapter 4) and their respective nutrients concentrations (Tables 6.1-6.5, Chapter 6). The range of total stock of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn in standing biomass of seedlings, saplings and trees was 515.36-629.88 kg/ha, 87.21-128.01 kg/ha,

261.15-464.95 kg/ha, 582.24-852.70 kg/ha, 213.85-317.47 kg/ha, 512.32-1085.87 kg/ha, 71.80-91.13 t/ha, 715.00-1659.80 g/ha, 65230.88-122136.12 g/ha and 1067.16-3264.01 g/ha, respectively, and the sequence was C>S>Ca>N>K>Mg>P>Fe>Zn>Cu. Above-ground components contributed to 85.93-86.22%, 84.75-86.28%, 74.74-76.49%, 86.51-89.44%, 70.11-70.66%, 68.36-75.99%, 87.65-88.63%, 82.37-87.80% and 85.26-86.65% stock of N, P, K, Ca, Mg, S, C, Cu and Zn, respectively, while 83.38-85.64% of Fe stock was observed in root biomass (Table 7.3). Moreover, saplings and trees stems contributed to about 50% of the total standing biomass but contained less amount of N, K, Ca, Mg and S compared to leaves and buds which contributed to only about 7% of standing biomass (Table 7.3).

The nutrients turnover rate is the ratio of the stock of a nutrient in biomass divided by the return of the nutrient through yearly litter production (Duvigneaud and Denaever-De Smet, 1970). By using this approach, the calculated range of turnover period of N, P, K, Ca, Mg, S, Cu, Fe and Zn was 9.27-9.83 yr, 10.53-11.48 yr, 20.89-26.05 yr, 5.65-6.27 yr, 8.24-9.12 yr, 10.83-17.67 yr, 14.53-15.77 yr, 102.69-130.13 yr and 11.43-13.38 yr, respectively (Table 7.4). Higher proportion of Fe stock (83.38-85.64%) and accumulation (85.22-87.22%) in the plants roots and lower amount of Fe in litter components (635.25-938.59 g/ha) result in very low return/accumulation ratio and longer turnover period for Fe (Tables 7.1-7.3).

The absorption coefficient of a nutrient is the ratio of annual uptake of the nutrient by plants per hectare and the amount of nutrient in soil pool per hectare (Jiao *et al.*, 1997). The nutrients pool in soil (0 to 30 cm depth) was calculated from the soil weight (1890 t/ha) and respective nutrients concentration. The calculated range of soil pool for N, P, K, Ca, Mg, S, C, Cu, Fe and Zn was 6444.90-6615.00 kg/ha, 585.90-642.60 kg/ha, 8183.70-13343.40 kg/ha, 5783.40-6822.90 kg/ha, 15649.20-20468.70 kg/ha, 6085.80-18559.80 kg/ha, 84747.60-127820.70 kg/ha, 27.82-47.25 kg/ha, 13541.85-24318.01 kg/ha and 120.22-181.86 kg/ha, respectively, and the sequence was C>Fe>Mg>S>K>N>Ca>P>Zn>Cu (Table 7.4). The range of absorption coefficients for N, P, K, Ca, Mg, S, Cu, Fe and Zn was 0.017-0.020, 0.029-0.040, 0.005, 0.027-0.035, 0.003, 0.010-0.017, 0.004-0.006, 0.001 and 0.002-0.003, respectively (Table 7.4).

Utilization coefficient is the annual uptake amount of a nutrient by plants per hectare divided by stock amount of the nutrient in plants per hectare (Jiao *et al.*, 1997). Cycling coefficient is the annual return rate of a nutrient divided by annual uptake amount of the element (Jiao *et al.*, 1997). The sequences of absorption coefficient and utilization coefficient were P>Ca>N>S>K=Cu>Mg>Zn>Fe and Ca>Mg>N>P>Zn>S>Cu>K>Fe, respectively. However, the sequence of cycling coefficient was similar with utilization coefficient and suggested that the flow of Ca, Mg, N were higher and lower flows which were associated with Cu, K, Fe and coincided with the turnover rate (Table 7.4). It has been reported that rate of nutrients accumulation, return and uptake in mangroves vary with plant species, age of stand, element characteristics, nutrient pool and soil physio-chemical characteristics (Jordan, 1985; Gong and Ong, 1990; Li, 1997; Jiao *et*

al., 1997). Moreover, accumulation, return, uptake and turnover rate may be affected by standing biomass, primary productivity and nutrients concentration in different components of plants.

According to Binkley (1986), nutrients in any forest ecosystem are cycled in a variety of chemical forms and the description of nutrient cycling is the part of the story. Nutrient cycling is never completely efficient. Nutrients released from trees through litter decomposition are rapidly taken up by the roots and retained within the system. Efficient nutrient cycling is characterized by low nutrient losses from the system, as a whole, despite relatively large amounts of nutrient cycling between trees and soil (Vitousek, 1984). There are continuous sources of nutrients input in the forest ecosystem through rainfall, weathering of soil minerals. On the contrary, there is a continuous loss of nutrients in water moving through the plant and soil to streams and rivers (Golley *et al.*, 1975). The general observation suggested that forest stores large mass of chemical elements in the wood of stem, branches and roots that move slowly through the system. On the other side, stored nutrients in leaves, other green parts and litter cycle rapidly between the soil and plants. There are many factors that control the nutrient flux in mangrove forest such as frequency of tidal inundation, runoff from surrounding land area, rainfall, canopy drip, stem flow, litter fall, litter decomposition and mineral uptake by plants. These factors also control the nutrients input, output, storage and cycling in mangrove ecosystem. Therefore, the measurement of nutrient cycling in mangrove forest represents a useful approach for describing the function and productivity of this ecosystem.

Present study demonstrated some aspects of ecosystem dynamics and within stand cycling of some selected nutrients in *B. parviflora* dominated mangrove forest at Kuala Selangor Nature Park, Malaysia, but does not mean complete. The results from this study will be useful for mangrove resource management strategy. The central goals of sustainable forest management are to maintain the soil capacity for production and quality of environment. Therefore, study on nutrients stock and cycling in mangroves can improve the idea of nutrients loss through harvesting and flow of nutrients within the ecosystem, which can help in formulating an effective forest management plan considering the ecological aspects. There are some limitations of the present study. The limitation of the present study and scope for further study are listed as follows:

1. Standing biomass and net primary productivity was estimated only for the *B. parviflora* as dominant species. Therefore, further study is needed to estimate total standing biomass and net primary productivity considering all the species present in the studied mangrove forest.
2. The increment of diameter at breast height of *B. parviflora* saplings and trees was monitored for only 2 years, but it needs longer time study.
3. Litter fall experiment was done for only 20 months period. However, litter fall study requires longer time to describe the influence of environmental parameters (rainfall, temperature, humidity, wind and soil salinity).

4. Leaf litter degradation experiments were done only for the *B. parviflora* leaf litter. Further study is needed to quantify the amount of nutrients, which are released through leaf litter and other litter components (small branches, bracts and roots).
5. Sediment accretion and erosion experiment was conducted for 20 months. But, detailed study on sediment dynamic is needed.

Table 7.1: Calculated annual accumulation range of nutrients in the biomass of saplings and trees of *B. parviflora*

Saplings	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	S (kg/ha)	C (t/ha)	Cu (g/ha)	Fe (g/ha)	Zn (g/ha)
Leaves	0.46-0.50	0.03-0.05	0.17-0.50	0.27-0.45	0.24-0.46	0.08-0.33	0.02	0.16-0.44	4.56-5.48	0.29-0.60
Branches	0.28-0.38	0.03-0.06	0.14-0.33	0.34-0.45	0.07-0.11	0.10-0.33	0.03	0.24-1.04	2.62-6.70	0.32-0.84
Stems	0.58-0.60	0.11-0.32	0.35-0.40	0.60-0.61	0.23-0.24	0.44-1.44	0.18-0.20	1.30-2.68	15.12-27.56	1.82-4.68
Bark	0.21-0.23	0.03-0.04	0.06-0.07	0.43-0.54	0.05-0.06	0.16-0.34	0.02-0.03	0.22-0.47	4.11-6.47	0.40-1.03
Roots	0.18-0.20	0.04-0.05	0.21-0.26	0.16-0.21	0.19-0.26	0.35-0.92	0.02	0.22-0.52	204.42-315.67	0.28-1.48
Sub-total	1.70-1.89	0.24-0.51	0.92-1.55	1.78-2.24	0.77-1.12	1.12-3.33	0.27-0.30	2.11-5.08	230.45-361.17	3.06-8.51
Trees										
Leaves	12.85-15.60	1.07-1.48	6.11-13.20	8.08-12.65	7.36-12.30	12.75-20.97	0.42-0.54	5.18-11.25	147.14-415.58	8.02-28.00
Buds	0.43-0.55	0.06-0.08	0.24-0.42	0.44-0.58	0.22-0.31	0.36-0.55	0.02-0.03	0.28-0.59	1.93-5.01	0.56-1.40
Branches	14.30-20.55	2.65-4.55	4.44-10.69	23.10-32.80	3.16-5.14	12.91-20.47	1.73-2.26	23.29-45.21	347.07-541.15	34.71-59.37
Stems	11.91-12.38	2.26-3.35	7.31-8.41	8.55-8.95	3.12-3.28	9.11-22.29	3.62-4.63	26.63-79.39	430.57-530.00	45.28-167.79
Bark	4.43-4.94	1.33-1.56	1.30-1.45	12.10-19.29	0.85-0.89	3.58-9.30	0.45-0.57	3.63-8.74	133.22-221.15	3.63-18.65
Roots	8.12-9.68	1.49-1.96	6.87-13.14	6.89-12.96	6.87-10.43	13.78-38.69	0.99-1.16	14.16-22.63	6055.68-11684.64	15.84-53.76
Sub-total	52.04-63.70	8.86-12.98	26.27-47.31	59.16-87.23	21.58-32.34	52.49-112.27	7.23-9.19	73.17-167.81	7115.61-13397.53	108.04-328.97
Total	53.74-65.59	9.10-13.49	27.19-48.86	60.94-89.47	22.35-33.47	53.61-115.60	7.50-9.49	75.28-172.89	7346.06-13758.70	111.10-337.48
% of nutrient accumulation in above ground components	84.56-84.94	83.19-85.10	72.57-73.96	85.28-88.43	68.06-68.41	65.74-73.64	86.53-87.57	80.90-86.61	12.78-14.78	83.63-85.49
% of nutrient accumulation in roots	15.06-15.44	14.90-16.81	26.04-27.43	11.57-14.72	31.59-31.94	26.36-34.26	12.43-13.47	13.39-19.10	85.22-87.22	14.51-16.37

Table 7.2: Calculated annual return range of nutrients through litter fall

Litter fall components	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	S (kg/ha)	C (t/ha)	Cu (g/ha)	Fe (g/ha)	Zn (g/ha)
Leaves	38.62-44.55	4.88-8.56	5.02-9.18	70.81-120.44	20.69-28.24	31.98-41.87	3.44-3.88	23.51-75.27	491.85-690.70	70.60-192.97
Branches	2.16-2.68	0.40-0.71	0.40-0.57	6.37-9.80	0.38-0.62	1.92-2.36	0.33-0.40	4.36-13.63	42.48-71.82	4.75-12.45
Bracts	4.41-5.74	0.67-1.16	0.82-1.55	11.60-15.07	3.08-4.02	1.99-4.88	0.43-0.52	4.81-10.75	44.46-113.37	8.93-25.06
Flowers	1.27-1.31	0.30-0.31	0.78-0.86	2.10-3.29	0.60-0.68	0.76-0.81	0.09-0.10	1.38-2.03	20.49-22.83	4.34-5.00
Propagules	9.14-9.80	1.35-1.42	5.48-5.69	2.02-2.34	1.20-1.24	10.67-11.53	0.65-0.68	11.27-12.57	35.97-39.87	4.77-8.45
Total	55.60-64.08	7.60-12.16	12.50-17.85	92.90-150.94	25.95-34.80	47.32-61.45	4.94-5.58	45.33-114.25	635.25-938.59	93.39-243.93
% of nutrients return through leaf litter	69.46-69.52	64.21-70.39	40.16-51.43	76.22-79.79	79.73-81.15	67.58-68.14	69.53-69.64	51.86-65.88	73.59-77.43	75.60-79.11
% of nutrients return through other litter components	30.48-30.54	29.61-35.79	48.57-59.84	20.21-23.78	18.85-20.27	31.86-32.42	30.36-30.47	34.12-48.14	22.57-26.41	20.89-24.40

Table 7.3: Calculated range of nutrients stock in different components of *B. parviflora* seedlings, saplings and trees

	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	S (kg/ha)	C (t/ha)	Cu (g/ha)	Fe (g/ha)	Zn (g/ha)
Seedlings										
Leaves	3.40-4.28	0.29-0.72	2.33-3.05	1.55-2.68	1.72-2.17	1.62-3.08	0.17-0.22	1.47-4.69	123.47-224.52	2.67-10.00
Stems	3.30-5.93	0.28-0.67	1.63-3.88	2.57-3.34	1.58-2.16	2.43-5.26	0.35-0.41	2.28-5.67	198.96-367.68	4.80-11.65
Roots	0.86-1.45	0.17-0.23	0.61-1.58	0.63-0.89	2.03-2.73	1.27-1.98	0.09-0.13	1.31-2.73	747.08-1314.71	2.83-5.67
Sub-total	7.56-11.66	0.74-1.62	4.57-8.51	4.75-6.91	5.33-7.06	5.32-10.32	0.61-0.76	5.06-13.09	1069.51-1906.91	10.30-27.32
Saplings										
Leaves	0.92-1.00	0.07-0.10	0.33-1.01	0.53-0.91	0.48-0.92	0.16-0.65	0.03	0.32-0.87	9.13-10.97	0.59-1.19
Buds	0.04-0.05	0.01	0.02-0.04	0.04-0.06	0.02-0.04	0.01-0.03	0.01	0.02-0.06	0.21-0.42	0.04-0.09
Branches	0.57-0.77	0.07-0.12	0.29-0.66	0.68-0.91	0.14-0.22	0.20-0.65	0.06	0.48-2.08	5.24-13.40	0.64-1.68
Stems	0.91-0.93	0.18-0.49	0.55-0.62	0.93-0.95	0.35-0.37	0.69-2.26	0.28-0.32	2.03-4.19	23.65-43.11	2.85-7.32
Bark	0.34-0.37	0.05-0.07	0.10-0.11	0.69-0.86	0.08-0.10	0.26-0.54	0.04	0.35-0.75	6.57-10.35	0.64-1.64
Roots	0.49-0.55	0.11-0.13	0.58-0.73	0.45-0.60	0.52-0.73	0.97-2.56	0.06-0.07	0.61-1.47	572.38-883.88	0.79-4.14
Sub-total	3.27-3.67	0.49-0.92	1.87-3.17	3.32-4.29	1.59-2.38	2.29-6.69	0.48-0.53	3.81-9.42	617.18-962.13	5.55-16.06
Trees										
Leaves	126.34-153.29	10.54-14.51	60.04-129.71	79.42-124.37	72.33-120.88	125.36-206.09	4.13-5.31	50.91-110.58	1446.18-4084.70	78.79-275.17
Buds	4.49-5.70	0.67-0.83	2.49-4.35	4.60-6.05	2.30-3.18	3.70-5.71	0.22-0.27	2.94-6.09	20.06-52.00	5.82-14.56
Flowers	3.26-3.29	0.59-0.62	3.10-4.25	4.62-4.74	2.29-2.32	5.74-6.09	0.19-0.20	3.58-5.06	40.35-48.20	7.43-10.56
Branches	133.04-191.15	24.62-42.31	41.33-99.45	214.85-305.08	29.44-47.79	120.04-190.39	16.07-21.02	216.64-420.53	3228.31-5033.62	322.83-552.21
Stems	121.11-125.98	22.98-34.13	74.33-85.55	86.97-91.03	31.70-33.32	92.66-226.77	36.79-47.08	270.93-807.56	4380.09-5391.57	460.59-1706.88
Bark	45.11-50.33	13.56-15.87	13.22-14.81	123.32-196.65	8.67-9.11	36.44-94.77	4.59-5.80	37.03-89.13	1357.89-2254.10	37.03-190.10
Roots	71.18-84.81	13.02-17.20	60.20-115.15	60.39-113.58	60.20-91.43	120.77-339.04	8.72-10.16	124.10-198.34	53071.31-102402.89	138.82-471.15
Sub-total	504.53-614.55	85.98-125.47	254.71-453.27	574.17-841.50	206.93-308.03	504.71-1068.86	70.71-89.84	706.13-1637.29	63544.19-119267.08	1051.31-3220.63
Total	515.36-629.88	87.21-128.01	261.15-464.95	582.24-852.70	213.85-317.47	512.32-1085.87	71.80-91.13	715.00-1659.80	65230.88-122136.12	1067.16-3264.01
% of nutrients stock in above-ground components	85.93-86.22	84.75-86.28	74.74-76.49	86.51-89.44	70.11-70.66	68.36-75.99	87.65-88.63	82.37-87.80	14.36-16.62	85.26-86.65
% of nutrients stock in roots	13.78-14.07	13.72-15.25	23.51-25.26	10.56-13.49	29.34-29.89	24.01-31.64	11.37-12.35	12.20-17.63	83.38-85.64	13.35-14.74

Table 7.4: Calculated range of nutrients uptake, return/accumulation ratio, turnover period (yr), soil nutrients pool, absorption coefficient, utilization coefficient and cycling coefficient of *B. parviflora* dominated mangrove forest at Kuala Selangor Nature Park, Malaysia

	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	S (kg/ha)	C (t/ha)	Cu (g/ha)	Fe (g/ha)	Zn (g/ha)
Nutrient stock	515.36-629.88	87.21-128.01	261.15-464.95	582.24-852.70	213.85-317.47	512.32-1085.87	71.80-91.13	715.00-1659.80	65230.88-122136.12	1067.16-3264.01
Accumulation	53.74-65.59	9.10-13.49	27.19-48.86	60.94-89.47	22.35-33.47	53.61-115.60	7.50-9.49	75.28-172.89	7346.06-13758.70	111.10-337.48
Return	55.60-64.08	7.60-12.16	12.50-17.85	92.90-150.94	25.95-34.80	47.32-61.45	4.94-5.58	45.33-114.25	635.25-938.59	93.39-243.93
Uptake	109.34-129.67	16.70-25.65	39.69-66.71	153.84-240.41	48.30-68.27	100.93-177.05	NE	120.61-287.14	7981.31-14697.29	204.49-581.41
Return/Accumulation ratios	0.98-1.03	0.84-0.90	0.37-0.46	1.52-1.69	1.04-1.16	0.53-0.88	0.59-0.66	0.60-0.66	0.07-0.09	0.72-0.84
Turnover rate (yr)	9.27-9.83	10.53-11.48	20.89-26.05	5.65-6.27	8.24-9.12	10.83-17.67	NE	14.53-15.77	102.69-130.13	11.43-13.38
Soil (0-30 cm depth) kg/ha	6444.90-6615.00	585.90-642.60	8183.70-13343.40	5783.40-6822.90	15649.20-20468.70	6085.80-18559.80	84747.60-127820.70	27.82-47.25	13541.85-24318.01	120.22-181.86
Absorption coefficient	0.017-0.020	0.029-0.040	0.005	0.027-0.035	0.003	0.010-0.017	NE	0.004-0.006	0.001	0.002-0.003
Utilization coefficient	0.206-0.212	0.191-0.200	0.143-0.152	0.264-0.282	0.215-0.226	0.163-0.197		0.169-0.173	0.120-0.122	0.178-0.192
Cycling coefficient	0.494-0.509	0.455-0.474	0.268-0.315	0.604-0.628	0.510-0.537	0.347-0.469	NE	0.376-0.398	0.064-0.080	0.420-0.457

NE: Not estimated.

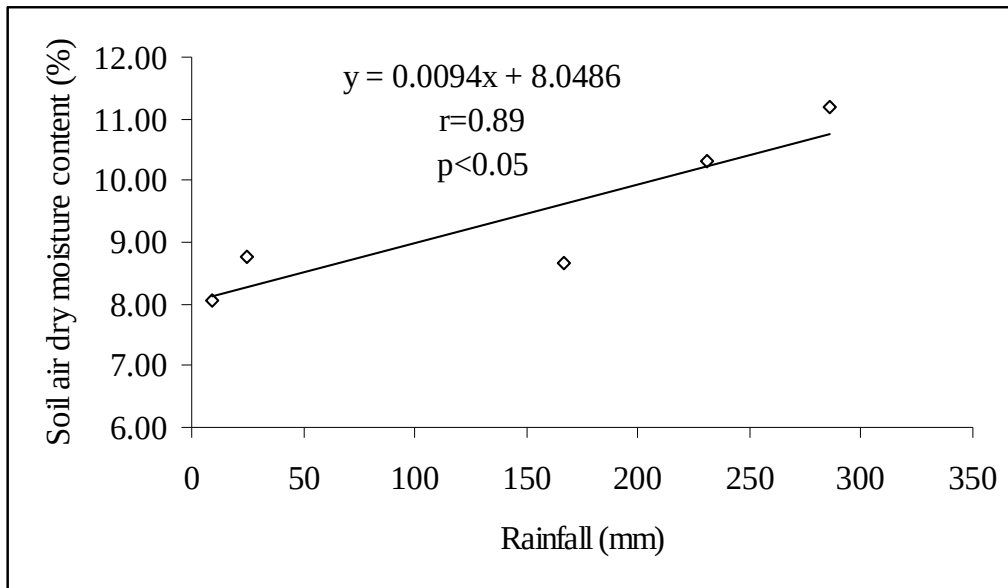


Figure 7.1: Relationship between soil air-dry moisture content and rainfall

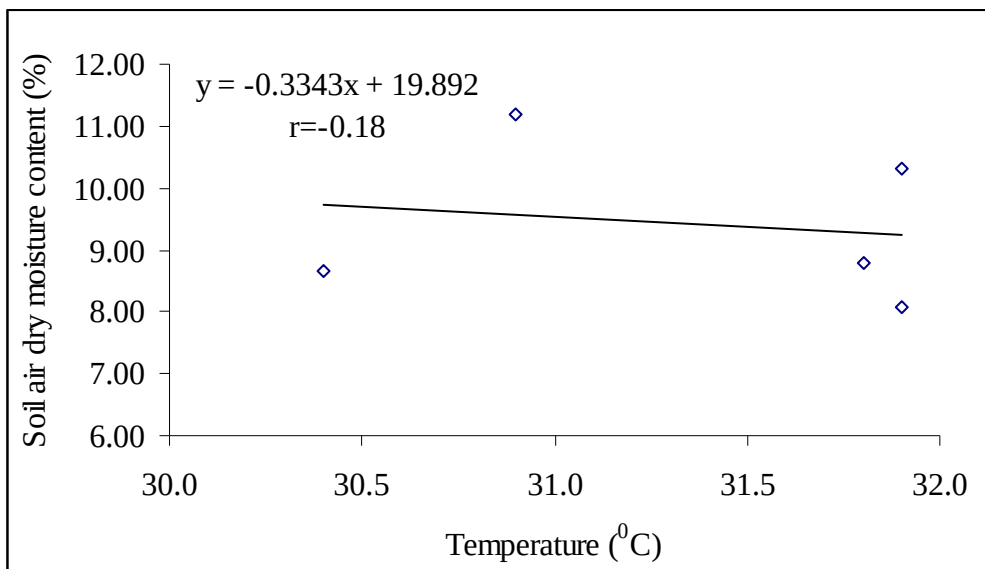


Figure 7.2: Relationship between soil air-dry moisture content and temperature

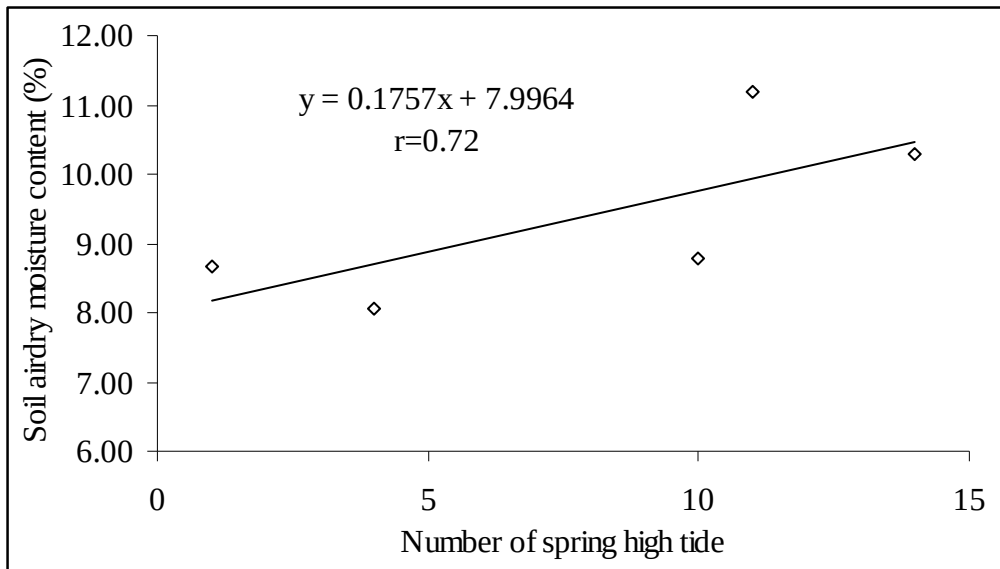


Figure 7.3: Relationship between soil air-dry moisture content and number of spring high tide that flooded the forest floor

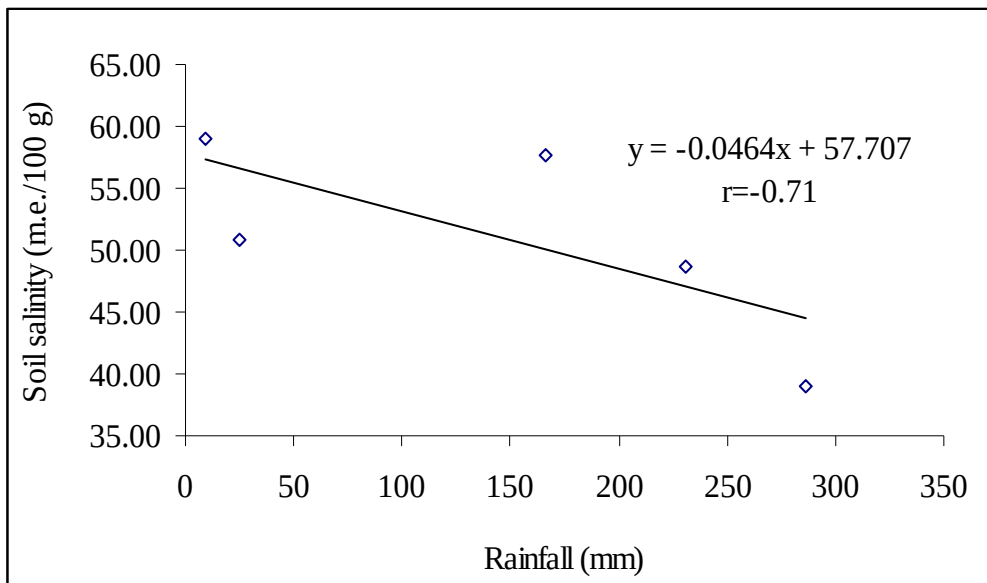


Figure 7.4: Relationship between soil salinity and rainfall

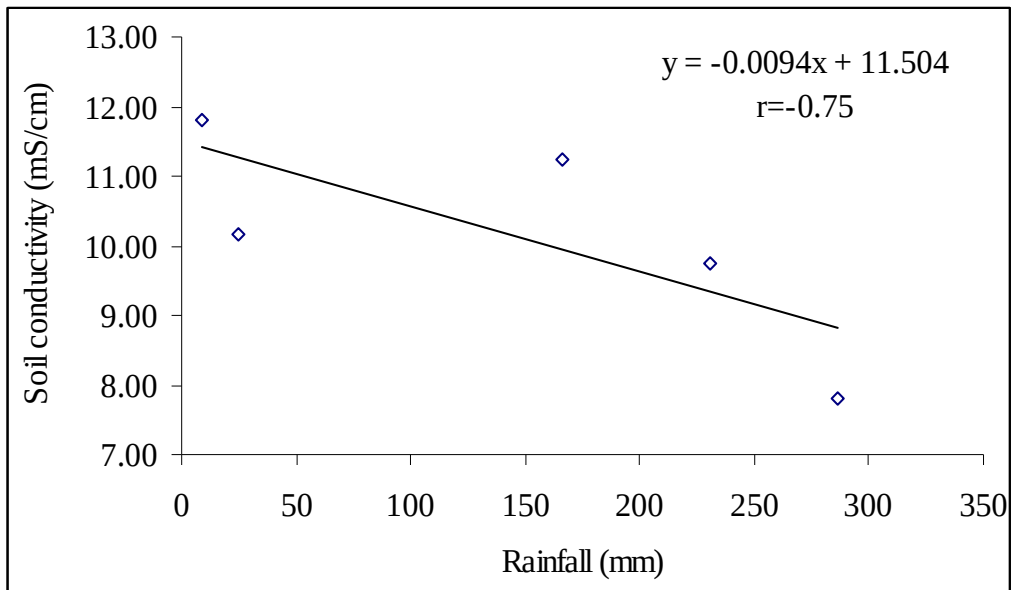


Figure 7.5: Relationship between soil conductivity and rainfall

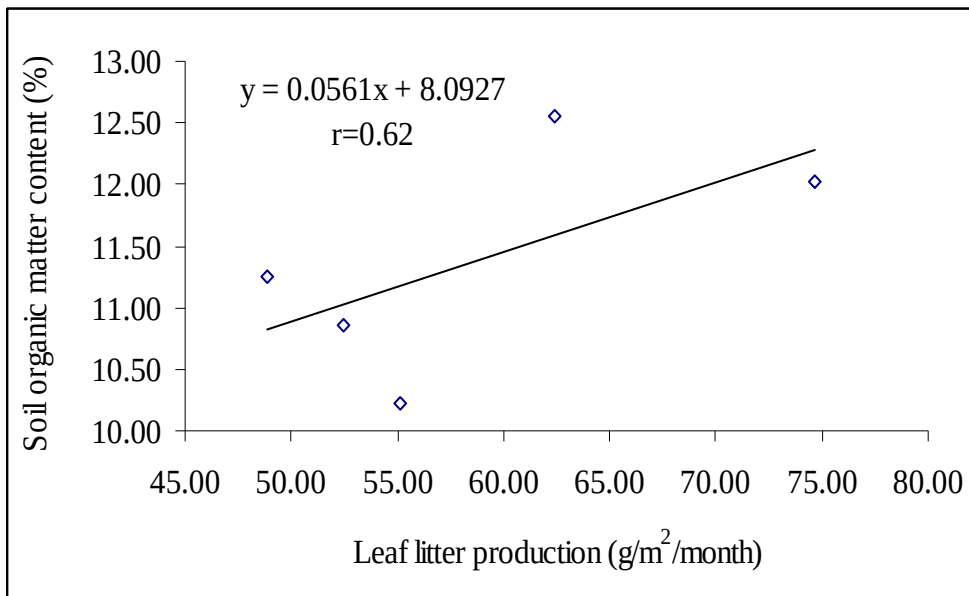


Figure 7.6: Relationship between soil organic matter and rate of leaf litter production

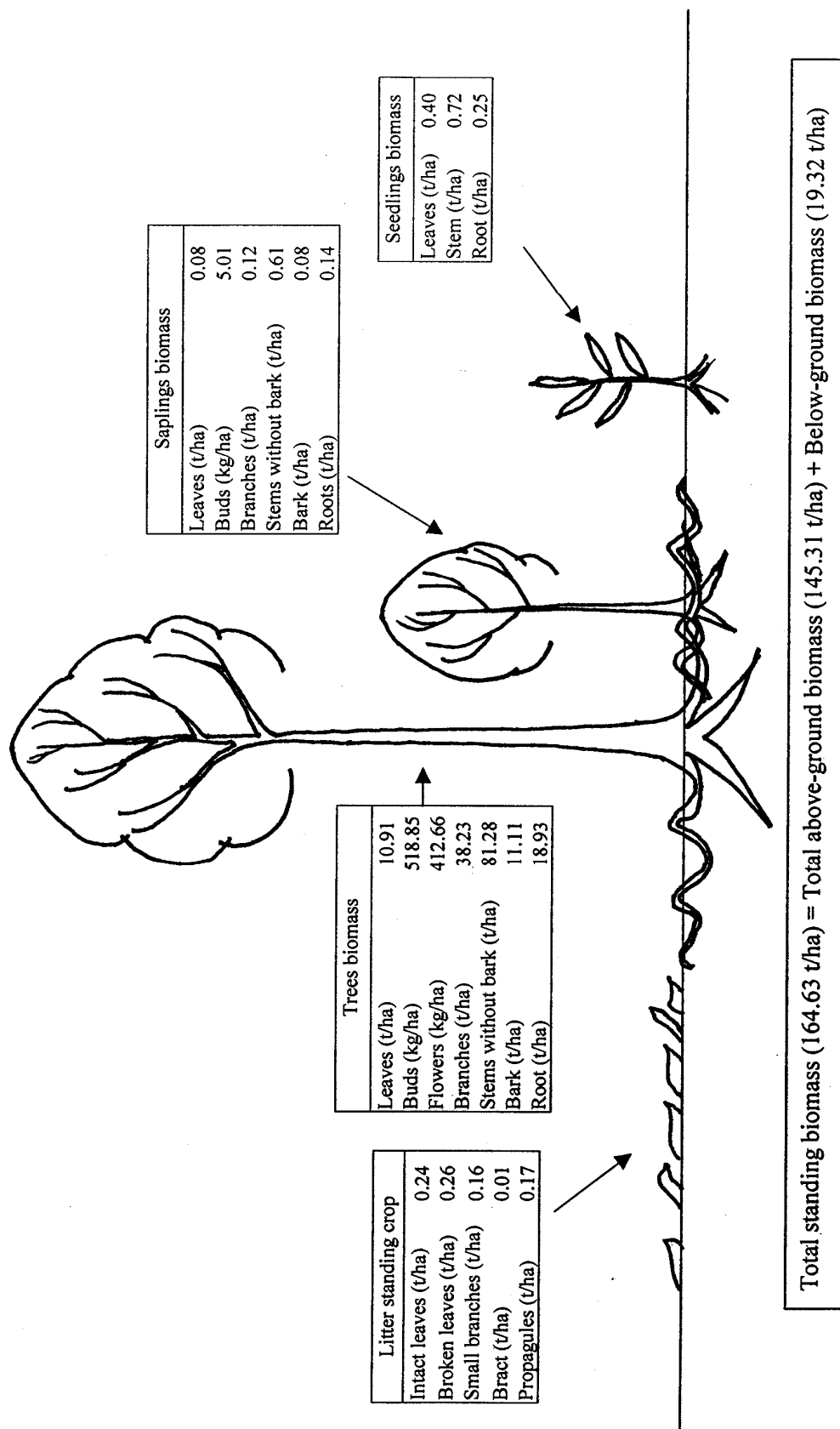


Figure 7.7: Total standing biomass of *B. parviflora* dominated mangrove forest at Kuala Selangor Nature Park, Malaysia

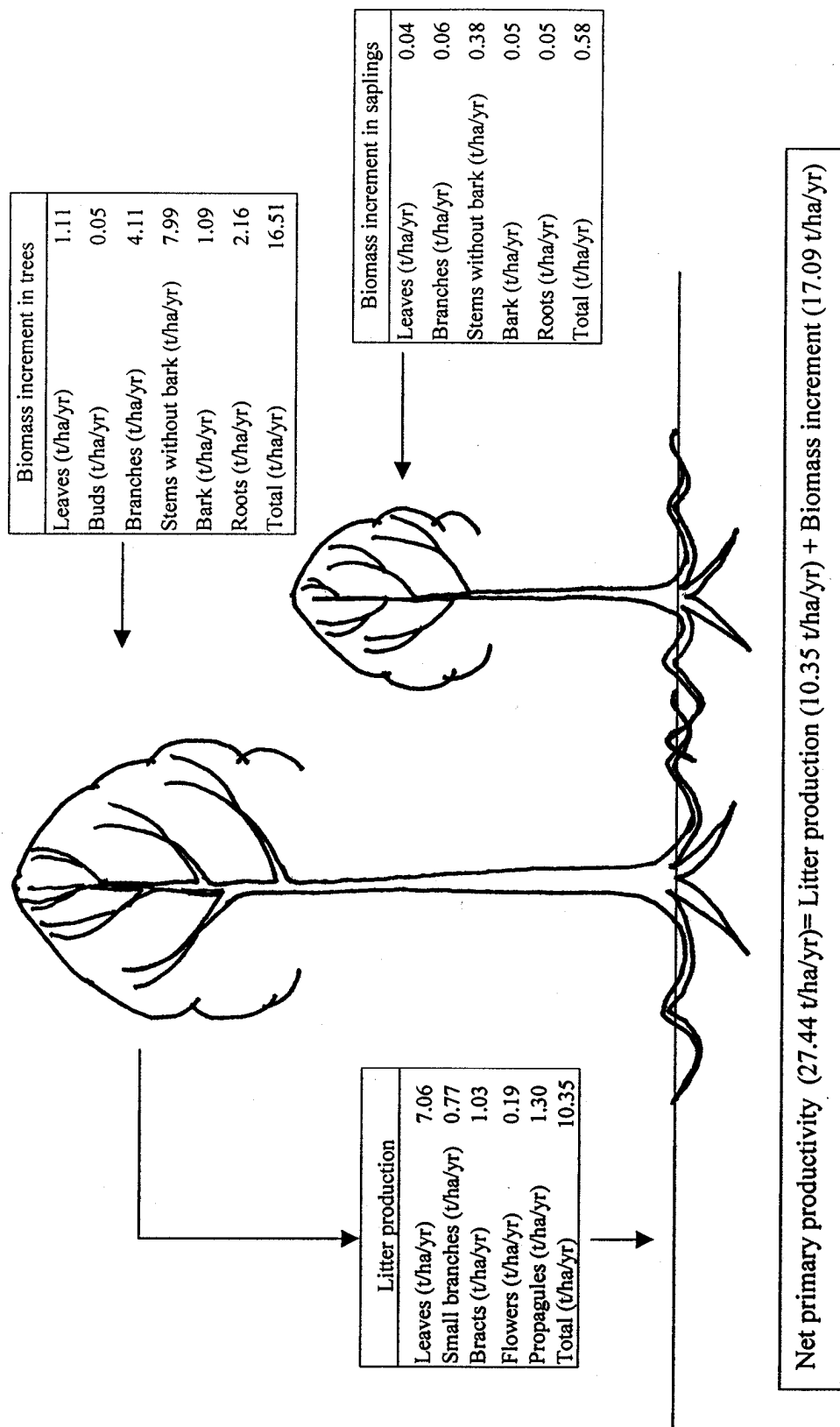


Figure 7.8: Net primary productivity of *B. parviflora* dominated mangrove forest at Kuala Selangor Nature Park, Malaysia

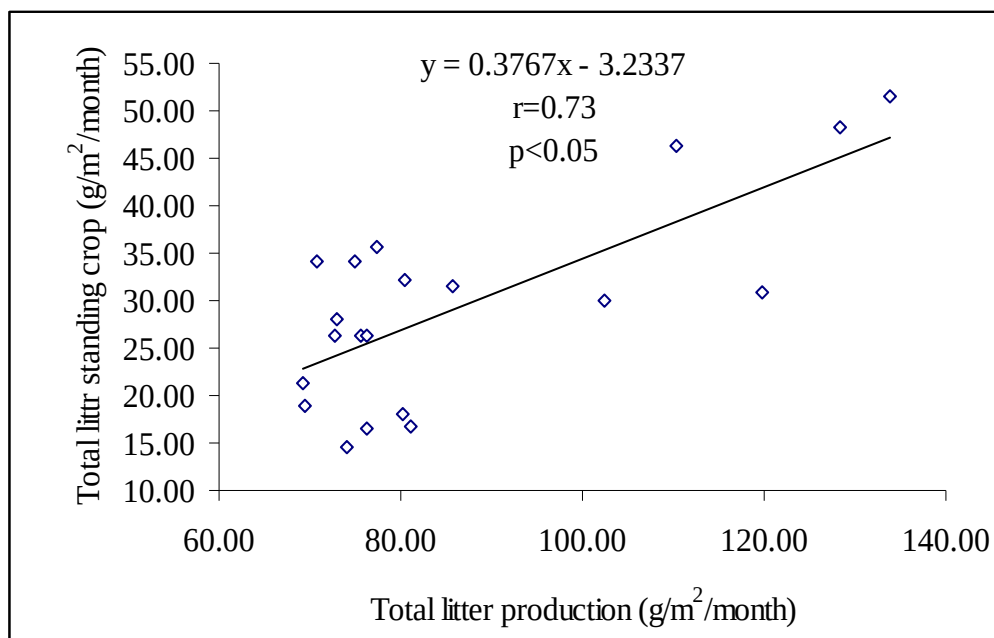


Figure 7.9: Relationship between the rate of total litter production and total litter standing crop

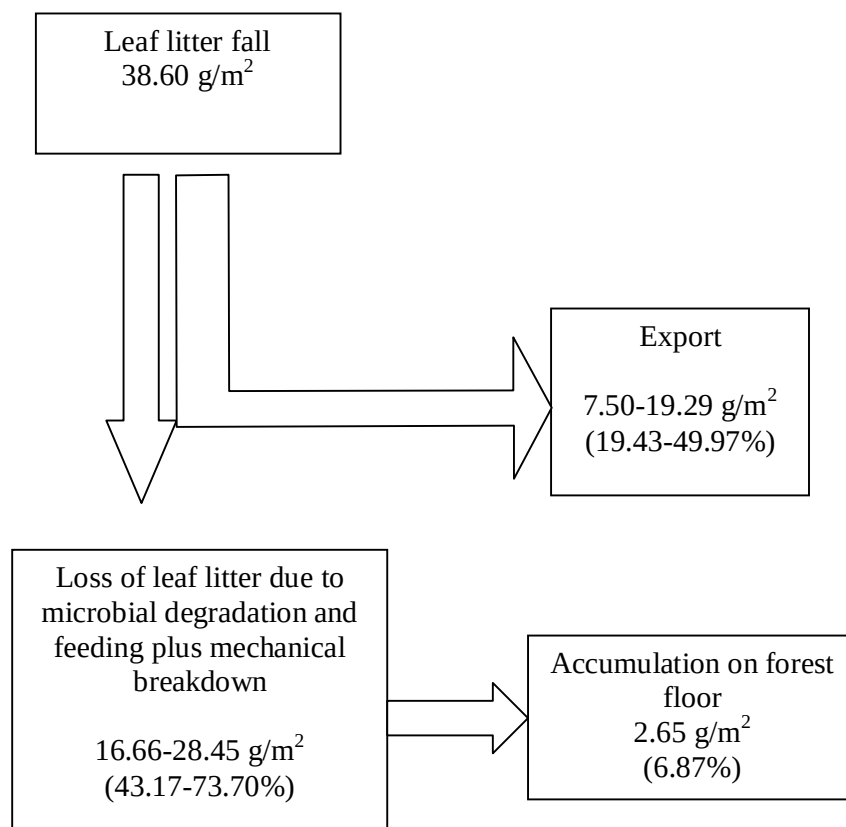


Figure 7.10: Disappearance of *B. parviflora* leaf litter from the study site based on disappearance period of 20 days during the dry and wet months. Percentage values are calculated from leaf litter production

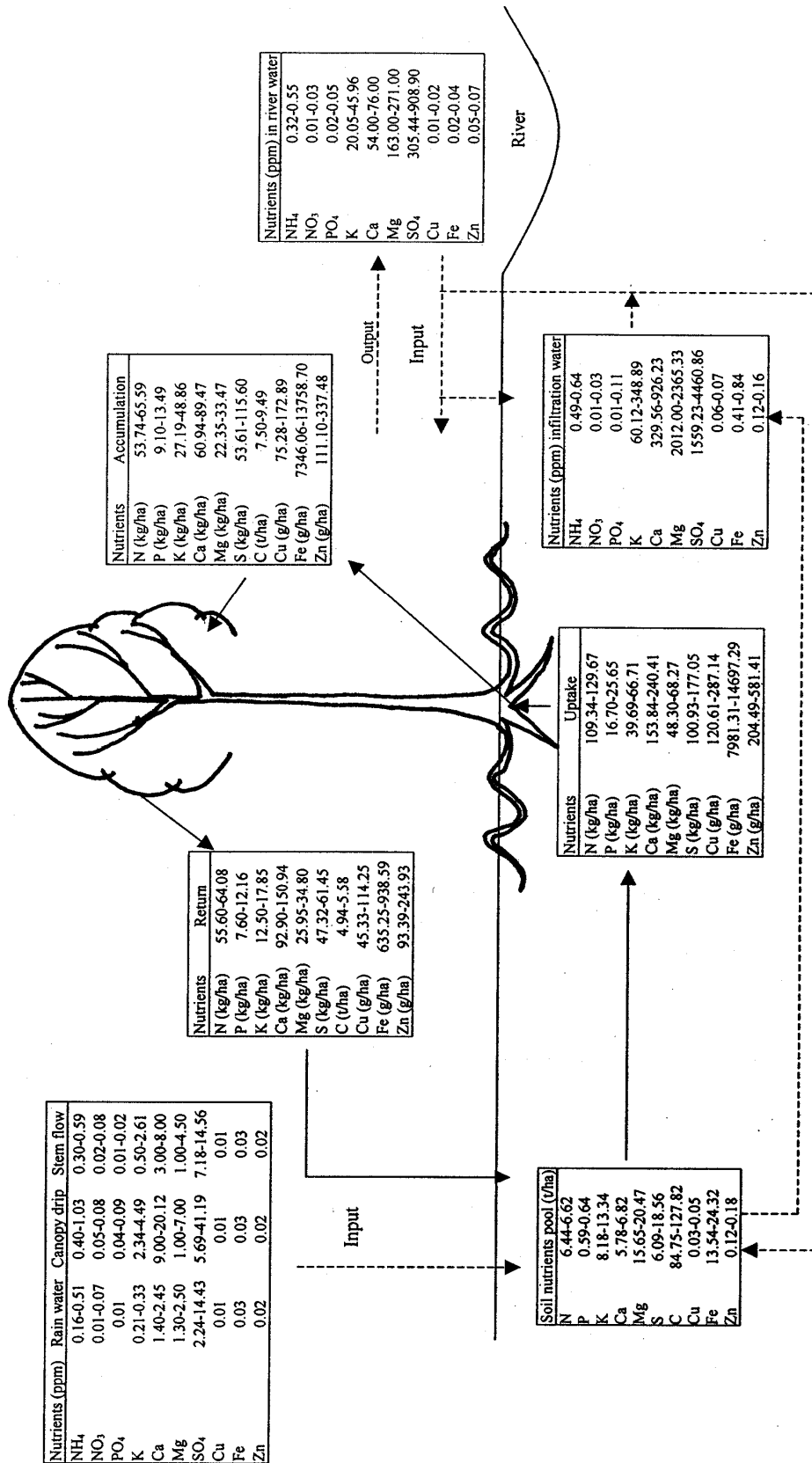


Figure 7.11: Relationship among nutrients input-output sources and within stand nutrient cycling in *B. parviflora* dominated mangrove forest at Kuala Selangor Nature Park, Malaysia. Broken line indicates the input-output sources of nutrients and their amount was not quantified

CHAPTER 8

SUMMARY

Five mangrove species belonging to the families of Avicenniaceae, Rhizophoraceae and Sonneratiaceae were recorded during the field sampling and the species were *Avicennia alba*, *Bruguiera parviflora*, *Rhizophora apiculata*, *R. mucronata* and *Sonneratia caseolaris*. *Bruguiera parviflora* appears as dominant species with an importance value of 74.47% and 75.35% for saplings and trees, respectively followed by *A. alba* and *R. mucronata*. Trees constituted the top stratum of 8.90 ± 0.02 to 10.27 ± 0.08 m height, 2180 ± 175 trees/ha, DBH range 4 to 26 cm and 18.90 ± 1.87 m²/ha of basal area. Saplings constituted the middle stratum of 2.55 ± 0.14 to 4.20 ± 0.02 m height, 695 ± 90 saplings/ha and DBH range 1 to <4 cm and 0.28 ± 0.03 m²/ha of basal area. The lower stratum (< 1 m height) consisted of dense seedlings ($408,000 \pm 34800$ seedlings/ha).

The above and below-ground biomass of seedlings, saplings and trees of *B. parviflora* were 1.12, 0.89 and 142.46 t/ha; 0.25, 0.14 and 18.93 t/ha, respectively. The mean percentage of total above-ground biomass for seedlings, saplings and trees were 81.75, 84.48 and 88.82%, respectively, but the below-ground biomass were 18.25, 15.52, and 11.18%, respectively. The annual amount of small litter production (leaves, small branches, bracts, flowers and propagules) was 1035 g/m² and the range of percentage contribution of leaves, small branches, bracts, flowers, propagules was 38.05-84.59%, 3.09-12.84%, 3.79-13.42%, 0.38-9.29% and 1.24-53.58%, respectively. Comparatively higher rate of total litter fall was observed during the drier months (July 02, July 03 and August 02). The net primary productivity of this mangrove forest was 27.44 t/ha/yr, which was estimated from the average annual biomass increments of 17.09 t/ha/yr (leaves, bud, branches, stems, bark and root) in saplings and trees and 10.35 t/ha/yr of annual litter fall (leaves, small branches, bracts, flowers and propagules).

The annual amount of small litter standing crop (intact leaves, broken leaves, small branches, bracts and propagules) was 337.72 g/m² in the permanent plots. Comparatively higher rate of total litter standing crop was observed during July 02, July 03 and February 02. Total litter standing crop showed a significant negative correlation with the number of spring high tides that flooded the forest areas.

Bruguiera parviflora leaf litter showed faster physical changes during the wet months (November 02 to March 03) compared to dry months (July 02 to November 02). Leaf litter showed higher microbial degradation (60% of initial dry mass) in wet months (November 02) than the dry month (20.17% of initial dry mass, July 02), but leaf litter loss due to feeding plus mechanical breakdown did not vary in dry and wet months. Leaf litter export from this mangrove forest was found to vary with the seasons. The

export of leaf litter was 19.43 and 49.97% of the leaf litter production during the wet (November 02) and dry (July 02) months, respectively.

Soil parameters (pH, redox potential, air-dry moisture content, organic matter, conductivity, salinity and cation exchange capacity) and nutrients (N, P, K, Ca, Mg, S, C, Cu, Fe and Zn) were found to vary in different seasons (intermediate, dry and wet). Comparatively higher soil air-dry moisture content was observed during the wet seasons (November 01 and 02), but relatively higher soil organic matter and cation exchange capacity were found during the intermediate seasons (March 02 and 03). Comparatively higher content of N (3.49 ± 0.01 - 3.50 ± 0.01 mg/g), P (0.33 ± 0.00 - 0.34 ± 0.00 mg/g), K (6.86 ± 0.03 - 7.06 ± 0.02 mg/g), C (63.29 ± 0.08 - 67.63 ± 0.11 mg/g) and Fe (11929.44 ± 31.27 - 12866.67 ± 57.74 µg/g) in soil was observed during the intermediate seasons (March 02 and 03) and soil organic matter showed significant ($p<0.05$) relationship on soil nutrients level.

Rainwater, canopy drip, stem flow, river water and infiltration water showed seasonal (intermediate, dry and wet) variation in their parameters (pH, redox potential, conductivity and salinity) and nutrients (NH_4 , NO_3 , PO_4 , K, Ca, Mg, SO_4 , Cu, Fe and Zn). Comparatively acidic pH (5.40 ± 0.05 - 6.72 ± 0.08) was observed in canopy drip and stem flow than the rainwater. River and infiltration water pH ranged from 6.32 ± 0.03 to 7.05 ± 0.06 . Comparatively higher conductivity and salinity of river and infiltration water were found during the dry seasons (July 02 and 03). Comparatively higher K, Ca, Mg, SO_4 , Cu, Fe and Zn were observed in infiltration water. Nutrients (NH_4 , NO_3 , PO_4 , K, Ca, Mg and SO_4) in rainwater, canopy drip, stem flow, river and infiltration water varied in intermediate (March), dry (July) and wet (November) seasons. Similar content of Cu (0.01 ± 0.00 ppm), Fe (0.03 ± 0.00 ppm) and Zn (0.02 ± 0.00 ppm) was observed in rainwater, canopy drip and stem flow, respectively in different seasons (intermediate, dry and wet). Macronutrients (except NO_3) in rainwater showed positive correlations with canopy drip and stem flow and NO_3 , PO_4 , Mg, SO_4 , Cu and Fe showed positive correlations between river and infiltration water.

Comparatively higher N, P, K and Mg were observed in the leaves of seedlings, leaves and buds of saplings and trees, and relatively lower content was observed in woody components (branches and stems) of saplings and trees. Relatively higher Ca content was found in leaves of seedlings, bark, leaves and buds of saplings and leaves, bark, buds and flowers of trees and comparatively lower content was observed in seedlings roots, stems of saplings and trees. Roots of seedlings and saplings, leaves, flowers, propagules and roots of trees contained relatively higher sulphur and lower content was observed in stems of seedlings, saplings and trees. Copper and zinc in different components of seedlings, saplings and trees showed different trends of distribution in each season. Comparatively higher iron was found in roots of seedlings, saplings and trees and lower content was observed in stems.

Nutrients and organic matter content in different components of *B. parviflora* seedlings, saplings and trees showed variation in intermediate (March), dry (July) and wet (November) seasons with the exception of N, K, C, Mg and organic matter content in stems of saplings and trees, K and Mg content in bark of saplings and trees. Different components of seedlings, saplings and trees contained comparatively higher N, P, K, Ca, Mg and Fe during the intermediate seasons (March 02 and 03) and relatively higher sulphur content was observed during the dry seasons (July 02 and 03). However, nutrients (N, P, K, Ca, Mg, S, Cu, Fe and Zn) in different components of seedlings, saplings and trees (except N in saplings and trees stems, P in seedlings roots) showed positive correlation with the soil nutrients levels.

The calculated range of total stock of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn in standing biomass of seedlings, saplings and trees was 515.36-629.88 kg/ha, 87.21-128.01 kg/ha, 261.15-464.95 kg/ha, 582.24-852.70 kg/ha, 213.85-317.47 kg/ha, 512.32-1085.87 kg/ha, 71.80-91.13 t/ha, 715.00-1659.80 g/ha, 65230.88-122136.12 g/ha and 1067.16-3264.01 g/ha, respectively, and the sequence was C>S>Ca>N>K>Mg>P>Fe>Zn>Cu. Above-ground components contributed to 85.93-86.22%, 84.75-86.28%, 74.74-76.49%, 86.51-89.44%, 70.11-70.66%, 68.36-75.99%, 87.65-88.63%, 82.37-87.80% and 85.26-86.65% stock of N, P, K, Ca, Mg, S, C, Cu and Zn, respectively, while 83.38-85.64% of Fe stock was observed in root biomass.

The annual accumulation range of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn in plant biomass was 53.74-65.59 kg/ha, 9.10-13.49 kg/ha, 27.19-48.86 kg/ha, 60.94-89.47 kg/ha, 22.35-33.47 kg/ha, 53.61-115.60 kg/ha, 7.50-9.49 t/ha, 75.28-172.89 g/ha, 7346.06-13758.70 g/ha and 111.10-337.48 g/ha, respectively, which were in the order C>S>Ca>N>K>Mg>P>Fe>Zn>Cu. Comparatively higher percentages of Fe (85.22-87.22%) accumulated in the root biomass and other nutrients accumulated in the above ground biomass.

The annual return range of N, P, K, Ca, Mg, S, C, Cu, Fe and Zn in the form of litter fall was 55.60-64.08 kg/ha, 7.60-12.16 kg/ha, 12.50-17.85 kg/ha, 92.90-150.94 kg/ha, 25.95-34.80 kg/ha, 47.32-61.45 kg/ha, 4.94-5.58 t/ha, 45.33-114.25 g/ha, 635.25-938.59 g/ha and 93.39-243.93 g/ha, respectively, with the order of C>Ca>N>S>Mg>K>P>Fe>Zn>Cu.

The annual uptake range of N, P, K, Ca, Mg, S, Cu, Fe and Zn was 109.34-129.67 kg/ha, 16.70-25.65 kg/ha, 39.69-66.71 kg/ha, 153.84-240.41 kg/ha, 48.30-68.27 kg/ha, 100.93-177.05 kg/ha, 120.61-287.14 g/ha, 7981.31-14697.29 g/ha and 204.49-581.41 g/ha, respectively, with the order of Ca>S>N>Mg>K>P>Fe>Zn>Cu. The range of turnover period of N, P, K, Ca, Mg, S, Cu, Fe and Zn was 9.27-9.83 yr, 10.53-11.48 yr, 20.89-26.05 yr, 5.65-6.27 yr, 8.24-9.12 yr, 10.83-17.67 yr, 14.53-15.77 yr, 102.69-130.13 yr and 11.43-13.38 yr, respectively. The sequences of absorption coefficient and utilization coefficient were P>Ca>N>S>K>Cu>Mg>Zn>Fe and Ca>Mg>N>P>Zn>S>Cu>K>Fe, respectively. However, the sequence of cycling

coefficient was similar with utilization coefficient and suggested that the flow of Ca, Mg, N were higher and lower flows which were associated with Cu, K, Fe and coincided with the turnover rate.

REFERENCES

- Abbey Kalio, N.J. 1992. A pilot study of mangrove litter production in the Bonny estuary of southern Nigeria. *Discovery and Innovation* 4 (3): 71-78.
- Abdulhadi, R and Suhardjono. 1994. The remnant mangroves of Sei Kecil, Simpang Hilir, West Kalimantan, Indonesia. *Hydrobiologia* 285: 249-255.
- Adriano, D.C. 1986. *Trace Element in the Terrestrial Environment*. New York: Springer Verlag.
- Aksornkoae, S. 1975. (Cited in Aksornkoae, S. 1993.) *Structure, Regeneration and Productivity of Mangroves in Thailand*. Ph.D Thesis, Michigan State University, USA.
- Aksornkoae, S. 1993. *Ecology and Management of Mangroves*. Bangkok, Thailand: IUCN.
- Aksornkoae, S. and Khemnark, C. 1984. Nutrient cycling in mangrove forest of Thailand. In *Proceedings of the Asian Symposium on Mangrove Environment Research and management*, ed. E. Soepadmo, A.N. Rao, and D.J. Macintosh, pp 545-557. Kuala Lumpur: University of Malaya.
- Aksornkoae, S., Kongsangchai, J., Painchsuko, S., Srisawatt, W., Panichchart, S., Aguru, V., Jintana, N., Krachaivong, J. and Koocha, B. 1989. (Cited in Aksornkoae, S. 1993). *Inventory and Monitoring of Mangroves in Thailand*. Final Report submitted to the Office of the National Environment Board, Bangkok, Thailand.
- Alias, S.A., Kuthubutheen, A.J. and Jones, E.B.G. 1995. Frequency of occurrence of fungi on wood in Malaysian mangroves. *Hydrobiologia* 295: 97-106.
- Allen, S.E. 1974. *Chemical Analysis of Ecological Materials*. Oxford: Blackwell Scientific publication.
- Alongi, D.M., Sasekumar, A., Tirendi, F. and Dixon, P. 1998. The influence of stand age on benthic decomposition and recycling of organic matter in managed mangrove forests of Malaysia. *Journal of Experimental Marine Biology and Ecology* 225: 197-218.
- Alongi, D.M., Boto, K.G. and Robertson, A.I. 1992. Nitrogen and phosphorus cycles. In *Tropical Mangrove Ecosystem*, ed. A.I. Robertson and D.M. Alongi, pp 251-292. Coastal and Estuarine Studies 41, Washington, DC: American Geophysical Union.
- Alongi, D.M., Christofferson, P. and Tirendi, F. 1993. The influence of forest type on microbial-nutrient relationships in tropical mangrove sediments. *Journal of Experimental Marine Biology and Ecology* 171: 201-223.
- Amarasinghe, M.D. and Balasubramaniam, S. 1992a. Net primary productivity of two mangrove forest stands on the northwest coast of Sri Lanka. *Hydrobiologia* 247: 37-47.
- Amarasinghe, M.D. and Balasubramaniam, S. 1992b. Structural properties of two types of mangrove stands on the northwest coast of Sri Lanka. *Hydrobiologia* 247:17-27.
- Anon., 1986. *Annual Report of the Forestry Department, Peninsular Malaysia*. Malaysia: Forest Department Publication.

- Arshad, A., Japar Sidik, B. and Zaki, M.S.M. 1997. Roles of mangrove ecosystem in Malaysian fisheries. In *Fisheries and the Environment: Beyond 2000*, ed. B. Japar Sikid, M.F. Yusoff, M.S.M. Zaki, and T. Petr, pp 95-104. Serdang: Universiti Putra Malaysia.
- Ashton, C.E., Hogarth, P.J. and Ormond, R. 1999. Breakdown of mangrove leaf litter in a managed mangrove forest in Peninsular Malaysia. *Hydrobiologia* 413: 77-88.
- Ashton, E.C. 2002. Mangrove sesarmid crab feeding experiments in Peninsular Malaysia. *Journal of Experimental Marine Biology and Ecology* 273: 97-119.
- Ashton, E.C. and Macintosh, D.J. 2002. Preliminary assessment of the plant diversity and community ecology of Sematan mangrove forest Sarawak, Malaysia. *Forest Ecology and Management* 166: 111-129.
- Attiwill, P.M. 1966. The chemical composition of rainwater in relation to cycling of nutrients in mature eucalyptus forest. *Plant and Soil* 24: 390-406.
- Baker, A.J. and Walker, P.I. 1990. Ecophysiology of metal uptake by tolerant plants. In *Heavy metal tolerance in plants; evolutionary aspects*, ed. A.J. Shaw, pp 155-78. Florida: CRC Press.
- Ball, M.C. 1988. Ecophysiology of mangroves. *Trees* 2: 129-142.
- Barber, S.A. 1984. *Soil Nutrient Bioavailability, A Mechanistic Approach*. New York: John Wiley & Sons.
- Barlett, R.J. 1961. Iron oxidation proximate to plant roots. *Soil Science* 92: 372-379.
- Beats, R.G. 1964. Determination of pH: Theory and practice. In: *Method of Soil Analysis*, ed. C.A. Black, Part 2, Madison, Wis, American Society of Agronomy. New York: John Wiley & Sons.
- Binkley, D. 1986. *Forest Nutrition Management*. New York: John Wiley & Sons.
- Black, C.A. 1965. *Method of Soil Analysis*, Part 1, Madison, Wis, American Society of Agronomy. New York: John Wiley & Sons.
- Blair, J.M. 1988. Nutrient release from decomposing foliar litter of three tree species with special reference to calcium, magnesium and potassium dynamics. *Plant and soil* 110: 49-55.
- Boar, B. 1996. Plants as soil indicators along the Saudi coast of the Arabian Gulf. *Journal of Arid Environments* 33: 417-423.
- Boonruang, P. 1984. The rate of degradation of mangrove leaves, *Rhizophora apiculata* Bl. and *Avicennia marina* (Forsk) Vierh. at Phuket island. Western Peninsular of Thailand. In *Proceedings of the Asian Symposium on Mangrove Environment Research and management*, ed. E. Soepadmo, N.A. Rao, and J.D. Macintosh, pp 200-208. Kuala Lumpur: University of Malaya.
- Boto, K.G. 1982. Nutrients and organic fluxes in mangroves. In *Mangrove Ecosystems in Australia, Structure, Function and Management*, ed. B.F. Clough, pp 239-258. Australia: Australian Institute of Marine science.
- Boto, K.G. 1992. Nutrients and mangroves. In *Pollution in Tropical Aquatic Systems*, ed. D.W. Connell, and D.W. Hawker, pp 129-146. Boca Raton: CRC Press.
- Boto, K.G. and Bunt, J.S. 1981. Tidal export of particulate organic matter from a northern Australia mangrove system. *Estuarine, Coastal and Shelf Science* 13:247-255.

- Boto, K.G. and Wellington, J.T. 1983. Phosphorus and nitrogen nutritional status of a northern Australian mangrove ecosystem. *Marine Ecology and Progress Series* 11: 63-75.
- Boto, K.G., Bunt, J.S. and Wellington, J.T. 1984. Variation in mangrove forest productivity in Northern Australia and Papua New Guinea. *Estuarine, Coastal and Shelf Science* 19: 321-329.
- Bremer, G.B. 1995. Lower marine fungi (Labyrinthulomycetes) and decay of mangrove leaf litter. *Hydrobiologia* 295: 89-95.
- Briggs, S.V. 1977. Estimates of biomass in a temperate mangrove community. *Australian Journal of Ecology* 2: 369-373.
- Brown, S. 1984. Mangrove litter production and dynamics. In *The mangrove ecosystem: research methods*, ed. C.S. Snedaker, and J.G. Snedaker, pp. 231-238. United Kingdom: Unesco.
- Bunt, J.S. 1995. Continental scale patterns in mangrove litter fall. *Hydrobiologia* 295:135-140.
- Bunt, J.S., Boto, K.G. and Boto, G. 1979. A survey method for estimating potential levels of mangrove forest primary production. *Marine Biology* 52: 123-128.
- Cahoon, D.R. and Reed, D.J. 1995. Relationships among marsh surface topography, hydroperiod and soil accretion in a deteriorating Louisiana salt marsh. *Journal Coastal Research* 11(2): 357-369.
- Cai, G.H. 1987. *Salt Relations of Mangroves Along Northeast Hainan Coasts*. M. Phil. Thesis, Zhongshan University, Guangzhou, China.
- Camilleri, J.C. and Ribí, G. 1986. Leaching of dissolved organic carbon (DOC) from dead leaves, formation of flakes from DOC, and feeding on flakes by crustaceans in mangroves. *Marine Biology* 91: 337-344.
- Chale, F.M.M. 1993. Degradation of mangrove leaf litter under aerobic conditions. *Hydrobiologia* 257: 177-183.
- Chale, F.M.M. 1996. Litter production in an *Avicennia germinans* (L.) eastern forest in Guyana, South Africa. *Hydrobiology* 330: 47-53.
- Chansang, H. 1984. Structure of mangrove forest at Ko Yao Yai, Southern Thailand. In *Proceedings of the Asian Symposium on Mangrove Environment Research and management*, ed. E. Soepadmo, N.A. Rao, and J.D. Macintosh, pp 86-105. Kuala Lumpur: University of Malaya.
- Chapman, V.J. 1976. *Mangrove Vegetation*. Vaduz: Cramer.
- Chiu, C.Y. and Chou, C.H. 1991. The Distribution and Influence of Heavy Metals in Mangrove Forests of Tamshui Estuary in Taiwan. *Soil Science and Plant Nutrition* 37 (4): 659-669.
- Christensen, B. 1978. Biomass and primary production of *Rhizophora apiculata* Bl. in a mangrove in south Thailand. *Aquatic Botany* 4: 43-52.
- Cintron, G. and Novelli, S.Y. 1984. Methods for studying mangrove structure. In *The mangrove ecosystem: research methods*, ed. C.S. Snedaker and J.G. Snedaker, pp 91-113. United Kingdom: Unesco.

- Clough, B.F, Tan, D.T., Phuong, D.X. and Buu, D.C. 2000. Canopy leaf area index and litter fall in stands of the mangrove *Rhizophora apiculata* of different age in the Mekong Delta, Vietnam. *Aquatic Botany* 66: 311-320.
- Clough, B.F. 1992. Primary productivity and growth of mangrove forests. In *Tropical Mangrove Ecosystem, Coastal and Estuarine Studies 41*, ed. A.I. Robertson and D.M. Alongi, pp 225-250. Washington DC: American Geophysical Union.
- Clough, B.F. and Attiwill, P.M. 1975. Nutrient cycling in a community of *Avicennia marina* in a temperate region of Australia. In *Proceedings of International Symposium on Biology and Management of Mangroves*, ed. G.E. Walsh, S.C. Snedaker and H.J. Teas, pp. 137-146. Florida: University of Florida.
- Clough, B.F. and Attiwill, P.M. 1982. Primary Productivity of Mangroves. In *Mangrove Ecosystems in Australia, Structure, Function and Management*, ed. B.F. Clough, pp 213-222. Australia: Australian Institute of Marine science.
- Clough, B.F. and Scott, K. 1989. Allometric relationships for estimating above-ground biomass in six mangrove species. *Forest Ecology and Management* 27: 117-127.
- Clough, B.F., Boto, K.G. and Attiwill, P.M. 1983. Mangrove and sewage: a reevaluation. In *Tasks for Vegetation Science* Vol. 8, ed. H.J. Teas, pp 151. The Hague.
- Clough, B.F., Dixon, P. and Dalhaus, O. 1997. Allometric relationships for estimating biomass in multi-stemmed mangrove trees. *Australian Journal of Botany* 45: 1023-1031.
- Conacher, C.A., Brien, C.O., Horrocks, J.L. and Kenyon, R.K. 1996. Litter production and accumulation in stressed mangrove communities in the Embley river estuary, Northeastern Gulf of Carpentaria. *Australian Journal of Marine and Freshwater Research* 47: 737-743.
- Cundell, A.M., Brown, S.M., Stanford, R. Mitchell, R. 1979. Microbial degradation of *Rhizophora mangle* leaves immersed in the sea. *Estuarine and Coastal Marine Science* 9: 281-286.
- Davis, S.E., Molina, C.C., Childers, D.L. and Day, J.W.Jr. 2003. Temporally dependent C, N, and P dynamics associated with the decay of *Rhizophora mangle* L. leaf litter in oligotrophic mangrove wetlands of the Southern Everglades. *Aquatic Botany* 75: 99-215.
- Day, J.W.Jr., Conner, W.H., Ley-Lou, F., Day, R.H. and Navarro, A.M. 1987. The productivity and composition of mangrove forests, Laguna de Terminos, Mexico. *Aquatic Botany* 27: 67-284.
- Day, J.W.Jr., Coronado-Molina, C., Vera-Herera, F.R., Twilley, R., Rivera-Monroy, V. H., Alvarez-Guillen, H., Day, R. and Conner, W. 1996. A 7 year record of above-ground net primary production in a southeastern Mexican mangrove forest. *Aquatic Botany* 55: 39-60.
- Department of Survey and Mapping. 2003. Tide Tables, Malaysia. Kuala Lumpur: DSM.
- Dick, T.M. and Osunkoya, O.O. 2000. Influence of tidal restriction floodgates on decomposition of mangrove litter. *Aquatic Botany* 68: 273-280

- Duke, N.C. 1988. Phenologies and litter fall of two mangrove trees, *Sonneratia alba* Sm. and *S. caseolaris* (L.) Engl., and their putative hybrid *S. X gulagai* N. C. Duke. *Australian Journal of Botany* 36: 473-482.
- Duke, N.C., Bunt, J.S. and Williams, W.T. 1981. Mangrove Litter Fall in North-eastern Australia. I. Annual Totals by Component in selected Species. *Australian Journal of Botany* 29: 547-553.
- Duvigneaud, P. and Denaever-De Smet, S. 1970. Biological cycling of minerals in temperate deciduous forest. In *Analysis of Temperate Ecosystems*, ed. D.E. Reichle, pp 199-225. New York: Springer-Hague.
- Etherington, J.R. 1975. *Environment and Plant Ecology*. New York: John Wiley & Sons.
- FAO, 1994. Mangrove Forest Management Guidelines. Rome: FAO
- FAO, 2003. FAO's Global Estimate of Mangroves (10 March 2003). <http://www.fao.org>. Accessed on 17 June 2003.
- Fell, J.W., Cefalu, R.C., Master, I.M. and Tallman, A.S. 1975. Microbial activities in the mangrove (*Rhizophora mangle*) leaf detrital system. In *Proceedings of International Symposium on Biology and Management of Mangroves*, ed. G.E. Walsh, S.C. Snedaker and H.J. Teas, pp 661-679. Florida: University of Florida.
- Field, C.D. 1995. *Journey Amongst Mangroves*. Okinawa: International Society for Mangrove Ecosystems.
- Gearing, J., Gearing, P., Rodelli, M., Marshall, N. and Sasekumar, A. 1984. Initial findings from stable carbon isotope ratios in West coast mangrove areas of Peninsular Malaysia. In *Proceedings of the Asian Symposium on Mangrove Environment: Research and Management*, ed. E. Soepadmo, A.N. Rao, and D.J. Macintosh, pp 488-495. Kuala Lumpur: University of Malaya.
- Gleason, S.M., Ewel, K.C. and Hue, N. 2003. Soil redox conditions and plant soil relationships in a micronesian mangrove forest. *Estuarine, Coastal and Shelf Science* 56: 1065-1074.
- Golley B.F., Mc Ginnis T.J., Clements G.R., Child I.G and Duever J.M. 1975. *Mineral Cycling in a Tropical Moist Forest Ecosystem*. Athens: University of Georgia Press.
- Gong, K.W., Ong, J.E., Wong, C.H. and Dhanarajan, G. 1984. Productivity of Mangrove Trees and its Significance in a Managed Mangrove Ecosystem in Malaysia. In *Proceedings of the Asian Symposium on Mangrove Environment Research and management*, ed. E. Soepadmo, A.N. Rao, and D.J. Macintosh, pp 216-225. Kuala Lumpur: University of Malaya.
- Gong, W.K. and Ong, J.E. 1990. Plant Biomass and Nutrient Flux in a Managed Mangrove Forest in Malaysia. *Estuarine, Coastal and Shelf Science* 31: 519-530.
- Gong, W.K., Ong, J.E. and Wong, C.H. 1991. The light attenuation method for measuring potential primary productivity in mangrove ecosystems: a evaluation. In *Proceedings of the Regional Symposium on Living Resources in Coastal Seas*, ed. A.C. Alcala, pp 399-406. Quezon City: University of the Philippines.

- Gordon, A.M., Chourmouzis, C. and Gordon, A.G. 2000. Nutrient input in litterfall and rainwater fluxes in 27 - year old red, black and white spruce plantation in Central Ontario, Canada. *Forest Ecology and Management* 138: 65-78.
- Goulter, P.F.E., and Allaway, W.G. 1979. Litter fall and decomposition in a mangrove stand, *Avicennia marina* (Forssk.) Vierh. in Middle Harbour, Sydney. *Australian Journal of Marine and Freshwater Research* 30: 541-546
- Gross, M.G. 1972. *Oceanography a View of Earth*. New Jersey: Prentice-Hall, EnglandWood Cliffs.
- Haines, E., Chalmers, A. Hanson, R. and Sherr, B. 1977. Nitrogen pools and fluxes in a Georgia salt marsh. In *Estuarine processes. Volume II. Circulation, Sediments and Transfer of Materials in the Estuary*, ed. Wiley, pp 241-254. New York: Academic Press.
- Harbison, P. 1986. Mangrove muds – a sink and a source for trace metals. *Marine Pollution Bulletin* 17(6): 246-250.
- Hardiwinoto, S., Nakasuga, T. and Igarashi, T. 1989. Litter production and decomposition of a mangrove forest at Ohura Bay, Okinawa. *Research Bulletins of the College Experiment Forests, Hokkaido University* 46(3): 577-594.
- Harter, R.D. 1992. Comparative sorption of cobalt, copper and nickel ions by a calcium-saturated soil. *Soil Science Society of America Journal* 56(2): 444-449.
- Heal, O.W. and Harrison, A.F. 1990. Turnover of nutrients: a technological challenge. In *Nutrient Cycling in Terrestrial Ecosystems: Field Methods, Application and Interpretation*, ed. A.F. Harrison, P. Ineson, and O.W. Heal, pp 170-178. New York: Elsevier Applied Science.
- Heald, E. 1971. *The production of organic detritus in a south Florida estuary*. University Miami Sea Grant Technical Bulletin 6.
- Heald, E.J. and Odum, W.E. 1970. The contribution of mangrove swamps to Florida fisheries. *Proceedings of the Gulf and Caribbean Fisheries Institute* 22: 130-135.
- Hegazy, A.K. 1998. Perspectives on survival, phenology, litter fall and decomposition, and caloric content of *Avicennia marina* in the Arabian Gulf region. *Journal of Arid Environments* 40: 417-429.
- Hesse, P.R. 1961. Some differences between the soils of *Rhizophora* and *Avicennia* mangrove swamps in Sierra Leone. *Plant and Soil* 14(4): 335-346.
- Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis*. London: Beccles and Colchester.
- Holdridge, L.R., Grenko, W.C., Hatheway, W.H., Liang, T. and Tosi, J. 1971. *Forest environment in tropical life zones; a plot study*. New York: Peragamon Press.
- Hutchings, P. and Saenger, P. 1987. *The Ecology of Mangroves*. Queensland, Australia: University of Queensland Press.
- Hyde, K.D. 1988. Studies on the tropical marine fungi of Brunei. *Bot. J. Linn. Soc.* 98:135-151.
- Ibrahim, S. and Chan, H.T. 1995. Inventory of coastal wetlands in Malaysia. In *Integrated Management of Watersheds in Relation to Coastal and Marine Environment*, ed. B. Japar Sidik, pp 31-47. Malaysian Inventory of Coastal

- Watersheds, Coastal Wetlands, Seagrasses and Coral Reefs. Kuala Lumpur: Department of Environment.
- ISME, 1993. *The Economic and Environmental Values of Mangrove Forest and their Present State of Conservation in the South-East Asia and Pacific Region*. Mangrove Ecosystems Technical Reports Vol 1. Okinawa: ISME.
- Japar Sidik, B. 1989. Studies on leaf litter decomposition of mangroves, *Rhizophora apiculata* BL. Ph. D. thesis. Universiti Sains Malaysia. (Unpublished)
- Jiao, Z.W., Yong, C.X and Peng, L. 1997. Accumulation and biological cycling of heavy metal elements in *Rhizophora stylosa* mangroves in Yingluo Bay, china. *Marine Ecology Progress Series* 159: 293-301.
- Jones, J.B.Jr. 1998. *Plant Nutrition Manual*. New York: CRC Press.
- Jones, J.B.Jr., Wolf, B. and Mills, H.A. 1991. *Plant Analysis Hand Book: A practical sampling, preparation, analysis and interpretation guide*. New York: Micro-Macro Publishing.
- Jordan, C.F. 1985. *Nutrient Cycling in Tropical Forest Ecosystems*. New York: John Wiley & Sons.
- Joshi, G.V., Jamale, B.B. and Bhosale, L. 1974. Ion regulation in mangroves. In *Proceedings of International Symposium on Biology and Management of Mangroves*, ed. G.E. Walsh, S.C. Snedaker and H.J. Teas, pp 595-607. Florida: University of Florida.
- Jungk, A. 1991. Dynamics of nutrient movement at the soil-root interface. In *Plant Roots, The Hidden half*, ed. J. Waisel, A. Eshel and U. Kafkafi, pp 455-481. New York: Marcel Dekker.
- Kabata-Pendias, A. and Pendias, H. 1984. *Trace Elements in Soils and Plants*. Florida: CRC Press.
- Ketterings, Q.M., Coe, R., Noordwijk, M.V., Amagau, Y. and Palm, C.A. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forest. *Forest Ecology and Management* 146: 199-209.
- Kitamura, H., Ishitani, H., Kuge, Y. and Nakamoto, M. 1982. Determination of nitrate in freshwater and seawater by a hydrazine reaction methods. *Japan Journal of Water Pollution Research* 5: 35-42.
- Kohlmeyer, J. and Volkmann-Kohlmeyer, B. 1991. Marine fungi from Queensland, Australia. *Australian Journal of Marine and Freshwater Research* 42: 91-99.
- Komiyama, A., Havanond, S., Srisawatt, W., Mochida, Y., Fujimoto, K., Ohnishi, T., Ishihara, S. and Miyagi, T. 2000. Top/root biomass ratio of a secondary mangrove (*Ceriops tagal* (Perr.) C.B. Rob.) forest. *Forest Ecology and Management* 139: 127-134.
- Komiyama, A., Ogino, K., Aksornkoe, S. and Sabhasri, S. 1987. Root biomass of a mangrove forest in southern Thailand. 1. Estimation by trench method and the zonal structure of root biomass. *Journal of Tropical Ecology* 3: 97-108.
- Kozlowski, T.T. 1973. Extend and Significance of Shedding of Plant Parts. In *Shedding of Plant Parts*, ed. T.T. Kozlowski, pp 1-44. New York: Academic Press.

- Kozlowski, T.T., Kramer, J.P. and Pallardy, S.G. 1991. *The Physiological Ecology of Woody Plants*. San Diego: Academic Press.
- Lacerda, L.D. 1998. Trace metals in mangrove plants: why such low concentrations? In *Mangrove ecosystem studies in Latin America and Africa*, ed. L.D. Lacerda and H.S. Diop, pp171-78. South America: UNESCO.
- Lacerda, L.D., Ittekkot, V. and Patchineelam, S.R. 1995. Biogeochemistry of Mangrove Soil Organic Matter: a Comparison Between *Rhizophora* and *Avicennia* Soils in South-eastern Brazil. *Estuarine, Coastal and Shelf Science* 40: 713–720.
- Lacerda, L.D., Martinelli, L.A., Rezende, C.E., Mozeto, A.A., Ovalle, A.R.C., Victoria, R.L., Silva, C.A.R. and Nogucira, F.B. 1988. The fate of trace metals in suspended matter in a mangrove creek during a tidal cycle. *The Science of the Total Environment* 75: 169-180.
- Lacerda, L.D., Resebde, C.E., Jose, D.V., Wasserman, J.C. and Francisco, M.C. 1985. Mineral Concentrations in Laves of Mangrove Trees. *Biotropica* 17(3): 260-262.
- Leach, G.J. and Burgin, S. 1985. Litter production and seasonality of mangroves in Papua New Guinea. *Aquatic Botany* 23: 215-224.
- Lee, S.Y. 1989. Litter Production and Turnover of the Mangrove *Kandelia candel* (L.) Druce in a Hong Kong Tidal Shrimp Pond. *Estuarine, Coastal and Shelf Science* 29: 75-87.
- Lee, S.Y. 1995. Mangrove outwelling: a review. *Hydrobiologia* 295: 203-212.
- Lee, S.Y. 1998. Ecological role of grapsid crabs in mangrove ecosystems: a review. *Marine and Freshwater Research* 49: 335-343.
- Leh, C.M.U. and Sasekumar, A. 1985. The food of Sesarmid crabs in Malaysian mangrove forest. *Malayan Nature Journal* 39: 135-145.
- Leite, J.O. and Valle, R.R. 1990. Nutrient cycling in the cacao ecosystem: rain and throughfall as nutrient sources for the soil and the cacao tree. *Agriculture, Ecosystems and Environment* 32: 143-154.
- Li, M.S. 1997. Nutrient dynamics of a Futian mangrove forest in Shenzhen, South China. *Estuarine, Coastal and Shelf Science* 45: 463-472.
- Lian, Y., Xu, J., Lin, P., Meguro, S. and Kawachi, S. 1999. Five heavy metals in propagules of ten mangrove species of China. *The Japan Wood Research Society* 45: 343-347.
- Liem, D.S. and Haines, A.K. 1977. The ecological significance and economic importance of the mangrove and estuarine communities of the Gulf Province, Papua New Guinea. In *Purari River (Wabo) Hydroelectric Scheme Environmental Study, Vol. 3*. Waigani, Office of Environment and Conservation and Konedobu, Department of Minerals and Energy.
- Lin, P. and Wang, W. 2001. Changes in the leaf composition, leaf mass and leaf area during leaf senescence in three species of mangroves. *Ecological Engineering* 16: 415-424.
- Lopez-Portillo, J. and Ezcurra, E. 1985. Litter fall of *Avicennia germinans* L. in a One-year Cycle in a Mudflat at the Laguna de Mecoacan, Tabasco, Mexico. *Biotropica* 17(3): 186-190.

- Lu, C. and Lin, P. 1990. Studies on litter fall and decomposition of *Bruguiera sexangula* (Lour.) Poir, community on Hainan Island. *China Bulletin of Marine Science* 47: 139-148.
- Lugo, A.E. and Snedaker, S.C. 1974. The ecology of mangroves. *Annual Review of Ecology and Systematics* 5: 39-64.
- Lugo, A.E. and Snedaker, S.C. 1975. Properties of a mangrove forest in southern Florida. In *Proceedings of international symposium on biology and management of mangroves*, ed. G. Walsh, S. Snedaker and H. Teas, pp 170-212, Gainesville, Florida: University of Florida, Institute of Food and Agricultural Sciences.
- Lugo, A.E., Sell, M. and Snedaker, S.C. 1976. Mangrove Ecosystem Analysis. In *Systems Analysis and Simulation in Ecology*, ed. B.C Patten, pp 114-145. New York: Academic Press.
- Lynch, J.C., Meriwether, J.R., McKee, B.A., Vera-Herrera, F. and Twilley, R.R. 1989. Recent accretion in mangrove ecosystem based on ^{137}Cs and ^{210}Pb . *Estuaries* 12: 264-299.
- MacFarlane, G.R. and Burchett, M.D. 2002. Toxicity, growth and accumulation relationships of copper, lead and zinc in the grey mangrove *Avicennia marina* (Forsk.) Vierh. *Marine Environmental Research* 54: 65-84.
- Macintosh, D.J., Aksornkoae, S., Vannucci, M., Field, C.D., Clough, B.F., Kjerfve, B., Paphavasit, N. and Wattayakorn, G. 1990. *Final Report, Integrated multidisciplinary survey and research programme of the Ranon mangrove researve*, Thailand.
- Mackey, A.P. and Hodgkinson, M.C. 1995. Concentrations and spatial distribution of trace metals in mangrove sediment from the Brisbane River, Australia. *Environmental Pollution* 90(2): 181-186.
- Mackey, A.P. and Smail, G. 1995. Spatial and temporal variation in litter fall of *Avicennia marina* (Forssk.) Vierh. in the Brisbane River, Queensland, Australia. *Aquatic botany* 52: 133-142.
- Mackey, A.P. and Smail, G. 1996. The decomposition of mangrove litter in a subtropical mangrove forest. *Hydrobiologia* 332: 93-98.
- MacNae, W. 1974. *Mangrove forests and fisheries*. Indian Ocean Programme Publication No. 34. Indian Ocean Fishery Commission.
- Mahmood, H. and Saberi, O. 2000. Distribution of Zinc in Sepang Mangrove Forest Environment, Malaysia. *Khulna University Studies* 2(1): 149-157.
- Mahmood, H., Saberi, O., Japar Sidik, B. and Lim, M. T. 2001. Distribution of Copper in the Sepang Mangrove Reserve Forest Environment, Malaysia. *Journal of Tropical Forest Science* 13(1): 130-139.
- Malaysian Metrological Service, 2003. Rainfall, temperature and relative humidity record of station Mardi Tanjong Karang, Kuala Lumpur: MMS
- Malley, D.F. 1978. Degradation of mangrove leaf litter by the tropical sesarmid crab *Chiromanthes onychophorum*. *Marine Biology* 49: 377-386.
- Marschner, H. 1995. *Mineral Nutrition of Higher Plants*. New York: Academic Press.

- Mason, F.C. 1977. *Decomposition*. The Institute of Biology's Studies in Biology no. 74. London: Edward Arnold Limited.
- Mattes, H. and Kapetsky, J.M. 1988. *World wide compendium of mangrove-associated aquatic species of economic importance*. FAO Fisheries Cic. No. 814. Rome: FAO.
- McKee, K.L. 1993. Soil physicochemical patterns and mangrove species distribution - reciprocal effects? *Journal of Ecology* 81: 477-487.
- Mengel, K. and Kirkby, E.A. 1982. *Principles of Plant Nutrition*. Berne: International Potash Institute.
- Meyer, B.S., Anderson, D.B., Bohning, R.H. and Fratiane, D.G. 1973. *Introduction to plant physiology*. New York: D. Van Nostrand Company.
- Micheli, F. 1993. Feeding ecology of mangrove crabs in North Eastern Australia: mangrove litter consumption by *Sesarma messa* and *Sesarma smithii*. *Journal of Experimental Marine Biology and Ecology* 171:165-186.
- Milliman, J.D. and Meade, R.H. 1983. World wide delivery of river sediments to the oceans. *Journal of Geology* 91: 1-21.
- Naidoo, G. 1980. Mangrove soils of the beach wood area, Durban. *South African Journal of Botany* 46: 293-304.
- Nickerson, N.H. and Thibodeau, F.R. 1985. Association between porewater sulfide concentrations and the distribution of mangroves. *Biogeochemistry* 1: 183-192.
- Nielsen, T. and Andersen, F.Ø. 2003. Phosphorus dynamics during decomposition of mangrove (*Rhizophora apiculata*) leaves in sediments. *Journal of Experimental Marine Biology and Ecology* 293: 73-88.
- Noakes, P.S.D. 1952. *A Working plan for the Matang Mangrove Forest Reserve Perak*. Kuala Lumpur: Caxton Press Ltd.
- Norhayati, A. and Latiff, A. 2001. Biomass and species composition of a mangrove forest in Pulau Langkawi, Malaysia. *Malaysian Applied Biology* 30(1 & 2): 75-80.
- Nye, P.H. 1961. Organic matter and nutrient cycles under moist tropical forests. *Plant and Soil* 13: 333-346.
- O'Connel, A.M. 1989. Nutrient accumulation in and release from the litter layer of Karri (*Eucalyptus diversicolor*) forest of southwestern Australia. *Forest Ecology and Management* 26: 95-111.
- Odum, W.E. and Heald, J.E. 1975. The detritus based food webs of an estuarine mangrove community. *Estuarine Research* 1: 265-286.
- Oliver, J. 1982. The geographic and environmental aspects of mangrove communities: climate. In *Mangrove Ecosystems in Australia, Structure, Function and Management*, ed. B.F. Clough, pp 31-54. Australia: Australian Institute of Marine science.
- Ong, E.J., Gong, W.K. and Wong, C.H. 1980. *Ecological survey of the Sungai Merbok estuarine mangrove*. Penang, Malaysia: Universiti Sains Malaysia.
- Ong, J.E. 1982. Mangroves and Aquaculture in Malaysia. *Ambio* 11(5): 252-257.

- Ong, J.E., Gong, W.K. and Clough, B.F. 1995. Structure and productivity of a 20-year-old stand of *Rhizophora apiculata* Bl. mangrove forest. *Journal of Biogeography* 22: 417-424.
- Ong, J.E., Gong, W.K. and Wong, C.H. 1985a. Seven Years of Productivity Studies in a Malaysian Managed Mangrove Forest, then What?. In *Coastal and Tidal Wetlands of the Australian Monsoon Region*, ed. K.N. Bardsley, J.D.S. Davie, and C.D. Woodroffe, pp 213-223. Australia: Australian National University.
- Ong, J.E., Gong, W.K. and Zubir, B.H.D. 1985b. *Productivity of the mangrove ecosystem: A manual of methods*. The UNDP/ UNESCO Regional Project, Penang, Malaysia: Universiti Sains Malaysia.
- Onuf, C. P., Teal, J. M. and Valiela, I. 1977. Interaction of nutrients, plant growth and herbivory in a mangrove ecosystem. *Ecology* 58: 514-526.
- Orson, R.A., Simpson, R.L. and Good, R.E. 1992. A mechanism for the accumulation and retention of heavy metals in tidal freshwater marshes of the upper Delaware River estuary. *Estuarine, Coastal and Shelf Science* 34: 171-186.
- Pannier, F. 1984. Analysis of soil, plant and water components. In *The mangrove ecosystem: research methods*, ed. C.S. Snedaker, and J.G. Snedaker, pp. 131-161. United Kingdom: Unesco.
- Pool, D.J., Lugo, A.E. and Snedaker, C.S. 1975. Litter production in mangrove forests of Southern Florida and Puerto Rico. In *proceedings of the international Symposium on Biology and management of Mangroves*, ed. E.G. Walsh, C.S. Snedaker, and H.J. Teas, pp 213-237. Institute of Food and Agricultural Sciences, Florida: University of Florida.
- Pool, D.J., Snedaker, S.C. and Lugo, A.E. 1977. Structure of mangrove forests in Florida, Puerto Rico, Mexico and Costa Rica. *Biotropica* 9(3): 195-212.
- Poovachiranon, S., Boto, K and Duke, N. 1986. Food preference studies and ingestion rate measurements of the mangrove amphipod *Parhyale hawaiiensis* (Dana). *Journal of Experimental Marine Biology and Ecology* 98: 129-140.
- Prause, J., Lifschitz, A.P., Dalurzo, H.C. and Agudo, D.E. 2002. Leaf litter fall and decomposition in a forest of the Chaco Argentino. *Communication in Soil Science and Plant Analysis* 33(20): 3653-3661.
- Putz, F.E. and Chan, H.T. 1986. Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. *Forest Ecology and Management* 17: 211-230.
- Ranger, J. and Turpault, M.P. 1999. Input-output nutrient budgets as a diagnostic tool for sustainable forest management. *Forest Ecology and Management* 122: 139-154.
- Rapp, M., Regina, I.S., Rico, M. and Gallego, H.A. 1999. Biomass, nutrient content, litterfall and nutrient return to the soil in Mediterranean oak forest. *Forest Ecology and Management* 119: 39-49.
- Reed, D.J. 1988. Sediment dynamics and deposition in a retreating coastal salt marsh creeks. *Estuarine, Coastal and Shelf Science* 26: 67-79.
- Reice, S.R., Spira, Y and Pro, F.D. 1984. Decomposition in the mangal of Sinai: The effect of spatial heterogeneity. In *Hydrobiology of the Mangal, the Ecosystem of*

- the Mangrove Forest*, ed. F.D. Pro and I. Dor, pp 193-199. The Hague: Dr. W. Junk Publishers.
- Reynolds, B and Neal, C. 1991. Through versus funnel collectors for measuring throughfall volumes. *Journal of Environmental Quality* 20: 518-521.
- Ricklefs, R.E. and Latham, R.E. 1993. Global patterns of diversity in mangrove floras. In *Species Diversity in Ecological Communities*. ed. R.E. Ricklefs and D. Schluter, pp 215-229. Chicago: University of Chicago.
- Robertson, A.I. 1986. Leaf-burying crabs: their influence on energy flow and export from mixed mangrove forests (*Rhizophora* spp.) in northeastern Australia. *Journal of Experimental Marine Biology and Ecology* 102: 237-248.
- Robertson, A.I. 1988. Decomposition of mangrove leaf litter in tropical Australia. *Journal of Experimental Marine Biology and Ecology* 116: 235-247.
- Robertson, A.I. and Daniel, P.A. 1989. The influence of crabs on litter processing in high intertidal mangrove forests in tropical Australia. *Oecologia* 78: 191-198.
- Robertson, A.I. and Duke, N.C. 1987. Insect herbivory on mangrove leaves in North Queensland. *Australian Journal of Ecology* 12: 1-7.
- Robertson, A.I., Alongi, D.M. and Boto, K.G. 1992. Food chains and carbon fluxes. In *Tropical Mangrove Ecosystem*, ed. A.I. Robertson, and D.M. Alongi, pp 293-326. Washington DC: American Geographical Union,
- Robertson, P.J. 1989. Influence of crabs on litter processing in high intertidal mangrove forests in tropical America. *Oecologia* 78: 191-198.
- Saberi, O. 1989. The Rate of Litter Production in Mangrove Forest at Siar Beach, Lundu, Sarawak. *Pertanika* 12(1): 47-51.
- Sadiq, M. and Zaidi, T.H. 1994. Sediment composition and metal concentrations in mangrove leaves from the Saudi coast of the Arabian Gulf. *The Science of the Total Environment* 155: 1-8.
- Saenger, P. and Snedaker, S.C 1993. Pantropical trends in mangrove above-ground biomass and annual litterfall. *Oecologia* 96: 293-299.
- Saenger, P., Hegerl, E.J. and Davie, S.D.J. 1983. Global status of mangrove ecosystems. *The Environmentalist* 3, Supplement no 3.
- Saifullah, S.M., Khafaji, A.K. and Mandura, A.S. 1989. Litter production in a mangrove stand of the Saudi Arabia Red sea coast. *Aquatic Botany* 36: 79-86.
- Salamanca, E.F., Kaneko, N and Katagiri, S. 1998. Nutrient dynamics in decomposing forest leaf litter: A comparison of field and laboratory microcosm approach. *Journal of Forest Research* 3: 91-98.
- Sasekumar, A. 1974. Distribution of Macrofauna on a Malayan Mangrove shore. *Journal of Animal Ecology* 43: 51-69.
- Sasekumar, A. and Loi, J.J. 1983. Litter production in three mangrove forest zone in the Malay Peninsula. *Aquatic Botany* 17: 283-290.
- Schlesinger, H.W. 1978. Community structure, dynamic and nutrient cycling in the Okefenokee Cypress swamp forest. *Ecological Monographs* 48: 43-65.
- Seasted, T.R. 1984. The role of microarthropods in decomposition and mineralization processes. *Annual Review of Entomology* 29: 25-46.

- Shahbudin, S. 1996. Sediment accretion and variability of sedimentological characteristics of a tropical estuarine mangrove: Kemaman, Terengganu. MS Thesis. Universiti Putra Malaysia. (Unpublished)
- Shriadah, M.M.A. 1999. Heavy Metals in Mangrove Sediments of the United Arab Emirates Shoreline (Arabian Gulf). *Water, Air, and Soil Pollution* 116: 523-534.
- Silva, C.A.R., Lacerda, L.D. and Rezende, C.E. 1990. Metals Reservoir in a Red Mangrove Forest. *Biotropica* 22 (4): 339-345.
- Silva, C.A.R., Lacerda, L.D., Ovalle, A.R., Rezende, C.E. 1998. The dynamics of heavy metals through litterfall and decomposition in a red mangrove forest. *Mangroves and Salt Marshes* 2: 149-157.
- Slim, F.J., Gwada, P.M. Kodjo, M. and Hemminga, M.A. 1996. Biomass and litterfall of *Ceriops tagal* and *Rhizophora mucronata* in the mangrove forest of Gazi bay, Kenya. *Marine and Freshwater Research* 47(8): 999-1007.
- Smith, T.J. 1987. Seed predation in relation to tree dominance and distribution in mangrove forests. *Ecology* 68(2): 266-273.
- Smith, T.J. 1992. Forest structure. In *Tropical Mangrove Ecosystem*, ed. A.I. Robertson and D.M. Alongi, pp 101-136. Coastal and Estuarine Studies 41, Washington, DC: American Geophysical Union.
- Smith, T.J., Chan, H.T., McIvor, C.C. and Robblee, M.R. 1989. Comparisons of seed predation in tropical tidal forests from three continents. *Ecology* 70(1): 146-151.
- Soekardjo, S. and Kartawinata, K. 1979. Mangrove forest of Banyuasin Musi river estuary, South Sumatra. In *Symposium on Mangrove & Estuarine Vegetation of Southeast Asia*, ed. P.B.L. Srivastava, A.M. Ahmad, G. Dhanarajan, and I. Hamzah, pp 61-79. Bogor, Indonesia: Biotrop.
- Spalding, M.D., Blasco, F. and Field, C.D. 1997. *World Mangrove Atlas*. Okinawa, Japan: The International Society for Mangrove Ecosystems.
- Spenceley, A.P. 1982. Sedimentation pattern in a mangal on Magnetic island near Townsville, North Queensland, Australia. *Singapore Journal of Geography* 3: 100-107.
- Srivastava, P.B.L., Majid, N.M. and Shariff, A.H. 1978. Some aspects of plant and soil nutrients in mangrove ecosystem. In *Proceedings Malaysian Seminar on Fertility and Management of Deforested Land*, ed. P.B.L. Srivastava, pp 79-91 Serdang: Universiti Pertanian Malaysia.
- Steinke, D.T., Ward, C.J. and Rajh, A. 1995. Forest structure and biomass of mangroves in the Mgeni estuary, South Africa. *Hydrobiologia* 295: 159-166.
- Steinke, T.D and Ward, C.J. 1987. Degradation of mangrove leaf litter in the St. Lucia Estuary as influence by season and exposure. *South African Journal of Botany* 53: 323-328.
- Steinke, T.D. and Charles, L.M. 1986. Litter production by mangroves. I: Mgeni estuary. *South African Journal of Botany* 52(6): 552-558.
- Steinke, T.D. and Ward, C.J. 1988. Litter production by mangroves. II. St. Lucia and Richards Bay. *South African Journal of Botany* 54(5): 445-454.

- Steinke, T.D. and Ward, C.J. 1990. Litter production by mangroves. III. Wavecrest (Transkei) with predictions for other Transkei estuaries. *South African Journal of Botany* 56(5): 514-519.
- Steinke, T.D., Holland, A.J., and Singh, Y., 1993a. Leaching losses during decomposition of mangrove leaf litter. *South African Journal of Botany* 59: 21-25.
- Steinke, T.D., Rajh, A. and Holland, A.J. 1993b. The feeding behaviour of the red mangrove crab *Sesarma meinerti* de man, 1887 (Crustacea: Decapoda: Grapsidae) and its effect on the degradation of mangrove leaf litter. *South African Journal of Marine Science* 13: 151– 160.
- Stewart, B.A., and Davies, B.R. 1989. The influence of different litter bag designs on the breakdown of leaf material in a small mountain stream. *Hydrobiology* 183: 173-177.
- Sukardjo, S. and Yamada, I. 1992. Biomass and productivity of a *Rhizophora mucronata* Lam. plantation in Tritih, central Java, Indonesia. *Forest Ecology and Management* 49: 195-209.
- Sukardjo, S., Kartwinata, K. and Yamada, I. 1984. The mangrove forest in Bungu River, Banyuasin South Sumatra. In *Proceedings of the Asian Symposium on Mangrove Environment Research and management*, ed. E. Soepadmo, N.A. Rao, and J.D. Macintosh, pp 121-141. Kuala Lumpur: University of Malaya.
- Suzuki, E. and Tagawa, H. 1983. Biomass of a mangrove forest and sedge marsh on Ishigaki Island, South Japan, *Japan Journal of Ecology* 33: 231-234.
- Swift, M.J., Heal, O.W. and Anderson, J.M. 1979. *Decomposition in Terrestrial Ecosystems*. Oxford: Blackwell Scientific Publisher.
- Tam, N.F.Y. and Wong, Y.S. 1996. Retention and distribution of heavy metals in mangrove soils receiving wastewater. *Environmental Pollution* 94(3): 283-291.
- Tam, N.F.Y. and Wong, Y.S. 1995. Spatial and Temporal Variation of Heavy Metal Contamination in Sediments of a Mangrove Swamp in Hong Kong. *Marine Pollution Bulletin* 31(4-12): 254-260.
- Tam, N.F.Y., Li, S.H., Lan, C.Y., Chen, G.Z., Li, M.S. and Wong, Y.S. 1995a. Nutrients and heavy metal contamination of plants and sediments in Futian mangrove forest. *Hydrobiologia* 295: 149-158.
- Tam, N.F.Y., Vrijmoed, L.L.P. and Wong, Y.S. 1990. Nutrient dynamics associated with leaf decomposition in a small subtropical mangrove community in Hong Kong. *Bulletin of Marine Science* 47(1): 68-78.
- Tam, N.F.Y., Wong, Y.S., Lan, C.Y. and Wang, L.N. 1998. Litter production and decomposition in a subtropical mangrove swamp receiving wastewater. *Journal of Experimental Marine Biology and Ecology* 226: 1-18.
- Tam, Y.F.N, Wong, Y.S. Lan, C.Y. and Chen, G.Z. 1995b. Community structure and standing crop biomass of a mangrove forest in Futin Natural Reserve, Shenzhen, China. *Hydrobiologia* 295: 193-201.
- Tamai, S., Nakasuga, T., Tabuchi, R. and Ogino, K. 1986. Standing biomass of mangrove forests in southern Thailand. *Journal of Japan Forest Science* 68(9): 384-388.

- Tandon, H.L.S. 1993. *Methods of Analysis of Soils, Plants, Waters and Fertilize*. New Delhi: Fertilizer Development and Consultation Organization.
- Teas, H.J. 1979. Silviculture with saline water. In *The Biosaline concept*, ed. A. Hollaender, pp 117-1161. New York: Plenum.
- Thibodeau, F.R. and Nickerson, N.H. 1986. Differential oxidation of mangrove substrate by *Avicennia germinans* and *Rhizophora mangle*. *American Journal of Botany* 73: 512-516.
- Thomas, G. and Fernandez, T.V. 1997. Incidence of heavy metals in the mangrove flora and sediments in Kerala, India. *Hydrobiology* 352: 77-87.
- Timothy, R.P., Yoshiaki, M. and Carol, M.L. 1984. *A manual of chemical and biological methods for seawater analysis*. Pergamon press.
- Tomlinson, B.P. 1986. *The Botany of Mangroves*. Cambridge: Cambridge University Press.
- Trudgill, S.T. 1988. *Soil and Vegetation Systems*. Oxford: Clarendon Press.
- Tukey, H.B.Jr. 1970. Leaching of substances from plants. *Annual Review of Plant Physiology* 21: 305-324.
- Turner, I.M., Gong, W.K., Ong, J.E., Japar Sidik, B. and Kohyama, T. 1995. The architecture and allometry of mangrove saplings. *Functional Ecology* 9: 205-212.
- Tusneem, M.E. and Patrick, W.H. 1971. *Nitrogen Transformation in waterlogged soil*. *Soil Bulletin No. 657*. Department of Agronomy, USA: Louisiana State University.
- Twilley, R.R. and Chen, R. 1997. The utility of ecological models in the assessment of oil impact to mangrove ecosystems. In *Managing Oil Spills in Mangrove Ecosystems: Effects, Remediation, Restoration, and Modeling*, ed. C.E. Proffitt. pp 29-52. U.S. Department of Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.
- Twilley, R.R., Lugo, A.E. and Patterson-Zucca, C. 1986 Litter production and turnover in basin mangrove forests in southwest Florida. *Ecology* 67: 670-683.
- Twilley, R.R., Pozo, M., Garcia, V H., Rivera, V H., Zambrano, M.R. and Boderio, A. 1997. Litter dynamics in riverine mangrove forests in the Guayas River estuary, Ecuador. *Oecologia* 111: 109-122.
- Ukpong, I.E. 1994. Soil-vegetation interrelationships of mangrove swamps as revealed by multivariate analysis. *Geoderma* 64: 167-181.
- Valiela, I., Teal, J.M., Allen, S.D., Etten, R.V., Goehring, D. and Volkmann, S. 1985. Decomposition in salt marsh ecosystems: the phases and major factors affecting disappearance of above-ground organic matter. *Journal of Experimental Marine Biology and Ecology* 89: 29-54.
- Valiela, I., Teal, M.J. Volkmann, S. Shafer, D. and Carpenter, J.E. 1978. Nutrient and particulate fluxes in a salt marsh ecosystem: Tidal exchanges and inputs by precipitation and ground water. *Limnology Oceanography* 23: 798-812.
- Van Breemen, N. 1976. *Genesis and solution chemistry of acid sulphate soil in Thailand*. Agricultural Research Report.

- Van de Valk, A.G. and Attiwill, P.M. 1984. Decomposition of leaf and root litter of *Avicennia marina* at Westernport Bay, Victoria, Australia. *Aquatic Botany* 18: 205-221.
- Vestergaard, P. 1979. A study of indication of trace metal pollution of marine areas by analysis of salt marsh soils. *Marine Environmental Research* 2: 19-31.
- Vitousek, M.P. 1984. Litter fall, Nutrient cycling, and nutrient limitation in tropical forests. *Ecology* 65(1): 285-298.
- Vrijmoed, L.L.P., Hyde, K.D. and Jones, E.B.G. 1994. *Diaporthe salsuginea* sp. nov. and *Aniptodera* sp. nov. from Hong Kong and Macau mangroves. *Mycology Research* 96: 699-704.
- Wafar, S., Untawale, A.G. and Wafar, M. 1997. Litter fall and energy flux in mangrove ecosystem. *Estuarine, Coastal and Shelf Science* 44: 111-124.
- Waisel, Y., Ethel, A. and Sagami, M. 1986. Salt balance of leaves of the mangrove *Avicennia marina*. *Physiologia Plantarum* 67: 67-72.
- Walbridge, M.R. 1991. Phosphorus availability in acid organic soils of the lower north Carolina coastal plain. *Ecology* 72: 2083-2100.
- Walsh, G.E. 1974. Mangroves: A review. In *Ecology of halophytes*, ed. R. Reimhold and W. Queen, pp 51-174. New York: Academic Press.
- Waring, R.H. and Schlesinger, W.H. 1985. *Forest Ecosystems Concepts and Management*. New York: Academic Press INC.
- Watson, G.J. 1928. *Malayan forest Record 6: Mangrove Forests of the Malay Peninsula*. Singapore: Fraser and Neave Ltd.
- Weatherburn, M.W. 1967. Phenol-hypochlorite reaction for determination of ammonia. *Analytical Chemistry* 39(8): 971-974.
- Westlake, D.F. 1963. Comparison of plant productivity. *Biological Review* 38: 385-425.
- Whittaker, R.H. and Marks, P.L. 1975. Methods of assessing terrestrial productivity. In *Primary productivity of the biosphere, Ecological Studies 1*, ed. H. Lieth and R.H. Whittaker, pp 55-118. New York: Springer-Verlag.
- Wolanski, E. 1995. Transport of sediment in mangrove swamps. *Hydrobiologia* 295: 31-42.
- Woodroffe, C.D. 1984. Litter fall beneath *Rhizophora stylosa* Griff., vaitupu, Tuvalu, South Pacific. *Aquatic Botany* 18: 249-255.
- Woodroffe, C.D. 1985. Studies of a mangrove basin, Tuff Carter, New Zealand. III. The flux of organic and inorganic particulate matter. *Estuarine, Coastal and Shelf Science* 20: 447-462.
- Woodroffe, C.D. 1990. The impact of sea level rise on mangrove shorelines. *Progress in Physical Geography* 14: 483-520.
- Woodroffe, C.D., Bardsley, K.N., Ward, P.J. and Hanley, J.R. 1988. Production of Mangrove Litter in a Macrotidal Embayment, Darwin Harbour, N.T., Australia. *Estuarine, Coastal and Shelf Science* 26: 581-598
- Yaalon, D.H. and Lomas, J. 1976. Factors controlling the supply and chemical composition of aerosols in a near shore and coastal environment. *Agricultural Meteorology* 7: 370-381.

- Young, B.M. and Harvey, L.E.A. 1996. A spatial analysis of the relationship between mangrove (*Avicennia marina* var. *australasica*) physiognomy and sediment accretion in the Hauraki Plains, New Zealand. *Estuarine, Coastal and Shelf Science* 42(2): 231-246.
- Zulkifli, Y., Rahim, N.A. and Baharuddin, 1997. Nutrients input-output budgets in secondary forest catchments of Bukit Tarek experimental watershed, Peninsular Malaysia. In *Conference on Forestry and Forest Products Research*, pp 111-123. Kuala Lumpur: FRIM.

Appendix A

Table 2.11: Analysis of variance of seasonal litter standing crop at different season

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Litter components, plots and seasons	28	470168.32	108.08	0.0001	0.89
Litter components	6	448574.42	481.22	0.0001	
Plots	17	6552.65	2.48	0.0008	
Seasons	5	15041.26	19.36	0.0001	
Error	727	112947.35			
Total	755	583115.67			

Table 3.10: Analysis of variance of NH_4 content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	7.83	391.64	0.0001	0.98
Water samples	4	3.35	997.66	0.0001	
Seasons	4	2.31	693.21	0.0001	
Water samples*Seasons	16	2.20	164.74	0.0001	
Error	200	0.17			
Total	224	8.00			

Table 3.11: Analysis of variance of NO_3 content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	0.12	183.55	0.0001	0.97
Water samples	4	0.08	705.79	0.0001	
Seasons	4	0.01	48.28	0.0001	
Water samples*Seasons	16	0.038	86.81	0.0001	
Error	200	0.005			
Total	224	0.12			

Table 3.12: Analysis of variance of PO₄ content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	0.18	425.79	0.0001	0.98
Water samples	4	0.10	1482.09	0.0001	
Seasons	4	0.02	317.69	0.0001	
Water samples*Seasons	16	0.05	188.74	0.0001	
Error	200	0.003			
Total	224	0.18			

Table 3.13: Analysis of variance of SO₄ content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	297079225.64	1089.42	0.0001	0.99
Water samples	4	2272450.94	5467.87	0.0001	
Seasons	4	299351676.58	300.94	0.0001	
Water samples*Seasons	16	248509503.66	191.93	0.0001	
Error	200	13677460.41			
Total	224	34892261.57			

Table 3.14: Analysis of variance of K content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	1925098.80	14520.33	0.0001	0.99
Water samples	4	1217997.58	55121.52	0.0001	
Seasons	4	130813.16	5920.06	0.0001	
Water samples*Seasons	16	576288.05	6520.10	0.0001	
Error	200	1104.83			
Total	224	1926203.63			

Table 3.15: Analysis of variance of Ca content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	12112893.13	99999.99	0.0001	0.99
Water samples	4	10270626.03	99999.99	0.0001	
Seasons	4	376870.14	87482.28	0.0001	
Water samples*Seasons	16	1465396.96	85040.08	0.0001	
Error	200	215.40			
Total	224	12113108.53			

Table 3.16: Analysis of variance of Mg content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	160948979.18	99999.99	0.0001	0.99
Water samples	4	160171367.71	99999.99	0.0001	
Seasons	4	181948.03	1638.74	0.0001	
Water samples*Seasons	16	595663.44	1341.23	0.0001	
Error	200	5551.47			
Total	224	160954530.65			

Table 3.17: Analysis of variance of Cu content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	0.11	635.23	0.0001	0.98
Water samples	4	0.11	3748.72	0.0001	
Seasons	4	0.001	24.99	0.0001	
Water samples*Seasons	16	0.001	9.43	0.0001	
Error	200	0.001			
Total	224	0.12			

Table 3.18: Analysis of variance of Fe content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	12.06	20748.38	0.0001	0.99
Water samples	4	10.58	99999.99	0.0001	
Seasons	4	0.33	3376.27	0.0001	
Water samples*Seasons	16	1.16	2983.96	0.0001	
Error	200	0.005			
Total	224	12.07			

Table 3.19: Analysis of variance of Fe content in different water samples at different seasons

Source of variation	Degree of freedom	Sum of square	F value	Pr > F	r value
Model	24	0.51	2001.29	0.0001	0.99
Water samples	4	0.50	11776.06	0.0001	
Seasons	4	0.001	33.33	0.0001	
Water samples*Seasons	16	0.008	49.59	0.0001	
Error	200	0.002			
Total	224	0.51			

Table 4.11: 't' values of regression slop and coefficient of different components of saplings and trees.

Plant components	Calculated 't' value
Total above ground	2.82
Roots	2.18
Stems	2.95
Branches	2.43
Leaves	3.00
Buds	2.81