NUTRIENT DYNAMICS IN DIFFERENT SUB-TYPES OF PEAT SWAMP FOREST IN CENTRAL KALIMANTAN, INDONESIA

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ABSTRACT

Nutrient dynamics of two sub-types of peat swamp forest, mixed swamp forest and low pole forest, in the upper catchment of the Sebangau River in Central Kalimantan, Indonesia were studied. Three permanent study plots, 50 x 50 m, were established in each forest sub-type to facilitate collection of throughfall, stemflow, litterfall, decomposition, above ground and below ground biomass, peat and water samples. Graphical presentation, Wilm's method, and analysis of variance were carried out for both sub-types of forest in order to analyse data to detect any significant differences.

Rainfall is slightly acid (pH 5.96±0.35) with a predominance of NH_4-N, Ca and K. Throughfall and stemflow are enriched in most elements analysed compared to rainfall and the pH values are lower. Throughfall pH is 4.76±0.33 in mixed swamp forest and 4.37±0.33 in low pole forest. Stemflow pH is 4.03±0.19 in mixed swamp forest and 3.57±0.11 in low pole forest.

Greater litter production was obtained in mixed swamp forest (8,411 kg ha^{-1} yr^{-1}) than in low pole forest (6,534 kg ha^{-1} yr^{-1}). Dry weight of the different fractions of litterfall (leaves, branches, reproductive parts and other debris) for MSF and LPF were 6216, 1246, 460 and 489 kg ha^{-1} and 4864, 1251, 169 and 251 kg ha^{-1}, respectively.

Decomposition rates (*k*) in the MSF and LPF are 0.396 yr^{-1} and 0.285 yr^{-1} respectively. Above ground biomass in MSF and LPF are 313,899 and 252,547 kg ha^{-1}, respectively, while below ground (root biomass) is 26,533 and 14,382 kg ha^{-1} respectively. Nitrogen is the predominant nutrient in peat soil at 50 cm depth in both MSF and LPF, while manganese is the lowest. Calcium is the element in greatest amount in water run off in MSF and LPF at 8.15 and 7.15 kg ha^{-1} yr^{-1} respectively, while manganese was the lowest at 0.01 and 0.02 kg ha^{-1} yr^{-1}, respectively.

Nutrient inputs were higher than nutrient losses during the 1-year study period with the greatest nutrient gain for calcium while manganese was the lowest in both sub-types of forest. Moreover, the results of this study highlight that nutrient concentrations in peat soils are low and the substrates are acidic. These factors are likely to be strongly limiting to agricultural development, including plantations of estate crops and trees. Under such conditions the maintenance of intact forest for natural ecosystem services (e.g. carbon storage, watershed, biodiversity maintenance, timber production in certain time period) is likely to be a far wiser land use from a long-term perspective.

SUMMARY

Nutrient dynamics of two sub-types of peat swamp forest, mixed swamp forest and low pole forest, in the upper catchment of the Sebangau River in Central Kalimantan, Indonesia were studied. The study area lies within the 'Natural Laboratory for Management of Peat Swamp Forest'. Three permanent study plots, 50 x 50 m, were established in each forest sub-type to facilitate collection of throughfall, litterfall, live biomass (above ground and below ground), peat and water samples.

Rainfall was sampled in four gauges located in the vicinity of the research plots. For the throughfall, a statistical sampling procedure, involving a combination of one fixed and two roving gauges (plastic funnels and polyethylene containers) was employed. For the collection of stemflow, water was obtained from five trees of different diameter by means of plastic collars placed around their stems. For the litterfall, three sampling containers 0.3845 m^2 (70 cm diameter) in area were established 1 m above the forest floor, involving a combination of one fixed and two roving gauges (same with throughfall). The sampling containers were constructed from 1-mm mesh plastic net, wood and wire. Above ground biomass of trees and shrubs, was measured in 27 sub-plots in each forest type within 5 x 5 m quadrats. Below ground biomass (living fine roots) was measured by excavating peat from one 1 x 1 m quadrat to a depth of 0.5 m from the middle of each study plot and another four 0.5 x 0.5 x 0.5 m samples from each of the four corners. Surface peat and water were sampled in the same plot as that used for standing crop (trees diameter < 5 cm).

Rainfall, throughfall, and stemflow samples were collected every two weeks from the beginning of November 2000 to the beginning of November 2001. Samples were stored in a refrigerator (4°C) after collection. Next day, water samples were filtered after pH analysis. Chemical analyses were carried out on the filtered samples for Ca, Mg, K, Na, Fe and Mn using atomic absorption spectrophotometry (AAS spectra 30). Ammonium was measured by the indophenol method (Scheiner, 1976), phosphate and nitrite were measured by the method in Tachibana (2000).

Litterfall samples were air dried for 2 weeks at room temperature, separated into leaves, branches, reproductive parts and other debris, oven dried for 48 hours at 70° C and dry weight determined. Chemical analysis was carried out on samples dried for 48 hours at 70° C. The determination of total nitrogen was carried out by persulphate digestion (Purcell & King, 1996). Ca, Mg, K, Na, P, Fe and Mn were determined following wet digestion of dried samples by 18% perchloric acid (Tolg, 1974 cit Jones & Case, 1990). Total phosphorus was determined by the Scheel method (Lambert, 1992). Ca, Mg, K, Na, Fe and Mn were measured by atomic absorption spectrophotometry (AAS spectra 30).

Chemical analysis for above ground and below ground biomass, peat, and decomposition were similar to litterfall. Chemical analysis for surface water was similar to rainfall and throughfall.

Rainfall is slightly acid (pH between 5.55 and 6.46 with average 5.96±0.35) with a predominance of Ca and K. Throughfall and stemflow is enriched in most elements analysed compared to rainfall and its pH values are lower. Throughfall pH ranges from 4.15 to 5.32 (average 4.76±0.33) in mixed swamp forest and from

pH 3.56 to 5.36 (average 4.37±0.33) in low pole forest. Stemflow pH ranges from 3.42 to 4.43 (average 4.03±0.19) in mixed swamp forest and from 2.88 to 4.01 (average 3.57±0.11) in low pole forest. Nutrient input in rainwater (rainfall), canopy leachate (throughfall), and stemflow showed temporal variation. The amount of throughfall and stemflow decreases with decreasing rainfall and in Mixed Swamp Forest throughfall is 1969 mm (71%) of the total precipitation whereas in Low Pole Forest throughfall it is 2170 mm (79%). Mixed swamp forest stemflow is 81.9 mm (2.97%) of the total precipitation whereas in Low pole forest stemflow it is 136 mm (4.9%). The order of magnitude of chemical elements reaching the forest floor in throughfall is calcium, potassium, ammonium, magnesium and sodium in Low Pole Forest, and potassium, calcium, ammonium, magnesium and sodium in Mixed swamp Forest.

Greater litter production was obtained in mixed swamp forest (8,411 kg ha^{-1} yr^{-1}) compared to low pole forest (6,534 kg ha^{-1} yr^{-1}). Dry weight of the different fractions of litterfall (leaves, branches, reproductive parts and other debris) for MSF and LPF were 6216, 1246, 460 and 489 kg ha^{-1} and 4864, 1251, 169 and 251 kg ha^{-1}, respectively. The proportions of each litter component obtained in this study are: (1) mixed swamp forest - leaf litter 74%, branches 15%, reproductive parts 5% and other debris 6%; (2) low pole forest - leaf litter 74%, branches 19%, reproductive parts 3% and other debris 4%. There are differences in nutrient concentration between the litterfall categories and leaves were high in Ca, Mg, Na, Fe and Mn while reproductive parts were high in N, P, and K. As far as the seasonal pattern of litterfall is concerned, mixed swamp forest and low pole forest exhibited the same bimodal peaks of leaf fall at the end of the wet season (Feb-March) and end of the dry season (August-Sept).

Weight loss (decomposition study) in both sub-type of forest, mixed swamp forest and low pole forest was fast in the first six months. Potassium was the fastest nutrient lost in the mixed swamp forest and low pole forest. Decomposition rate (k) in the mixed swamp forest and low pole forest are 0.396 yr^{-1} and 0.285 yr^{-1} respectively.

The live above ground biomass in the mixed swamp forest and low pole forest were 313,899 and 252,548 kg ha^{-1}, respectively. Calcium is the cation present in the greatest amount in above ground biomass in both sub-type of forest while manganese is the lowest. The live below ground biomass (roots) 50 cm deep in the mixed swamp- forest and low pole forest are 26533 and 14382.7 kg ha^{-1}, respectively. Nitrogen is the nutrient present in the greatest amount in roots biomass in both sub-type of forest while manganese is the lowest.

Nitrogen is the greatest amount of nutrient in peat 50 cm deep in the mixed swamp forest and low pole forest that are 21478 and 16426 kg ha^{-1} respectively, while manganese was the lowest that are 2.7 and 2.7 kg ha^{-1} respectively. Calcium is the greatest amount of calcium in water run off in the mixed swamp forest and low pole forest that were 8.15 and 7.15 kg ha^{-1} yr^{-1} respectively, while manganese was the lowest with 0.01 and 0.02 kg ha^{-1} yr^{-1}, respectively.

Comparison methods between Wilm's method (co variance methods) and Excel (conventional statistic) for throughfall and litterfall show that Wilm's method has advantages. For example, it leads to reductions in the standard errors of the mean values for each collection period and the total values for the year. Wilm's method reduced the variability in the means of 4 weekly period sampling during the 1-year period. Disadvantages of Wilm's method, such as, if there is big variation in sample values between successive time periods high standard errors result and mean differences are smoothed out. The other Wilm's method disadvantage is the long time it takes to input data and carry out the analyses. These operations have to be carried out on every component separately.

The pH of rainwater in the Sg. Sebangau catchment is slightly acidic (mean 5.96±0.35). Neutralization of the weak acidity in the rain falling on the Sebangau catchment could also be caused by atmospheric NH_3 originating in the agriculture area, near to the study plot, where NH_4NO_3 and $(NH_4)_2$ SO_4 containing fertilizers are used intensively and biomass burning produces inorganic N and basic cations such as Ca^{2+}, Mg^{2+} and K^+. Biomass burning in the tropics is an important major source of trace gases and particulate matter (including nutrient) to the atmosphere. Furthermore, deforestation, intensification of agricultural practices, fossil fuel combustion and emision of natural soil ecosystems also affect the fluxes of trace gases and particulates to the atmosphere.

Various reasons have been suggested to explain the changes that occur in the pH of precipitation as it passes through a vegetation canopy and temporal variations. Throughfall may contain pollutants leached from the canopy (dry deposit) or organic acids from tree organs. Temporal variations may result from differences in intensity and duration of precipitation and variations in the intensity of airborne aerosols and particulates throughout the year.

Litter production in mixed swamp forest was 8,411 kg ha^{-1} yr^{-1} and low pole forest was 6,534 kg ha^{-1} yr^{-1}. Tropical peat swamp forest is less productive compared to tropical lowland forests in general. This relatively low productivity of natural vegetation is believed to reflect the relative poverty of the tropical peat as a result of its anaerobic condition and acidity. The low oxygen content and low pH are known to inhibit biological processes involved in organic matter decomposition, thus resulting in mineral lock up in a form unavailable for plant use.

In this study k (decomposition rate) in mixed swamp forest (MSF) was 0.396 and 0.285 in low pole forest (LPF) and is relatively low compared to other decomposition studies of tropical forests except for similar results from another peatland area in Central Kalimantan ($k = 0.438$). The low k values obtained in this study are a result of anaerobic conditions for most of the year in this study area, the plant species are poor in nutrients, (plant species from nutrient-poor environments are produce litter that is more difficult to decompose than litter of species from nutrient-rich environments) and the acidity of peat soil (pH 2.82 – 3.80).

The total biomass and amount of nutrients in mixed swamp forest was higher than in low pole forest as a result of differences in decomposition processes, water table depth and peat-pore water chemistry. Soil pH and nutrient concentrations in this study area were low because thick peat (the nutrient content and pH in thin peat was higher than thick peat) and the nature of the underlying mineral soil quartz sand (peat developed over quartz sand is poorer in nutrients compared to that developed on top of loam or clay). Nutrient inputs were higher than nutrient losses during the 1-year study period for all nutrients studied.

Based on the results of this study (nutrient input, transfer, output and storage), it is concluded that nutrient concentrations in peat soils are low and the substrates are acidic. These factors are likely to be strongly limiting to agricultural development, including plantations of estate crops and trees. Because of that, the management and conservation of the peat swamp forest in a natural condition is the best choice. The other alternative is that provision of natural ecosystem services (e.g. carbon storage, watershed, biodiversity maintenance, timber production in certain time period) is likely to be a far wiser land use from a long-term perspective.

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CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Large areas of peatland occur in Indonesia with estimates ranging from 16 to 27 million hectares (Rieley *et al.*, 1997). According to Kalmari (1982) there are 26 million hectares of peatland in Indonesia, which places the country fourth in terms of area of peatland globally behind Canada, the former USSR and USA (Joosten & Clarke, 2002). Radjagukguk (1997) provides a lower estimate of almost 20 million hectares of which 8.2 million hectares are in Sumatra, 6.8 million hectares in Kalimantan, 4.6 million hectares in Irian Jaya, 311,450 hectares in Sulawesi, and 97,225 hectares in Halmahera and Seram. The large range of estimates of total peatland area in Indonesia results from different approaches to inventory for different purposes, lack of standardization of surveying and mapping techniques and loss of natural peatland area to development since surveys were first carried out (Rieley *et al.*, 1996).

There have been few detailed ecological studies of tropical peatlands (Anderson, 1976; Rieley *et al.*, 1992) and a search of Bioabstracts from 1988-1995 produced 27 references relating to tropical peatlands of which only 5 were concerned with present day ecology (Stoneman, 1997). A major scientific effort is needed to establish how various tropical peatland ecosystems actually function and what links exist between them (Maltby & Immirzi, 1996).

Forests are dynamic systems formed through a succession of different stages including invasion, adaptation, aggregation, competition and reaction in that place, followed by stabilization. These processes require a long time for development of tropical peat swamp forest and may be extended over many millennia (Page *et al.*, 1999).

Forest ecosystems are open systems that chemical elements can enter and leave thereby linking them to larger global cycles. Some elements always cycle in situ (closed cycles). These 'biogeochemical cycles' transfer elements from the non living to the living component and back to the nonliving environment (Brinman, 1985 cit. Ruhiyat, 1993; Likens & Bormann, 1999).

Nutrient inputs to a peat swamp forest ecosystem come from wet deposition (i.e. precipitation) and dry deposition (i.e. dust) that are referred to collectively as atmospheric precipitation. Other, smaller, nutrient inputs occur from nitrogen fixation (gaseous incorporation by a biological organism) (Jordan, 1985; Barnes *et al.*, 1998; Wild, 1989) and fauna migration (i.e. faeces of birds and mammals) (Sturges *et al.*, 1974).

Within a forest the tree canopy loses chemical elements through leaching of nutrients from foliage and branches, rainwash of dry deposits, litterfall and also, to some extent, emission of particles by the foliage which do not represent inputs to the system. These processes transfer elements from one part to another in the same ecosystem (e.g. stemflow moves elements from the canopy to the forest floor).

The outputs of nutrients from a peat swamp forest ecosystem are mainly through water drainage (Likens & Bormann, 1999) and harvesting (timber removal), although fire and fauna migration also play a part.

Peat swamp forest is a fragile ecosystem, and small impacts may have large affects on, for example, water storage and nutrient cycling. According to Rieley & Page (1998) tropical peatlands are unique ecosystems because they are both peat-forming wetlands and tropical rainforests.

The ecological functions of peat swamp forest, including their nutrient dynamics, are poorly understood. Information on nutrient cycling in peat swamp forest is important since management for wise use may involve maximizing wood production without neglecting sustainability of the forest itself (Ruhiyat, 1993). Unfortunately, there is little information in the literature on nutrient outputs from timber harvesting on peat swamp areas even though nutrient cycling studies are very important owing to nutrient scarcity for sustained productivity in both disturbed and undisturbed peat swamp forests (Jordan,1985).

1. 2. PEAT SWAMP FOREST ECOSYSTEM

Several studies of tropical peat swamp forests have been carried out since the 1950s (Anderson, 1961; 1964; 1983; Rieley *et al.*, 1997 all; cited by Stoneman (1997). According to these, lowland tropical peatlands are usually dome-shaped (Rieley *et al.*, 1997; Sugandhy, 1997) and the only input of water and nutrients to them is from precipitation.

Peat swamp forest is less diverse than dry land rain forest but, nevertheless, it provides important reservoirs of biodiversity (Whitmore, 1984 cited by Rieley *et al.*, 1997). Peat swamp forest has, however, a relatively high diversity of tree species compared to mangrove forest with which it often shares geographical location (Sugandhy, 1997). A total of 132 tree species from 39 families of >1 cm dbh were recorded in peat swamp forest in Peninsular Malaysia (Ibrahim, 1997). A total of 113 tree species of > 5 cm dbh were recorded in peat swamp forest in Riau, Sumatra, Indonesia (Brady, 1997). Simbolon & Mirmanto (2000) and Waldes & Page (2002) who worked in the upper catcment of Sungai Sebangau, Central Kalimantan, Indonesia reported nearly the same results with 110 and 106 tree species, respectively. Peat swamp forest contains a number of tree species that are endemic to this habitat, including several of commercial importance (e.g. *Gonystylus bancanus, Shorea* spp.) (Shepherd *et al.*, 1997).

There is variation in the canopy structure and vegetation composition of peat swamp forest throughout Southeast Asia (Rieley & Ahmad-Shah, 1996; Ibrahim, 1997). In East Malaysia (Sarawak), Anderson (1963) cited by Rieley & Ahmad-Shah (1996) identified six forest types which form a complex zonation of plant communities that replace each other from the edge to the centre of the swamp in response to changing ecological conditions. The first is mixed swamp forest (*Gonystylus-Dactylocladus-Neoscortechinia* association); second, alan forest (*Shorea albida-Gonystylus-Stemonurus* association); third, alan bunga forest (*Shorea albida* consociation); fourth padang alan forest (*Shorea albida-Litsea-Parastemon* association); fifth (*Tristania-Parastemon-Palaquium* association); sixth padang keruntum (*Combretocarpus-Dactylocladus* association). There is a general reduction in the number of tree species per unit area and in their height from the edge to the centre. In contrast, in the upper catchment of Sungai Sebangau, Central Kalimantan, Indonesia, there are only five main types of forest based on differences in forest structure and tree species from the river's edge to the watershed (Rieley & Ahmad-Shah, 1996; Shepherd *et al.*, 1997; Page *et al.*,1999). These are riverine forest, mixed swamp forest, low pole forest, tall interior forest, and very low canopy forest.

According to Rieley & Ahmad-Shah (1996) and Shepherd *et al.*, (1997) riverine forest is affected by river flooding during the rainy season and has its boundary approximately 1 km from the dry season river channel. In this forest Cyperaceae (sedge) and Pandanaceae (pandan) are dominant and *Shorea balangeran* is the only tree to exceed 35 m height. Other canopy trees, including *Calophyllum sclerophyllum*, *C. rhizophorum*, *Campnosperma coriaceum*, *Combretocarpus rotundatus*, *Diospyros evena*, *Eugenia* spp. and *Ganua motleyana*, achieve heights between 25 and 35 m. The characteristic of the ground vegetation is the sedge *Thorachostachyum bancanum* (Page *et al.*, 1999). Over recent years a large area of riverine forest has been burnt and replaced by sedge swamp (Waldes & Page, 2002).

Mixed swamp forest occurs between 1 and 4 km from the bank of Sungai Sebangau (Page *et al.*, 1999) on peat 2 to 6 metres thick. In the rainy season, the forest floor is very wet, with a series of interconnected pools. In the dry season, the water table falls below the surface of the hollows and by the end of the dry season there is no water in either pools or outflow streams (Shepherd *et al.*, 1997). The canopy of mixed swamp forest is tall and stratified. There are few emergent trees, however, and there is a closed canopy at a height of about 35 metres above ground. Below this there is a dense under layer between 15 and 25 m and a more open bottom layer of smaller trees 7 – 12 m in height. Typical trees of the middle and upper canopy include *Aglaia rubiginosa, Calophyllum hosei, C. Lowii, C. scerophyllum, Combretocarpus rotundatus, Cratoxylum glaucum, Dactylocladus stenostachys, Dipterocarpus coriaceus, Dyera costulata, Ganua mottleyana, Gonystylus bancanus, Mezzetia leptopoda, Neoscortechinia kingii, Palaquium cochlearifolium, P. Leiocarpum, Shorea balangeran, S. teysmanniana* and *Xylopia fusca.*

From 4 km onwards towards the watershed the upper height of the canopy decreases progressively and there is a transition to low pole forest that expresses itself at a distance of 6 to 11 km from the river (Shepherd *et al.*, 1997) on peat from 7 to 10 m thick. The water table in the low pole forest is permanently high, close to the surface in the dry season and above the surface in the rainy season. The forest floor is uneven with large hummocks interspersed with deep (0.5-1.0 m), depressions that become filled with water in the wet season Only two canopy layer are discernible in this LPF. The upper is very open and reaches a maximum height of only 20 m, while the lower occurs at about 12 – 15 m (Page *et al.*, 1999). The principal species are *Combretocarpus rotundatus, Calophyllum fragrans, C. Hosei, Campnosperma coriaceum, Dactylocladus stenostachys* and *Garcinia cuneifolia. Pandanus* spp. *and*

Freycinetia spp. (pandans) contribute to a very dense undergrowth in which *Nepenthes* spp. are abundant.

Beyond the LPF there is a further transition in the height of the forest canopy, this time an increase towards the tall interior forest that is located on the watershed between Sg. Sebangau and Sg. Bulan at a distance of 12 to 24.5 km from Sg. Sebangau (Page *et al.*, 1999). The thickness of peat here varies between 7.7 and 9.6 m. The forest floor is relatively flat and easier to walk on than in the LPF and the peat water table is below the surface throughout the year. Three sub-canopy layers can be distinguished, the upper canopy reach height 35-45 m, below which two further layers occur at 15-25 m and 8-15 m. The upper canopy is dominated by *Agathis dammara, Calophyllum Hosei, C. Lowii, Cratoxylum glaucum, Dactylocladus stenostachys, Dipterocarpus coriaceus, Dyera costulata, Eugenia havilandii, Gonystylus bancanus, Gymnostoma sumatrana, Koompassia malaccensis, Pallaquium* spp. Additional species of the lower layer include *Artocarpus spp., Blumeodendron tokbrai, Calophyllum fragrans, Cinnamomum sintoc, Diospyros evena, Eugenia* spp., *Garcinia cuspidate, Gardenia pterocalyx,* and *Randia* sp.. *Pandanus* spp. are absent except where there are gaps in the canopy; on the other hand there is a greater abundance of climbers and epiphytes (Shepherd *et al.*, 1997).

A very low canopy forest occurs on the highest point of the watershed between the two river systems where it occupies approximately 13 x 6 km, surrounded by tall forest (Page *et al.*, 1999). In this very low, open canopy forest there are many large open water pools up to 200 m across and 1 m depth; elsewhere the water table is very high. Only a few trees reach the maximum canopy height of 15 m height, the commonest of which are *Calophyllum* spp., *Combretocarpus rotundatus, Cratoxylum* spp., *Dactylocladus stenostachys, Litsea* spp., *Ploiarium alternifolium* and *Tristania* spp. There is only a relatively sparse growth of *Pandanus* spp.

1.2.1 Hydrological conditions

Most virgin tropical peatlands are usually permanently wet, with the water table close to or above the surface of the soil. Groundwater fluctuation in an ombrogenous peatland in Padang-Sugihan, South Sumatra, Indonesia was between 28 and -180 cm; watertable in Sugihan East, South Sumatra, Indonesia, mixed swamp forest type, was between + 35 and – 170 cm, while watertable in Padang island a, Riau, Indonesia, mixed swamp forest type, was between +20 and – 110 cm (Brady, 1997). The peat water table levels below the surface recorded at the end of the 1993 dry season (1994 dry season for tall interior forest) in the Sungai Sebangau catchment, Central Kalimantan, Indonesia were 150.0 ± 7.6 cm in tall interior forest (16 – 24.5 km from Sungai Sebangau), 24.0 ± 2.8 cm in low pole forest (12.5 – 16 km from Sungai Sebangau) and 39.0 ± 4.2 cm in mixed swamp forest (1.5 - 5.5 km from Sungai Sebangau) (Page *et al.,* 1999). Furthermore, the water table in the tall interior forest never rose above the peat surface in the rainy season and reached a minimum depth of 20-30 cm. In the other forest types the water table was at or above the peat surface at that time.

An understanding of the hydrological conditions in peat swamp forest is important for revealing the nutrient dynamics, especially since precipitation is the only input of water to this ecosystem and surface water flow is the only major route for nutrient losses.

1.2.2 Physical and chemical characteristic of peat

Thick peat in the tropics has different chemical and physical properties compared to thin peat (Suharjo & Widjaja-Adhi, 1976). The nutrient content and pH of the latter is higher than the former. In addition, the nutrient status of tropical peat varies with the degree of organic matter decomposition, which is also related to the thickness of the peat (Notohadiprawiro, 1996). Thick peats are less decomposed and poorer in nutrients than thin peats. Physical characteristics of peat include very low bulk density (Driessen & Rochimah, 1976; Rieley *et al.*, 1996), a low load-bearing capacity, and high total porosity (Radjagukguk, 1992).

The thickness of peat, and the nature of the underlying mineral soil, determine the chemical characteristics of peat soils. The surface layer of thick peat is poorer than the surface of thin peat (Radjagukguk, 1992). In the latter the mineral substrate influences the peat chemistry through the plants that growth upon it. In general, since mineral soil has a higher nutrient content than peat, plants growing upon it or shallow peat will have a higher nutrient content than those growing on thick peat. Leaf fall from vegetation growing on thin peat soils results in a higher nutrient return to the soil surface. Peat developed over quartz sand is poor in nutrients compared to that developed on top of loam or clay (Widjaja-Adhi, 1988). The chemistry of peat is affected by many factors, including the nature of the original plant material, environmental conditions, the supply of inorganic solutes, the activities of plants and animals including microorganisms, and the history of peat development (Brady, 1997).

In general, the peat in Indonesia is characterized by low nutrient status and low pH (Radjagukguk, 1992). For example, the average pH (H_2O) of surface peat in the upper Sungai Sebangau catchment area is between pH 2.9 and pH 3.2 (Page *et al.*, 1999) and in Riau, Sumatra it is between pH 3.80 and pH 4.16 (Suhardjo & Widjaja-Adhi, 1976). Nutrient element content in Central Kalimantan (inland) is lower than in Riau (coastal) (Table 1.1).

Table 1.1: Nutrient content of peat from several locations in Indonesia.

No	Location	PH (H_2O)	N (%)	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Reference
1	Sg. Enok, Riau	4.16	1.63	500	800	2800	1600	Suhardjo & Widjaja-Adhi (1976)
2	Sg. Siak, Riau	3.55	1.98	500	600	1700	800	Suhardjo & Widjaja-Adhi (1976)
3	Sg.Rokan, Riau	3.80	2.13	900	800	-	1200	Suhardjo & Widjaja-Adhi (1976)
4	Sg. Sebangau (MSF) Central Kalimantan	2.9	1.8	278	135*	22*	21*	Page *et al.*, 1999 * (extractable)
5	Sg. Sebangau (MSF) Central Kalimantan	3.2	1.0	272	125*	35*	25*	Page *et al.*, 1999 * (extractable)
6	Sg. Sebangau (LPF) Central Kalimantan	3.2	1.4	340	130*	48*	40*	Page *et al.*, 1999 * (extractable)

There is a close relationship between peat acidity (pH) and the rate of organic matter decomposition, with higher pH resulting from more rapid decomposition (Murayama & Zahari, 1992). In addition, there is also a relationship between the poor chemical characteristics of tropical peat and the rate of organic matter decomposition (Murayama & Zahari, 1992). In the peat swamp forest ecosystem the low nutrient content in the peat results from the "poor" nutrient content of trees and greatly reduced decomposition in a waterlogged medium with a very low pH.

1.3. NUTRIENT DYNAMICS

The relationships between the nutrient and hydrological cycles and fluxes in some ecosystems has been recognised for several decades (Pastor & Bockheim, 1984; Jordan, 1985; Bruijnzeel, 1989). This link results from the special characteristics and functions of water as a transporting agent, solvent and catalyst and quantitative data on these are vital in order to understand nutrient fluxes (Likens *et al.*, 1999; Loescher *et al.*, 2002).

Comprehensive studies of nutrient dynamics have been carried out in several places and in different ecosystems, (for example, Chartley Moss basin mire, UK (Ahmad-Shah, 1984), montane rain forest in New Guinea (Edwards, 1982), lowland rain forest in Malaysia (Proctor *et al.*, 1983), *Pinus tabulaeformis* plantation at Long Hua, China (Daoping *et al.*, 1993), *Pinus sylvestris* plantation at Sierra de la Demanda, Spain (Regina & Tarazona, 2001), but to date none have been reported for the tropical peat swamp forest ecosystem.

Ecosystem nutrient dynamics involves determination of routes of input and output of nutrient elements as well as the various transfer pathways, including uptake (foliage and roots), storage (biomass) and removal (leaching and litterfall)(Bowden, 1991). Nutrient transfer processes vary spatially and temporally (Ahmad-Shah, 1984; Stinner *et al.*, 1984). In deserts, for example, precipitation is very low or non-existent in marked contrast to tropical rain forest where precipitation is extremely high. Even in the latter, in the dry season, rainfall can be very low, giving rise to very different conditions from the wet season when there is much rain, and leading to near drought conditions for part of the year. In the first example (desert), nutrient input through precipitation is very low or even negligible while in the second (rain forest) it is considerable. Consequently, each ecosystem needs to be studied separately throughout the different seasons and ideally over several years.

Since net primary productivity differs between ecosystems the pattern of nutrient dynamics also varies (Barnes *et al.*, 1998). In addition, plants have evolved positive feedback mechanisms in nutrient-poor habitats, by slow growth, efficient use and production of poor-quality material that deters herbivores and microorganisms and results in slowly decomposing litter, so that the rate of nutrient release is decreased (Hobbie (1992) cited in Van Breemen, 1995). In contrast, plants of nutrient-rich ecosystems grow more rapidly, sustaining high rates of herbivory and producing litter that is more readily decomposed, so that the rate of nutrient cycling is enhanced.

1.3.1 Nutrient inputs

1.3.1.1 Precipitation

Input of inorganic and organic materials from the atmosphere (precipitation) is an important supply route for forest ecosystems (Spurr & Barnes, 1980; Jordan, 1985;

Bruijnzeel, 1991; Mabberley, 1992; Grimshaw & Dolske, 2002). It can be in the form of dust, particles or aerosols and gases that originate from a number of sources (e.g. agricultural activity, quarrying, sea).

Aerial inputs are important in the areas where soils have low nutrient availability, such as ombrogenous peatland (Van Breemen, 1995; Marcos & Lancho, 2002). The continued growth of peat bog plants is made possible only by nutrient input from the atmosphere, coupled with various adaptive mechanisms of bog plants (Moore & Bellamy, 1974).

It is difficult to obtain a realistic estimate of the amounts of nutrients entering tropical high forest through wet and dry deposition (Bruijnzeel, 1991), especially for nutrients with a gaseous phase, such as, SO_2, NH_3 (Qin & Huang, 2001). Nutrient input from the atmosphere to forest ecosystem are traditionally approximated by multiplying the periodical (e.g. every 4 weeks, monthly, or annual) total of rain by the nutrient concentrations (Ahmad-Shah, 1984, Ahmad-Shah & Rieley, 1989; Bruijnzeel, 1989;1991). In some areas, additional nutrient inputs and enrichment may arise from dust raised by vehicles from nearby roads or fields, bird faeces (Ahmad-Shah, 1984; Sturges *et al.*, 1974), smoke from adjacent shifting cultivation (Whitmore, 1989), and insect frass.

Analyses of calcium, potassium, magnesium and sodium in precipitation collected at Anak Bt. Takun, Selangor, Malaysia showed that calcium is the predominant cation (1.48 mg l^{-1}) with lower concentrations of sodium, potassium, and magnesium of 0.21, 0.15 and 0.14 mg l^{-1}, respectively (Crowther, 1987a).

Elsewhere in the Gua Tempurong, Kinta Valley, Perak, Malaysia, the concentrations of calcium, sodium, potassium and magnesium were 0.40, 0.28, 0.12 and 0.05mg l^{-1}, respectively. Crowther (1987a) attributed the higher calcium concentration in precipitation from the first site to be the result of dust generated by limestone quarrying operations confirming that nutrient inputs to ecosystems depend on their source (Herwitz, 1986; Crowther, 1987a; Bruijnzeel, 1991).

Veneklaas (1990) studied the relationship between nutrient fluxes in bulk precipitation and throughfall in two montane tropical rain forests in Colombia and reported that nutrient input was higher in periods of heavy precipitation than light precipitation because of the larger volume of water under the former condition. Concentrations in precipitation, however, were generally lower in wetter periods. Losses of nutrients from the canopy, both total amount and amount per unit of precipitation, were also higher in heavy rain. Other workers have shown that nutrients in precipitation are important in maintaining fertility of certain agricultural soils, for example Spodosols (Burke *et al.*, 1990 cited by Pandey & Singh, 1992; Stinner *et al.*, 1984).

In a study of plant nutrient fluxes in an afforested mire at Chartley Moss, England, Ahmad-Shah (1984) concluded that nutrient input in rain water (precipitation) and throughfall showed temporal variations. Moreover, the acidity of precipitation (mean pH 4.23) resulted in a correspondingly higher acidity of throughfall (mean pH 3.53) under the pine woodland canopy. Similarly low precipitation pH was reported in studies carried out at the Bowl, New Hampshire, USA (Martin, 1979), ranging from pH 3.3 to pH 5.2, with a mean of pH 4.0.

In coastal areas sodium tends to be the most abundant cation in the precipitation (Westman, 1978) since the composition of rainfall normally reflects the origin, in this case maritime or contribution of sea salt (Veneklaas, 1990). In continental areas, however, calcium usually exceeds other cations (Likens *et al.*, 1977; Martin, 1979; Crowther, 1987a). Analysis of Ca, Mg, N and P in three Minnesota, USA forests also showed Ca^{2+} to be the most abundant cation (Reiners, 1972) and is similar to results obtained from elsewhere in the USA and in several other countries including Watubelah, Indonesia, Gua Anak Takun, Malaysia, Lien-Hua-Chi, Taiwan and Darien, Panama (Brinson *et al.*, 1980; Bruijnzeel, 1991). Table 1.2 below indicates nutrient inputs for several locations.

Table 1.2: Mean annual precipitation nutrient input (kg ha^{-1}) in several locations

No	Location	Ca (kg ha^{-1})	Mg (kg ha^{-1})	K (kg ha^{-1})	Na (kg ha^{-1})	PO_4-P (kg ha^{-1})	Reference
1	Hubbard Brook, New Hampshire	2.17	0.58	0.89	1.59	0.131	Liken *et al*, 1999
2	Itasca County, Minnesota	3.6	0.7	1.1	1.1	0.5	Verry & Timmons, 1982
3	Pitt County, North Carolina	4.8	1.43	3.0	-	0.49	Brinson *et al*, 1980
4	Caura River, Venezuela	1.3	0.3	1.0	8.2	0.14	Lewis *et al.*, 1987
5	Yunnan, China	7.95	3.23	2.97	1.72	1.25	Liu *et al.*, 2002b
6	Beaujolais, France	3.1	0.6	2.0	-	-	Dambrine & Ranger, 2000
7	Vosges, France	2.8	0.7	1.8	-	-	Dambrine & Ranger, 2000
8	Boundary Range, Malaysia	21.3	1.9	2.7	5.4	-	Crowther (1987a)

There is an indication that precipitation promotes soil organic matter mineralization in *Metrosideros polymorpha* in forests on Hawai but this has still to be confirmed in tropical peat swamp forest (Austin & Vitousek, 2000).

1.3.1.2. Mineralisation of peat

The basic elements involved in plant mineral nutrition are derived from the weathering of soil minerals and external inputs (e.g. precipitation, flooding, nitrogen fixation) (Ahmad-Shah, 1984; Van Breemen, 1995). The vegetation of peat soils, however, obtain their nutrients from mineralisation of the peat itself supplemented by products of the vegetation (litter and leachates) and inputs from precipitation (Spurr & Barnes, 1980). It is fairly easy to quantify vegetation recycling and decomposition inputs but it is difficult to estimate the rate and contribution of peat mineralisation.

1.3.1.3. Nitrogen fixation and Mycorrhizae

Atmospheric nitrogen fixation can contribute to the input of nitrogen into ecosystems by organisms that are adapted to perform this function (Forman, 1975; Waughman & Bellamy, 1980; Waring & Running, 1998 cit Son, 2001; Knops *et al.*, 2002). The principal nitrogen fixers are symbiotic bacteria in the roots of higher plants and in the cells of blue-green algae (e.g. *Nostoc* and *Anabaena* spp.) and asymbiotic (free-living) bacteria in the soil (e.g. *Azotobacter* and *Clostridium* spp.). Son (2001) reported that rates of N-fixing algae and lichens or moss on the surfaces of trees or soil range from 0.01 to 5 kg N ha^{-1} yr^{-1}.

Nitrogen-fixing bacteria living symbiotically in root nodules, for example, *Rhizobium* spp. supply nitrogen directly from the atmosphere to plants (Dommergues, 1997; Hungria & Vargas, 2000). Leguminosae is the plant family with most widespread nitrogen-fixing capability but members of a wide range of other families are also involved (Boyd, 2001). In the tropics, there is an abundance of nitrogen-fixing plants (Spurr & Barnes, 1980; Dommergues, 1997).

Nitrogen fixation at a rate of 1.0 g N $m^{-2}yr^{-1}$ (10 kg N $ha^{-1}yr^{-1}$) has been detected at the peat surface and on the leaves of *Sphagnum* spp. in an ombrotrophic bog, in Massachusetts, USA, through the activities of heterotrophic bacteria, such as, *Beijerinckia,* a genus related to *Azotobacter* (Chapman & Hemond, 1982). Otherwise, it has been reported that heterotrophic bacteria fix nitrogen ranging from 0.7 kg $ha^{-1}yr^{-1}$ for bog peat to 21 kg $ha^{-1}yr^{-1}$ for fen peat, in mires in the south of Germany mires (Waughman & Bellamy, 1980). The lichen *Lobaria* sp. (symbiotic association between an algae and a fungus) contributed between 8 and 10 kg N $ha^{-1}yr^{-1}$ (Spurr & Barnes, 1980).

The non-symbiotic diazotrophs on the forest floor under pitch pines (*Pinus rigida* Mill*)* and red pines (*P. resinosa* Ait*)* contributed less than 0.06 N $ha^{-1}yr^{-1}$ (Barkmann & Schwintzer, 1998). In contrast, Bowden (1991) reported that N-fixation in forest floor moss (*Polytrichum*) in New Hampshire, USA from cyanobacteria contributed 0.6 kg N ha^{-1} yr^{-1}.

Mycorrhizae (symbiotic association between fungus and plant roots) are widespread on the roots of trees and very few woody species are non-mycorrhizal (Alexander, 1989; Thain & Hickman; 1994; Lawrence, 2000). There are more than 5000 species of fungi capable of forming symbioses (Molina *et al.*, 2001 cit Read & Perez-Moreno, 2003).

Ectomycorrhizae (the fungal sheath surrounds the host roots and some hyphae penetrate between the cells of the epidermis and cortex) and vesicular-arbuscular mycorrhizae (the fungus penetrates the root cortex intercellularly and intracellularly and gives rise to characteristic hyphal coils, vesicles and arbuscules) in the same and different plant species can be interconnected by hyphal bridges and carbon and phosphorus can be transferred between plants via these connections (Heap & Newman, 1980; Francis and Read, 1984). Nutrient uptake by forest trees is largely dependent on associated mycorrhizae since the presence of extramatrical mycelium produced by mycorrhizae fungi allows trees to exploit a larger soil volume than that occupied by their roots, particularly in infertile soil (Wallander,1995).In general, most plant species in natural ecosystems depend to varying extents on mycorrhizal fungi for the uptake of nutrients and water from the soil to maintain steady growth (Muthukumar *et al.*, 2003). The role of the mycorrhizal fungi is to capture nutrient in ionic form and release N and P from the accumulated microbial biomass (Perez-Moreno & Read, 2000; Tian *et al.*, 2002; Tian *et al.*, 2003). Moreover, mycorrhizal fungi have abilities to degrade organic polymers, which are the primary source of element in terrestrial ecosystems. (Read & Perez-Moreno, 2003). Because of these attributes mycorrhizae are an important factor in nutrient cycling in forests (Perez-Moreno & Read, 2000; Perez-Moreno & Read, 2001).

So far there has not been any comprehensive study of tropical forest trees, especially the transfer of soil nutrients (weathered rock) to plant roots through the mediation of mycorrhizae and the distribution (Muthukumar *et al.*, 2003) and nutrient mobilization processes of the latter (Read & Perez-Moreno, 2003).

1.3.1.4. Fauna movements

Movement of animals can be within the same ecosystem or between different ecosystems. For example, ants (Sagers *et al.*, 2000), usually in the same ecosystem have potential to transport a large amount of material containing nutrients. Ants consume plant products that, in turn, can provide nutrients to trees. Other animals, such as termites *(Nasutitermes ephratae)*, can also transport a major amount of nutrients within ecosystems (Lopez-Hermandez, 2001) and they play an important role, for example, in decomposition processes in savanna and tropical forest ecosystems. In addition, termite mounds contain more nitrogen and phosphorus than nearby top soil owing to the use of faecal material to build gallery walls (Lopez-Hermandez, 2001).

Long-distance movement of animals, for example birds, has the potential to process and redistribute large amounts of nutrients in ecosystems (Erskine *et al.*, 1998). Birds contribute to nutrient inputs to forest ecosystems through their faeces that are scattered over the vegetation and forest floor from their roosts and perches (Weir, 1969; Ahmad-Shah & Rieley, 1989; Erskine *et al.*, 1998). Bird droppings have been shown to contain high concentrations of PO_4^{3-}, K^+ and $NH4^+$ (Grimshaw *et al.*, 1958; Ahmad-Shah & Rieley, 1989; Asman *et al.*, 1982).

The input from rook (*Corvus corvus*) droppings, grit and faeces, was higher than that from precipitation in a woodland in Leicestershire, United Kingdom (Weir, 1969). The rooks droppings contributed large amounts of potassium in the pine woodland at Chartley Moss (Ahmad-Shah, 1984). The deposition of calcium, for example, in an eight week period was 13.26 kg ha^{-1} from grit, 75.8 kg ha^{-1} from faeces, compared to only 14.0 kg ha^{-1} from precipitation in a whole year (Weir, 1969). Input of potassium over the same period was 0.76 kg ha^{-1}, 8.74 kg ha^{-1} and 14.0 kg ha^{-1}, respectively. Much greater quantities of calcium and potassium were imported into the Leicestershire wood by rooks within 8 weeks than in an entire year's rainfall. Moreover, the effect of these birds is not only to introduce organic and inorganic nutrients into the woodlands but also to alter the overall composition of the total inorganic nutrient input (Weir, 1969). Similarly, bird droppings in the Hubbard Brook Experimental Forest in Central Hampshire, USA are a significant nutrient input to that area (Sturges *et al.*, 1974). Other animals that should be taken into account include orang utan feeding patterns and movements in the peat swamp forest ecosystem, which could have a significant role in nutrient input and outputs. Unfortunately studies on this aspect have not yet been carried out.

1.3.2 Nutrient transfers

1.3.2.1.Throughfall and stemflow

Some of the precipitation falling on tree canopies is intercepted while the rest of it reaches the forest floor as throughfall (the fraction of rainfall reaching the ground under a vegetation canopy) (Ahmad-Shah, 1984; Neal *et al.*, 1993; Hansen *et al.*, 1994). The amount of throughfall decreases with decreasing rainfall (Edwards, 1982; Loescher *et al.*, 2002). Nutrients deposited on foliar surfaces through rainfall or dry fallout may be carried downwards to the soil surface in throughfall, but some may be adsorbed or absorbed by plants on the way (Carlisle *et al.*, 1966; Brinson *et al.*, 1980; Hansen *et al.*, 1994, Clark *et al.*, 1998a) or taken up by the microorganisms growing on the surface of branches, leaves and stems (Carlisle *et al.*, 1967; Wilson, 1992; Marcos & Lancho, 2002). Nutrients can also be leached from foliar surfaces by incident precipitation (Reiners, 1972; Clark *et al.*, 1998a) thereby enriching the nutrient content of the throughfall that reaches the forest floor (Eaton *et al.*, 1973; Whitmore, 1984; Amezaga *et al.*, 1997; Jean-Paul *et al.*, 2000). Canopy throughfall therefore represents an important nutrient pathway in forest ecosystems (Loescher *et al.*, 2002), combining input of new nutrients with the cycling of "old" nutrients that have been carried up to the crowns as a result of plant metabolism and translocation to be subsequently leached out and returned to the soil once more (Comerford & White, 1977).

The chemistry of throughfall and stemflow includes not only nutrients leached from the vegetation (exudation and senescence), but also elements washed from the surface of the vegetation that were impacted previously from incident precipitation (Eaton *et al.*, 1973; Comerford & White, 1977).

The input of different nutrients varies from one location to another (spatial variation) and at different times of the year (temporal variation) (Veneklaas, 1990) (Table 1.3).

Table 1.3: Annual fluxes of nutrients in bulk precipitation (R) and throughfall (T) in tropical forest

No	Location	Rain (mm)	Ca (kg ha^{-1})	Mg (kg ha^{-1})	K (kg ha^{-1})	Na (kg ha^{-1})	NH_4-N (kg ha^{-1})	PO_4-P (kg ha^{-1})	Reference
1	New Guinea (R)	3800	3.6	1.3	7.3	-	-	0.5	Edwards. (1982)
	(T)	2585	19.0	10.9	71.1	-	-	2.5	
2	Puerto Rico (.R)	3750	21.8	4.9	18.2	57.2	-	-	Veneklaas (1990)
	(T)	2775	34.8	9.2	155.0	83.2	-	-	
3	Colombia (.R)	2115	10.1	3.2	7.9	24.1	18.28	0.72	Veneklaas (1990)
	(T)	1854	27.1	10.7	95.2	26.9	21.45	1.67	
4	Selangor (R)	2665	20.15	5.12	26.36	31.42	18.12	-	Ahmad-Shah *et al.* 1992
	Malaysia (T)	1986	46.74	13.41	50.87	48.50	17.19	-	
5	Central cordillera, (R)	3510	27.87	4.06	13.51	63.51	7.27	0.7	Cavelier *et al.*, 1997
	Panama (T)	2190	35.07	7.60	63.22	131.18	2.15	7.18	

The nutrients passing through tree canopies in throughfall in greatest quantity are sodium, potassium, calcium, and magnesium, although these fluctuate at different times of the year (Edwards, 1982; Ahmad-Shah & Rieley, 1989; Hansen *et al*, 1994; Grimshaw & Dolske, 2002). Various reasons have been suggested to explain the changes that occur in the chemical composition of precipitation as it passes through a vegetation canopy and the temporal variations. For example, Hansen *et al.* (1994) reported that calcium, magnesium and sodium show a slight increase in concentration in the beginning of the event (rain), followed by a slow decrease during the rest of the event. In addition, dry deposited and foliar materials, either from internal or external sources, are easily lost in the initial stages of wetting (Reiners & Olson, 1984).

Fluctuations in the nutrient inputs in precipitation and throughfall can be attributed to a variety of factors including agricultural land use that creates dust from ploughing and fertiliser application, mobilization of certain elements during leaf senescence and high pollen in the atmosphere (Ahmad-Shah & Rieley, 1989). Other sources could be pollution from domestic and industrial sources (Crowther, 1987a) and smoke and dust from fires used in shifting cultivation (Whitmore, 1984).

Precipitation that reaches the ground (forest floor) by flowing down the surface of tree trunks is referred to as stemflow (Carlisle *et al.*, 1967; Hanchi & Rapp, 1997). The amount of stemflow that reaches the ground is mostly less than 5 % of the total precipitation that falls on the forest canopy (Edwards, 1982; Rode, 1995). Stemflow is very important, however, because it is deposited in a small area around the base of trees (Brinson *et al.*, 1980; Levia, 2003). The total quantities of mineral elements in stemflow are generally less than those in throughfall and this is mainly because the volume of stemflow and concentration of elements in it are substantially less then in throughfall (Westman, 1978). Stemflow solution concentration lies somewhere between the composition of the rain and that of the throughfall and therefore contributes smaller amounts of total nutrients compared to throughfall (Eaton *et al.*, 1973; Rodrigo *et al.*, 2003). In contrast, Moreno *et al.* (2001) stated that solute concentrations were generally significantly higher in stemflow than in throughfall and precipitation. Estimates of annual addition of water and nutrients to the ground in rainfall (R), throughfall (T), and stemflow (S), at several places are presented in Table 1.4.

Table 1.4: Annual addition of nutrients in rainfall, throughfall and stemflow in several places .

No	Location	Vegetation type	Ca (kg ha^{-1})	Mg (kg ha^{-1})	K (kg ha^{-1})	NH_4-N (kg ha^{-1})	Reference
1	Berkshire,	*Pinus* (R)	43.4	2.42	2.8	20.0	Allock & Morton, 1985
	UK	(T)	21.2	2.90	15.5	14.8	
		(S)	2.5	0.59	2.9	1.47	
		Betula (T)	37.5	4.71	19.4	15.4	Allock & Morton, 1985
		(S)	0.47	0.11	1.3	0.17	
2	Kuala Lumpur,	Dipterocarp (R)	18.2	9.7	27.0	52.0	Abas *et al.*, 1992
	Malaysia	(T)	35.3	10.5	38.8	44.2	
		(S)	0.55	0.18	0.66	0.71	
3	Amazon,	Tropical rainforest (R)	-	-	-	-	Jordan, 1978
	Venezuela	(T)	-	-	-	-	
		(S)	0.4	0.2	2.8	2.2	
4	North	Sessile oak forest(R)	6.7	6.1	2.8	-	Carlisle *et al.*, 1967
	Lancashire	(T)	14.3	7.1	26.9	-	
		(S)	2.0	0.7	1.56	-	

Research on stemflow in dogwood (*Cornus florida* L) using ^{45}Ca showed that direct leaching from the bark probably does not contribute as much to the chemical composition of the stemflow as does leaching of the leaves (Thomas, 1969 cited in Eaton *et al.*, 1973). Moreover, Eaton et al. (1973); Reiners & Olson (1984); Moreno *et al.*, (2001); Levia & Frost (2003) state that the leaching of tree bark is a complex process, often involving resident populations of mosses, lichens, microorganisms, meteorological conditions, canopy structure and atmospheric pollutants in urban environments.

1.3.2.2. Litterfall

Leaves, small branches, reproductive parts, and unclassified debris falling from tree canopies reaches the forest floor as "fine litter" (Vitousek, 1984; Chestnut *et al.*, 1999) or "small litter" (Proctor,1983; Scott *et al.*, 1992). Litterfall is the last part of complex physiological processes in the trees. These processes are influenced by several environmental factors in different ways and the actual fall of litter may be caused by a combination of these factors including wind, rain (Spain, 1984), mechanical stress and, not least, the physiological characteristics of species and their phenological cycles (the reproductive cycles of many species are long and often irregular) (Brown & Lugo, 1982).

Many workers have studied litterfall in forests in different regions and their results exhibit considerable variation (Vitousek, 1984; Crowther, 1987a; Madeira *et al.*, 1995). Brinson *et al.*, (1980) observed that mean annual litterfall in alluvial forest in the North Carolina Coastal Plain was 6428 kg dry mass ha^{-1} yr^{-1}, for example, that is considerably higher than the 5725 kg ha^{-1} yr^{-1} obtained for Mixed hardwood forest in the North Carolina Piedmont (Wells *et al*, 1972 cited by Brinson *et al.*, 1980). The latter value, however, is similar to that for both the bottomland hardwood forest (5740 kg ha^{-1} yr^{-1}) and a cypress-tupelo stand (6200 kg ha^{-1} yr^{-1}) in Louisiana (Conner & Day, 1976). These, in turn, are lower than the mean litterfall in *Eucalyptus globulus* plantation at Furadouro, Portugal which ranges between 8410 and 12810 kg ha^{-1} yr^{-1}(Madeira *et al.*, 1995). More detail for the amount of litterfall in different locations can be seen in Table 1.5:

Table 1.5: Annual litterfall and associated nutrient return in different locations and types of forest.

No	Location	Forest type	Litterfall					Source
			Dry mass (ton/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	
1	New Guinea	Lower montane forest	7.6	90	5	28	95	Edwards, 1982
2	Malaysia	Dipterocarp rainforest	8.8	81	1.2	33	13	Proctor *et al*, 1983
3	Malaysia	Alluvial forest	11.5	111	4.1	26.1	286	Proctor *et al*, 1983
4	Malaysia	Heath forest	9.2	55	1.6	18	83	Proctor *et al*, 1983
5	Malaysia	Dry land forest	5.19	-	-	20.6	198	Crowther (1987a)
6	Australia	Rain forest	9.0	136	13.1	77.8	229	Brasell *et al.*, 1980
7	Australia	*Araucaria* plantation	10.2	91	11.5	66.8	177	Brasell *et al.*, 1980
8	Palembang, Indonesia	Peat swamp	11.9	24	1.6	-	-	Brady, 1997
9	Palembang, Indonesia	Peat swamp	7.3	13	0.9	-	-	Brady, 1997
10	Cetral Kalimantan, Indonesia	Heath forest	6.65	-	-	-	-	Rahajoe *et al.*, 2000
11	China	Evergreen broad-leaved forest	7.1	80	5.1	30	58	Liu *et al.*, 2002b

Litterfall is the major pathway for the return of dead organic matter and much of its contained nutrients, essential and non-essential, from the aerial parts of the vegetation community to the soil surface (Spain, 1984). Annual litterfall has been reported to play a major role in the removal of nitrogen, phosphorous, calcium, magnesium, and organic carbon from the canopy and the amount transferred in this way exceeds that in throughfall and stemflow (Carlisle *et al.*, 1967; Likens *et al.*, 1977; Brinson *et al.*, 1980; Regina & Tarazona, 2001).

More detail of the amount of rainfall, throughfall and litterfall in different locations can be seen in Table 1.6.

Table 1.6: Annual quantities of certain nutrient elements in rainfall (R), throughfall (T) and litterfall (L) in several locations.

No	Location	N ($kg\ ha^{-1}\ yr^{-1}$)	P ($kg\ ha^{-1}yr^{-1}$)	K ($kg\ ha^{-1}yr^{-1}$)	Ca ($kg\ ha^{-1}yr^{-1}$)	Mg ($kg\ ha^{-1}yr^{-1}$)	Reference
1	New Guinea (R)	6.5	0.53	7.3	3.6	1.3	Edwards (1982)
	Throughfall (T)	29.6	2.5	71.1	19.0	10.9	
	Litterfall (L)	90.8	5.1	27.8	94.7	19.2	
2	North Carolina (R)	5.8	0.49	3.0	4.8	1.43	Brinson *et al.*, (1980)
	Throughfall	9.6	1.29	10.4	13.3	6.9	
	Litterfall	72.8	5.4	21.1	45.1	17.0	
3	Malaysia (R)	-	-	3.4	11.4	1.4	Kinta Valey, Crowther (1987a)
	Throughfall	-	-	135	98.9	21.8	
	Litterfall	-	-	20.6	198	16.2	
4	Malaysia (R)	-	-	3.7	36.1	3.4	Selangor, Crowther (1987a)
	Throughfall (T)	-	-	98.2	89.5	32.1	
	Litterfall (L)	-	-	19.2	386	34.1	
5	Spain (R)	-	-	6.6	5.9	2.8	Regina & Tarazona (2001)
	Throughfall (T)	-	-	7.0	5.9	2.8	
	Litterfall (L)	46.3	0.19	8.6	19.7	2.9	

The temporal variations in dry mass and nutrient content of litter probably reflect differences in the nutrient concentrations of the various litterfall components (i.e. leaves, twigs, branches and reproductive parts) and the changes in their quantity between seasons (Brinson *et al.,* 1980). Leaves, for example, are high in S, Ca, and Mg while reproductive parts contain most N, P, and K. Changes in element concentrations of total litter between leaf and leafless seasons are not as great as the differences between litter components (Proctor *et al.*, 1983; Sulistiyanto *et al.*, 2002). Similarly, observations in New Guinea rain forest showed that concentrations of minerals in the falling leaves varied during the course of the year, although clear seasonal trends were apparent only for N, K, and Mg (Edwards, 1982) with K showing the greatest fluctuations. K and Mg concentrations were highest in August, probably because leaching was reduced in the drier months; N was highest in January but declined steadily throughout the ensuing year.

1.3.2.3. Decomposition

Decomposition of plant litter is a key process in the nutrient cycles of most terrestrial ecosystems (Vitousek *et al.*, 1994; Almendros *et al.*, 2000, Regina & Tarazona, 2001). It is essential for maintaining the nutritional status of forest stands (Raulund-Rasmussen & Vejre, 1995; Guo & Sims, 1999) and the rate of decomposition varies between species (Kochy & Wilson, 1997).

Decomposition is a complex interaction of processes involing several factors (Dezzeo *et al.*, 1998). Litter decomposition rates are controlled by environmental factors, such as pH (Van Breemen, 1995; Reich *et al.*, 1997); climate (temperature, humidity and moisture) (Guo & Sims, 1999); the chemical composition of the litter (Aerts & Caluwe, 1997; Berg & Ekbohm, 1991; Kochy & Wilson, 1997); and by soil organisms (Saetre, 1998).

In general, the rate of decomposition is less at low pH than at neutral pH (Murayama & Zahari, 1992). In addition, organic material with a high C/N ratio is more difficult to decompose than that with a low C/N ratio (Murayama & Zahari, 1992; Kochy & Wilson, 1997; Sadaka-Laulan & Ponge, 2000). Moreover, litter in which the number of soil organisms is high tends to decompose faster than litter with a small number of soil organisms (Saetre, 1998). Moreover, decomposition rates are higher in aerobic conditions than in anaerobic conditions (Johnson & Damman, 1991).

Different plant species may affect rates of decomposition either directly through litter quality and mass (Berendse *et al.*, 1989; Berendse, 1990), or indirectly through microclimate or decomposer communities (McClaugherty *et al*, 1985; Saetre, 1998; Haraguchi *et al.*, 2002). For example, the quality of litter differs among plant species, and litter quality may directly affect the decomposition rate through the palatability of the substrate to the decomposer community (Berg & Ekbohm, 1991). Substrate quality may also strongly influence the composition of the decomposer community (Swift *et al.*, 1981; Zimmer, 2002), which in turn may effect decomposition of plant material. The nutritional status of the foliage and also the litter, to some extent, is influenced by soil properties (Liu & Truby, 1989 cit Raulund-Rasmussen & Vejre, 1995).

In general, plant species from nutrient-poor environments produce litter that is more difficult to decompose than litter of species from nutrient-rich environments. This is because low-nutrient species generally have higher C:N ratios and higher concentrations of decay-resistant (i.e. lignin) plant compounds than high-nutrient species (Pastor *et al.*, 1984). Owing to differences in decomposability of the litter it has been postulated the species from nutrient-poor environments slow down the rate of nutrient cycling in their habitat, whereas species of more nutrient-rich habitats have an accelerating effect on the rate of nutrient cycling (Vitousek *et al.*, 1994; Van Breemen, 1995; Aerts & Caluwe, 1997).

1.3.2.4. Biomass

The nutrient capital in tropical forests resides mainly in the living plant biomass and its loss for any purpose will result in the disappearance of the ecosystem nutrient capital with consequent drastic reduction in natural soil fertility (Medina & Cuevas, 1989). Regina & Tarazona (2001) state that aboveground litter plays a fundamental role in the nutrient turn over and in the transfer of energy between plant and soil, as the source of the nutrients accumulated in the uppermost layers of the surface ground. This is particularly important in nutrient budgets of forest ecosystems on nutrient-poor soils, where the vegetation largely depends on recycling the nutrients contained in plant detritus (Regina, 2000; Regina & Tarazona, 2001).

The primary net productivity of forest vegetation is subject to external environmental factors such as, soil and climate and to inherent factors such as age and the type of tree cover (Laurance *et al.*, 1999; Regina & Tarazona, 2001). The soil-fertility parameter contributes the variation in aboveground biomass (Laurance *et al.*, 1999).

The aboveground biomass estimate of total tree biomass of 420-649 t ha $^{-1}$ obtained in a forest at Karnataka, India (Rai & Proctor, 1986) is similar to that for mixed dipterocarp in East Kalimantan, Indonesia (Yamakura *et al.*, 1986). Edwards (1982) reported a total aboveground living plant biomass of 310 t ha $^{-1}$ that was in the range of above ground biomass in Amazon, Brazil (Laurance *et al.*, 1999). A sselection of above-ground biomass and amounts of nutrients in several places are presented in Table 1.7.

Table 1.7: Total above ground biomass (ton ha $^{-1}$) and amount of nutrient (kg ha^{-1}) in several places.

No	Location	Forest type	Biomass (ton/ha)	N (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Source
1	New Guinea	Lower montane forest	310	-	-	-	-	Edwards, 1982
2	New Guinea	Montane rain forest	331	853	699	1487	212	Grubb & Edwards, 1982
2	Malaysia	Dipterocarp rainforest	650	-	-	-	-	Proctor *et al*, 1983
3	Malaysia	Alluvial forest	250	-	-	-	-	Proctor *et al*, 1983
4	Malaysia	Heath forest	470	-	-	-	-	Proctor *et al*, 1983
5	East Kalimantan, Indonesia	Dry land forest	460	1177	796	1394	231	Ruhiyat, 1993
6	East Kalimantan, Indonesia	Mixed Dipterocarp	509	-	-	-	-	Yamakura *et al.*, 1986
7	Central Kalimantan, Indonesia	Heath forest	200-250	-	-	-	-	Miyamoto *et al.*, 2000
8	Spain	Scots pine plantation	152.1	-	-	-	-	Regina & Tarazona, 2001
9	Amazon, Brazil	Tropical evergreen forest	288-346	-	-	-	-	Cummings, *et al.* 2002
10	Central Amazonia, Brazil	Tropical Rain forest	231-492	-	-	-	-	Laurance *et al.*, 1999
11	New Zealand	*Nothofagus* forest	331.5	449.8	139.6	554	1130	Hart *et al.*, 2003

Root biomass is usually less than aboveground biomass. Roots/shoots ratio (root weight/shoot weight) for woody species in moist tropical forests ranges from 0.03 to 0.81 (Deans *et al.*, 1996). Belowground biomass value of 13.9 - 20.2 t ha $^{-1}$ from Karnataka forest, India is relatively low but it could be almost the same when they include fine roots (because Rai and Proctor (1986) did not have data for fine roots less than 5 cm girth). Roots of less than 5 cm have substantial proportion of belowground biomass in most tropical forests (Klinge, 1978). His most extreme example is for an Amazonian caatingan forest in which about 80 % of the below ground biomass was of roots less than 1 cm diameter. Schulze *et al.*, (1996) found 90% of total root biomass within 0.60 m depth for *Nothofagus pumilio.* Jackson *et al.*, (1996) reported 52 % of root biomass for temperate coniferous forests was usually found in the upper 30 cm. Laclau (2003) found 75 % of total root biomass of ponderosa pine (*Pinus ponderosa*) in 50 cm depth. Root biomass and amount of nutrient in several places are presented in Table 1.8.

Table 1.8: Total roots biomass (ton ha $^{-1}$) and amount of nutrient (kg ha^{-1}) in several places

No	Location	Forest type	Roots ton ha^{-1}	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Source
1	New Guinea	Lower montane forest	40	137	6	186	333	Edwards, 1982
2	Malaysia	*Acacia mangium* plantation	1.7-2.0	-	-	-	-	Hogberg & Wester, 1998
3	Palembang, Indonesia	Peat swamp (mixed)	5.4	70	4	-	-	Brady, 1997
4	Palembang, Indonesia	Peat swamp (mixed)	22	290	13	-	-	Brady, 1997
5	Riau, Indonesia	Peat swamp (mixed)	28.1	350	17	-	-	Brady, 1997
6	Cameroon	Tropical moist forest	9	-	-	-	-	Deans *et al.*, 1996
7	New Zealand	*Nothofagus* forest	93.2	105.9	55.7	188.5	206.4	Hart *et al.*, 2003
8	Argentina	*Pinus ponderosa* plantation	1.7-27	-	-	-	-	Laclau, 2003

1.3.3. Nutrient output

1.3.3.1. Runoff

Little work has been done on the magnitude of runoff from mires and peatlands or the resultant erosion and loss of nutrients (Heathwaite, 1993). Since ombrogenous bogs are slightly dome-shaped their gradient and near water-saturated condition of their peat make overland flow a reality. Loss of chemical elements in drainage water is the principal nutrient output from blanket bogs in the Pennine moorlands of England (Crisp, 1966) and total output of N, P, K, Ca, and Na was greater than their input in that ecosystem in precipitation. For example, K loss was 7.95 kg ha^{-1} yr^{-1}; P was 0.39 kg ha^{-1} yr^{-1}.

1.3.3.2. Fauna movement

There is little information on nutrient dynamic within and between forest animals, as components of ecosystem dynamics (Sturges *et al.*, 1974) and this topic has received very little attention (Grimshaw *et al.*, 1958).

Nutrient cycling in an ecosystem may be affected by animals through two major ways: first, by animals affecting the nutrient input or output in the annual nutrient budgets; second, by influencing the rate of circulation of nutrients within the system (Grimshaw *et al.*, 1958; Sturges *et al.*, 1974).

The annual loss of nutrients via birds from the Hubbard Brook catchment are calcium 3.0 g ha^{-1}; nitrogen 3.1 g ha^{-1}; phosphorus 1.9 g ha^{-1} and 0.4 g ha^{-1} sodium (Sturges *et al.*, 1974). These nutrient losses occur during migration ((Sturges *et al.*, 1974). It is difficult to obtain reference data on fauna migration in tropical forests, such as, orang utan and birds, although their impact is probably negligible.

1.3.3.3. Harvesting

Timber harvesting is another way by which nutrients leave ecosystems (Ruhiyat, 1993; Ranger & Turpault, 1999) but, unfortunately, there appears to be no data on the extent of nutrient loss from tropical peat swamp forest as a result of harvesting of timber. Illegal logging, which is currently a major problem in tropical forests is contributing greatly to biomass and nutrient losses from peat swamp forests and it is unlikely that the magnitude of this can ever be calculated because it is not documented.

1.3.3.4. Fire

During burning of large areas of peat, large amounts of nutrients are lost from ecosystems (Pearsall 1950 cited in Crisp, 1966; Muraleedharan *et al*, 2000; Radojevic & Tan, 2000). Some materials lost from one area may be redeposited on adjacent areas. Many workers have reported on peat burnt in several places, such as, Heathwaite (1993) in Ontario in 1959 noted that peat burnt to a depth of around 1 m. Page *et al.* (2002) reported in Central Kalimantan, Indonesia in 1997 that 25- 85 cm of peat burned away with an average of 51±5 cm resulting in the release of between 0.81 – 2.57 Gt of carbon to the atmosphere during 1997.

1.4. NUTRIENT BUDGETS

Nutrient budgets of forest ecosystems are commonly characterized by an imbalance between inputs and outputs (Chestnut *et al.*, 1999). When nutrients entering and leaving are measured, the budget will describe the direction of soil fertility (Ranger & Turpault, 1999). A positive budget means that the nutrient is accumulating in the system while a negative budget means the nutrient is depleted in the system (Pare *et al.*, 2002). Maintaining, and if possible increasing, soil fertility is a major goal for sustainable management, because it determines to a large extent the site's capacity for biomass (wood) production (Jordan, 1985; Ranger & Turpault, 1999; Pare *et al.*, 2002).

In natural ecosystems, losses by drainage strongly decrease when a 'climatic ' equilibrium is reached. The nutrient budget is then theoretically balanced apart from catastrophic events such as strong wind, parasitic attack, and atmospheric pollution. Soil fertility decreases very slowly because there is no harvest and because most losses by drainage are compensated for by atmospheric input. In this situation, budgets are of great scientific interest as a reference (Ranger & Turpault, 1999).

Information on nutrient budgets are useful because they can help to predict the depletion of nutrients before the ecosystem itself shows the effects of the nutrient depletion. Furthermore, they give useful quantitative data for recommending appropriate forest management practices (Ranger & Turpault, 1999), and for evaluating important criteria of sustainable forest development (Pare *et al.*, 2002).

Nutrient inputs and outputs in several places have been reported by several workers, for example, Crisp (1966) in an area of Pennine Moorland, UK; Crowther (1987a&b) in Kinta Valley, Malaysia; and Bruijnzeel (1991) in Watubelah, Indonesia.

Many workers have reported that total output of five elements (N, P, K, Ca, and Na) was greater than the input. Table 1.9 presents nutrient additions in precipitation, losses in drainage and the nutrient budget for calcium, magnesium, potassium, phosphorus, and nitrogen in several places.

Table 1.9: Nutrient additions in bulk precipitation (**I**), losses in drainage water (**L**) and the nutrient budget (differences) (**I-L**) for calcium, magnesium, potassium, phosphorus and nitrogen (kg ha^{-1} yr^{-1}) in selected places.

Location		Caura River (Venezuela) 1	Gua anak takun (Malaysia) 2	Kinta Valley (Malaysia) 2	Watubelah (Indonesia) 3
Annual rainfall (mm)		3850	2440	2845	4670
Annual runoff (mm)		2425	1255	1605	3590
Calcium	I	1.3	36.1	11.4	9.9
	L	15.5	764	795	29.0
	I-L	-14.2	-728	-784	-19.1
Magnesium	I	0.3	3.4	1.4	4.0
	L	6.0	45	89.9	30.5
	I-L	-5.7	- 42	-88.5	-26.5
Potassium	I	1.0	3.7	3.4	9.6
	L	14.6	20	75.7	22.00
	I-L	- 13.6	-16	-72.3	-12.4
Phosphorus	I	0.14	-	-	1.2
	L	0.24	-	-	0.7
	I-L	- 0.1	-	-	+0.5
Nitrogen	I	2.3	-	-	15.4
	L	6.3	-	-	10.6
	I-L	-4.0	-	-	+4.8

Sources: 1, Lewis (1986) and Lewis *et al.* (1987); 2. Crowther (1987a; 1987b); 3. Bruijnzeel (1991)

1.5. KNOWLEDGE GAPS AND NULL HYPOTHESIS

There have been few detailed ecological studies of tropical peatlands (Anderson, 1976; Rieley *et al.*, 1992) and a search of Bioabstracts from 1988-1995 produced 27 references relating to tropical peatlands of which only 5 were concerned with present day ecology (Stoneman, 1997). A major scientific effort is needed to establish how various tropical peatland ecosystems actually function and what links exist between them (Maltby & Immirzi, 1996). Search of various journals up to now, indicates that there is no research or information on integrated nutrient dynamics studies of tropical peat swamp forest. On the other hand, there are numerous published accounts of nutrient transfers in terrestrial tropical forest ecosystems and, although lessons can be learned from these, they do not reveal the significance of the peatland component of peat swamp forest. The main problem that is addressed in this present study, and which needs to be expanded to other similar situations, is the dual nature of the forested peatland ecosystem that functions above ground largely as a forest and at its surface and below ground as a peatland. These may appear to operate quite independently but, in reality, they have co-evolved over a long period of time during which one component contributed to the development and maintenance of the other although the only physical interface between them is the surface 50 cm or so of the peat.

The null hypothesis to be tested in this study is that the ombrotrophic peatland in the upper catchment of Sungai Sebangau in Central Kalimantan, Indonesia is a self sustaining ecosystem, which receives all of its nutrient elements from precipitation, some of which are stored in the forest biomass and accumulating peat and surplus is removed in runoff water. Furthermore, it is hypothesised that the separate nutrient dynamics of different forest sub-types will be similar even though their gross structure and overall species composition and density are different. The hypotheses will be tested by investigating rainfall, throughfall, stemflow, above ground biomass, below ground biomass, litter production, litter decomposition, peat soil and water run off and the chemical element capital within each of these in two sub-types of peat swamp forest. The data obtained will be used to produce a holistic model of nutrient apportionment and possible transfer pathways within the two forest sub-types in order to determine whether or not the null hypotheses are justified.

1.6. OBJECTIVE OF THE STUDY

The main aim of this study is to obtain data on the nutrient inputs, nutrient transfer, nutrient storage (peat soil) and outputs of nutrients in sub types of tropical peat swamp forest in Central Kalimantan, Indonesia. Operational objectives of this study are to:

1. describe the physical, chemical and biological attributes of peat swamp forest;
2. determine inputs of nutrients to and outputs;
3. investigate relationships between nutrients in peat, peat water and vegetation;
4. determine nutrient budgets for, and chemical element cycling and transfers within, the different peat swamp forest types relating these to overall landscape ecological and natural resources functions;
5. determine nutrient storage in peat soil in the two forest sub-types;
6. infer from the data the possible future for sustainable management of this peat swamp forest ecosystem.

CHAPTER 2

SITE DETAILS AND METHODS

2.1. FIELD ACTIVITIES

Fieldwork was carried out from October 2000 to July 2002, including, preparation for collection of samples from October to November 2000.

Precipitation and throughfall were collected every two weeks for a period of one year, from 10th November 2000 to 9th November 2001 making a total of 26 consecutive collections.

Canopy litterfall collection was also determined every two weeks during one year, simultaneously with the precipitation and throughfall collections.

Decomposition studies were carried out over the following periods: 6 months (10 November 2002 - 26th May 2001), 12 months (10 November 2002 - 4th November 2001), and 18 months (10 November 2002 - 25th May 2002).

Ground vegetation cropping, of trees less than 5 cm diameter and shrubby plants for biomass determination, was carried out twice during the research, on 10th November 2001 and 24th November 2001. Data for biomass of trees more than 5 cm diameter was obtained from Nicola Waldes from her studies within the same study area (see section 2.8). Root biomass determinations were carried out on 2nd February 2002 and 5th, 6th July 2002. Peat soil samples (0 –50 cm depth) were collected once during the wet season (31st March 2001). Surface water samples were obtained during the wet season (on 31st March 2001 when the water table was above the surface).

2.2. STUDY SITE

2.2.1. Description of study site / physical features.

The study area is situated between the Sebangau and Katingan Rivers near to the source of Sg. Sebangau in Central Kalimantan, Indonesia. This area is known as the Natural Laboratory for Management of Tropical Peat Swamp Forest (NAMTROP) and is an area of 500 km^2 (20 x 25 km) of peat swamp forest located 15 km south west of Palangka Raya, the capital of Central Kalimantan Province. The surface of study area from river's edge to the watershed was dome shape (ombrogenous) (Weiss *et al.*, 2002).

The micro-topography of the peat surface consists of mounds, hummocks, hollows and depressions of varying shapes and sizes. The elevated mounds are formed by aggregations of various types of roots - arching, buttress and stilt roots and pneumatophores – breathing roots on which organic debris becomes trapped and accumulates. The depressions form a network of inter-connected pools and channels that facilitate surface water movement over the peat swamp during the wet season.

There are differences in forest structure and tree species composition from the river's edge to the watershed, a distance of about 25 km. These have been classified into five sub-types – riverine forest, mixed swamp forest, low pole forest, tall interior forest, and very low canopy forest type – according to their canopy height, stratification and structure (Page *et al.*, 1999; Shepherd *et al.*, 1997).

This research was focussed in two different sub-types of peat swamp forest, mixed swamp forest and low pole forest in each of which three study plots were established to provide the basis for sample collection and replication (Figure 2.1).

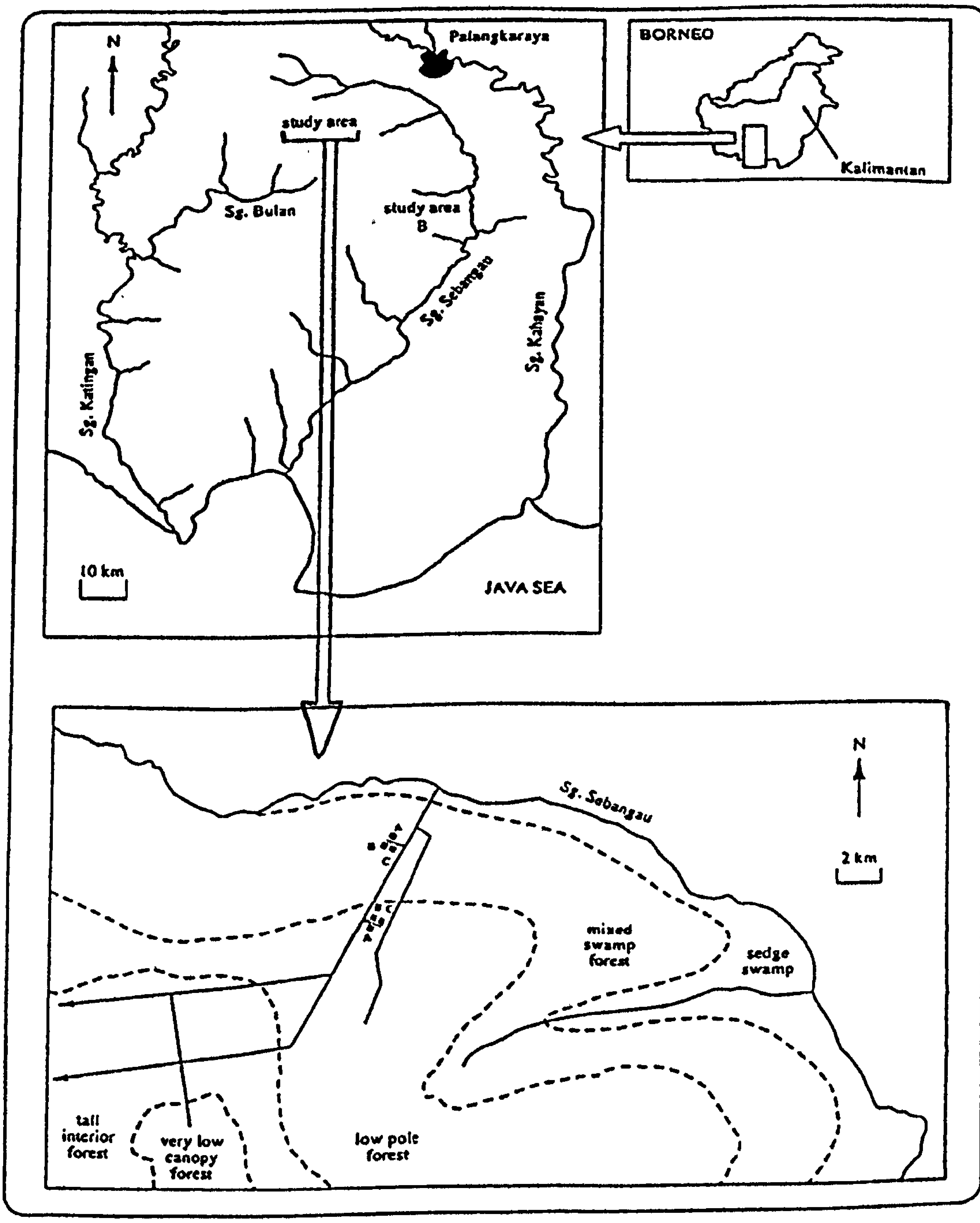


Figure 2. 1: Location of research (study plot) in the upper catchment area of Sungai Sebangau. Approximate boundaries of principal forest types are indicated (broken line) (after Page *et al.*, 1999).

2.2.2. Permanent plots

For the collection of throughfall, canopy litterfall, decomposition, and ground vegetation, three sample plots 50 x 50 m (0.25ha) were established in mixed swamp forest and low pole forest. Details of the location of sampling positions throughout the sampling period (fixed and roving collectors for litter and throughfall), and the dates of collections can be seen in Figures 2.2 and Section 2.11.4 (mixed swamp forest) and Figure 2.3 and Section 2.11.4 (low pole forest).

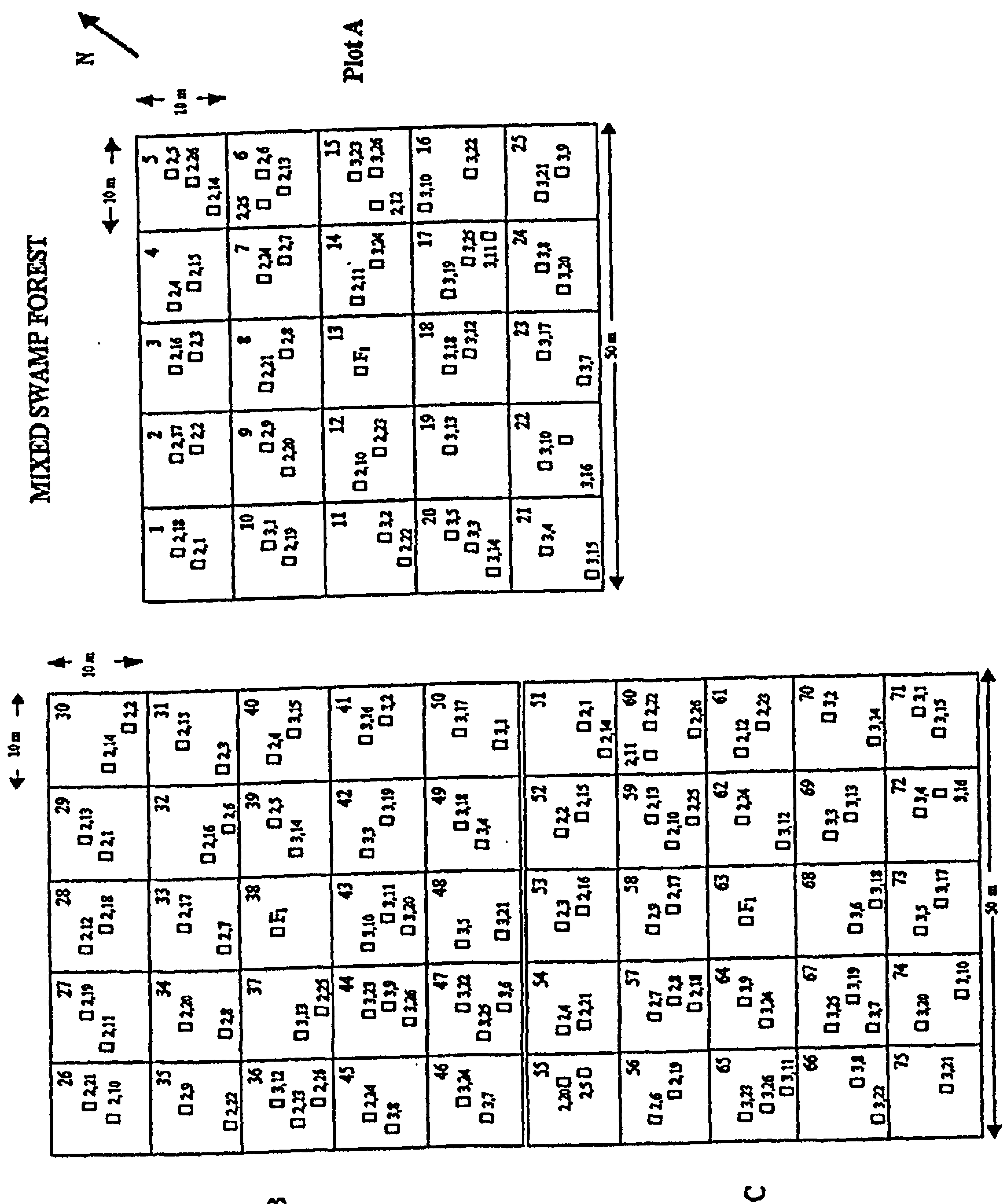


Figure 2.2: The mixed swamp forest plot showing the fixed (F1) and the roving (2,- & 3,-) sampling positions and dates of collection

LOW POLE FOREST

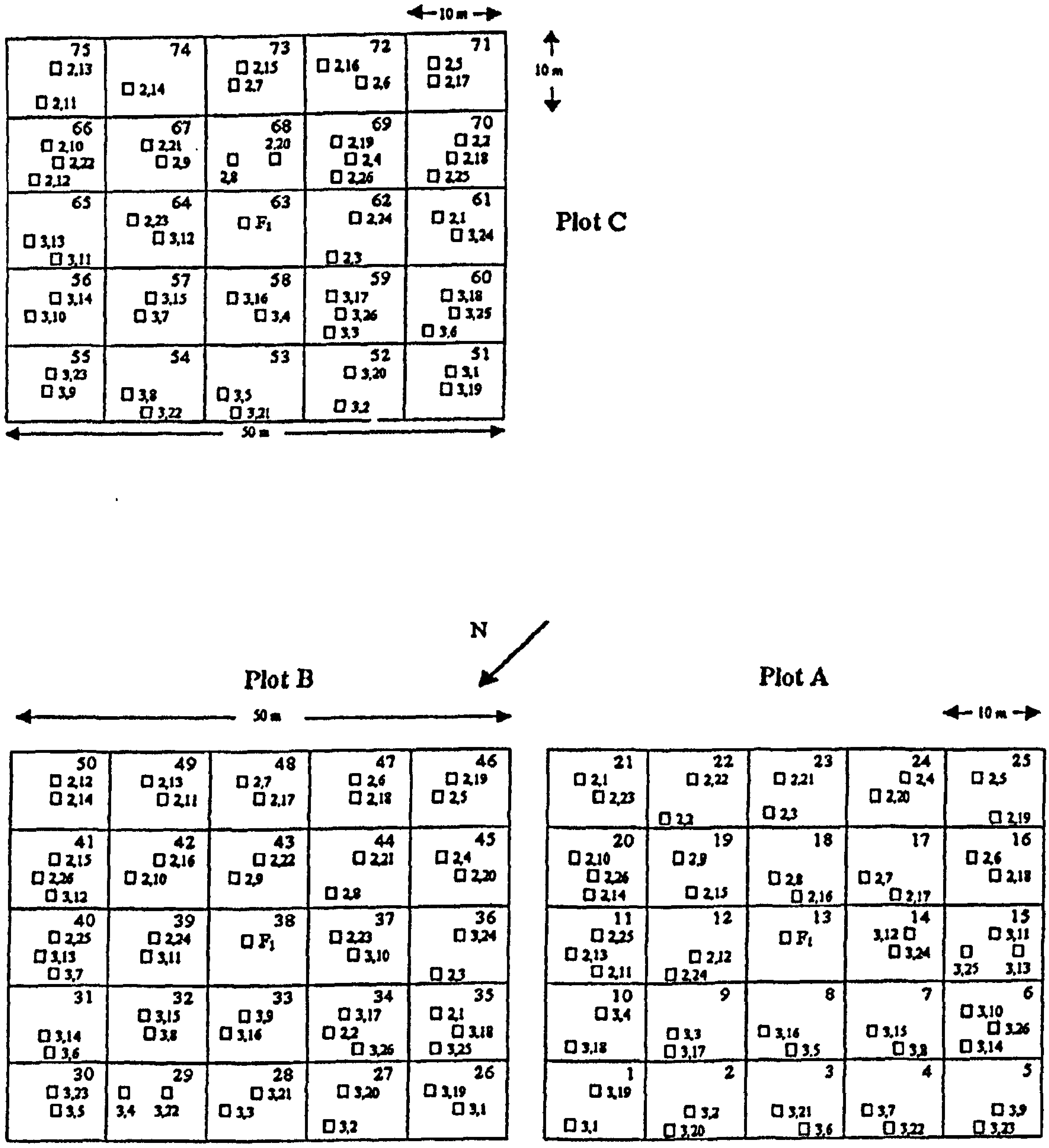


Figure 2.3 : The low pole forest plot showing the fixed (F1) and the roving (2, - & 3, -) sampling positions and dates of collection

2.3. PRECIPITATION

2.3.1. Method:

Fixed location rain gauges were placed in four locations in such a way as to sample above the vegetation. One rain gauge was placed in riverine swamp, two rain gauges in mixed swamp forest and one in low pole forest. In riverine swamp, where the forest has been removed, gauges were sited on the ground in the open, whilst in mixed swamp and low pole forests the sampling device was positioned above the tree canopies in order to eliminate any 'shelter' effect of surrounding trees (Rutter, 1963; Painter, 1976 cited by Ahmad-Shah, 1984; Lewis *et al.*, 1987).

The positions of these rain gauges were fixed throughout the sampling period because there is little variation in replicate samples of rainfall over short distances in the open (Rieley *et al.*, 1969; Ahmad-Shah & Rieley, 1989). Each collecting device consisted of a 25 litre polyethylene container fitted with a 25 cm diameter, steep sided, plastic funnel, with or without an extension tube depending upon whether it was located on the ground in the riverine swamp or in the air above the forest canopy in mixed swamp forest and low pole forest. The collecting bottles were mounted and fixed within a frame of wood and at least 50 cm above the peat surface in order to eliminate soil splash (Ahmad-Shah, 1984) as shown in Figures 2.4 and 2.5.

Steep-sided funnels were used to minimise any "splash out" from the gauges during heavy rainstorms. Collecting bottles were large enough to store the rain falling during the collection periods. Precipitation was collected every 2 weeks, over the 1-year period yielding 26 sets of data in each case. Atmospheric nutrient input (precipitation) to the peat swamp forest sub-types was obtained by multiplying the periodical totals of rain (4 weekly) by the corresponding nutrient concentrations (Likens *et al.*,1977; Ahmad-Shah & Rieley, 1989; Bruijnzeel, 1989, 1991; Crowther, 1987a & b; Veneklaas, 1990).

2.3.2. Materials

Rainwater collection gauges were constructed from 4 polyethylene containers (25 l), 4 funnels (25 cm diameter), nails, timber (5 cm diameter 1.25 m long), 48 bottles (0.5 l), and 10 m polyethylene tubing.

Figure 2.4 : A rain gauge in the riverine forest (open area)

Figure 2.5: A rain gauge in the MSF and LPF (above the canopy)

2.4. THROUGHFALL

2.4.1. Method

Throughfall was collected using the "fixed" and "roving" sampling gauge method of Wilm (Rieley *et al.*, 1969; Ahmad-Shah, 1984; Ahmad-Shah & Rieley, 1989). One fixed and 2 roving gauges were established in each study plot in the research area providing for 9 samples in every collection period for both mixed swamp and low pole forest. For the collection of throughfall, water was collected in 25 litre polyethylene containers fitted with 25 cm diameter plastic funnels mounted at least 50 cm above the ground (Figure 2.6).

Throughfall was collected every 2 weeks throughout the 1 year period (26 data sets). Volume was measured on site and 500 ml sub samples were taken for subsequent laboratory analysis.

2.4.1. Materials

Materials used for construction of throughfall collection gauges consisted of 18 polyethylene containers (25 l), 18 funnels (25 cm diameter), nails, timber (5 cm diameter 1.25 m long) and 48 sub-sample bottles (0.5 l).

Figure 2.6: Throughghfall gauge in mixed swamp forest

2.5. STEMFLOW

2.5.1. Method

Stemflow was collected by constructing plastic pipe collars (flexible tubing) at breast height (Eaton *et al.*, 1973; Nakanishi *et al.*, 2001) around tree trunks. The pipe (tubing) was nailed to the tree trunk and sealed with silicone sealant to ensure good adherence of the collar and to plug nail heads (Herwitz & Levia, 1997). The lower, uncut section of each stemflow collar was connected to 30 litre polyethylene containers. Five (5) stemflow collectors were established in each study plot covering the range of tree diameters and providing 15 samples in every collection period for both mixed swamp forest and low pole forest (Figure 2.7).

Similarly to rainfall and throughfall, stemflow was collected every 2 weeks throughout the 1-year period (26 data sets). Volume was measured on site and 500 ml sub samples were taken for subsequent laboratory analysis.

2.5.1. Materials

Materials used for construction of stemflow collection gauges consisted of 30 polyethylene containers (30 l), plastic pipe, nails, silicone sealant and 60 sub-sample bottles (0.5 l).

Figure 2.7: Stemflow gauge in mixed swamp forest

2.6. LITTERFALL

2.6.1. Method

The 'fixed and roving' sampling method was also used to collect litterfall (Ahmad-Shah, 1984). Fixed litter traps were placed near to the fixed throughfall gauges (one in each sampling plot), and roving litter traps were located beside each roving throughfall gauge (2 per plot). The roving traps were moved to new randomly determined positions after every collection period, in tandem with the roving throughfall gauges. This provided 26 data sets of 9 samples of litterfall for both mixed swamp and low pole forest sub-types over the one-year sampling period.

Litter traps were constructed from 0.2 mm plastic net, attached to a circular wood and wire frame, 0.3845 m^2 in area (70 cm diameter), mounted 1 metre above the peat surface (Figure 2.8).

The litter traps were emptied every two weeks in order to minimise decomposition of litter in the traps, especially during the wet season. The content of each litter trap was transferred to a labelled plastic bag, which had been prepared previously with the code of the trap and the date of collection. Litter collection was carried out from 10 November 2000 to 10 November 2001.

After collection, the litter was air-dried in the laboratory and then sorted into the following fractions that are equivalent to the 'fine litter' of Vitousek (1984) and the 'small litter' of Proctor (1983) and Chestnut *et al.* (1999):

1. Leaves,
2. reproductive parts (i.e. flowers, fruits and seed),

3. small branches and bark (wood and branches less than 5 cm diameter);
4. debris (i.e. minor or unidentifiable components, such as, leaf bracts, petioles, rachises, fine and broken leaf fragments, bryophytes, insect frass, faeces of other animals (e.g. birds) and other unrecognisable materials).

After sorting, each fraction was oven dried in paper bags at 70° C for 48 hours, the weights were recorded and chemical analysis for N, P, Ca, Mg, K, Na, Fe and Mn total carried out (see Section 2.11.2).

2.6.2. Materials

Materials used for construction of litter traps were plastic net, nails, timber (5 cm diameter 1.25 m long), small plastic bags, and paper envelopes (oven drying) and rubber bands.

Figure 2.8: The litter trap in mixed swamp forest (MSF)

2.7. DECOMPOSITION

2.7.1. Method

The litterbag method was used for the decomposition study (Bocock & Gilbert, 1957; Crossley & Hoglund, 1962; Swift *et al.,* 1981; Ribeiro *et al.*, 2002). This method involves enclosing fresh leaf litter in net bags that are placed on the forest floor (*in situ* incubation) thereby ensuring that the environmental conditions reflect those of the natural soil surface as closely as possible (Moore, 1984). Monitoring of the bags at intervals permits estimates to be made of the rate of breakdown of the litter (Crossley & Hoglund, 1962; Haraguchi *et al.*, 2002).

After weighing, air dried leaf litter was mixed thoroughly and approximately 100 g transferred to 25 x 22 cm net bags of plastic net, 1 mm mesh size (Figure 2.9). 75 litterbag samples were placed in each of the study plots that the leaf litter had been collected from. Initially, 4 replicated samples of air-dried material were dried for 48 h at 70° C to determine the ratio between air-dry mass and oven dry mass in each forest type. Every six months 12 litterbag samples were harvested from the study plots (MSF and LPF) and these were air dried, oven dried and weighed. Six litterbag samples were taken from hollows and other six samples from hummocks. The litter dry mass loss and nutrient release were calculated as (Guo & Sims, 1999; Guo & Sims, 2001):

$$L\,(\%) = \frac{100\,(Wo - Wt)}{Wo}$$

And

$$R\,(\%) = \frac{(WoCo - WtCt)}{WoCo} \times 100$$

Where L is litter dry mass loss, Wo the initial litter dry mass before the experiment started, Wt is the dry mass of the remaining litter after t time. R is nutrient release; Co is the nutrient concentration (mg kg^{-1}) in the initial litter; Ct is the nutrient concentration (mg kg^{-1}) in the remaining litter.

Many workers who carried out decomposition studies, for example, Edwards, (1977), Guo & Sims (1999), Regina & Tarazona (2001), Ribeiro *et al* (2002), and

Rogers (2002), and all have assumed that there is an exponential loss in weight as a result of decay, i.e.

$$Wt = Wo\ e^{-kt}$$

Where Wt is the dry weight at time t, Wo is the initial leaf litter dry weight, and k the rate of decomposition constant.

2.7.2. Materials

Materials used for construction of decomposition bags and subsequent collection of residual litter include plastic net, plastic rope, knitting needles, plastic bags, and paper bags.

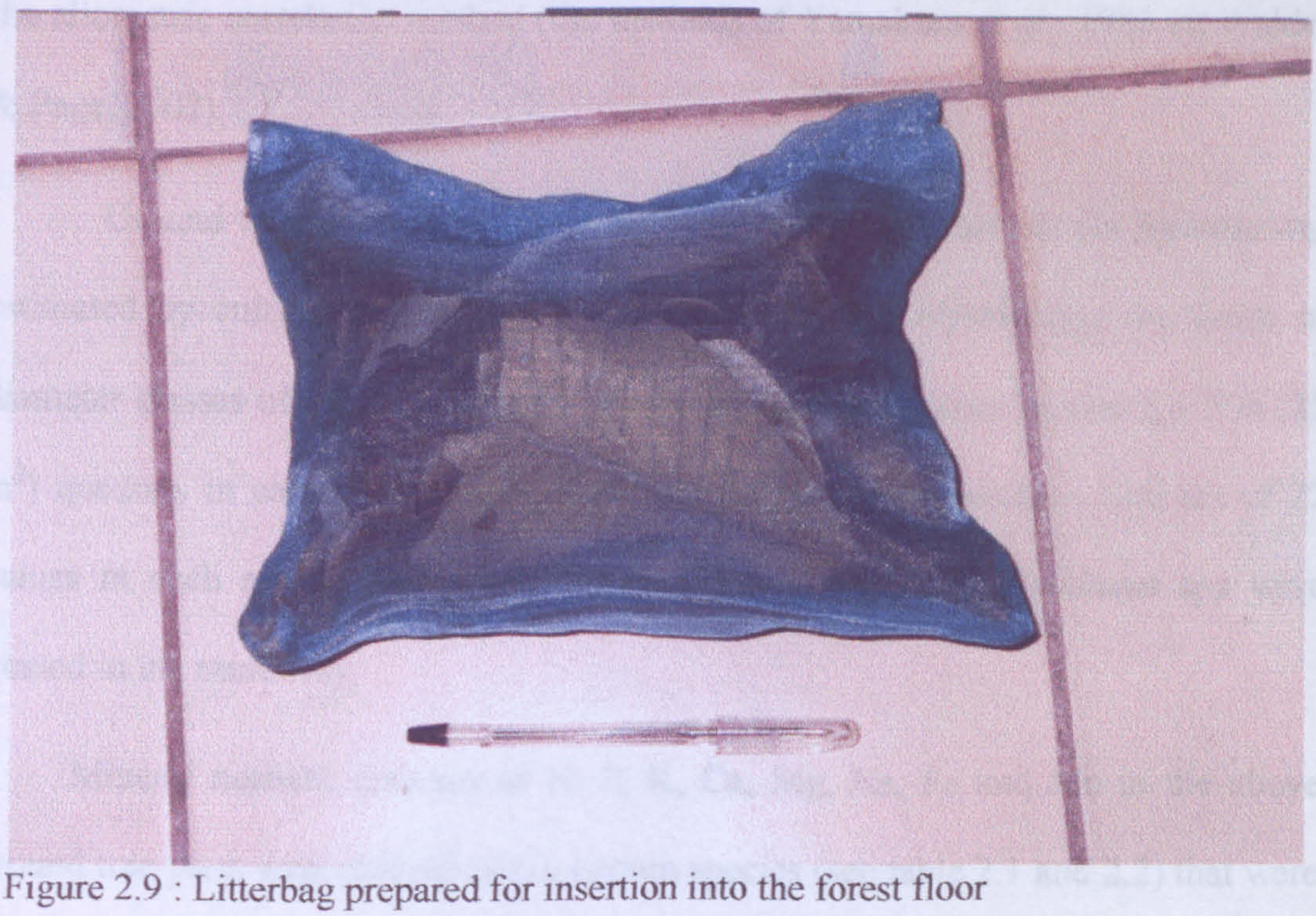


Figure 2.9 : Litterbag prepared for insertion into the forest floor

2.8. BIOMASS

2.8.1. Method

2.8.1.1. Above ground (ground vegetation cropping)

Aerial biomass (ground vegetation cropping) data for trees more than or equal to 5 cm diameter was obtained from Nicola Waldes (personal communication) who was carrying out her studies in the same area. Each plot was divided into twenty five 10 x 10 m subplots. Within each subplot, every tree equal to or more than 5 cm diameter at breast height (dbh, 1.3 m above the ground) was allotted a number and measurements taken of dbh, total tree height and canopy point height (cph). Trunk, branch and leaf estimates of biomass were calculated for all live trees in each plot by the allometric correlation method (the methods of Yamakura *et al.*, 1986 cit Waldes & Page, 2002).

Ground vegetation cropping of trees less than 5 cm diameter for biomass was estimated by cutting and weighing a random selection representing the range of diameter classes of the tree and multiplying by number of trees in nine 5 x 5 m (25 m^2) quadrats in each plot (Figures 2.10 and 2.11). This provided a data set of 27 values in each sub-type of forest. Shrubby plants, especially *Pandanus* spp were treated in the same way.

Mineral nutrient contents of N, P, K, Ca, Mg, Na, Fe and Mn in the above ground tree parts were determined in certain species (see table 2.1 and 2.2) that were harvested in MSF and LPF. In MSF, nutrient analyses were carried out in seven replications by mixing the leaves of the principal species, in plot A two replications, plot B three replications, and C two replications (see table 2.1 and 2.2).

The branches of tree species mentioned above (table 2.1 and 2.2) were also treated in the same way as leaves. Shrubs, especially *Pandanus sp* were also analysed to determine their nutrient content.

Table 2.1. : Plot, replication and tree species for mineral nutrient content analysis in mixed swamp forest (MSF).

Plot	Replication	Tree species
Plot A	1	*Calophyllum hosei, Elaeocarpus mastersii* and *Palaquium sp*
	2	*Eugenia sp, Mezzetia leptopoda* and *Neoscortechinia sp.*
Plot B	1	*Tetramerista glabra, Rubiaceae* and *Diospyros pseudomalabarica*
	2	*Shorea sp, Calophyllum hosei* and *Xanthophyllum sp*
	3	*Neoscortechinia sp, Eugenia sp* and *Palaquium sp.*
Plot C	1	*Pandanus sp, Actinodaphe sp* and *Elaeocarpus maskrsii*
	2	*Diospyros pseudomalabarica, Eugenia havilandii, Stemonurus sp* and *Antidesma sp*
Total	7	

In LPF, nutrient analyses were carried out in nine replications, plot A three replications, plot B three replications, and plot C three replications (see table below)

Table 2.2. : Plot, replication and tree species for mineral nutrient content analysis in low pole forest (LPF).

Plot	Replication	Tree species
Plot A	1	*Tetramerista glabra, Castanopsis foworthyii* and *Calophyllum sp*
	2	*Tetractomia sp, Eugenia sp. 1* and *Eugenia sp. 2*
	3	*Ternstroemia hosei, Garcinia cuspidata, Shorea sp* and *Eugenia sp*
Plot B	1	*Tetramerista glabra, Eugenia sp and Ternstroemia hosei.*
	2	*Garcinia cuspidata, Eugenia sp* and *Mesua sp.*
	3	*Meliaceae, Tetractomia sp.* and *Pandanus sp.*
Plot C	1	*Calophyllum ferrugineum, Tetramerista glabra* and *Garcinia sp*
	2	*Shorea sp., Garcinia bancana* and *Ixora havilandii*
	3	*Tetractomia sp, Eugenia sp* and *Calophyllum sp.*
Total	9	

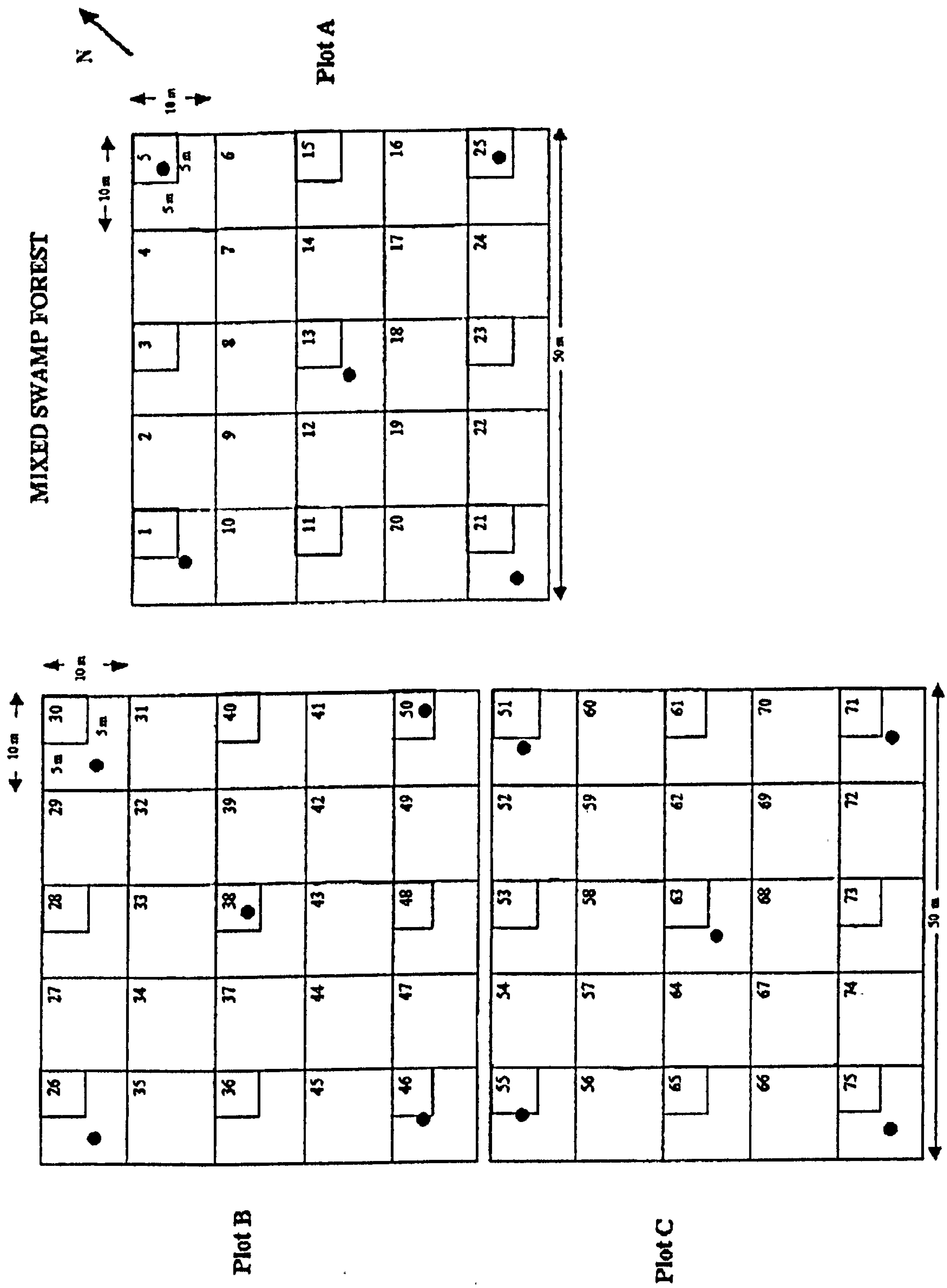


Figure 2.10: Location of aerial biomass (□) and root samples (•) in MSF

LOW POLE FOREST

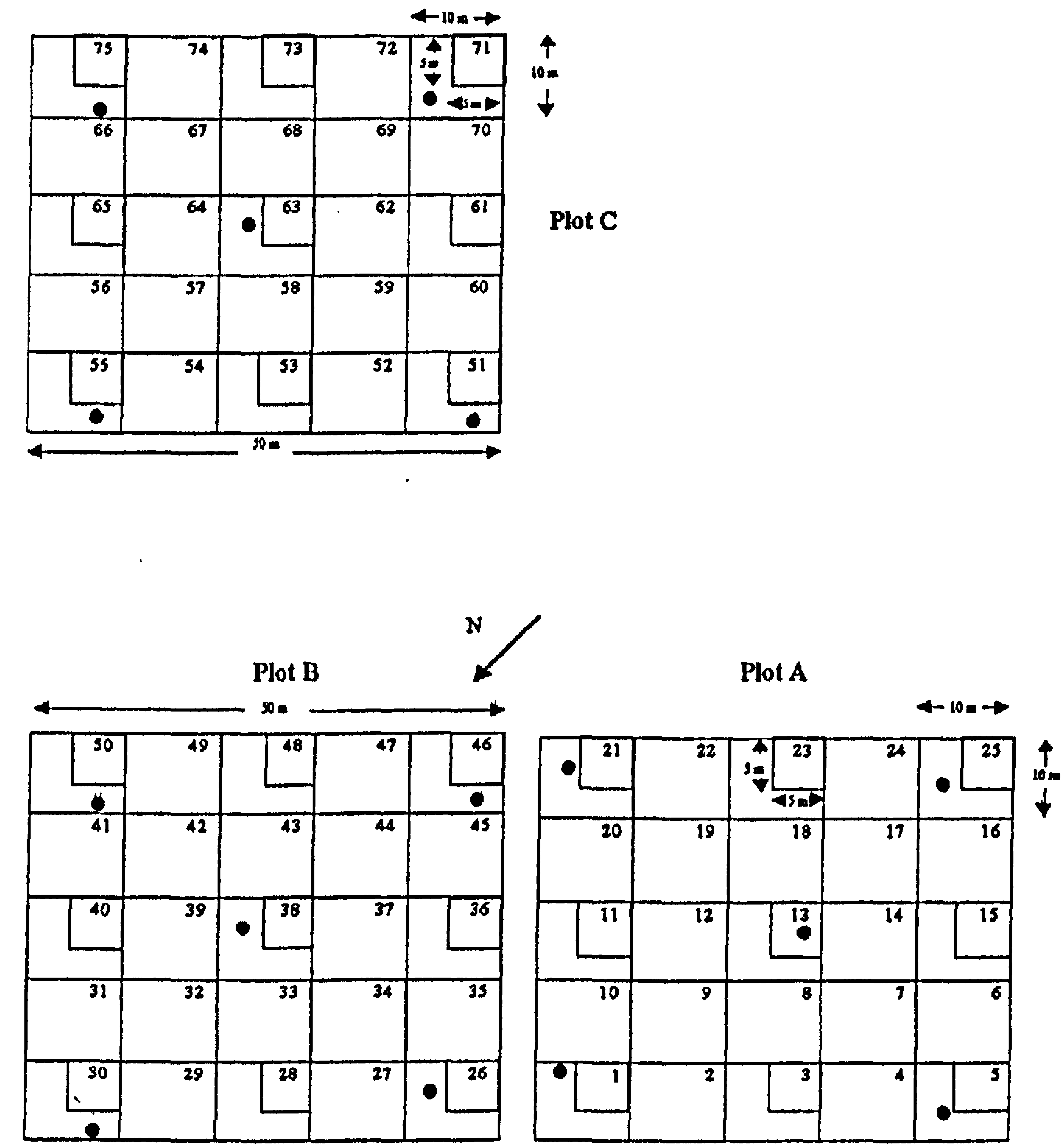


Figure 2. 11: Location of aerial biomass (□) and roots samples (•) in LPF

2.8.1.2. Below ground (root biomass)

Fine and large roots (underground stumps) were removed from one metre square areas in the middle of mixed swamp and low pole forest plots to depths of 0-25 cm and 25 – 50 cm below the peat surface. In addition, four 50 x 50 cm samples were removed, one from each corner of the plots from the same two depths. In the latter case, only living roots were collected. Visual criteria to distinguish live from dead roots included colour and physical integrity. A light coloured inner bark was present in live roots while dead roots had dark coloured bark (Kurz & Kimmins, 1987 cit Brady, 1997).

The roots were divided into three fractions according to their diameter: <0.5 cm; 0.5 – 3 cm; and >3 cm. The roots were washed and shaken before weighing (Edwards & Grubb, 1977). In order to reduce errors in calculating root biomass, similar sized sample areas were chosen in hummocks, hollows and mixed areas in both sub types of forest. The roots were transferred to the laboratory and air dried for two weeks followed by oven drying at 70° C for 48 hours before chemical analysis.

Roots of all diameter classes within each sample were bulked prior to analysis of N, P, K, Ca, Mg, Na, Fe and Mn (see Section 2.11). Fifteen replicate analyses were made of roots from both mixed swamp and low pole forests. Amount of nutrient in roots was obtained by multiplying the weight of roots per unit area by the nutrient concentrations.

2.8.2. Materials

Materials used for determination of biomass were balances, knives, scissors, saws, mandau (traditional knives), plastic bags, paper bags, and rubber bands.

2.9. PEAT SOIL

2.9.1. Method

Peat soil samples were collected from 0 to 50 cm depth in 9 sub plots in each of the three study plots, (Figures 2.12 and 2.13) providing 27 replicates for each forest type. Samples were collected twice, once in the dry season and once in the wet season. Samples were placed in plastic bags and transported to the Laboratory for chemical analysis. Soils were air dried for 1 month before sieving through a 0.5 mm mesh sieve to homogenize the samples.

2.9.2. Materials

Materials used for peat soil sample are mandau (traditional knives), plastic bags, and rubber bands.

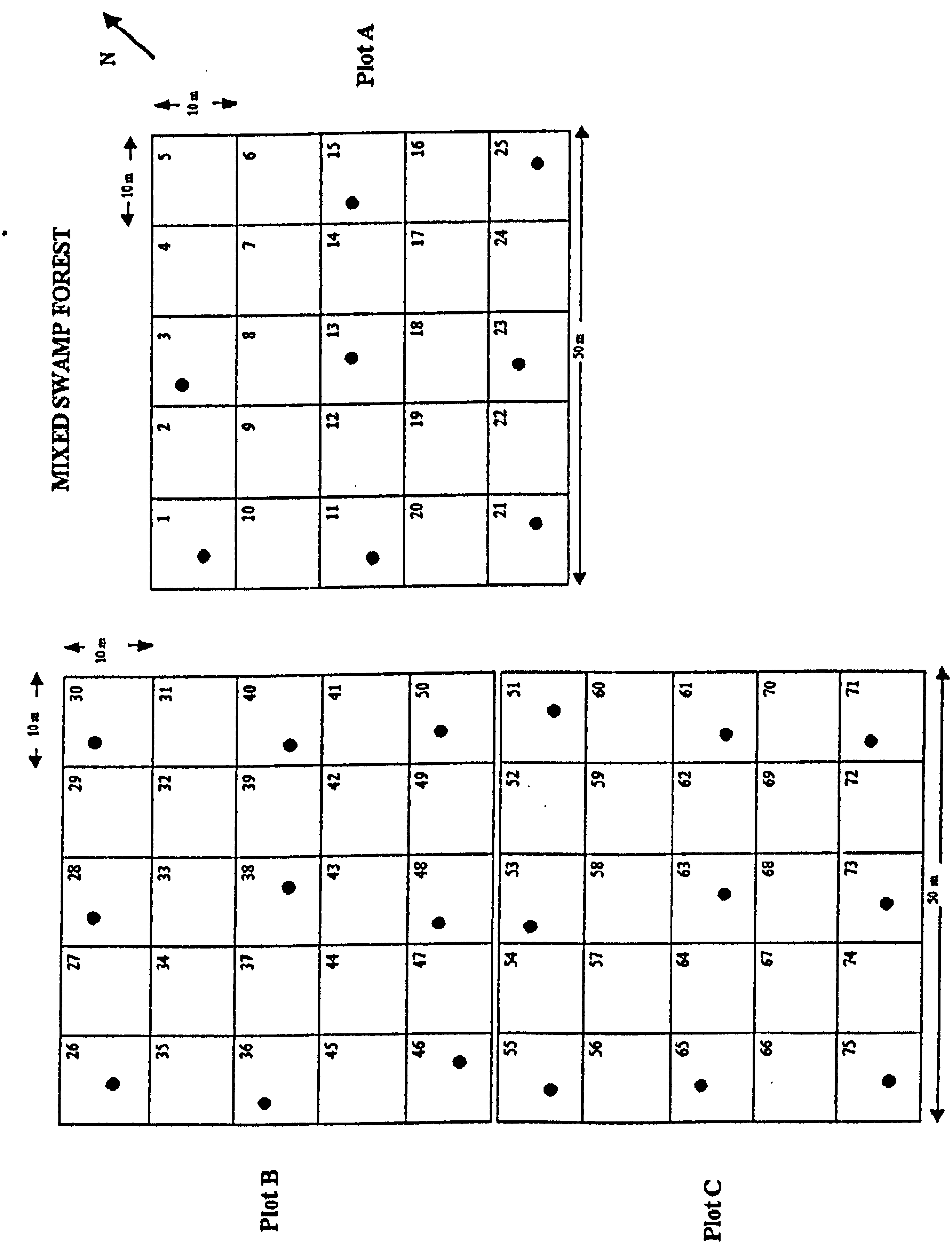


Figure 2.12: Location of peat soil samples collected (•) in MSF

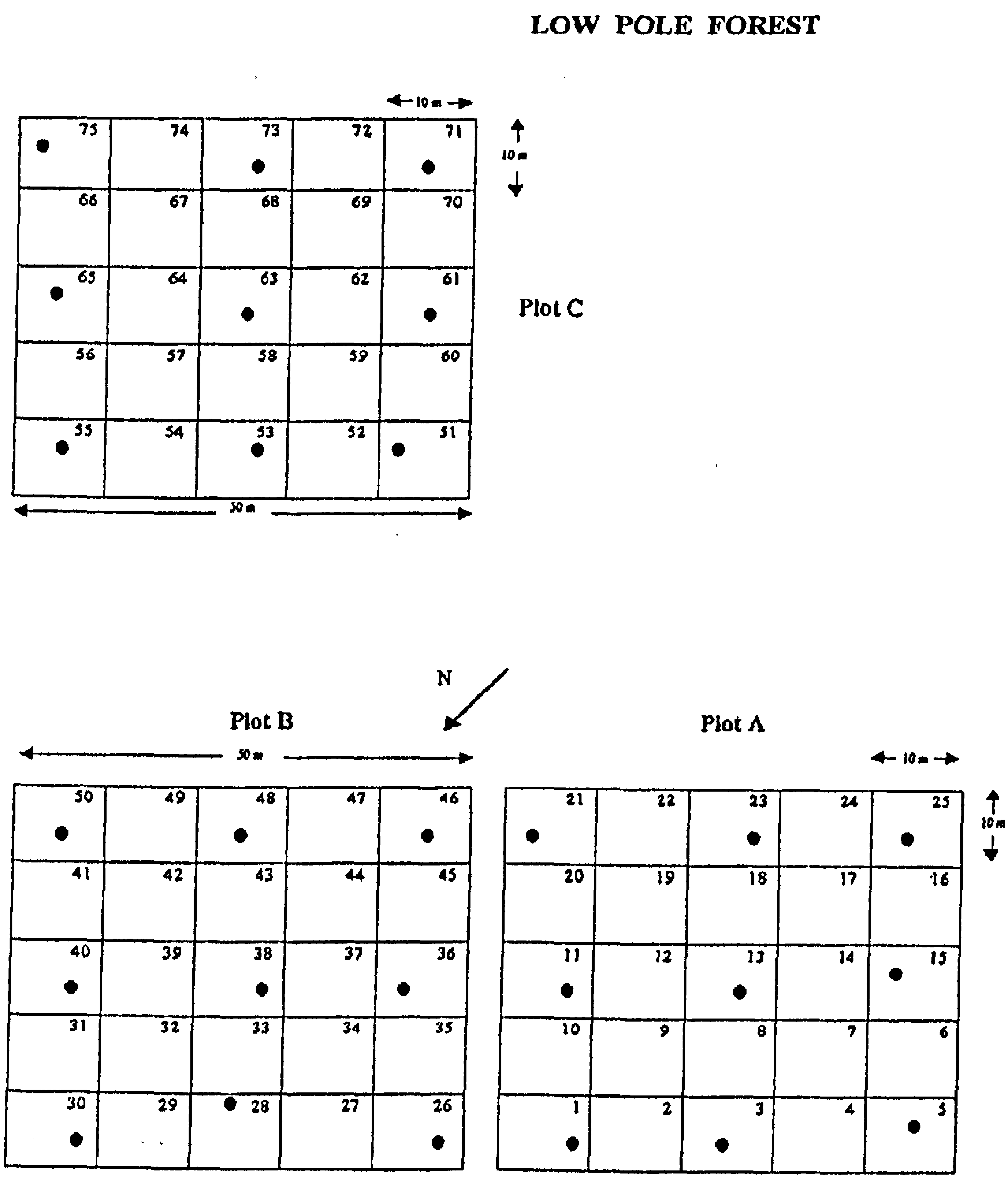


Figure 2. 13: Location of peat soils collected (•) in LPF

2.10. RUNOFF

2.10.1. Method

Mass surface water flow, in the surface peat layer and above the surface, is the principal route of nutrient losses from peatland ecosystems.

Water samples were collected from the peat surface during the wet season from 9 locations in each sub-plot of each forest type, giving rise to 27 replicate samples for both mixed swamp and low pole forest. Mass flow of water from the peat swamp forest ecosystem is calculated from the relationship:

$$MFWO = R - ET$$

Where $MFWO$ is mass flow water output, R is annual rainfall and ET is annual water loss from evapo-transpiration in mm.

Evapotranspiration estimates were obtained from Dr. Takahashi of the University of Hokkaido, Japan who was carrying out microclimatic research in the upper catchment of Sg. Sebangau. The mean value was 3.4 mm day $^{-1}$ (Takahashi *et al.*, 2002). Acidity (pH) of the water samples was determined immediately upon return to the laboratory and mineral nutrient contents (P, K, Ca, Mg, Na, Fe, and Mn) were analysed after filtration (see Section 2.11.1).

2.10.2. Materials

Materials used for the collection of mass flow water samples were 54 bottles (0.5 l) and plastic bags.

2.11. LABORATORY AND CHEMICAL ANALYSIS PROCEDURES

2.11.1. Water samples

2.11.1.1. Methods

500 ml samples of rainfall, throughfall and mass water flow at the peat surface (see section 2.3, 2.4, and 2.9 respectively) were transported to the laboratory in plastic bottles on the day of collection. pH was determined electrometrically using an Activon Model 210 pH meter before water samples were filtered. After filtering through Whatman No. 1 papers, samples were stored in a refrigerator at less than 4° C for up to 2 weeks after collection, prior to chemical analysis.

2.11.1.1.1. Determination of Anions

(a) Phosphorus

Total phosphorus was determined following the method of Tachibana (2000). A 25 ml sample, was transferred to an Erlenmeyer flask 100 ml and 4 ml $K_2S_2O_8$ 5% w/v (by diluting 50 g $K_2S_2O_8$ in distilled water made up to 1 l and heated up to 30 – 40°C) added. The Erlenmeyer flask was covered in aluminium foil and autoclaved for 30 minutes. After cooling, to 20 ml was added 4 ml of combination solution (made by mixing 50 ml 50N H_2SO_4, 5 ml potassium antimonyl tartrate, 15 ml ammonium molybdate, and 30 ml ascorbic acid) and made up to 25 ml. Colour development is complete after 10 minutes then absorbance is measured at 882 nm wavelength. The standard series samples for calibration were treated in the same way.

(b) Nitrite -nitrogen

Nitrogen in the form of nitrite-nitrogen was measured by the method in Tachibana (2000)

To a 25 ml sample in an Erlenmeyer flask is added 0.1 g of mixed powder (1 g sulphanilic acid, 0.1 g naphthylamine, and 8.9 g tartaric acid). Absorbance is measured at a wavelength of 520 nm between 20 and 40 minutes afterwards. The standard series samples for calibration are treated in the same way.

2.11.1.1.2. Cations

The concentrations of potassium, calcium, magnesium, sodium, iron and manganese were determined using an atomic absorption spectrophotometer (Varian Spectra 40).

Ammonium-nitrogen

Inorganic nitrogen in the form of ammonium-nitrogen was measured by the indophenol method (Scheiner, 1976). To 25 ml of sample in a 50 ml volumetric flask is added 10 ml of "A solution" that was made from 60 g phenol, 0.2 g $Na_2Fe(CN)_5\ NO.2H_2O$ and 1 l buffer reagent (30 g $Na_3PO_3.12\ H_2O$, 30 g $Na_3C_6H_5O_7.2H_2O$ and 3 g EDTA in 1 litre of distilled water). Promptly, 15 ml of "B solution" (30 ml NaClO and 400 ml 1 M NaOH filling up by distilled water up to 1 l) was added. Colour development is complete after 45 minutes at room temperature and absorbance is measured at 635 nm wavelength. The standard series samples for calibration are treated in the same way.

2.11.2. Canopy litter

2.11.2.1. Methods for litter analysis

An acid wet digestion method was used after each litter fraction was ground to a homogenous powder, by passing it through a 0.5 mm mesh sieve in a hammer mill. 0.25 g samples of each fraction were digested in 15 ml of 18% perchloric acid (Jones & Case, 1990) together with 2 blanks containing a similar volume of the acid but without litter samples. Digestion was allowed to proceed for more than four hours until the solution became colourless. After cooling, distilled deionised water was added to dissolve the residue and made up to 25 ml in a volumetric flask and then transferred to polyethylene bottles prior to subsequent analysis for calcium, magnesium, potassium, sodium, iron, and manganese concentration by atomic absorption spectrophotometry (Varian Spectra 30).

Total phosphorus was determined by the Scheel method (Lambert, 1992). To 2 ml of the acid digest is added 5 ml distilled water, 2 ml Scheel I (1 g methol-phenol-sulphate, 5 g $Ns_2SO_3.7H_2O$, and 137 g $Na_2S_2O_5$ in 1 l distilled water), 2 ml Scheel II (50 g ammonium molybdate and 140 ml pure sulphuric acid in 1 l distilled water) and mixed carefully. After 15 minutes 4 ml Scheel III (205 g anhydrous sodium acetate in 1 l distilled water) are added, and the volume increased to 20 ml by the addition of 5 ml distilled water and mix. After a further 15 minutes the resultant colour intensity is measured on a spectrophotometer at a wavelength of 700 nm. The standard series samples for calibration was treated in the same way.

Total nitrogen was determined following persulphate digestion (Purcell & King, 1996). To 0.025 g of sample in a boiling tube is added 50 ml of a mixture of

$K_2S_2O_8$ and NaOH, made by dissolving 22.5 g $K_2S_2O_8$ and 9.5 g NaOH in 1 litre of distilled water (digestion mixture). A blank containing a similar volume of the $K_2S_2O_8$ and NaOH mixture but without sample is also prepared. The tubes are placed in an autoclave at 120°C and 100 kpa or 14 psi pressure for 1.5 hours and then allowed to cool overnight in the autoclave. To 0.2 ml of the extract, in Erlenmeyer flask, is added 0.8 ml of the salicylic acid-H_2SO_4 reagent (5 % w/v), reaction for about 20 minutes. Slowly add 19 ml of 2N Na OH, cool samples to room temperature and determine the absorbance at a wavelength of 410 nm. The standard series samples for calibration was treated in the same way.

2.11.3. Peat

2.11.3.1. Methods

Peat samples (0-50 cm depth) were brought to the laboratory for chemical analysis (N, P, K, Ca, Mg, Na, Fe, and Mn). They were air dried for 2 weeks, then milled to a homogenous powder in a hammer mill and digested in 18% perchloric acid similar to leaves/branch analysis . Subsequent analytical methods were the same as those described in section 2.11.2.

2.12. DATA ANALYSIS

2.12.1. Wilm's method

Wilm's method (a co-variance method) and conventional statistics (Excel) were used to analyse and evaluate throughfall and litterfall data.

Throughfall and litterfall were collected using the "fixed" and "roving" sampling gauge method proposed by Wilm (1946) as modified by Rieley *et al.*, (1969) and used by Ahmad-Shah & Rieley (1989). This approach was used in order to reduce variation in throughfall and litterfall underneath the vegetation canopies otherwise a much larger number of fixed collecting gauges would be required. Rutter (1963), for example, found that as many as twenty randomly placed gauges produced an error up to 11 % of the mean for each time period. If collecting gauges are moved to new random positions after each time period this error is reduced to 3 – 5 % of the mean (Rieley *et al.*, 1969). In addition, Wilm's method has therefore proved to be adequate and useful to the measurement of throughfall, litterfall, and for biomass determination of ground vegetation where spatial variation of information in data sets is likely to be large (Ahmad-Shah, 1984; Ahmad-Shah & Rieley, 1989).

2.12.2. Rainfall, throughfall, litterfall

In order to obtain comparative information on mineral cycling in the peat swamp forest ecosystem in Central Kalimantan, Indonesia the data for chemical analysis concentration of rainfall, throughfall and litterfall were converted to kg ha^{-1} yr^{-1}. Correlation and regression analyses between ions from each sampling fraction (e.g. rainfall, throughfall, litter) and also between fractions (e.g. rainfall and throughfall; throughfall and litter, and so on) were carried out. Analysis of variance was also carried out for both sub-types of forest, mixed swamp forest and low pole forest, in order to detect any significant differences.

Graphical presentation of results represents four weekly means for each parameter over one year (13 sample periods) for rainfall, throughfall and litterfall although samples were collected every 2 weeks.

Data handling of throughfall and litterfall data was carried out using both methods, Excel and Wilm's method (see chapter 2.12.1). Comparison of the two methods of data analysis can give more understanding of the advantages and disadvantages of both methods. This information can then be used in the future to determine which one is more suitable for specific research purposes. Unfortunately, nutrient concentrations and nutrient totals in litterfall could not be analysed using the Wilm method because leaf, branch, reproductive part and other debris samples were bulked prior to nutrient analysis.

2.12.3. Biomass, peat soil, run off, and decomposition

The chemical analysis concentration data for above ground vegetation biomass (trees), below ground biomass (roots), and peat soil were converted to kg ha^{-1}. In order to determine nutrient losses from the peatland ecosystem, the chemical elements concentrations in mass water outflow (mg l^{-1}) were also converted to kg ha^{-1} yr^{-1}.

All of the data are presented in summary diagrams of mineral cycling of the peat swamp forest ecosystem in Central Kalimantan, Indonesia using the two forest sub types, MSF and LPF as models (see section 4.10). Nutrient budgets are also presented in order to show differences between nutrient input (rainfall) and nutrient out put (run off) during the 1 year period of this study (see section 4.10).

Decomposition data from both forest sub-types, mixed swamp forest and low pole forest (see chapter 2.6) are presented in graphical form for mass and nutrient losses during 6, 12, and 18 month periods. Analysis of variance was also carried out to compare decomposition rates between the two sub-types using SPSS 11.0 for Windows.

2.12.4. Sampling dates

The individual collection dates over the one-year period (rainfall, throughfall, and litterfall) were as follows:

10/10/00 (start)	24/10/00 (1)	08/12/00 (2)	21/12/00 (3)
05/01/01 (4)	20/01/01 (5)	03/02/01 (6)	17/02/01 (7)
07/03/01 (8)	17/03/01 (9)	31/03/01 (10)	14/04/01 (11)
28/04/01 (12)	12/05/01 (13)	26/05/01 (14)	09/06/01 (15)
23/06/01 (16)	07/07/01 (17)	21/07/01 (18)	04/08/01 (19)
18/08/01 (20)	01/09/01 (21)	15/09/01 (22)	29/09/01 (23)
13/10/01 (24)	27/10/01 (25)	09/11/01 (26)	

Sampling dates for the decomposition study were as follows:

26/05/01 (1)	04/11/01 (2)	25/05/02 (3)

Sampling dates for ground vegetation study were as follows:

10/11/01 (1)   24/11/01 (2)

Sampling dates for root biomass were as follows:

02/02/02 (1)   05/07/02 (2)   06/07/02 (3)

Sampling date for soil samples was as follows:

31/03/01 (1)

Sampling date for water surface was as follows:

31/03/01 (1)

CHAPTER 3

RESULTS

3.1. PRECIPITATION

3.1.1. The Quantity and pH of rainfall

Seasonal pattern of rainfall every 4 weeks during a 1-year study period from 10 November 2000 to 9 November 2001 in the upper Sg. Sebangau are presented in figure 3.1.1. The total amount of rainfall, determined from 4 rain gauges, was 2761± 388 mm.

Figure 3.1.1 shows that there is variation in the amount of precipitation falling on the peat swamp forest during the study period. The mean 4 weekly amounts ranged from 24±8 mm to 424±47 mm and the mean over the 1 year period was 213± 30 mm with the highest value obtained between 4 February and 7 March 2001 (424±47 mm), followed by 14 October to 9 November 2001 (362±78 mm) both of which occurred during the rainy season. In contrast, the lowest amount of water was collected between 24 June and 21 July 2001 (24±8 mm).

The pH of rainfall varied throughout the study period (Figure 3.1.2) ranging from pH 5.55±0.22 to 6.50±0.08 and the mean over the 1 year period was 5.96±0.35. The highest value obtained was between 6 January and 3 February 2001 (6.50±0.08) during the wet season, followed by 24 June – 21 July 2001 (6.46±0.07) in the dry season. In contrast, the lowest value occurred during 14 October-9 November 2001 (5.55±0.22).

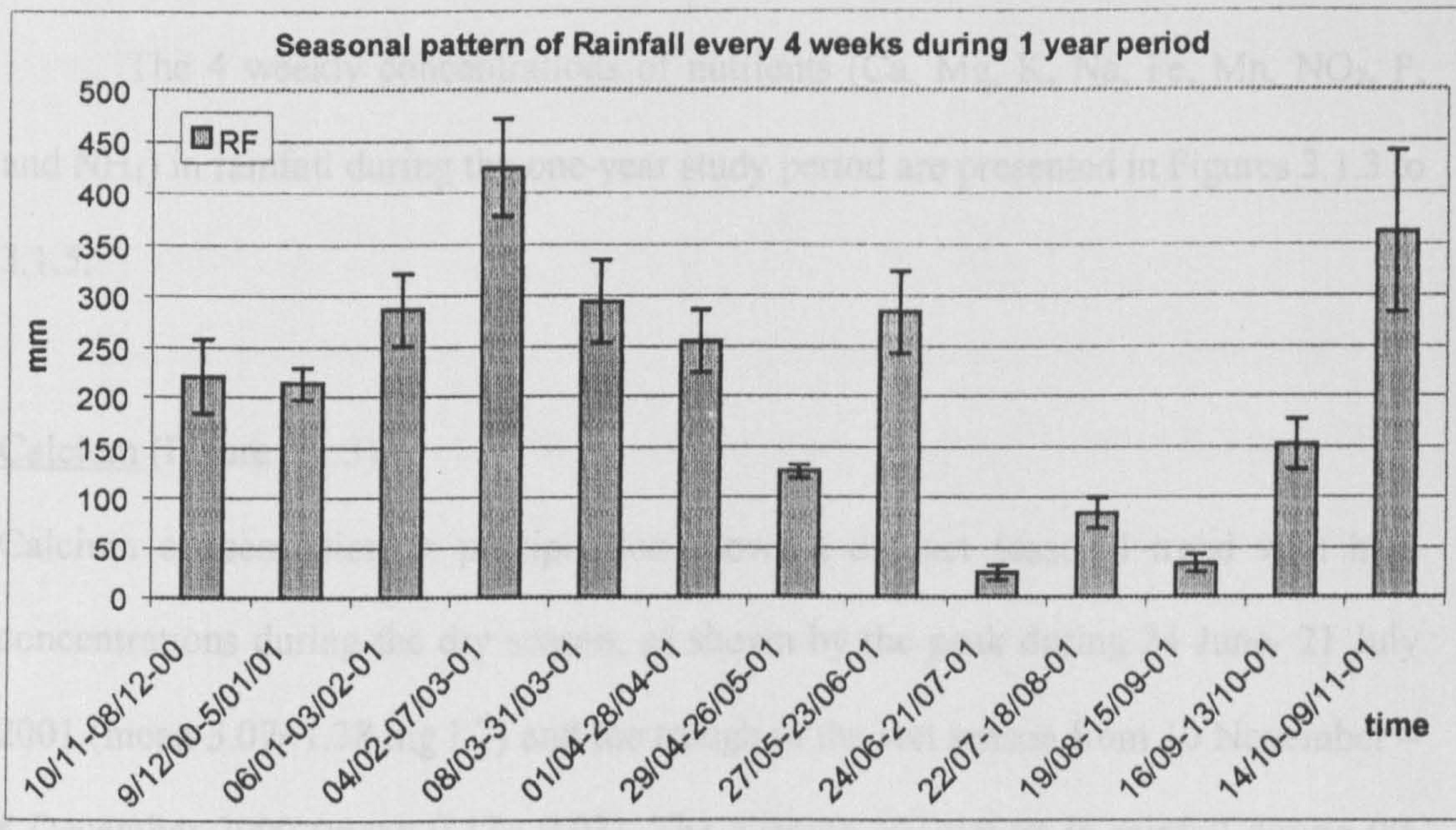


Figure 3.1.1: Seasonal pattern of rainfall every 4 weeks during 1 year period

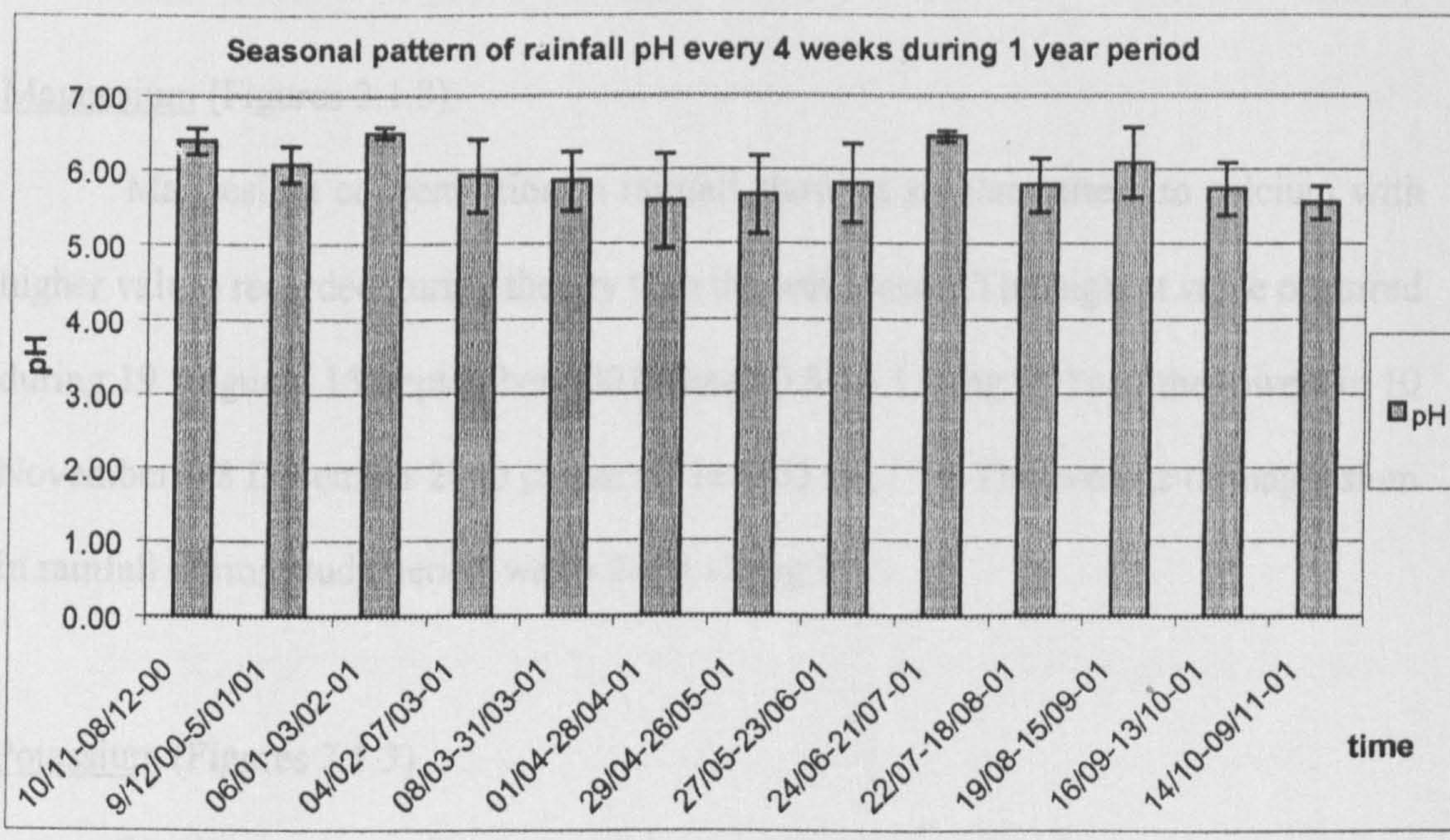


Figure 3.1.2: Seasonal pattern of rainfall pH every 4 weeks during 1 year period

3.1.2. Concentration of chemical elements in rainfall

The 4 weekly concentrations of nutrients (Ca, Mg, K, Na, Fe, Mn, NO_2, P, and NH_4) in rainfall during the one-year study period are presented in Figures 3.1.3 to 3.1.5.

Calcium (Figure 3.1.3)

Calcium concentration in precipitation shows a distinct seasonal trend with high concentrations during the dry season, as shown by the peak during 24 June- 21 July 2001 (mean 3.07±1.38 mg l^{-1}) and the trough in the wet season from 10 November – 8 December 2000 (mean 0.17± 0.03). The average of calcium in rainfall during the study period was 0.89±0.43 mg l^{-1}.

Magnesium (Figures 3.1.3)

Magnesium concentration in rainfall shows a similar pattern to calcium with higher values recorded during the dry than the wet season. The highest value occurred during 19 August - 15 September 2001 (mean 0.84 ± 1.7 mg l^{-1}) and the lowest in 10 November – 8 December 2000 (mean 0.11± 0.03 mg l^{-1}). The average of magnesium in rainfall during study period was 0.28±0.12 mg l^{-1}.

Potassium (Figures 3.1.3)

Similar to magnesium, potassium concentration was higher in the dry season than in the wet season peaking during 24 June- 21 July 2001 (mean 0.1.51 ± 1.28 mg l^{-1}). The wet season minimum occurred during 9 December 2000 – 5 January 2001 (mean 0.09± 0.02 mg l^{-1}). The average potassium concentration in rainfall during the 1-year study period was 0.59±0.55 mg l^{-1}.

Sodium (Figures 3.1.4)

Sodium concentration in rainfall was high during 6 January – 3 February 2001 and from 24 June to 15 September 2001 and peaked during 22 July- 18 August 2001 with a mean of 0.83±0.25 mg l^{-1}. It was lowest during the wet season with a mean of 0.01±0.01 mg l^{-1} during 1-28 April 2001. The average concentration of sodium in rainfall during the study period was 0.30±0.10 mg l^{-1}.

Iron (Figures 3.1.4)

Concentration of iron in rainfall was generally low except during 4 February-7 March 2001 and 1-28 April 2001 when there were means of 0.40±0.07 and 0.27±0.04 mg l^{-1}, respectively. The lowest iron concentration was 0.009±0.008 mg l^{-1} during 2 May-23 June 2001 and 22 July-18 August 2001. The average iron concentration in rainfall during the 1-year study period was 0.09±0.02 mg l^{-1}.

Manganese (Figures 3.1.4)

Manganese concentrations in rainfall were very low throughout the study period and undetectable in most months, for example, during 10 November – 8 December 2000, from 6 January to 31 March 2001 and during 19 August – 15 September 2001. Only in 1-28 April 2001 was a significant concentration of 0.07±0.02 mg l^{-1} obtained.

Nitrite (Figures 3.1.5)

Similarly to iron, nitrite concentration in rainfall was generally low. The peak concentration occurred during 19 August - 15 September 2001 with a mean of 0.19±0.08 mg l^{-1} and the lowest in 1-28 April and 27 May – 23 June 2001 with means of 0.002±0.015 and 0.002±0.001 mg l^{-1}, respectively. The average nitrite concentration in rainfall during the study period was 0.03±0.02 mg l^{-1}.

Phosphate (Figures 3.1.5)

There were several peak concentrations of phosphate in rainfall, for example during 4 February- 7 March 2001 with a mean of 0.38±0.53 mg l^{-1} and 24 June – 21 July 2001 with a mean of 0.35±0.36 mg l^{-1}, although there were no clear seasonal trends. The mean phosphate concentration in rainfall during the study period was 0.17±0.17 mg l^{-1}.

Ammonium (Figures 3.1.5)

The average ammonium concentration in rainfall during the study period was 0.84±0.32 mg l^{-1} and it showed a similar seasonal pattern to calcium. The highest concentration was recorded during the dry season with a peak during 29 April - 26 May 2001 (mean 5.51±0.25 mg l^{-1}) while the lowest during 16 September – 13 October 2001 (mean 0.011±0.022 mg l^{-1}).

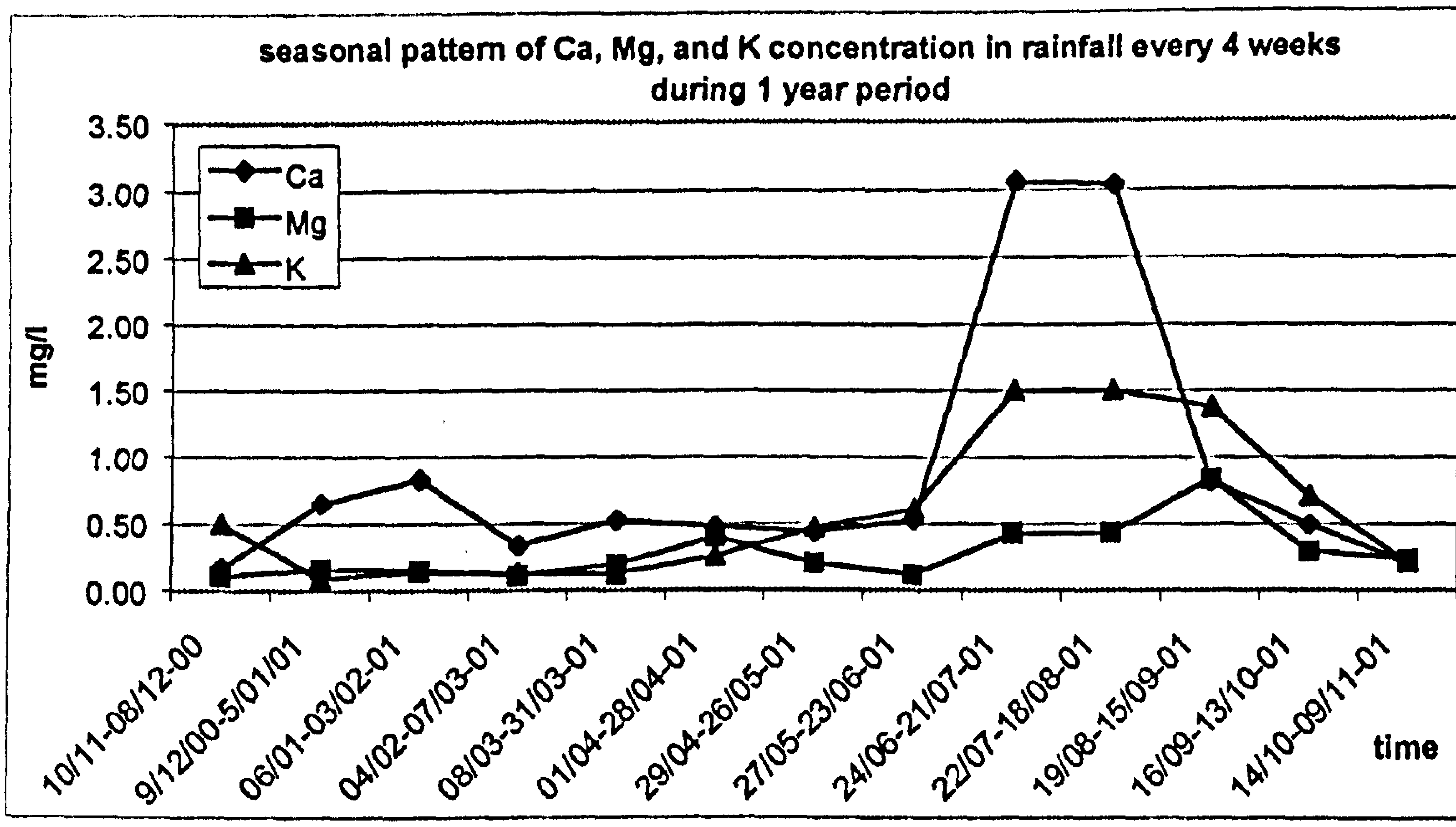


Figure 3.1.3: Seasonal pattern of Ca, Mg, and K concentration in rainfall every 4 weeks during 1 year period

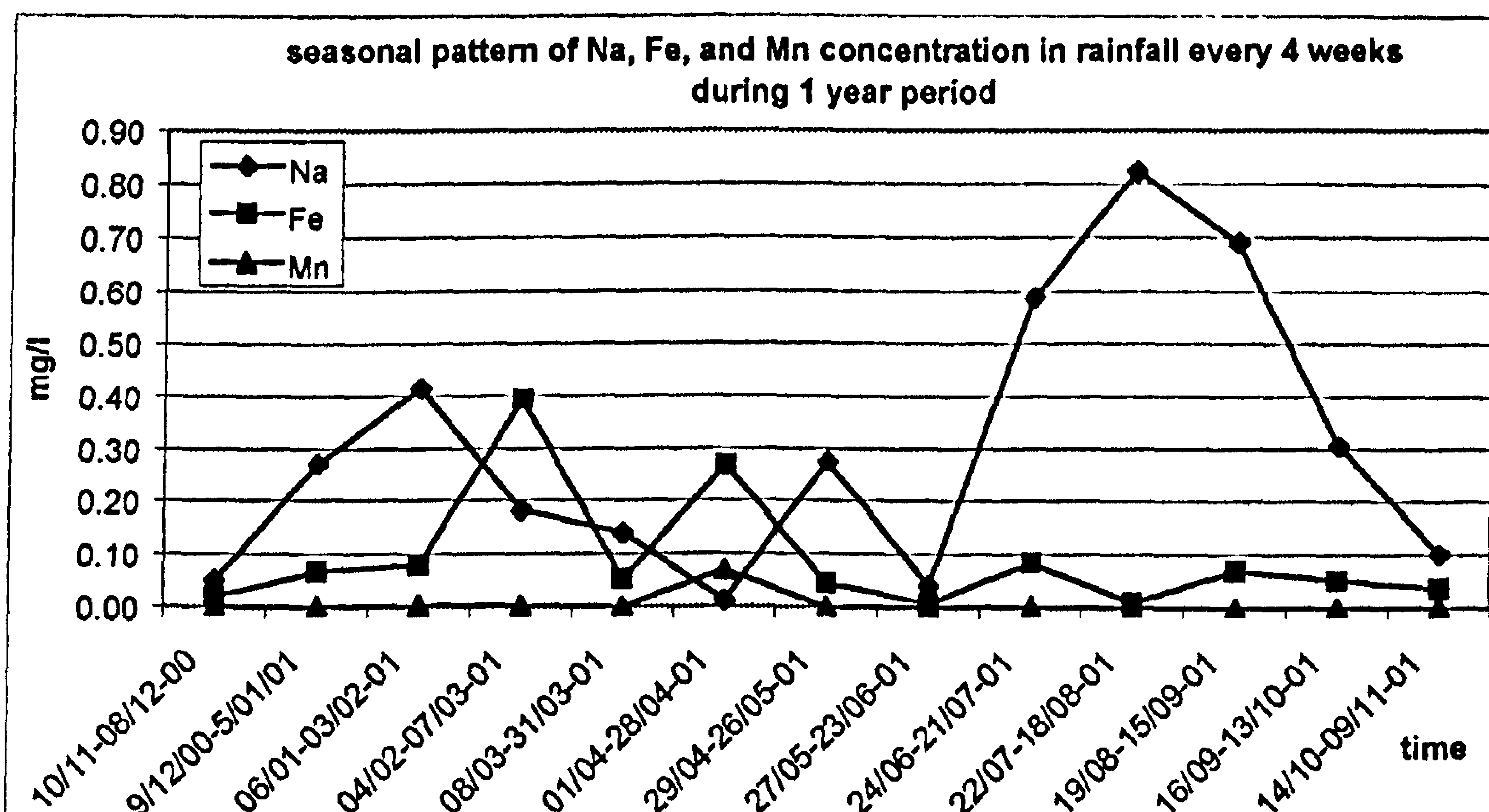


Figure 3.1.4: Seasonal pattern of Na, Fe, and Mn concentration in rainfall every 4 weeks during 1 year period

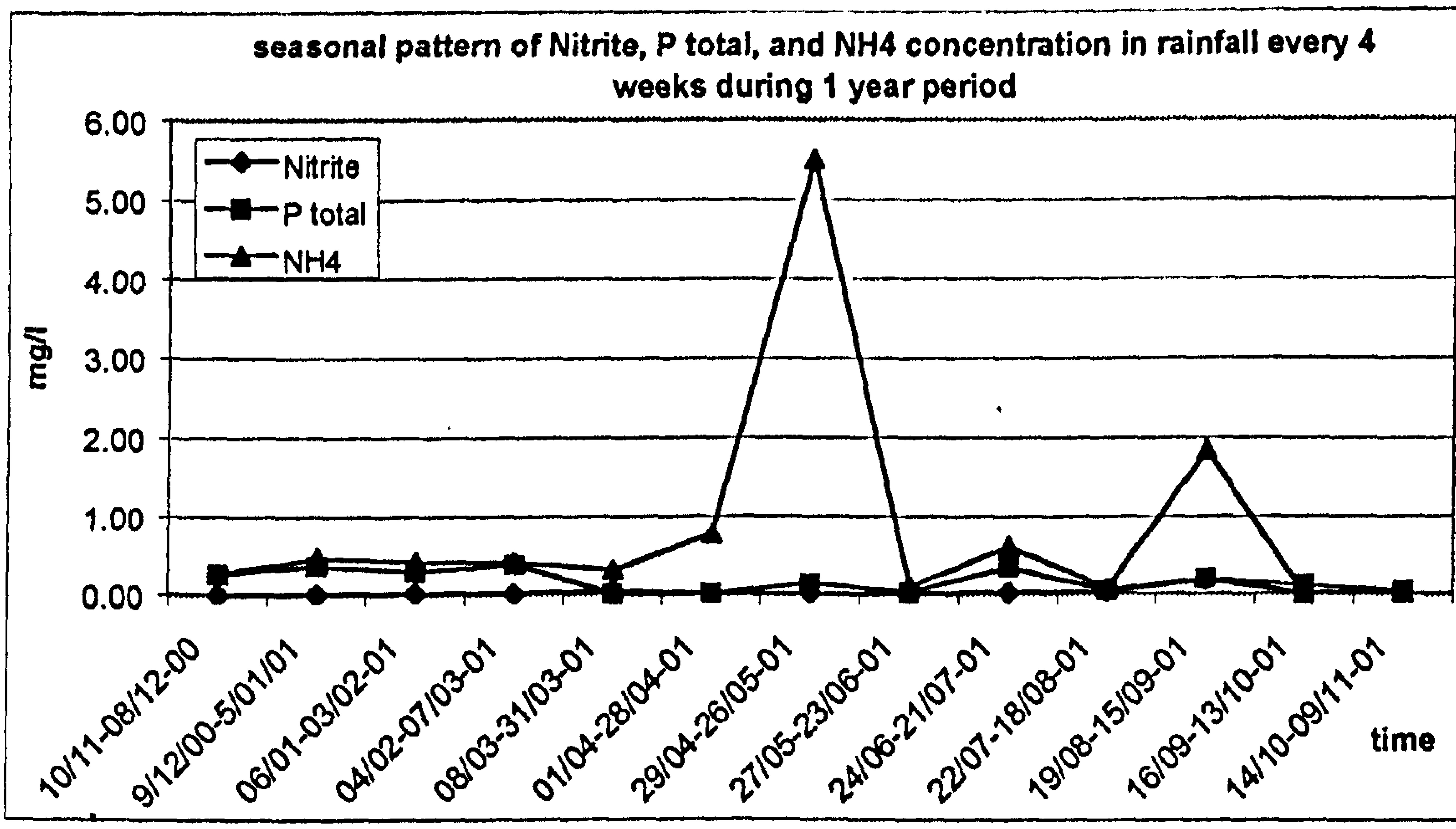


Figure 3.1.5: Seasonal pattern of Nitrite, Phosphate, and Ammonium concentration in rainfall every 4 weeks during 1 year period

3.1.3. Amount of nutrient elements in rainfall

3.1.3.1. Periodic variations

Atmospheric nutrient inputs (precipitation) to the peat swamp forest sub-types were obtained by multiplying the 4 weekly periodical totals of rainfall by the corresponding nutrient concentrations. These are expressed in kilograms per hectare (kg ha^{-1}). Four-weekly means of each element are presented in Figures 3.1.6. to 3.1.8 for the one year study period (13 mean values for every element).

Calcium (Figures 3.1.6)

Precipitation reaching the study area was high in calcium during 6 January-3 February 2001 and 22 July-18 August 2001 and low in 10 November-8 December 2000, 29 April- 26 May 2001 and from 19 August to 15 September 2001. The highest 4 weekly mean was 2.52±0.23 kg ha^{-1} during 22 July-18 August 2001 while the lowest was 0.27± 0.04 kg ha^{-1} during August-September 2001.

Magnesium (Figure 3.1.6)

The highest 4 weekly input of magnesium in rainfall occurred during 1 – 28 April 2001 at 1.03±0.20 kg ha^{-1} and the lowest was 0.11±0.07 kg ha^{-1} during 24 June-21 July 2001. The average of magnesium input during 1 year study period was 0.45±0.25 kg ha^{-1}.

Potassium (Figure 3.1.6)

Similarly to calcium and magnesium, potassium input fluctuated during the 1-year study period. Potassium input in rainfall was high during 10 November- 8 December 2000, 22 July – 18 August 2001 and 27 May - 23 June 2001 when there was a very marked peak of 1.68 ± 1.06 kg ha^{-1}. The lowest input was 0.19±0.05 kg ha^{-1} in 9 December 2000-5 January 2001.

Sodium (Figure 3.1.7)

The highest input of sodium was detected during 6 January-3 February 2001 with 1.20±0.23 kg ha^{-1} in the middle of the rainy season while the lowest input of

0.04±0.03 kg ha^{-1} occurred in 1-28 April 2001 corresponding with the end of the rainy season. The average of sodium input during the 1-year study period was 0.425±0.21 kg ha^{-1}.

<u>Iron</u> (Figure 3.1.7)

The peak in iron reaching the study area in rainfall took place in 4 February-7 March 2001 with 1.68±0.39 ka ha^{-1}. Lowest iron input occurred during 10 November-8 December 2000 and from 29 April to 13 October 2001 with a minimum in 22 July- 18 August 2001 of 0.01±0.01 kg ha^{-1}.

<u>Manganese</u> (Figure 3.1.7)

In general, manganese content in rainfall during study period was very low and was undetectable in some samples. The highest manganese content just reached 0.18 kg ha^{-1} during April 2001 while for the rest of the year it was less than 0.009 kg ha^{-1} in every 4-weekly sampling period. Manganese was the lowest nutrient input in the study area with an average during the 1-year period of only 0.017±0.005 kg ha^{-1}.

<u>Nitrite</u> (Figure 3.1.8)

Similarly to manganese, nitrite content in rainfall during the one year study period was low with the highest input of only 0.17±0.19 kg ha^{-1} during 14 October-10 November 2001. Nitrite input was low from 10 November 2000 to 7 March 2001 and from 1 April to 13 October 2001 with the minimum during 10 November-8 December 2000 of 0.005±0.005 kg ha^{-1}.

Phosphate (Figures 3.1.8)

Peak phosphate input in rainfall occurred during 4 February-7 March 2001 with 1.62±2.23 kg ha^{-1}. Phosphate inputs were low from 8 March to 9 November 2001 with values not more than 0.18 kg ha^{-1} in every 4 weekly period; a minimum phosphate input occurred in April 2001 of 0.006±0.013 kg ha^{-1}.

Ammonium (Figures 3.1.8)

The highest and most variable values of nutrient input through precipitation was ammonium which ranged between 0.019±0.039 (16 September – 13 October 2001) and 6.913±0.390 kg ha^{-1} (29 April-26 May 2001)with a mean of 1.270±0.15 kg ha^{-1}.

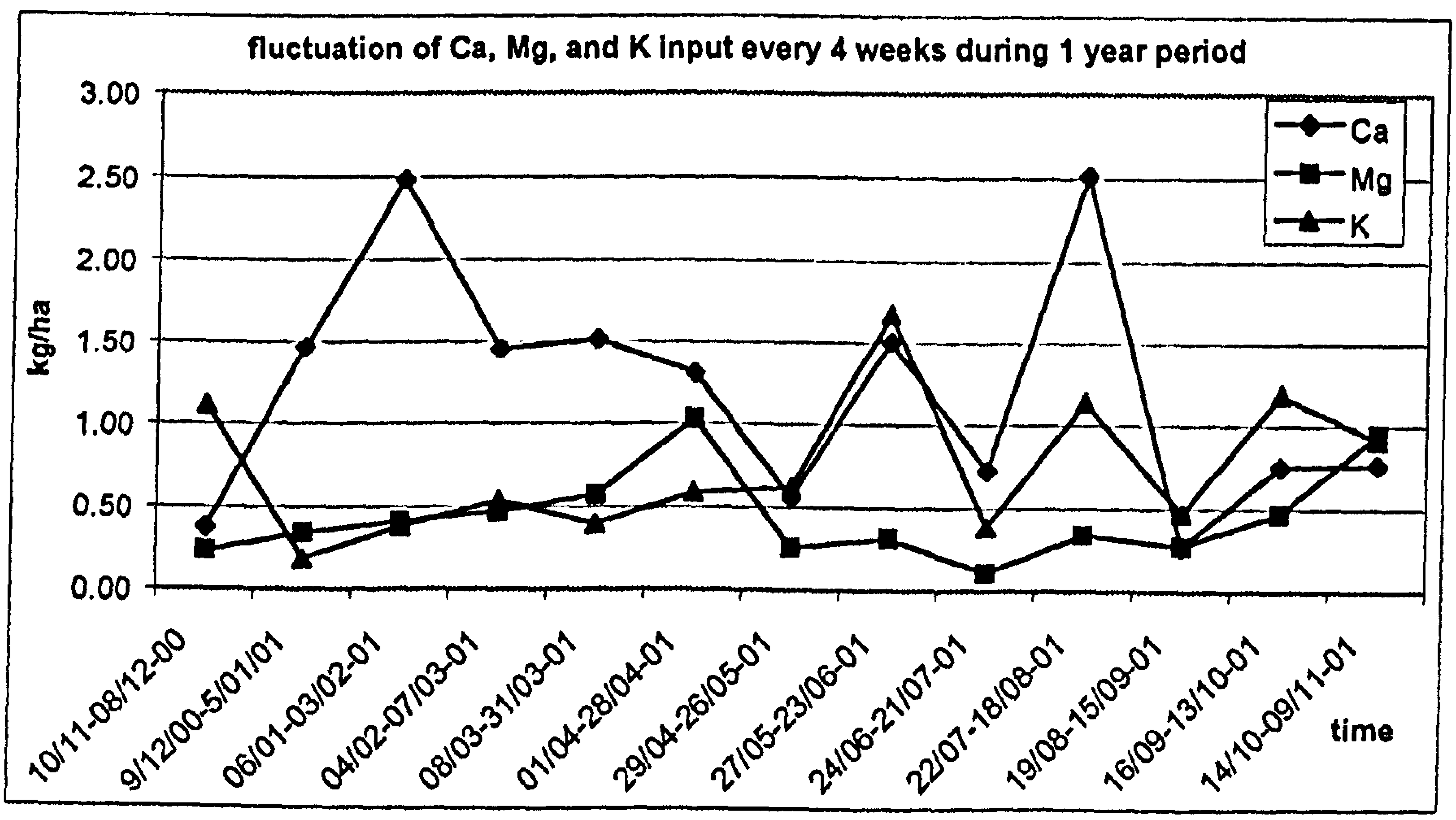


Figure 3.1.6: Fluctuation of Ca, Mg, and K input every 4 weeks during 1 year period

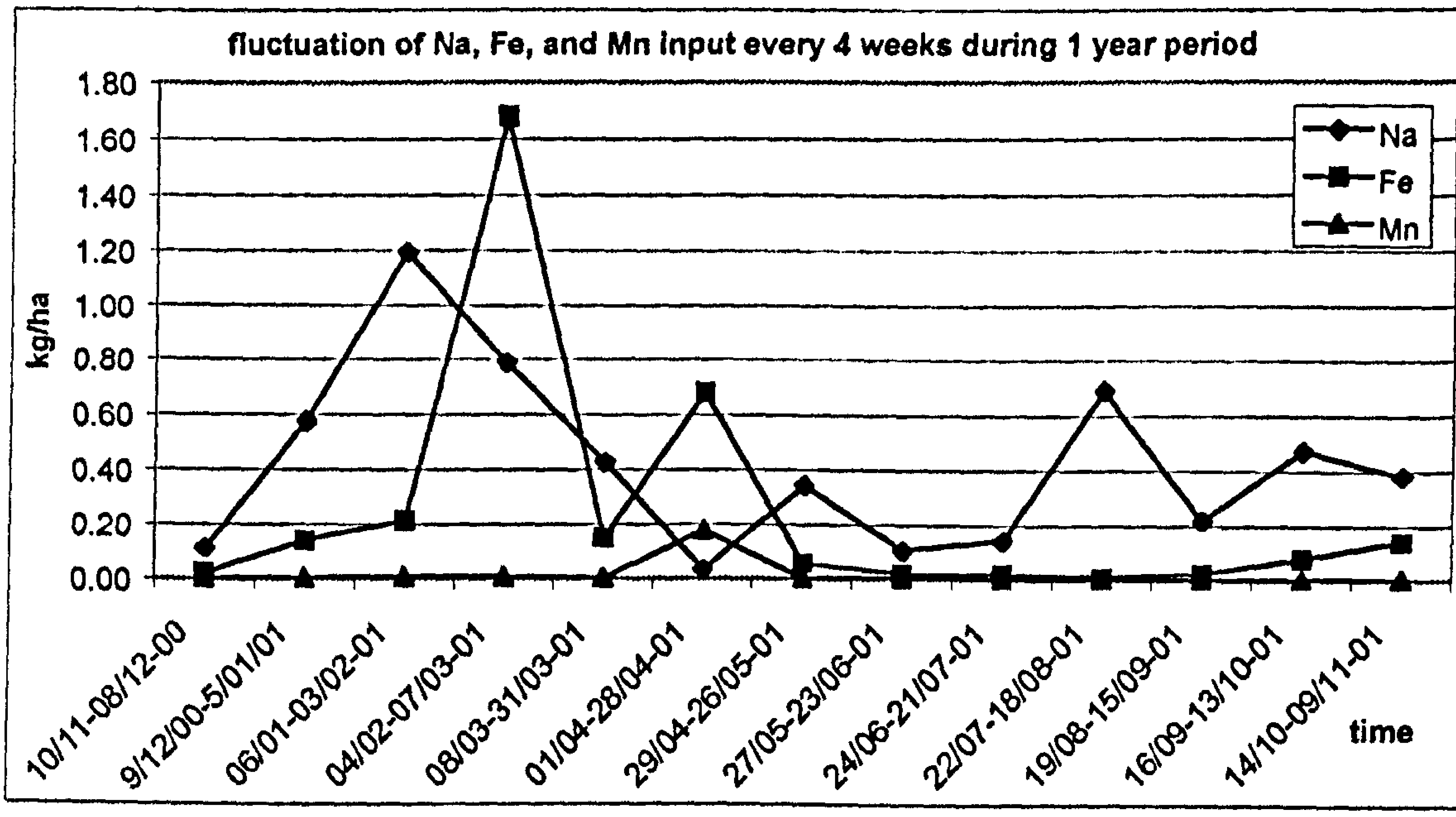


Figure 3.1.7: Fluctuation of Na, Fe, and Mn input every 4 weeks during 1 year period

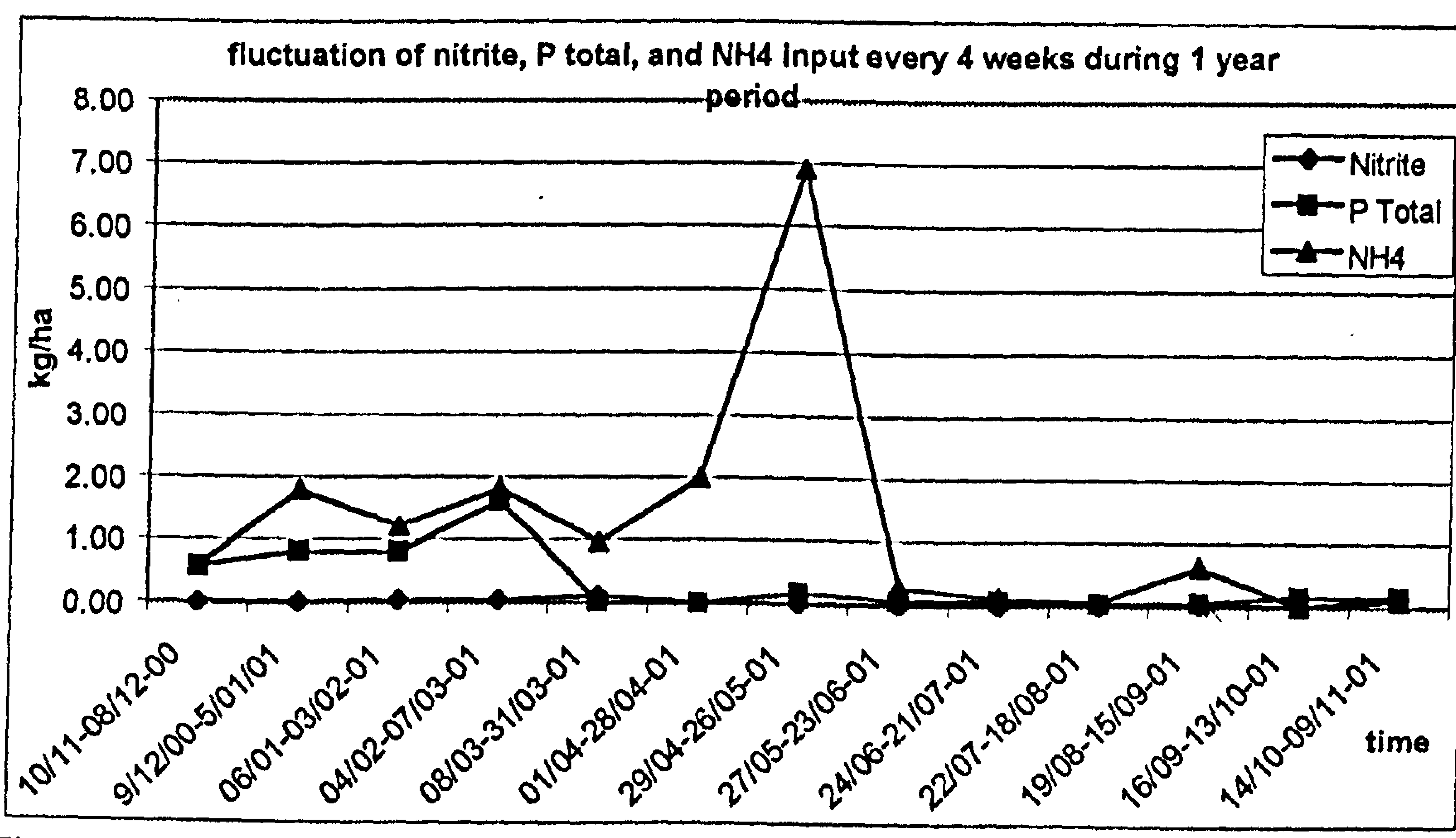


Figure 3.1.8: Fluctuation of Nitrite, Phosphate, and Ammonium input every 4 weeks during 1 year period

3.1.3.2. Annual total input of nutrients

The annual input of chemical ions in rainfall to peat swamp forest in Central Kalimantan is shown in Table 3.1.1.

Table 3.1.1: Mineral nutrient content of rainfall, standard deviation, and % standard deviation during the one year period from 10 November 2000 to 9 November 2001 (kg ha^{-1}).

Rain fall	Ca kg ha^{-1}	Mg kg ha^{-1}	K kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	NO_2-N kg ha^{-1}	P kg ha^{-1}	NH_4-N kg ha^{-1}
Mean	15.72	5.79	9.61	5.52	3.25	0.22	0.54	4.62	16.51
SD	10.62	3.22	9.54	2.78	0.96	0.06	0.42	4.30	1.93
% SD	67.54	55.56	99.24	50.31	29.45	26.91	77.67	93.10	11.67

Ammonium–N is the predominant cation in rainfall, followed by calcium, potassium, magnesium, sodium, iron, and manganese, the last is present in lowest amount. Of the anions, phosphate is highest (4.62±4.3 kg ha^{-1}) followed by nitrite (0.54±0.42 kg ha^{-1}).

3.1.3.3. Correlation between volume, pH and nutrients of rainfall

Correlation coefficients (r) between volumes of rainfall or throughfall (mm), pH and 4 weekly input of cation and anion (kg ha^{-1}) were calculated in order to examine their possible relationships. These values for the Rainfall are given in Tables 3.1.2.

Table 3.1.2: Correlation coefficients (r) between quantity (mm), pH and ionic content ($kg\ ha^{-1}$) of rainfall ($n = 4$) (* $p < 0.05$; **, $P < 0.01$, N.S=Not Significant)

	Water	pH	Ca	Mg	K	Na	Fe	Mn	Nitrit	P Total
PH	-0.249									
	N.S									
Ca	0.280	0.045								
	N.S	N.S								
Mg	0.563	-0.638	0.102							
	*	*	N.S							
K	0.060	-0.318	-0.018	-0.014						
	N.S	N.S	N.S	N.S						
Na	0.300	0.233	0.686	-0.055	-0.299					
	N.S	N.S	**	N.S	N.S					
Fe	0.608	-0.154	0.166	0.319	-0.240	0.278				
	*	N.S	N.S	N.S	N.S	N.S				
Mn	0.159	-0.352	0.069	0.670	-0.102	-0.324	0.314			
	N.S	N.S	N.S	**	N.S	N.S	N.S			
Nitrite	0.419	-0.279	0.015	0.506	-0.145	0.196	0.016	-0.199		
	N.S	N.S	N.S	*	N.S	N.S	N.S	N.S		
P total	0.542	0.322	0.212	-0.121	-0.296	0.583	0.724	-0.182	-0.076	
	*	N.S	N.S	N.S	N.S	*	**	N.S	N.S	
NH4	-0.024	-0.250	-0.161	-0.075	-0.306	0.020	0.138	0.115	-0.227	0.114
	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

The pH does not show significant correlation with rainfall volume. There is high positive correlation between Ca and Na; Mg and Mn; Fe and phosphate. Correlation also shows between rainfall volume and Mg; rainfall volume and Fe; rainfall volume and phosphate. Mg and nitrite; Na and phosphate are also show correlation. Negative correlation are shown between Mg and pH.

3.2. THROUGHFALL

3.2.1. The Quantity of throughfall

Calculation of throughfall was carried out using two methods, that were conventional statistics (Excel) and Wilm's method. Rainfall is also presented as a comparison.

During the year 10 November 2000 – 9 November 2001 the total amounts of throughfall determined by Excel and Wilm, respectively, were 1969±264 mm and 1954±158 mm in mixed swamp forest (MSF) and 2170±334 mm and 2109±126 mm in low pole forest (LPF) . The seasonal pattern of the amounts of throughfall in 4-weekly periods throughout the study period are shown in Figure 3.2.1.a using Excel and Figure 3.2.1.b using Wilm methods. Rainfall is included as comparison.

Figure 3.2.1.a (Excel method) and Figure 3.2.1.b (Wilm's method) shows that there is variation in the amount of throughfall falling on the peat swamp forest during the study period.

In mixed swamp forest (MSF) using Excel, the mean 4 weekly amounts of throughfall (MTH) ranged from 10.40±0.74 mm to 298.34±42.10 mm and the mean over the 1-year period was 151.50±20.33 mm with the highest value obtained between 4 February and 7 March 2001 (298.34±42.10 mm), followed by 27 May to 23 June 2001 (216.81±35.83 mm). In contrast, the lowest amount of water was collected between 24 June and 21 July 2001 (10.40±0.74 mm). Using Wilm's method, the amount of throughfall (MTH) every 4 weeks ranged from 38.74±16.23 mm to 289.12±19.10 mm and the mean over the 1 year period was 150.27±3.95 mm. The highest values for throughfall occurred in the same period as with Excel, i.e.

during 4 February – 7 March 2001 (289.12±19.10 mm). The lowest value occurred in 24 June-21 July 2001 (same as Excel) but with the value higher than the Excel method (38.74±16.23 mm).

Similarly to the mixed swamp forest, the highest throughfall volume in low pole forest (LPF) using Excel, occurred during 4 February- 7 March 2001 (290.70±64.22 mm) while the lowest was in 24 June- 21 July 2001 (23.39±1.25 mm). The mean 4 weekly throughfall in LPF over the 1-year period was 166.95±25.66 mm. According to Wilm's method, the highest throughfall volume of 275.98±11.77 mm was collected in 4 February – 7 March 2001, followed by 253.26±10.32 mm during 8-31 March 2001. The lowest value was during 24 June-21 July 2001 (22.74±13.55 mm).

In general, throughfall as a proportion of rainfall is higher in Low Pole Forest (78.6%) than in Mixed Swamp Forest (71.3%) using Excel and 76.4 % in LPF and 70.8 % in MSF using the Wilm method. There is a positive correlation between rainfall and throughfall with the latter always less than the former. Analysis of variance (Appendix 2) among rainfall and throughfall in both sub-type of forest indicated that there is a significant difference between rainfall and both, throughfall in MSF and LPF and there is no significant difference between throughfall in MSF and LPF.

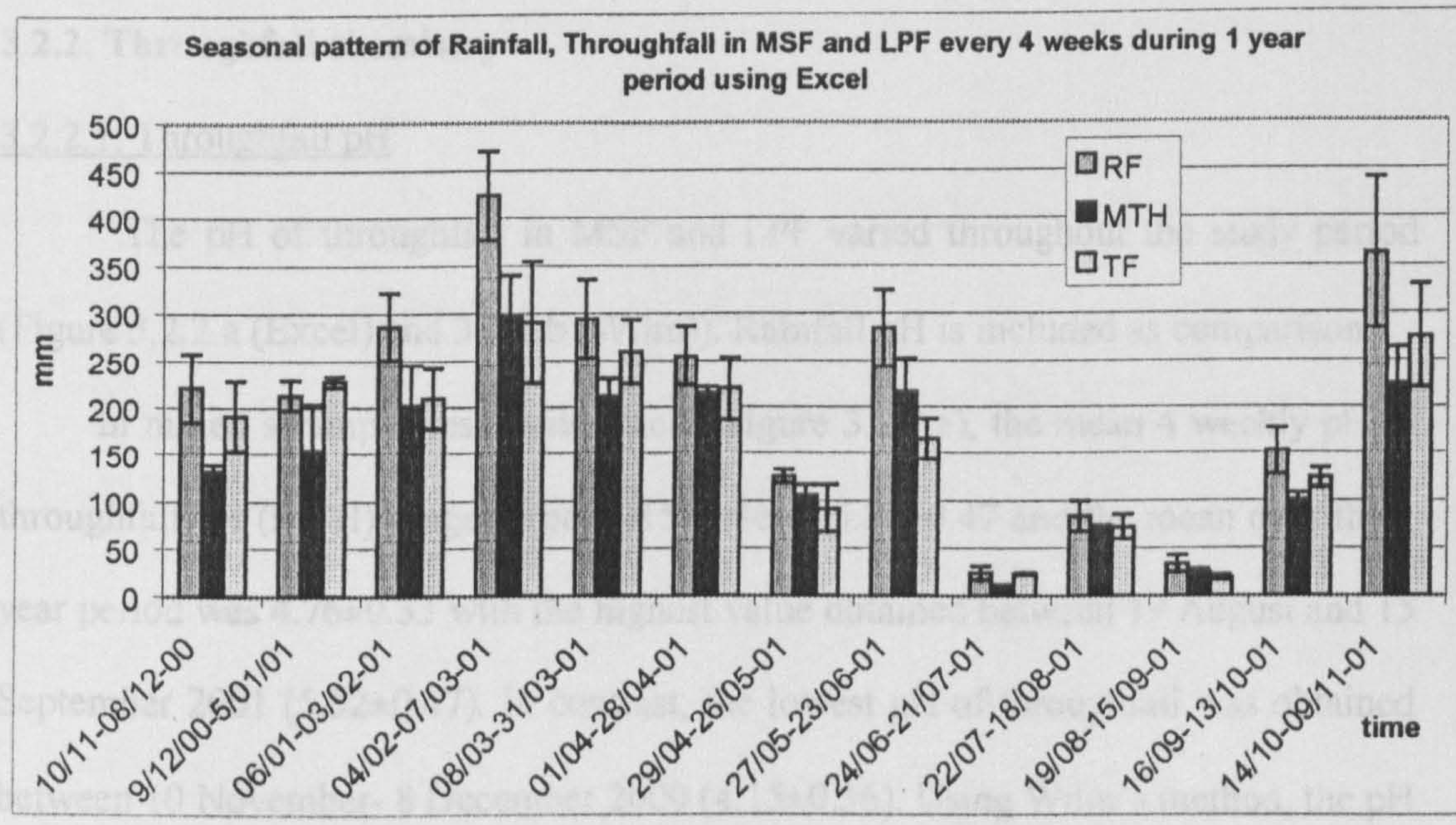


Figure 3.2.1.a: Seasonal pattern of rainfall (RF), throughfall in MSF (MTH) and throughfall in LPF (TF) every 4 weeks during 1 year period using Excel

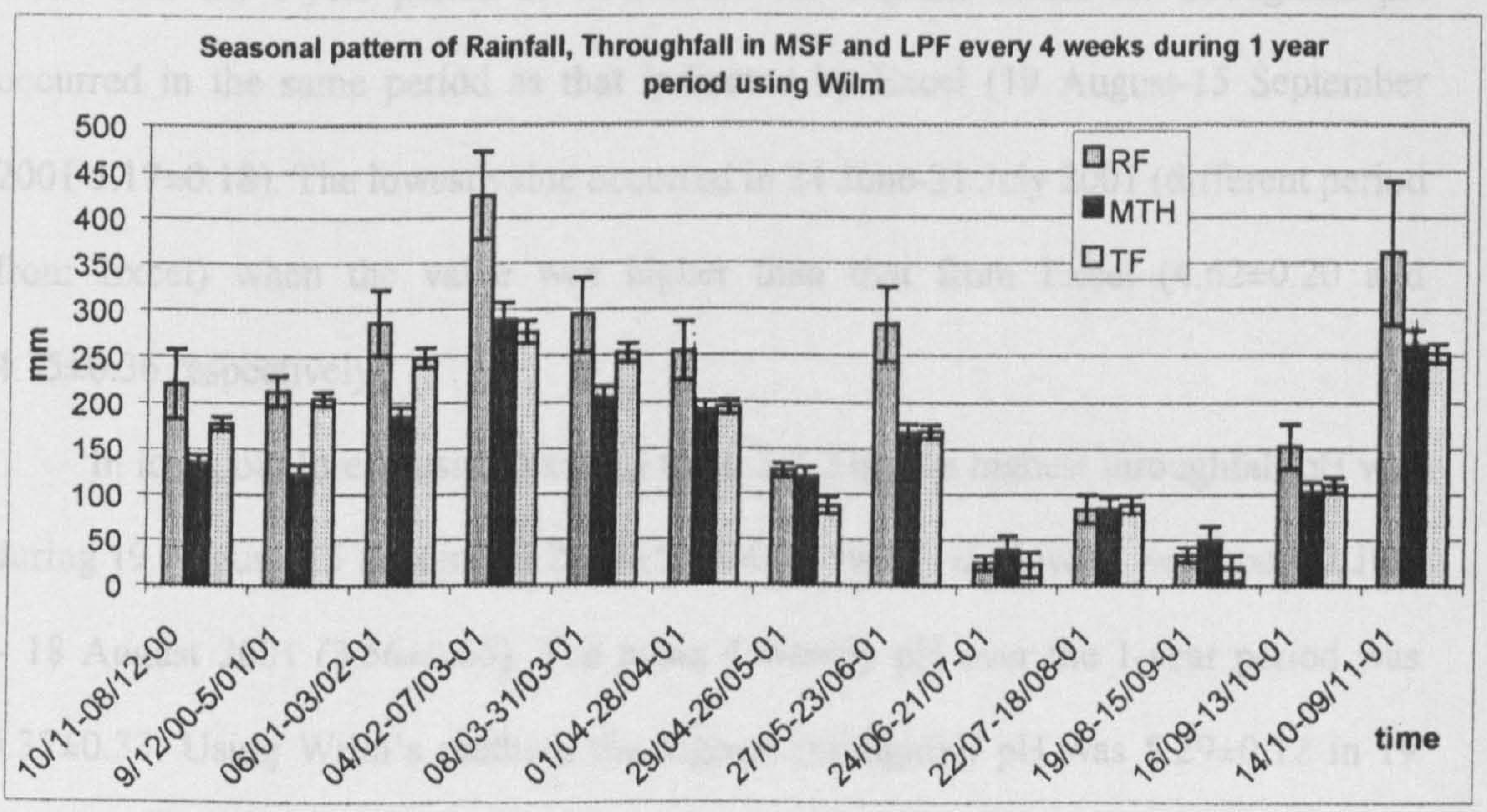


Figure 3.2.1.b: Seasonal pattern of rainfall (RF), throughfall in MSF (MTH) and throughfall in LPF (TF) every 4 weeks during 1 year period using Wilm's method

3.2.2. Throughfall chemistry

3.2.2.1. Throughfall pH

The pH of throughfall in MSF and LPF varied throughout the study period (Figure 3.2.2.a (Excel) and 3.2.2.b (Wilm)). Rainfall pH is included as comparison.

In mixed swamp forest using Excel (Figure 3.2.2.a), the mean 4 weekly pH of throughfall pH (MTH) ranged from 4.15±0.36 to 5.32±0.47 and the mean over the 1 year period was 4.76±0.33 with the highest value obtained between 19 August and 15 September 2001 (5.32±0.47). In contrast, the lowest pH of throughfall was obtained between 10 November- 8 December 2000 (4.15±0.36). Using Wilm's method, the pH of throughfall (MTH) every 4 weeks ranged from 4.62±0.20 to 5.17±0.18 with a mean over the 1-year period of 4.92±0.05. The highest values for throughfall pH occurred in the same period as that indicated by Excel (19 August-15 September 2001 5.17±0.18). The lowest value occurred in 24 June-21 July 2001 (different period from Excel) when the value was higher than that from Excel (4.62±0.20 and 4.15±0.36 respectively).

In low pole forest, using Excel (Figure 3.2.2.b), the highest throughfall pH was during 19 August- 15 September 2001 (5.36±0.27) while the lowest was from 22 July – 18 August 2001 (3.56±0.66). The mean 4 weekly pH over the 1-year period was 4.37±0.33. Using Wilm's method, the highest throughfall pH was 5.29±0.12 in 19 August – 15 September 2001. In contrast, the lowest value was 22 July – 18 August 2001 (similar period using Excel) with 3.64±0.12. This result was higher than that from Excel (3.56±0.27).

In general, throughfall pH using both methods was higher in mixed swamp forest (MSF) than in low pole forest (LPF). In mixed swamp forest, throughfall pH was 4.76±0.33 while in low pole forest it was 4.37±0.33 using Excel while pH in MSF was 4.92±0.05 and 4.45±0.06 in LPF using Wilm.

Analysis of variance (Appendix 2) on pH shows that among rainfall, MSF throughfall and LPF throughfall are significantly different.

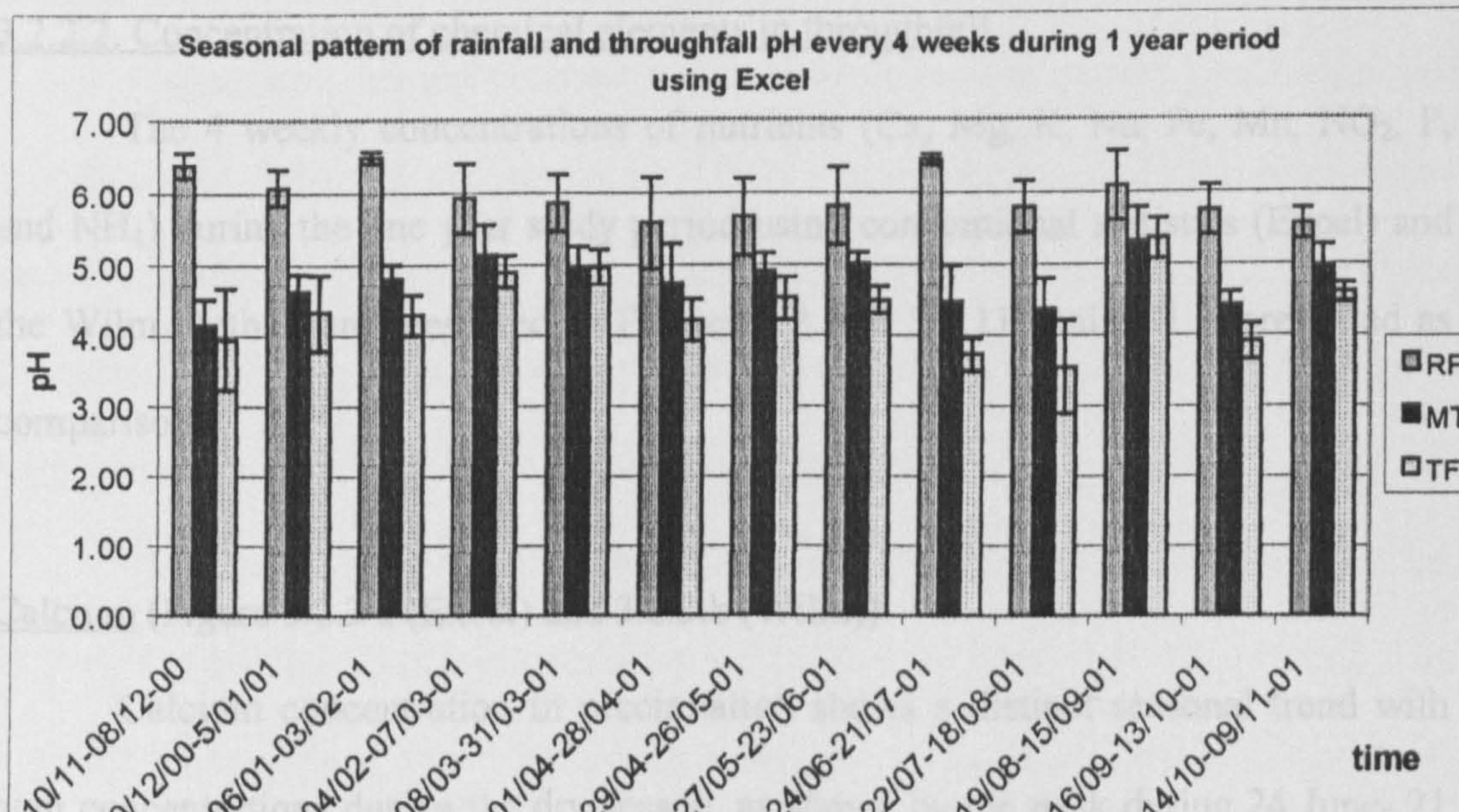


Figure 3.2.2.a : Seasonal pattern of rainfall pH (RF), throughfall pH in MSF (MTH), and throughfall pH in LPF (TF) every 4 weeks during 1 year period using conventional statistics (Excel).

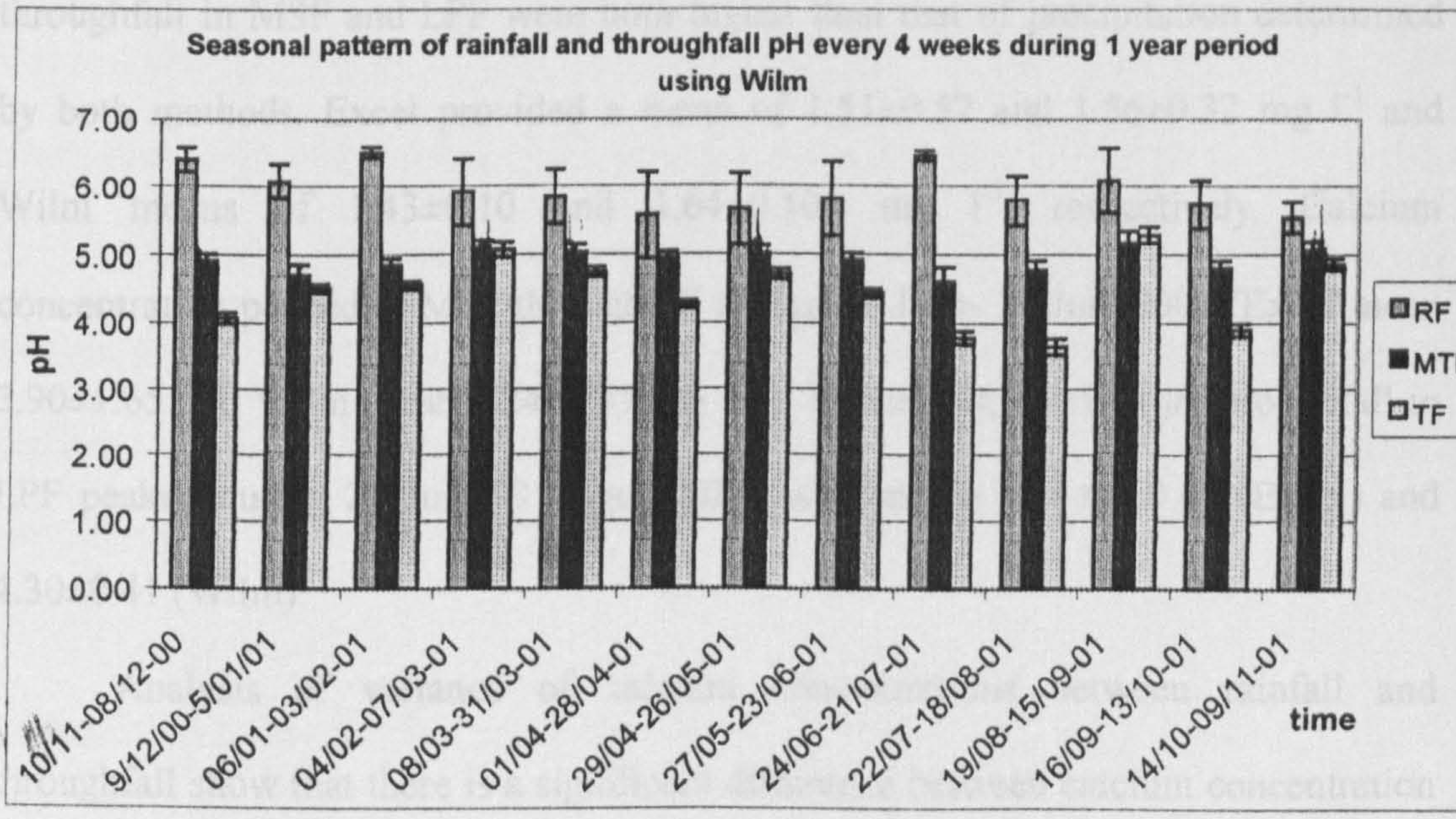


Figure 3.2.2.b: Seasonal pattern of rainfall pH (RF), throughfall pH in MSF (MTH), and throughfall pH in LPF (TF) every 4 weeks during 1 year period using Wilm's method

3.2.2.2. Concentration of chemical elements in throughfall

The 4 weekly concentrations of nutrients (Ca, Mg, K, Na, Fe, Mn, NO_2, P, and NH_4) during the one year study period using conventional statistics (Excel) and the Wilm method are presented in Figures 3.2.3 to 3.2.11. Rainfall is presented as comparison.

Calcium (Figure 3.2.3 a (Excel) and 3.2.3.b (Wilm))

Calcium concentration in precipitation shows a distinct seasonal trend with high concentrations during the dry season, as shown by the peak during 24 June- 21 July 2001 (mean 3.07±1.38 mg l^{-1}) and the trough in the wet season during 10 November – 8 December 2000 (mean 0.17±0.03). Calcium concentration of throughfall in MSF and LPF were both higher than that of precipitation determined by both methods. Excel provided a mean of 1.51±0.52 and 1.56±0.32 mg l^{-1} and Wilm means of 1.43±0.10 and 1.64±0.104 mg l^{-1}, respectively. Calcium concentration peaked in MSF throughfall during 24 June- 21 July 2001 (Excel mean 3.90±1.65 and Wilm mean 4.24±0.55 mg l^{-1}). In contrast, calcium in throughfall in LPF peaked during 22 July-18 August 2001 with means of 4.64±0.47 (Excel) and 4.30±0.41 (Wilm).

Analysis of variance of calcium concentrations between rainfall and throughfall show that there is a significant difference between calcium concentration in rainfall and throughfall for (MSF and LPF) while between throughfall in MSF and LPF it is not significantly different.

Magnesium (Figures 3.2.4a (Excel) and 3.2.4b (Wilm))

Magnesium concentration in rainfall shows a similar pattern to calcium with higher values recorded during the dry than the wet season. The highest value occurred during 19 August-15 September 2001 (mean 0.84 ± 1.7 mg l^{-1}) and the lowest in 10 November–8 December 2000 (mean 0.11± 0.03 mg l^{-1}). The average of magnesium in rainfall during study period was 0.28±0.12 mg l^{-1}.

Magnesium throughfall concentrations in both MSF and LPF were higher than that of precipitation during the study period (0.72 ± 0.15 and 0.78 ± 0.15 mg l^{-1} by conventional statistics and 0.70±0.04 and 0.76±0.06 mg l^{-1} by the Wilm method, respectively). Magnesium concentration peaked in MSF throughfall during 19 August-15 September 2001 by both methods (Excel mean 2.01±0.40 and Wilm mean 1.98±0.11 mg l^{-1}). In contrast, throughfall magnesium in LPF peaked during 22 July-18 August 2001 with a mean of 2.42±0.19 (excel) and during 19 August-15 September 2001 with a mean of 2.11±0.16 mg l^{-1} (Wilm).

Similarly to calcium concentration, analysis of variance of magnesium concentrations between rainfall and throughfall for both MSF and LPF are significant different while between MSF and LPF throughfalls there are no significant differences.

Potassium (Figures 3.2.5a (Excel) and 3.2.5b (Wilm))

Similarly to magnesium, potassium concentration was higher in the dry season than in the wet season, peaking during 24 June-21 July 2001 (mean 0.1.51±1.28 mg l^{-1}). The wet season minimum occurred during 9 December 2000-5

January 2001 (mean 0.09±0.02 mg l^{-1}). The average potassium concentration in rainfall during the 1-year study period was 0.59±0.55 mg l^{-1}.

Potassium concentrations of throughfall in MSF and LPF determined by conventional statistics and Wilm's method were higher than that of rainfall (1.84±0.54 and 1.52±0.59 mg l^{-1}, respectively (Excel) and 1.74±0.13 and 1.44±0.16 mg l^{-1}, respectively (Wilm)). Potassium concentration peaked in MSF throughfall during 24 June- 21 July 2001 using both methods (Excel mean 4.88±0.18 and Wilm mean 3.91±0.69 mg l^{-1}). In contrast, throughfall potassium concentration in LPF peaked in 22 July-18 August 2001 according to conventional statistics with a mean of 3.72±1.29 and during 19 August- 15 September 2001 using Wilm with a mean of 3.27±0.50 mg l^{-1}.

Similarly to calcium and magnesium concentration, analysis of variance potassium concentration is significantly different between rainfall and throughfall for both MSF throughfall and LPF throughfall. In contrast, there is no significant difference between MSF throughfall and LPF throughfall.

Sodium (Figures 3.2.6a (Excel) and 3.2.6b (Wilm))

Sodium concentration in rainfall was high during 24 June – 15 September 2001 and peaked during 22 July- 18 August 2001 with a mean of 0.83 ±0.25 mg l^{-1}. It was lowest during the wet season with a mean of 0.01±0.01 mg l^{-1} during 1-28 April 2001. In general, sodium concentration throughout the year in throughfall was higher than in precipitation. The average concentration of sodium in rainfall during study period was 0.30±0.10 mg l^{-1}. Sodium concentrations in MSF and LPF were

0.50±0.07 and 0.60±0.12 mg l^{-1}, respectively using Excel and 0.51±0.02 and 0.63±0.05 mg l^{-1}, respectively, using Wilm. Sodium concentration in MSF throughfall peaked in 22 July- 18 August 2001 (1.354±0.18 mg l^{-1} (Excel)) and in 19 August-15 September (mean 1.291±0.145 mg l^{-1} (Wilm)). In LPF, sodium concentration peaked in 22 July- 18 August 2001 as determined by both methods with means of 2.63±0.71 (Excel) and 2.05±0.25 mg l^{-1} (Wilm).

Sodium concentration was significantly different between rainfall and throughfall for both sub type of forest (MSF throughfall and LPF throughfall) while sodium concentration in MSF throughfall and LPF throughfall are not significantly different.

Iron (Figures 3.2.7a (Excel) and 3.2.7b (Wilm))

Concentration of iron in rainfall is generally low except during 4 February- 7 March 2001 and 1-28 April 2001 when there were means of 0.40±0.07 and 0.27±0.04 mg l^{-1}, respectively.

Similarly to sodium, in general, iron concentration throughout the year in throughfall was higher than in precipitation. The average iron concentration in rainfall during the 1-year study period was 0.09±0.02 mg l^{-1}. Mean iron concentrations in MSF and LPF throughfall using Excel were 0.15±0.03 mg l^{-1} and 0.16±0.03, respectively while the Wilm method provided concentrations of 0.15±0.00 and 0.16 ±0.01 mg l^{-1}, respectively.

Analysis of variance of iron concentrations between rainfall and both types of throughfall (MSF and LPF) are significantly different whilst MSF throughfall and LPF throughfall there is not significant difference.

Manganese (Figures 3.2.8a (Excel) and 3.2.8b (Wilm))

Manganese concentrations in rainfall and throughfall in both types of forest, MSF and LPF were very low throughout the study period and undetectable in most months, for example, during 10 November- 8 December 2000, from 6 January – 31 March 2001, and from 19 August- 15 September 2001. Only in 1-28 April 2001 was a significant concentration of 0.07±0.02 mg l^{-1} obtained.

Analysis of variance of manganese concentrations between rainfall and both throughfalls (MSF and LPF) are not significantly different. Between MSF throughfall and LPF throughfall there is no significant difference as well.

Nitrite (Figures 3.2.9a (Excel) and 3.2.9b (Wilm))

Similarly to iron, nitrite concentration in rainfall is generally low. The peak concentration occurred during 19 August-15 September 2001 with a mean of 0.19±0.08 mg l^{-1} and the lowest in 1-28 April and during 27 May - 23 June 2001 with means of 0.002±0.015 and 0.002±0.001 mg l^{-1}, respectively. Concentration of nitrite in throughfall was consistently higher than in precipitation.

The average nitrite concentration in rainfall during the study period was 0.03±0.02 and in MSF and LPF was 0.20 ±0.08 and 0.11±0.04 mg l^{-1}, respectively using Excel. The Wilm Method produced a slightly difference result of 0.20±0.02 in MSF and

0.13±0.01 mg l^{-1} in LPF. Peak nitrite concentrations in MSF using both Excel and Wilm methods occurred in 8 – 31 March 2001 with means of 0.87±0.17 and 0.86±0.07 mg l^{-1}, respectively. In LPF, peak nitrite concentrations by Excel and Wilm were also in 8 – 31 March 2001 with means of 0.48±0.07 and 0.44±0.0.05 mg l^{-1}, respectively.

Analysis of variance of nitrite concentrations among rainfall, MSF throughfall, and LPF throughfall show significant difference.

Phosphate (Figures 3.2.10a (Excel) and 3.2.10b (Wilm))

There were several peak concentrations of phosphate in rainfall and throughfall, for example in precipitation, during 4 February-7 March 2001 with a mean of 0.38±0.53 mg l^{-1} and 24 June- 21 July 2001 with a mean of 0.35±0.36 mg l^{-1}, although there are no clear seasonal trends.

The mean phosphate concentration in rainfall during the study period was 0.17±0.17 mg l^{-1}. Throughfall phosphate concentrations in MSF and LPF were higher than in precipitation as determined by Excel with a mean of 2.21±0.06 and 0.17±0.07 mg l^{-1} and using Wilm a mean of 0.20±0.02 and 0.18±0.02 mg l^{-1}, respectively.

Similarly to manganese, there is no significant difference among phosphate concentrations in rainfall, MSF thoughfall, and LPF throughfall.

Ammonium (Figures 3.2.11a (Excel) and 3.2.11b (Wilm))

The average ammonium concentration in rainfall during the study period was 0.84±0.32 mg l^{-1} and it showed a similar seasonal pattern to calcium. The highest concentration was recorded during the dry season with a peak during 29 April – 26 May 2001 (mean 5.51±0.25 mg l^{-1}).

The ammonium concentration peak in MSF throughfall occurred during 22 July-18 August 2001 by both methods (Excel mean of 4.06±2.29 and Wilm mean 3.58±0.35 mg l^{-1}). In contrast, the LPF ammonium throughfall peak occurred in 29 April – 26 May 2001 with a mean of 3.41±0.89 with Excel and 24 June- 21 July 2001 with Wilm giving a mean of 1.96±0.65. Ammonium concentrations of throughfall in MSF and LPF using Excel were 1.15±0.58 and 0.75±0.19 mg l^{-1}, respectively.

Similarly to manganese and phosphate concentrations, ammonium concentrations are not significantly different among rainfall, MSF throughfall and LPF throughfall.

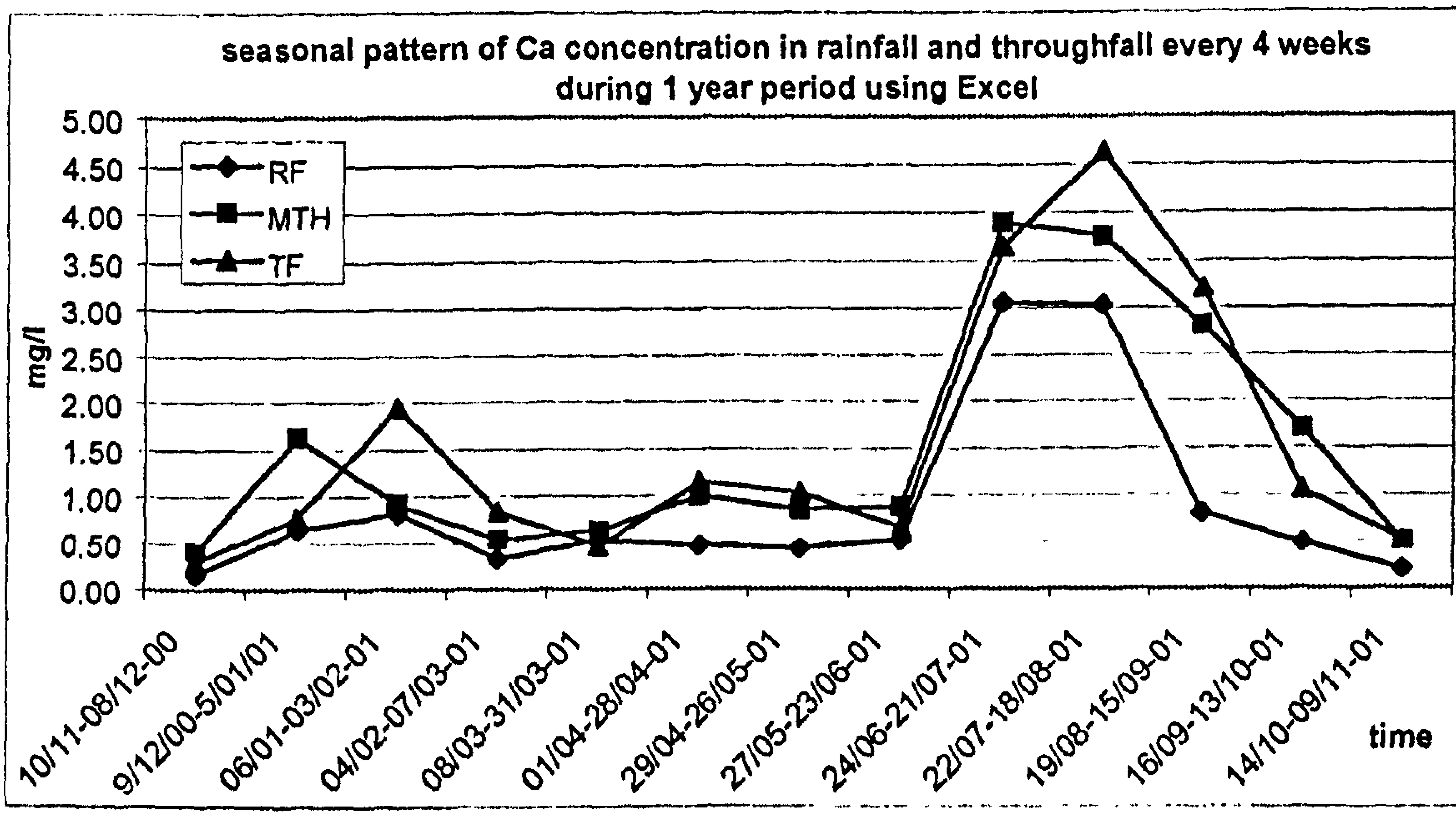


Figure 3.2.3.a: Seasonal pattern of Ca concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

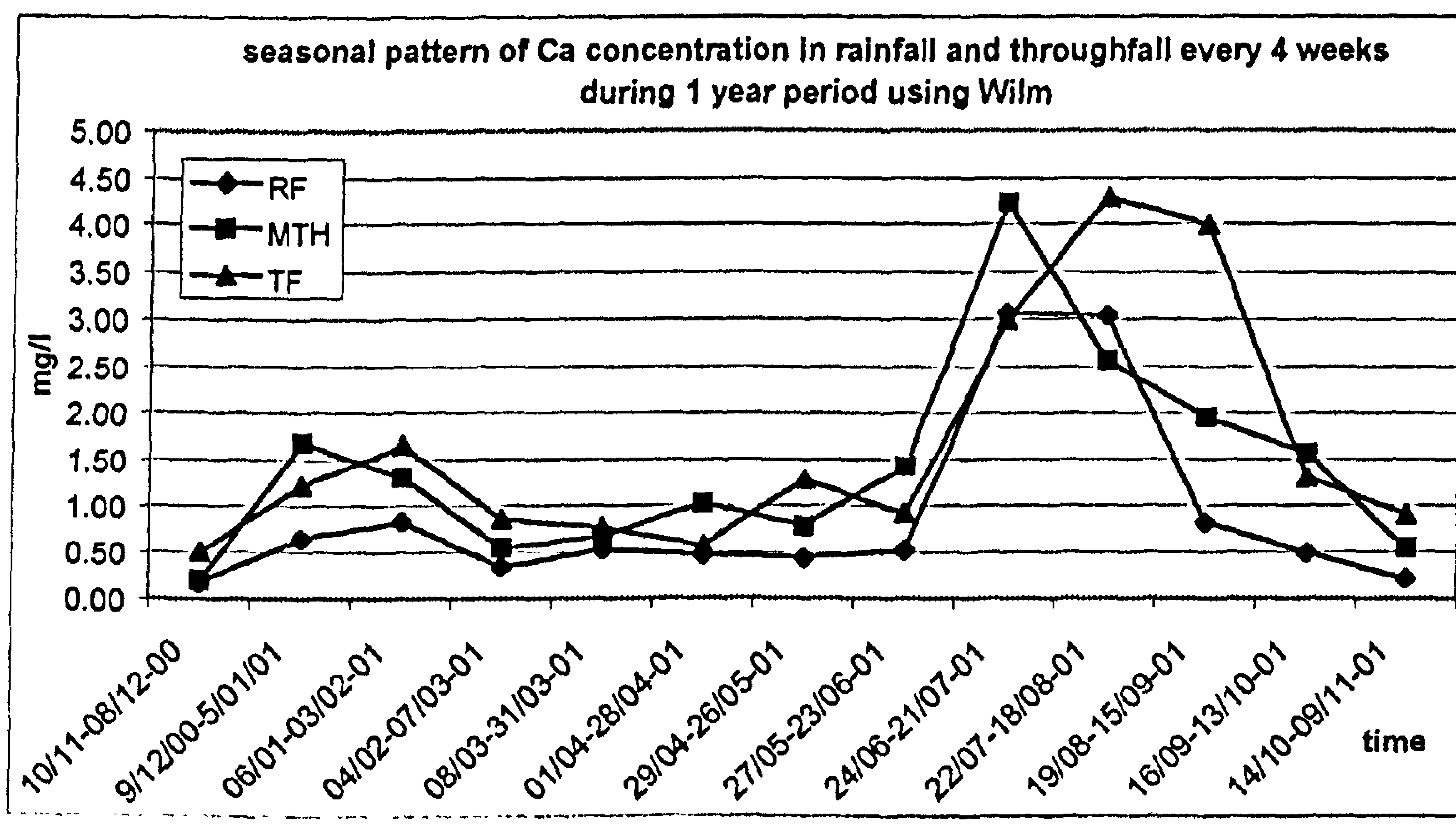


Figure 3.2.3.b: Seasonal pattern of Ca concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Wilm

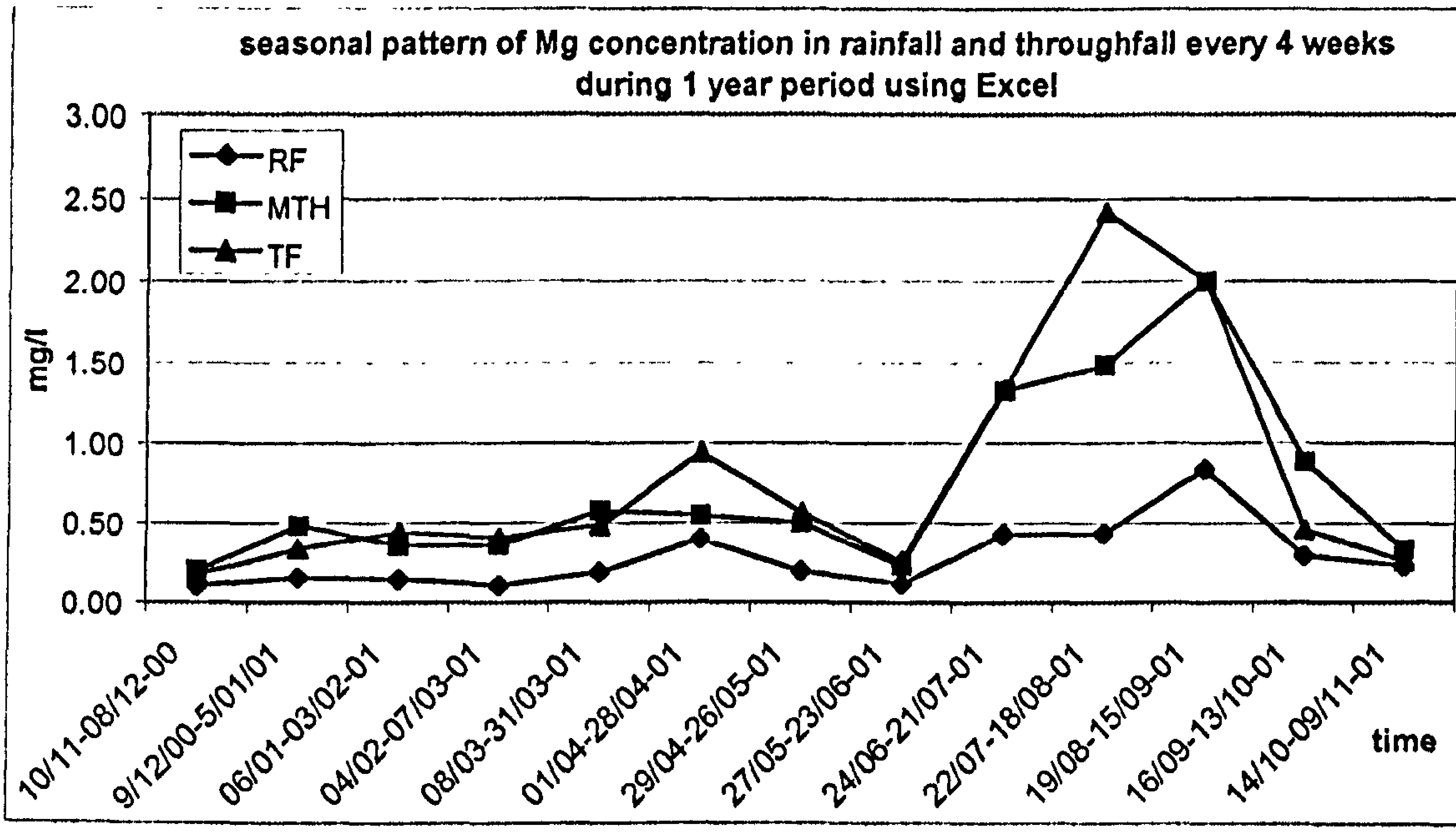


Figure 3.2.4.a: Seasonal pattern of Mg concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

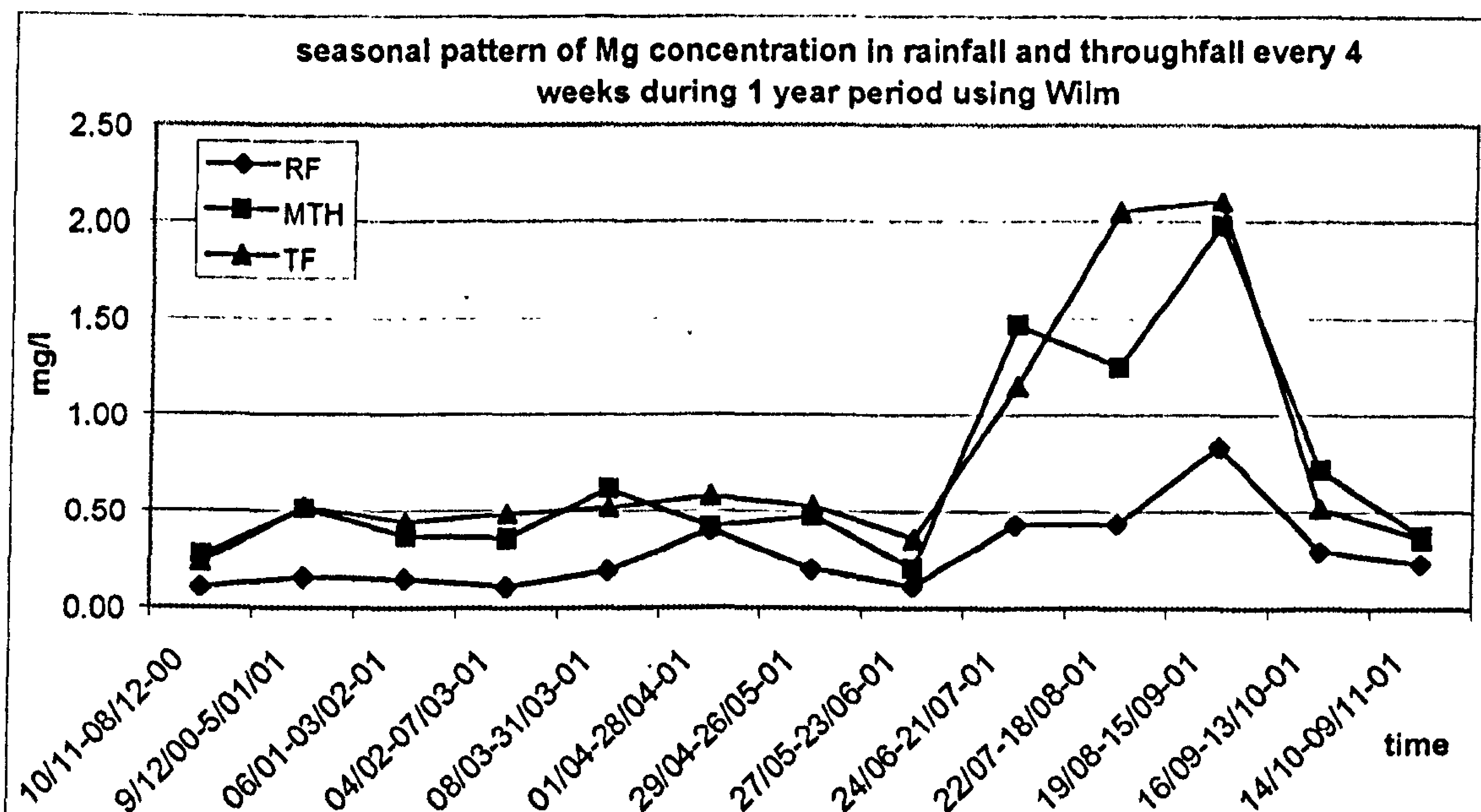


Figure 3.2.4.b: Seasonal pattern of Mg concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Wilm

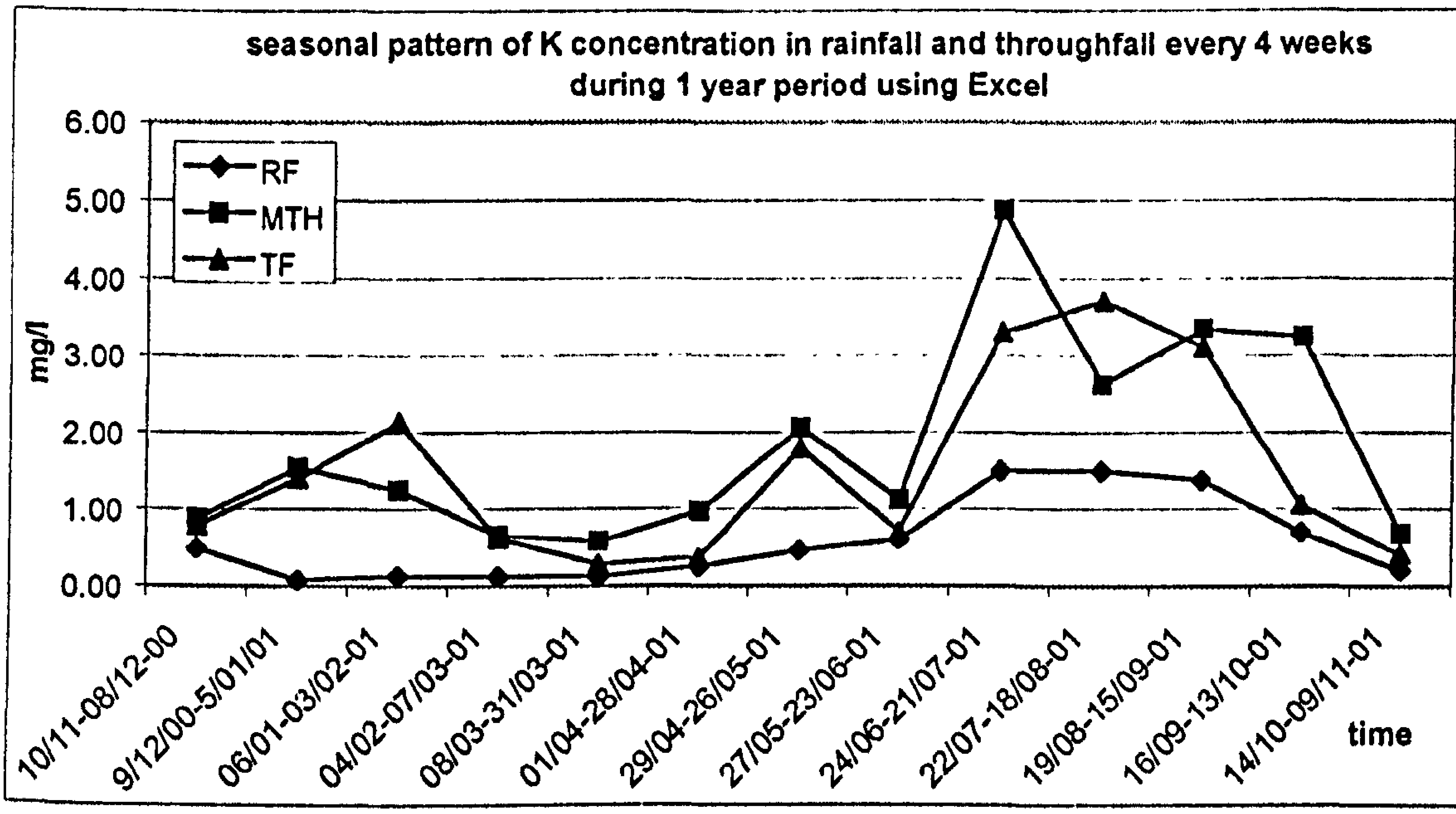


Figure 3.2.5.a: Seasonal pattern of K concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

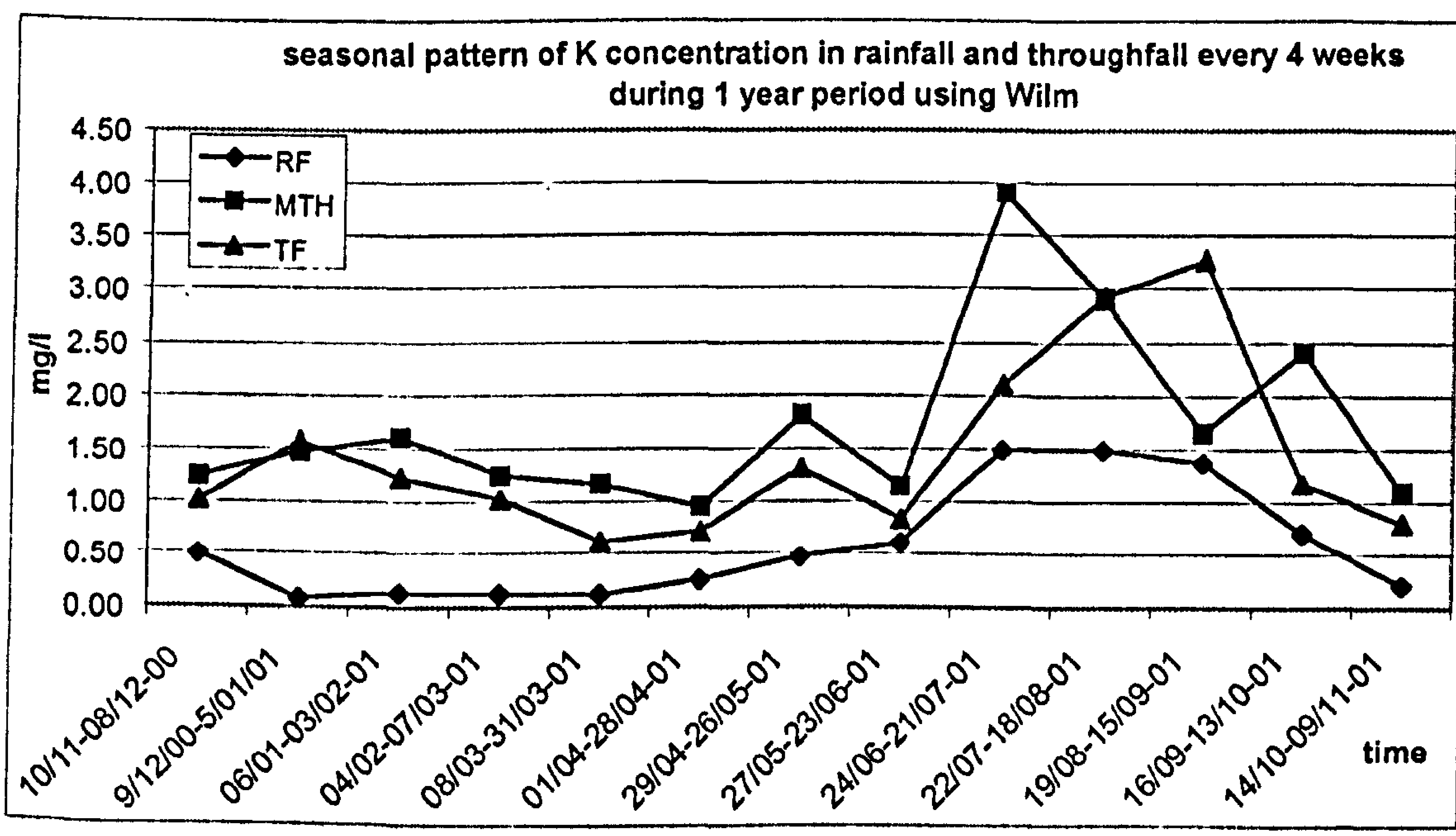


Figure 3.2.5.b: Seasonal pattern of K concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the *1 year study period using Wilm*

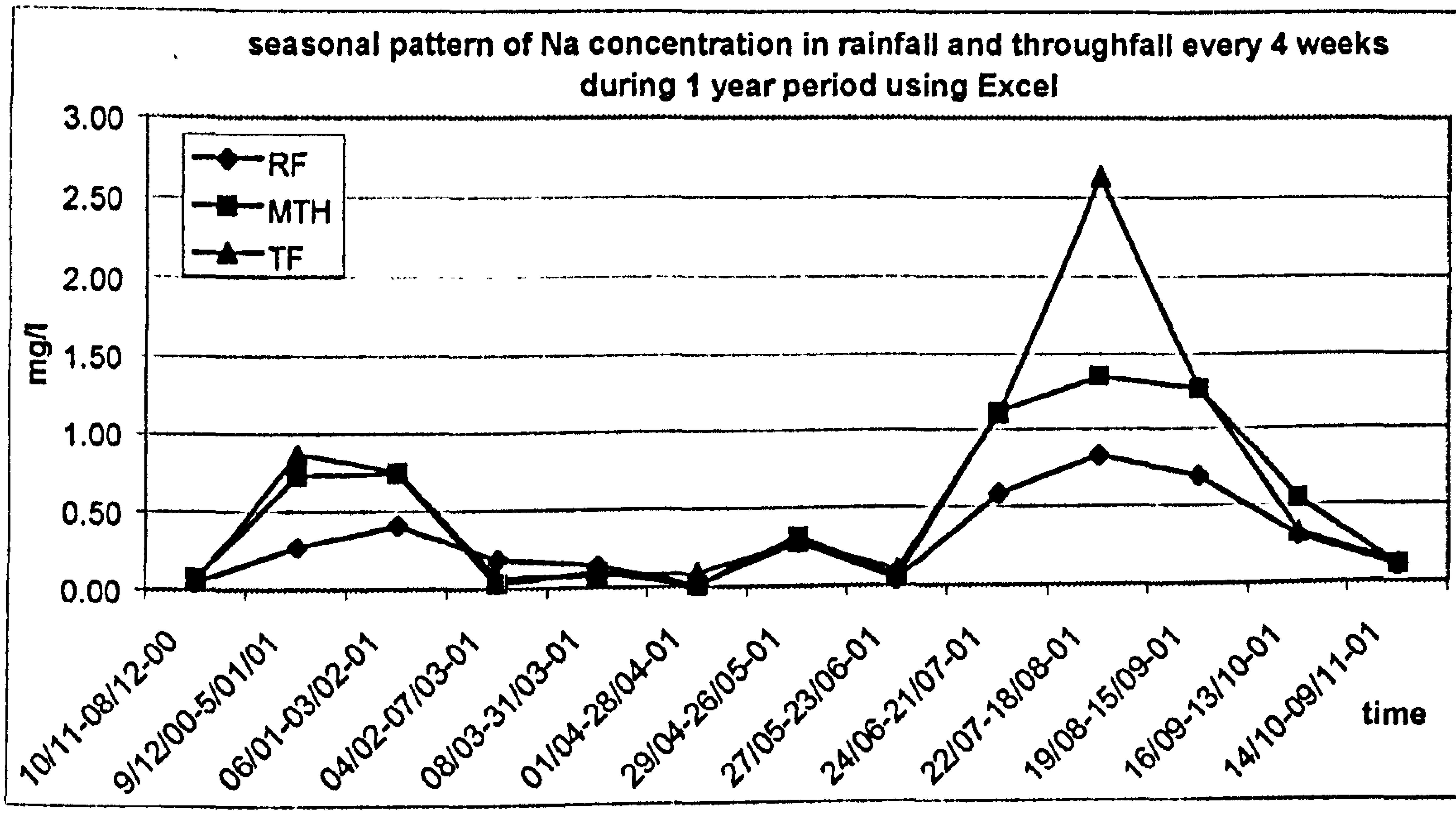


Figure 3.2.6.a: Seasonal pattern of Na concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

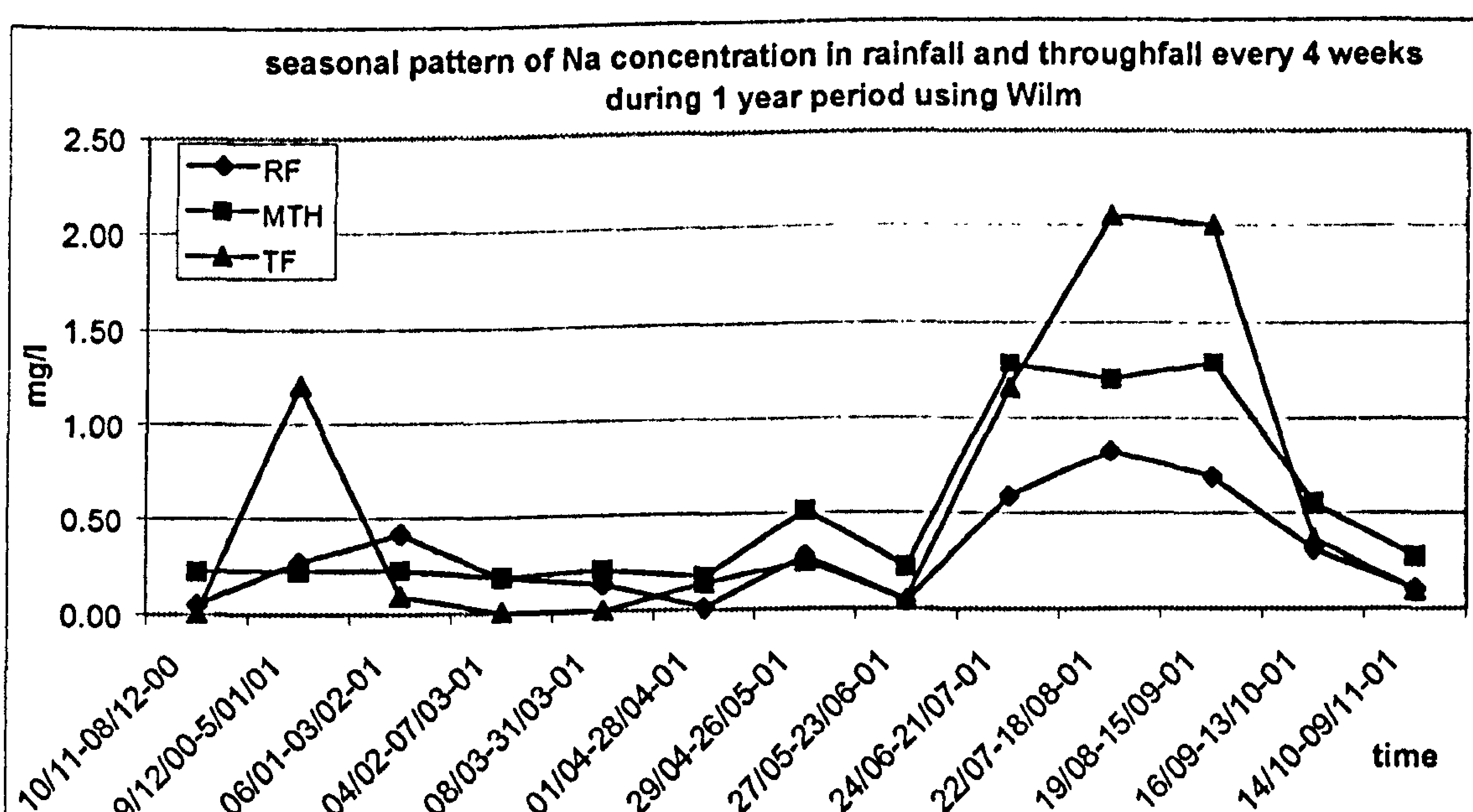


Figure 3.2.6.b: Seasonal pattern of Na concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Wilm

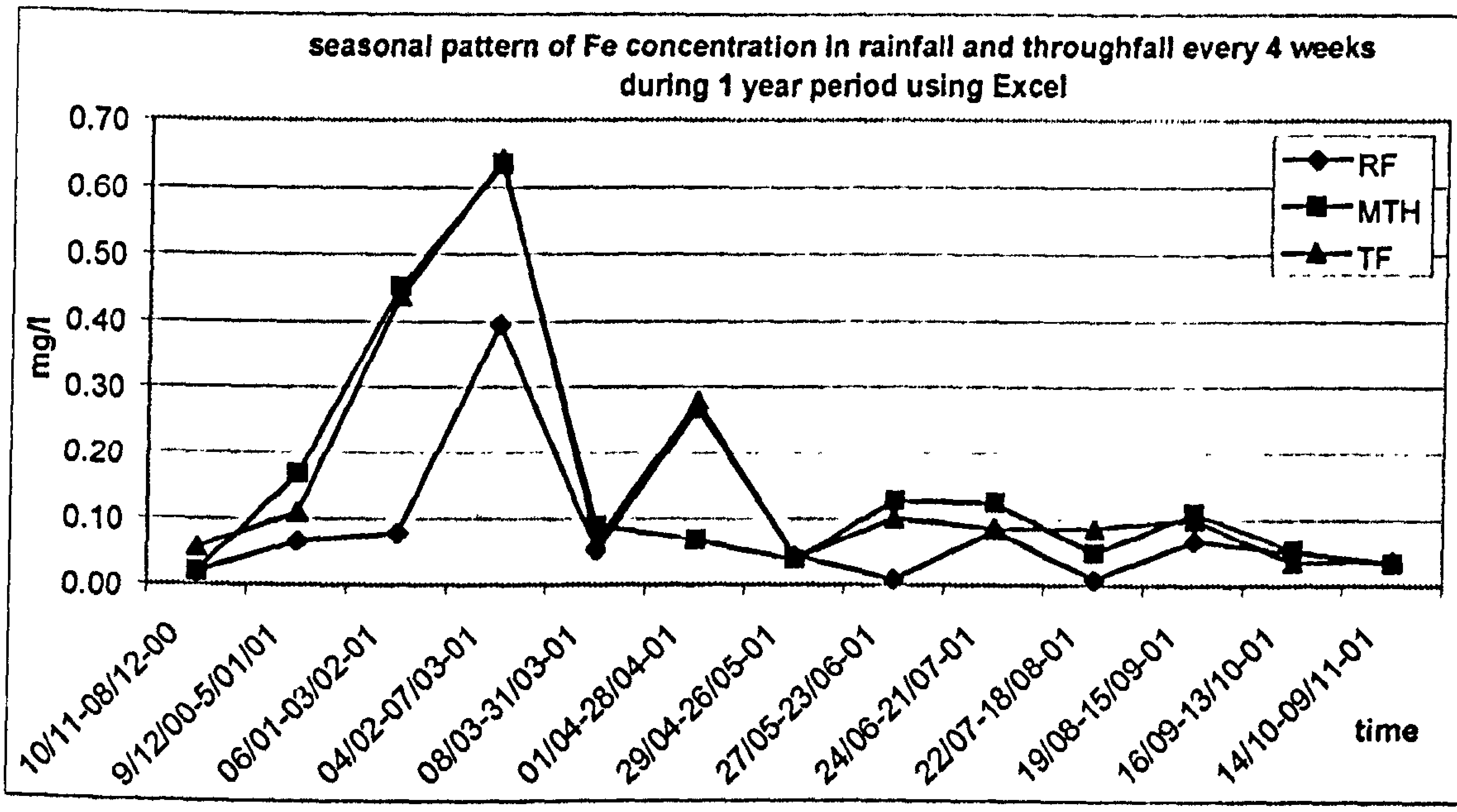


Figure 3.2.7.a: Seasonal pattern of Fe concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

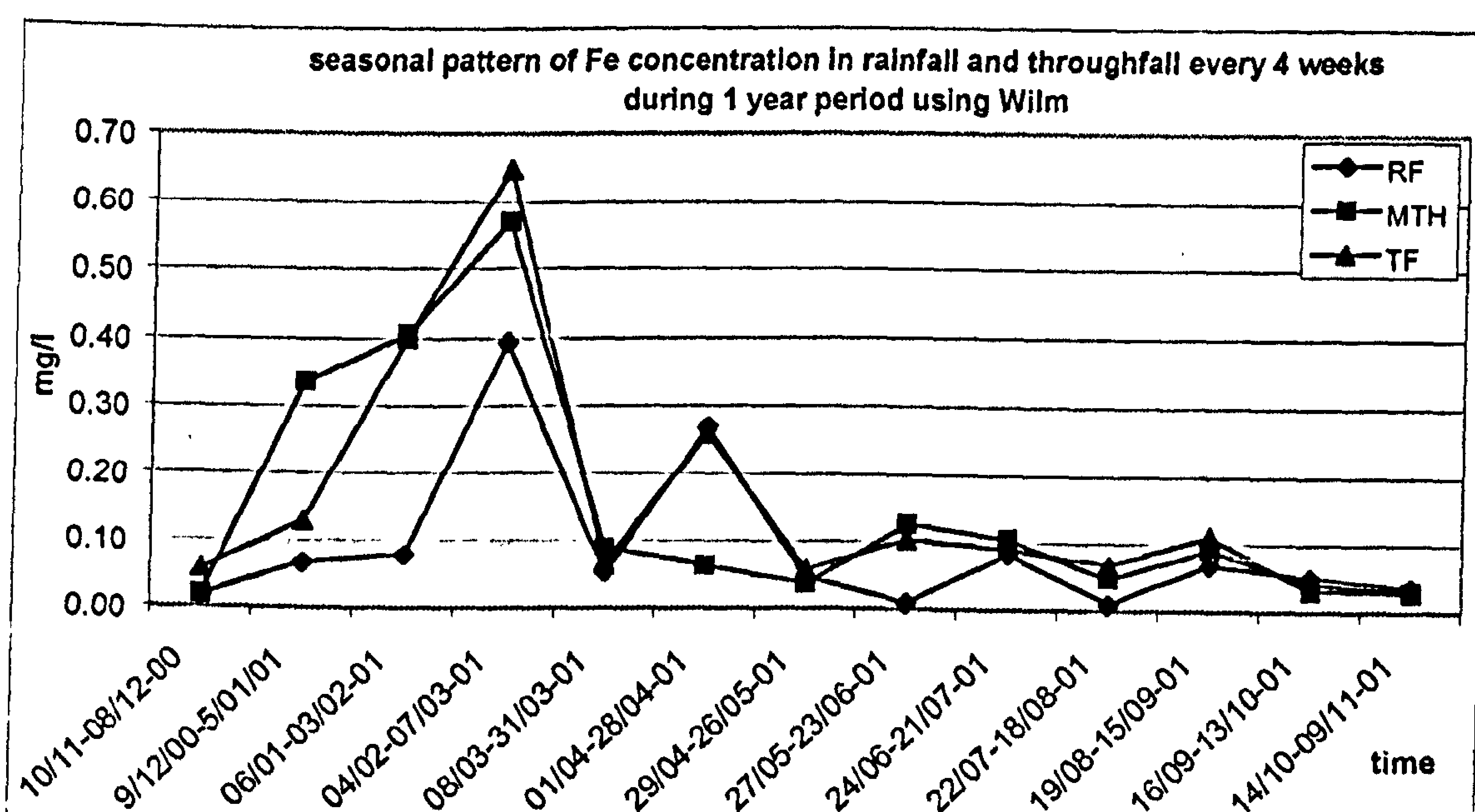


Figure 3.2.7.b: Seasonal pattern of Fe concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Wilm

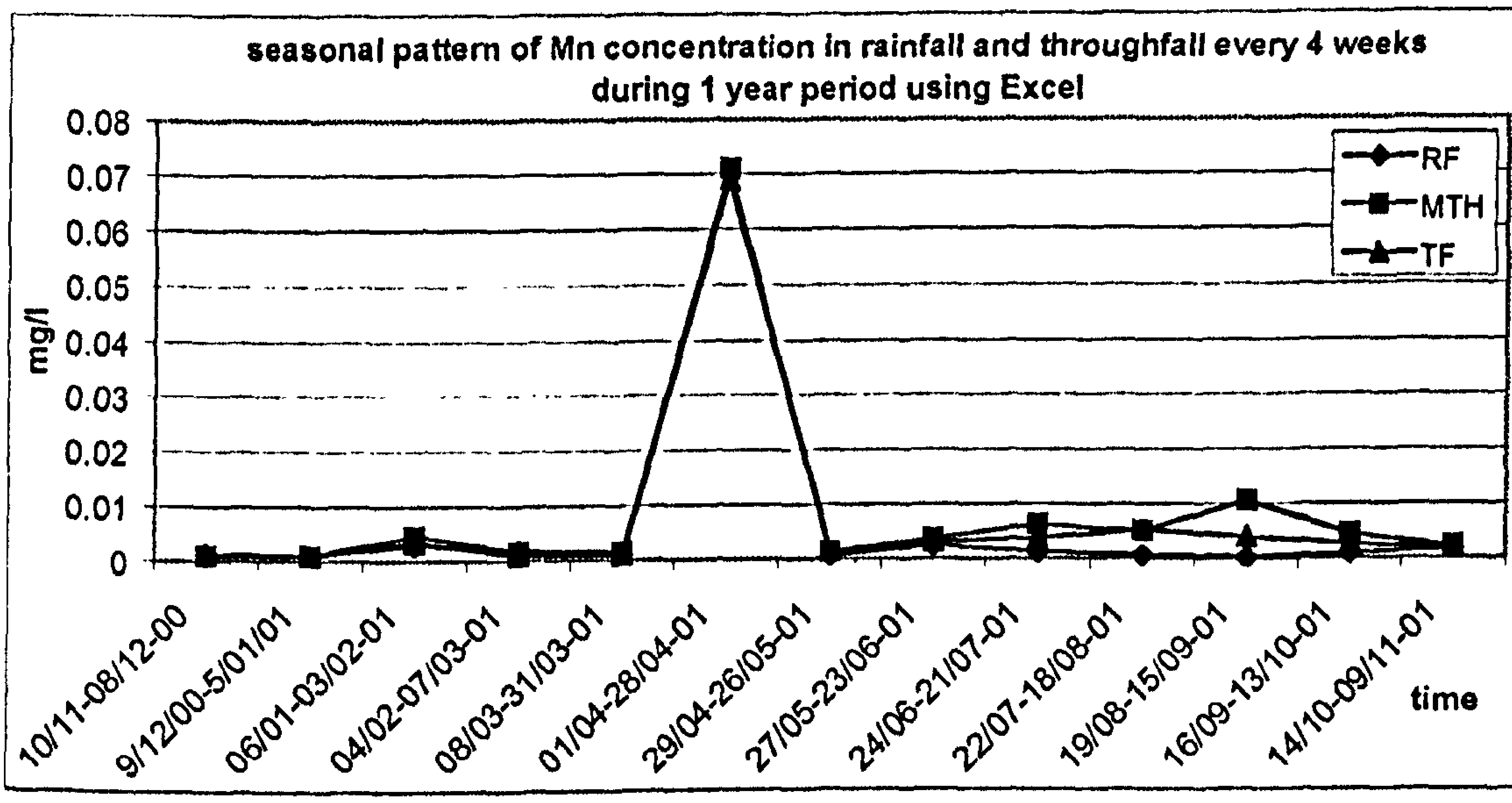


Figure 3.2.8.a: Seasonal pattern of Mn concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

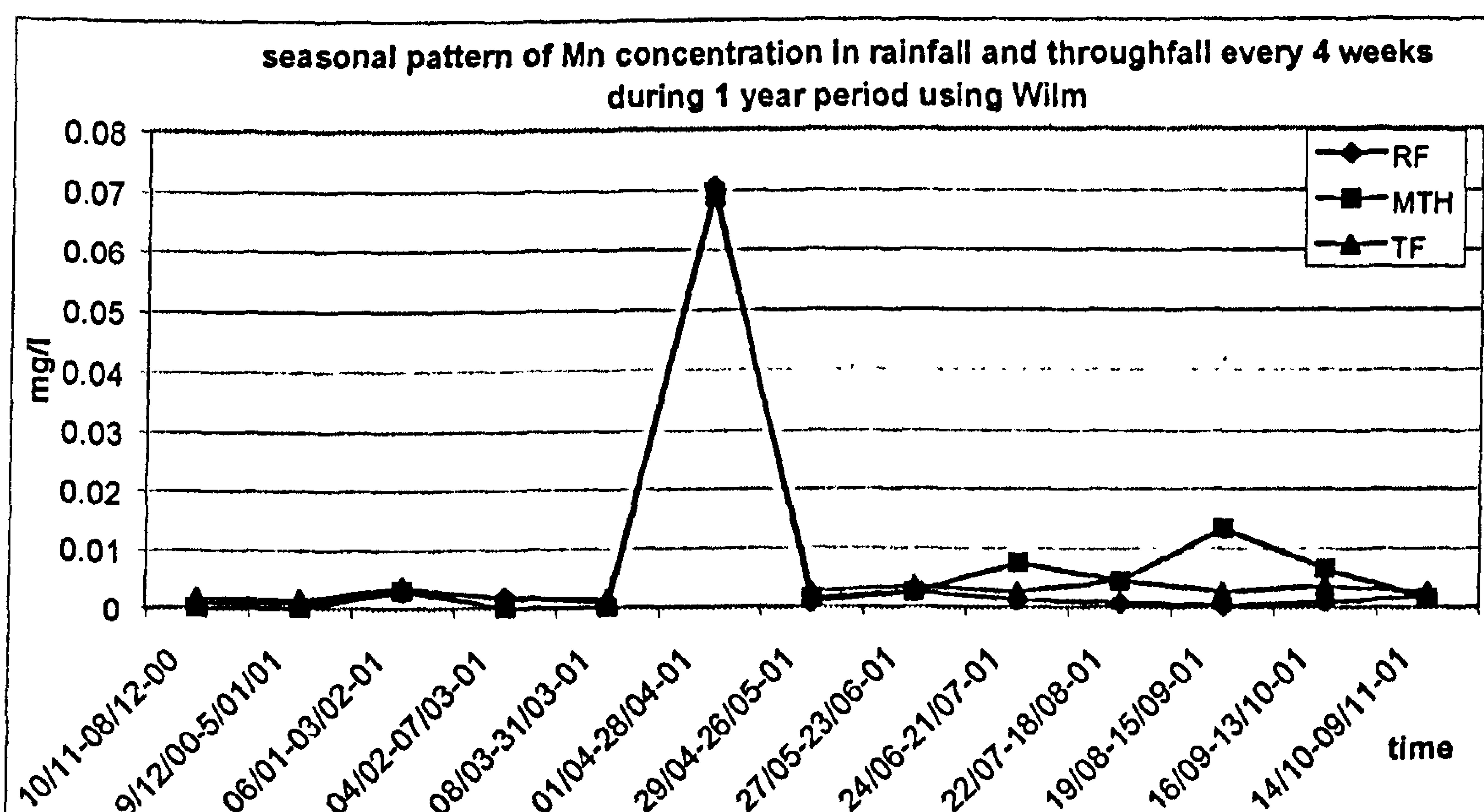


Figure 3.2.8.b: Seasonal pattern of Mn concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Wilm

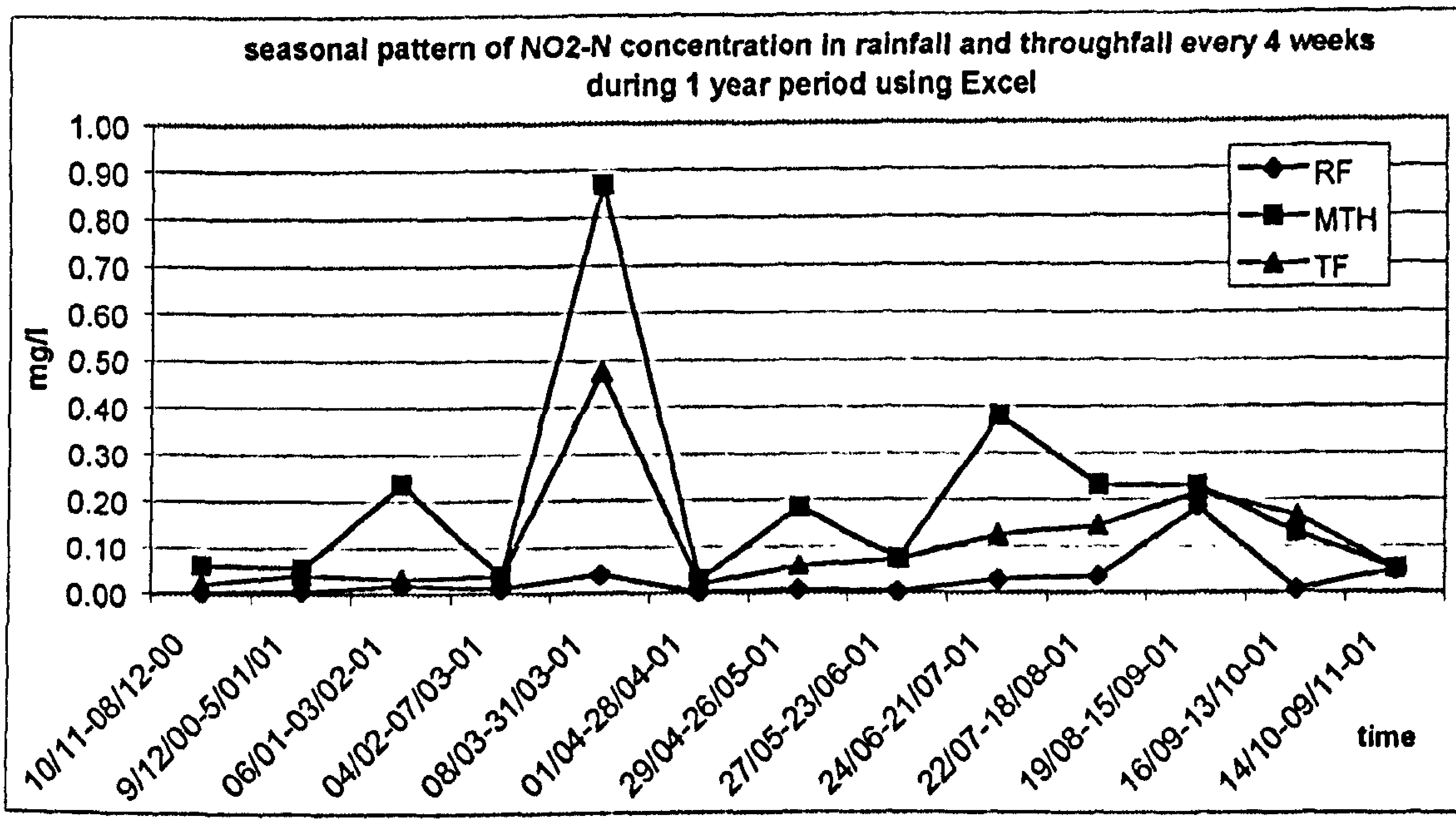


Figure 3.2.9.a: Seasonal pattern of nitrite concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

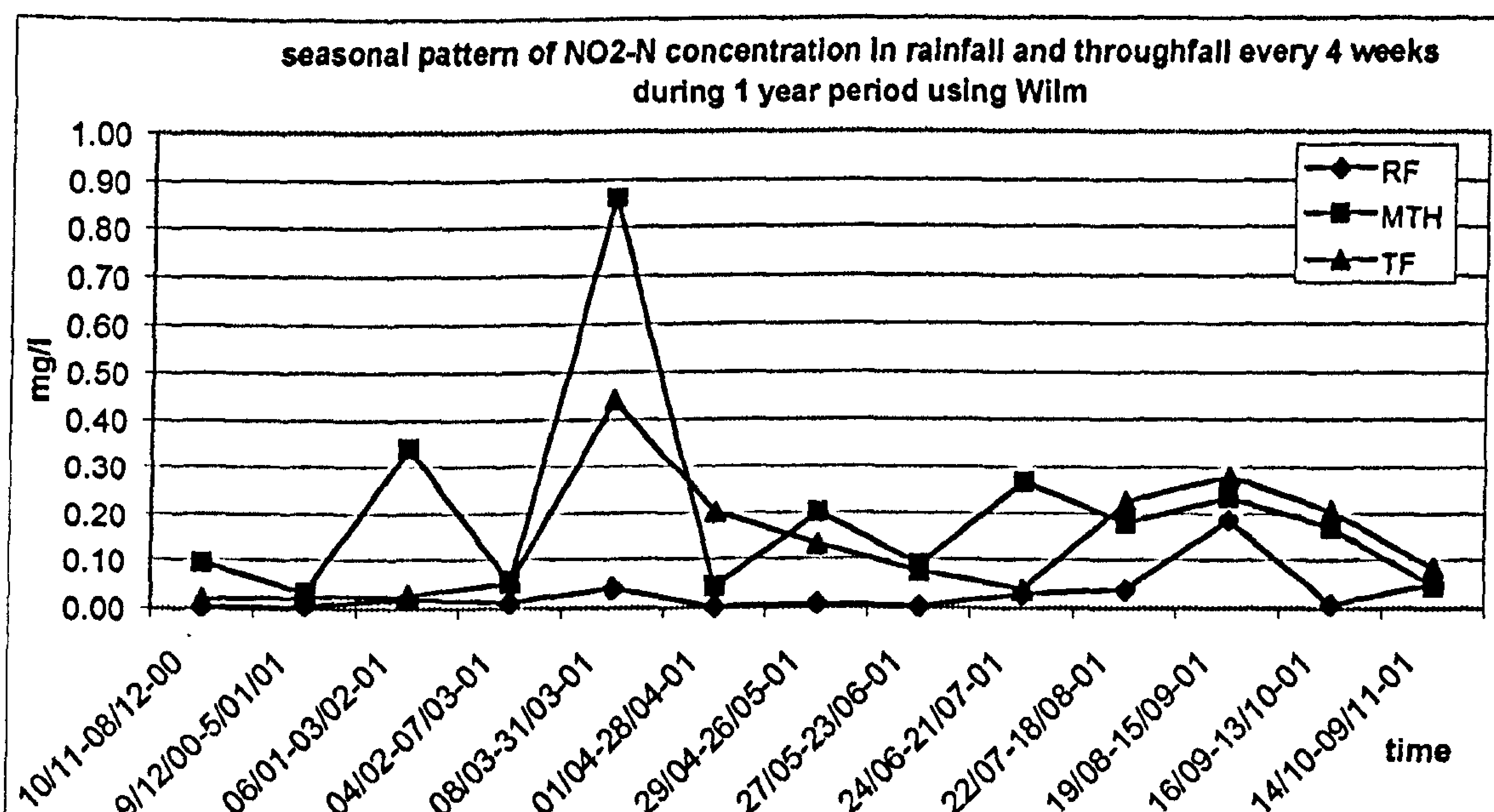


Figure 3.2.9.b: Seasonal pattern of nitrite concentration in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Wilm

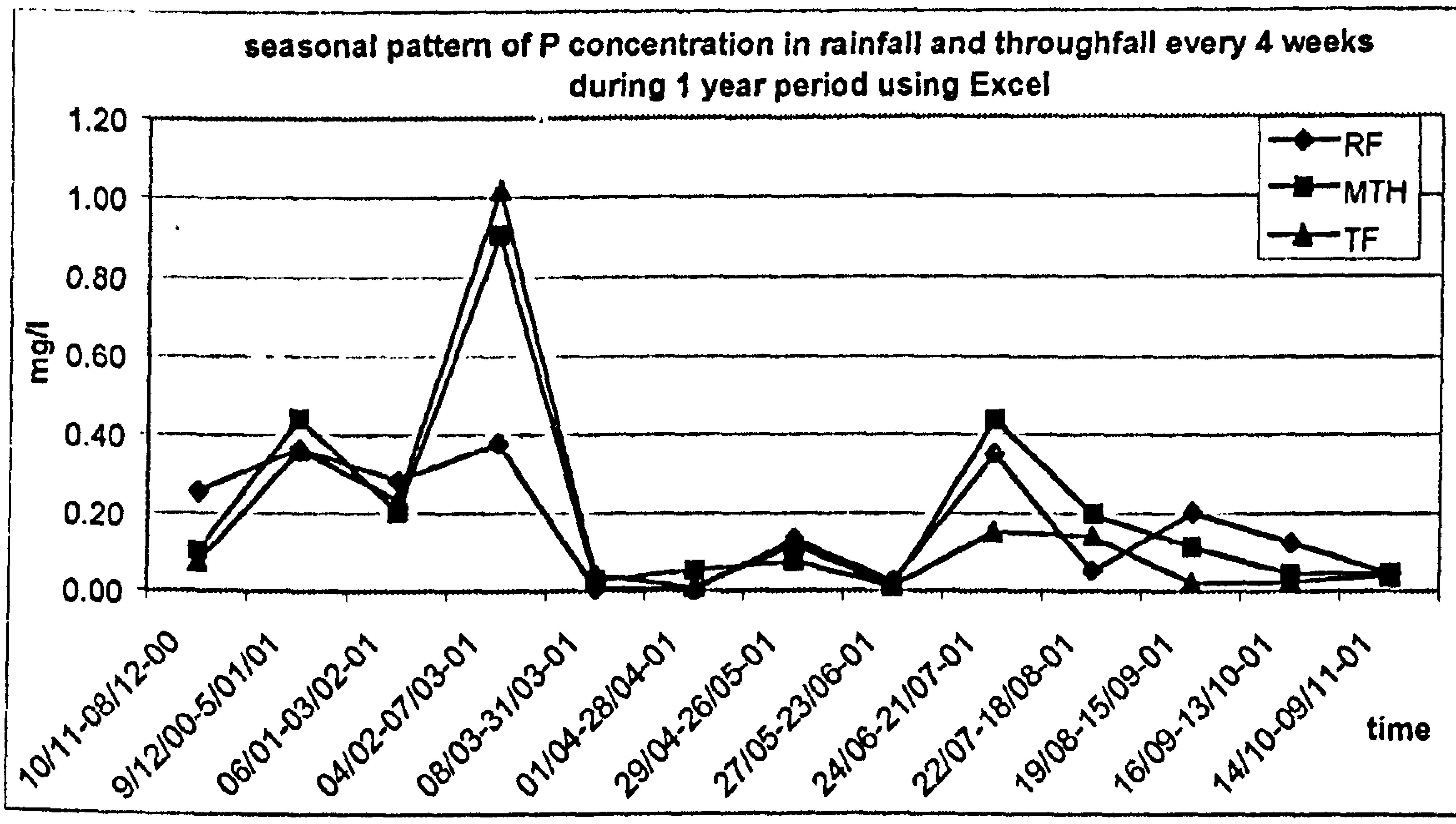


Figure 3.2.10.a: Seasonal pattern of phosphate concentration in rainfall (RF), throughfall inMSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

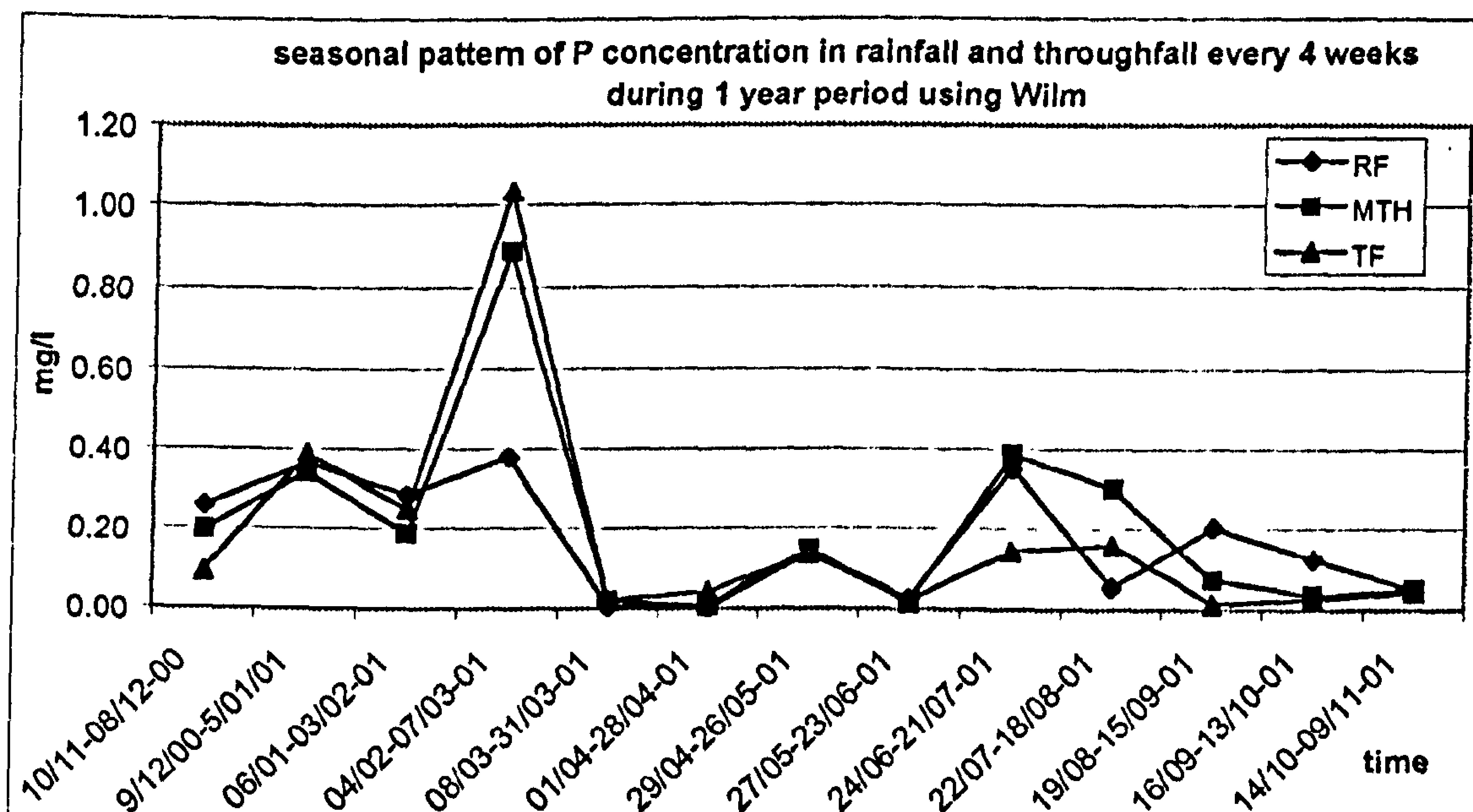


Figure 3.2.10.b: Seasonal pattern of phosphate concentration in rainfall (RF), throughfall inMSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Wilm

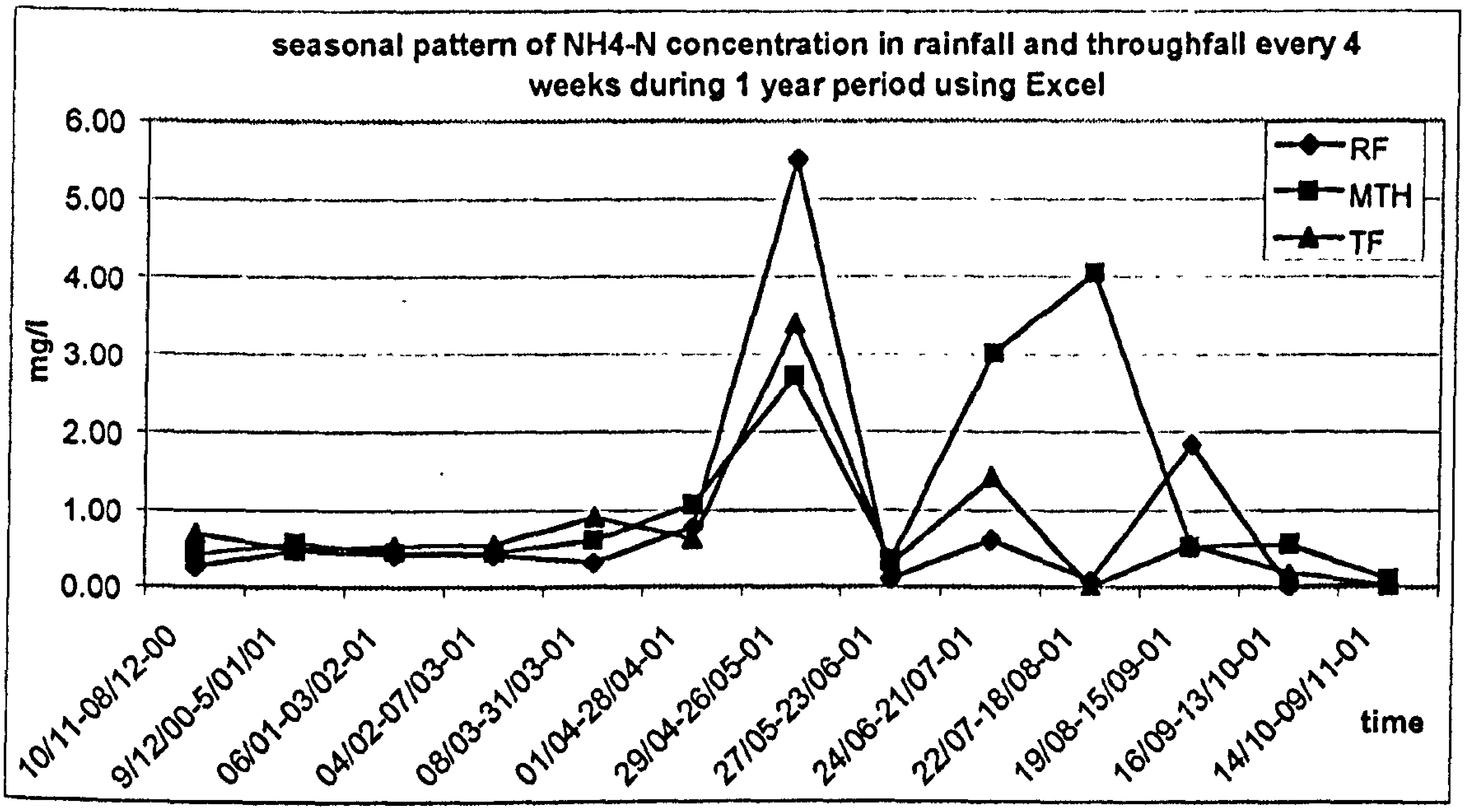


Figure 3.2.11.a: Seasonal pattern of ammonium concentration in rainfall (RF), throughfall inMSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Excel

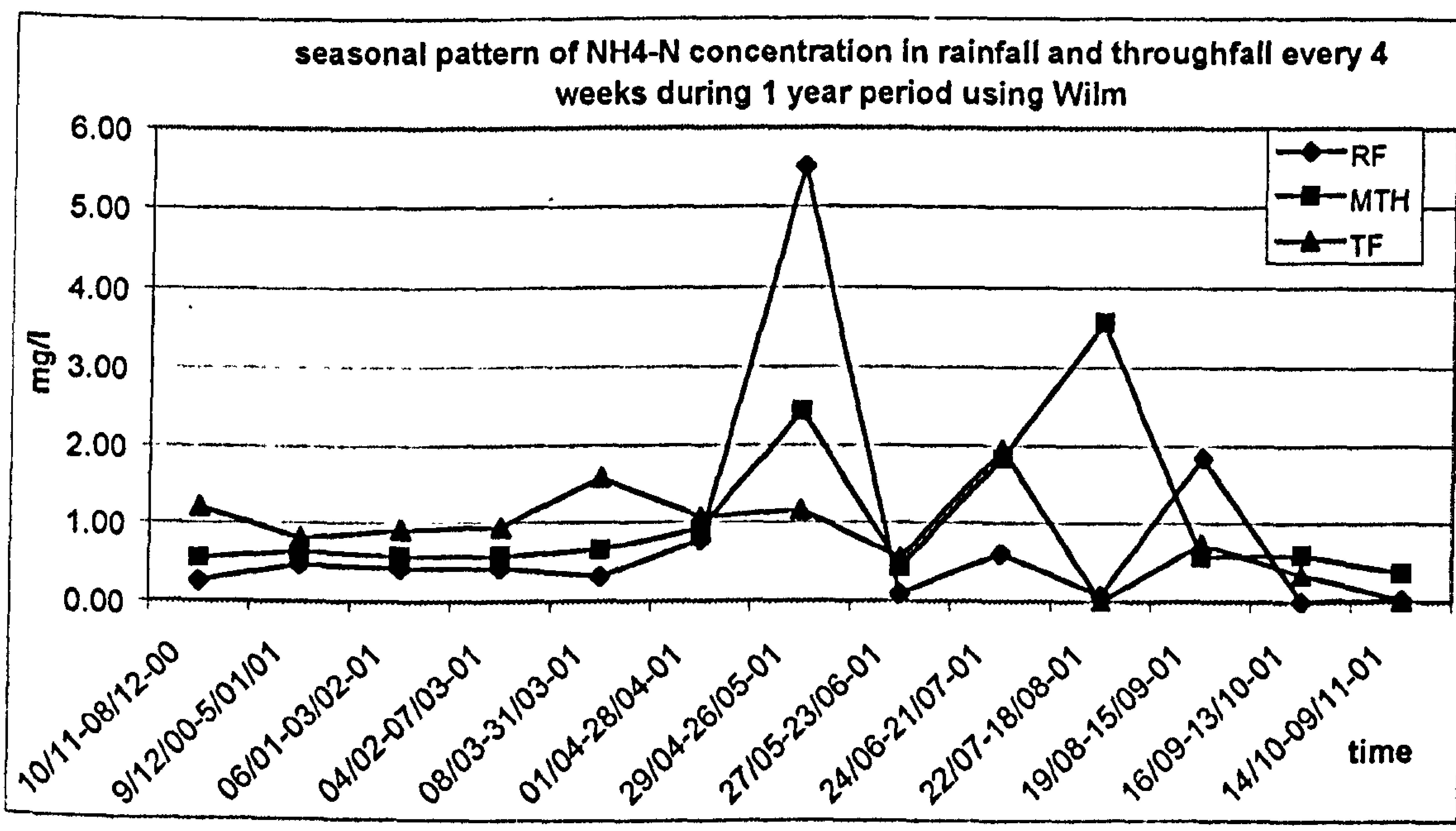


Figure 3.2.11.b: Seasonal pattern of ammonium concentration in rainfall (RF), throughfall inMSF (MTH), and throughfall in LPF (TF) every 4 weeks during the 1 year study period using Wilm

3.2.2.3. Nutrient inputs in throughfall

3.2.2.3.1. Periodic variations

Similarly to rainfall, throughfall nutrient inputs to the forest floor were obtained by multiplying the 4-weekly periodical totals of throughfall by the corresponding nutrient concentrations. These are expressed in kilogram per hectare (kg ha^{-1}). Four-weekly means of each element derived from conventional statistics (Excel) and Wilm Analysis (throughfall only) are presented in Figures 3.2.12. to 3.2.20 for the one year study period (13 mean values for every element). Rainfall is presented as a comparison.

Calcium (Figures 3.2.12.a (Excel) and 3.2.12.b (Wilm))

Precipitation reaching the study area was high in calcium during 6 January-3 February 2001 and 22 July-18 August 2001 and low in 10 November- 8 December 2000, 29 April-26 May 2001 and from August to October 2001. The highest 4 weekly mean was 2.52± 0.23 kg ha^{-1} during 22 July-18 August 2001 while the lowest was 0.27± 0.04 kg ha^{-1} during 19 August-15 September 2001.

In general, calcium content of throughfall closely followed the seasonal pattern of calcium content in rainfall and usually exceeded that in rainfall, especially during peak input periods. In MSF, the highest mean input was 2.80±0.70 kg ha^{-1} during 22 July-18 August 2001 (Excel) and 1.87±0.37 kg ha^{-1} during 27 May-23 June 2001 using the Wilm method. The lowest Excel mean of 0.43±0.23 was obtained in 24

June-21 July 20001 and Wilm mean of 0.82±0.35 kg ha^{-1} during 10 November-8 December 2000.

The highest throughfall input in LPF was 4.09±0.44 kg ha^{-1} during 6 January-3 February 2001 while the lowest was 0.55±0.11 kg ha^{-1} in 10 November-8 December 2000 (Excel). Using Wilm the highest input was 3.62±0.67 kg ha^{-1} during 22 July-18 August 2001 and the lowest was 0.96±0.41 kg ha^{-1} in 10 November-8 December 2000.

Analysis of variance between amount of calcium in rainfall and MSF throughfall are not significant different while rainfall and LPF througfall are significantly different. In contrast, MSF throughfall and LPF throughfall are not significantly different.

Magnesium (Figure 3.2.13.a (Excel) and 3.2.13.b (Wilm)

The highest 4 weekly input of magnesium in rainfall occurred in 1-28 April 2001 at 1.03± 0.20 kg ha^{-1} and the lowest was 0.11 ± 0.07 kg ha^{-1} during 24 June-21 July 2001.

In the mixed swamp forest (MSF), throughfall magnesium content showed a marked peak input during 8-31 March 2001 of 1.24±0.12 kg ha^{-1} (Excel) and 1.16±0.15 kg ha^{-1} (Wilm). The lowest input was during 24 June- 21 July 2001 using both Excel and Wilm of 0.14±0.04 kg ha^{-1} and 0.30±0.14 kg ha^{-1}, respectively. The average 4 weekly during 1 year period using excel was 0.73±0.13 kg ha^{-1} and 0.70±0.03 kg ha^{-1} (Wilm).

Throughfall magnesium content in LPF was high from 4 February to 28 April and 22 July-18 August 2001 with a marked peak 2.50±2.39 kg ha^{-1} in 1-28 April 2001 (Excel). With the Wilm method the peak occurred during 22 July-18 August 2001 of 1.98±0.51 kg ha^{-1}. The lowest inputs of 0.30±0.04 kg ha^{-1} (Excel) occurred in 24 June-21 July 2001 while with Wilm it was 0.39±0.28 kg ha^{-1} in 10 November-8 December 2000. The average 4 weekly during 1 year period using excel was 0.89±0.35 kg ha^{-1} and 0.88±0.17 kg ha^{-1} (Wilm).

The amount of magnesium in rainfall is significantly different from MSF and LPF throughfall while MSF throughfall and LPF throughfall are not significantly different.

Potassium (Figures 3.2.14.a (Excel) and 3.2.14.b (Wilm)

Potassium input in rainfall was high during 10 November-8 December 2000, 27 May-23 June 2001 and 22 July-18 August 2001 when there was a very marked peak of 1.68 ± 1.06 kg ha^{-1}. The lowest input was 0.19±0.05 kg ha-1 in 9 December 2000-5 January 2001.

In the mixed swamp forest (MSF), throughfall potassium content was high during 9 December 2000 – 3 February 2001, 1 April – 23 June 2001, and 16 September – 13 October 2001 determined by Excel. The highest input of 3.24 ±0.59 kg ha^{-1} occurred during 16 September-13 October 2001 while the lowest input was during 24 June –21 July 2001 of 0.51±0.04 kg ha^{-1}. The Wilm method indicated that the highest potassium input was 2.25±0.50 kg ha^{-1} in 6 January-3 February 2001 and the lowest during 19 August-15 September 2001 of 1.42±0.40 kg ha^{-1}.

In LPF, potassium input using both Excel and Wilm methods was high during 9 December 2000 to 3 February 2001 and 22 July-18 August 2001 with peak of 3.82±2.62 kg ha^{-1} in 6 January – 3 February 2001 (excel) and 2.86±0.37 kg ha^{-1} in 9 December 2000– 5 January 2001 (Wilm) . The lowest inputs for Excel and Wilm, were during 24 June- 21 July 2001 of 0.71±0.14 kg ha^{-1} and 0.956±0.22 kg ha^{-1}, respectively.

Similarly to magnesium, amount of potassium in rainfall is significantly different from both MSF and LPF throughfall while MSF throughfall and LPF throughfall are not significantly different.

Sodium (Figures 3.2.15.a (Excel) and 3.2.15.b (Wilm))

The highest input of sodium was detected in 6 January-3 February 2001 with 1.12±0.23 kg ha^{-1} in the middle of the rainy season while the lowest input 0.04±0.03 kg ha^{-1} occurred in 1-28 April 2001 corresponding with the end of the rainy season.

Lowest sodium throughfall inputs in MSF determined by both Excel and Wilm methods were at the end of the wet season (1-28 April 2001) with 0.02±0.01 kg ha^{-1} and 0.05±0.06 kg ha^{-1}, respectively. Highest sodium inputs by both methods occurred during 6 January-3 February 2001 of 1.51 ±0.28 kg ha^{-1} (Excel) and 1.735 ±0.12 kg ha^{-1} (Wilm). The average 4 weekly during 1 year study period was 0.436±0.091 kg ha^{-1} (Excel) and 0.456±0.021 kg ha^{-1} (Wilm).

In the low pole forest (LPF) the highest nutrient input occurred during 9 December 2000-5 January 2001 for both methods at 1.93±0.39 kg ha^{-1} and 1.85±0.14 kg ha^{-1} for Excel and Wilm, respectively. The lowest sodium inputs for both Excel and Wilm were detected in 10 November-8 December 2000 of 0.11±0.03 kg ha^{-1} and 0.10±0.07 kg ha^{-1}, respectively. The average 4 weekly during the 1-year study period using Excel was 0.595±0.142 kg ha^{-1} and 0.568±0.042 kg ha^{-1} (Wilm).

Analysis of variance amount of sodium among rainfall, MSF throughfall, and LPF throughfall are not significantly different.

<u>Iron</u> (Figures 3.2.16.a (Excel and 3.2.16.b Wilm)

The peak in iron reaching the study area in rainfall took place in 4 February-7 March 2001 with 1.68±0.39 ka ha^{-1}. Lowest iron input occurred during 10 November-8 December 2000 and from 29 April to 9 November 2001 with a minimum in 22 July-18 August 2001 of 0.01±0.01 kg ha^{-1}.

The highest iron 4 weekly inputs in the MSF determined by both Excel and Wilm was detected in 4 February-7 March 2001 of 1.90± 0.27 kg ha^{-1} (excel) and 1.91 ±0.09 kg ha $^{-1}$ (Wilm). Lowest inputs by both methods were in 24 June- 21 July 2001 of 0.01±0.00 kg ha^{-1} (Excel) and 0.002±0.032 kg ha^{-1} (Wilm).

The highest iron content in LPF throughfall by both Excel and Wilm occurred in 4 February- 7 March 2001 of 1.86±0.46 kg ha^{-1} and 1.73 ±0.06 kg ha^{-1}, respectively. Lowest iron throughfall inputs were detected in 10 November-8 December 2000, 29 April – 26 May 2001, and from 24 June to 9 November 2001 with lowest inputs of 0.020±0.001 kg ha^{-1} in 24 June-21 July 2001 (Excel) and 0.027±0.02 kg ha^{-1} in 24 June- 21 July 2001 (Wilm).

Similarly to sodium, amount of iron among rainfall, MSF throughfall, and LPF throughfall are not significantly different.

Manganese (Figures 3.2.17.a (excel) and 3.2.17.b (Wilm)

In general, manganese content in rainfall during study period was very low and was undetectable in some samples. The highest manganese content just reached 0.18 kg ha^{-1} during 1-28 April 2001 while for the rest of the year it was less than 0.009 kg ha^{-1} in every 4 weekly sampling period.

The highest manganese inputs in throughfall in MSF by both Excel and Wilm methods were during 1-28 April 2001 with 0.15±0.004 kg ha^{-1} and 0.167±0.0005 kg ha^{-1}, respectively. At all other sampling periods manganese input was low and in some was only 0.001 kg ha^{-1}, for example 10 November-8 December 2000, 29 April-26 May 2001 and 24 June- 21 July 2001. Manganese was the lowest input during the study with average at 0.0154±0.0017 kg ha^{-1} (Excel) and 0.0163±0.0011 kg ha^{-1} (Wilm).

In low pole forest (LPF), manganese content in throughfall showed the same pattern as MSF. The highest manganese input occurred during 1-28 April 2001 by both methods of 0.15±0.02 kg ha^{-1} (Excel) and 0.16±0.002 kg ha^{-1} (Wilm). At all other 4 weekly periods manganese inputs were negligible. The average during the 1-year study period was only 0.0146±0.0025 kg ha^{-1} (Excel) and 0.0148±0.0015 kg ha^{-1} (Wilm).

Analysis of variance on the amount of manganese among rainfall, MSF throughfall, and LPF throughfall are not significantly different.

Nitrite (Figures 3.2.18.a (Excel) and 3.2.18.b (Wilm)

Similarly to manganese, nitrite content in rainfall during the one year study period was low with the highest input of only 0.17±19 kg ha^{-1} during 14 October-9 November 2001. Nitrite input was low from 10 November 2000 to 7 March 2001 and from 1 April to 13 October 2001 with the minimum during 10 November-8 December 2000 of 0.005±0.005 kg ha^{-1}.

In the mixed swamp forest (MSF), the highest nitrite content using both Excel and Wilm occurred during 8-31 March 2001 with 1.74±0.54 kg ha^{-1} (Excel) and 1.72±0.06 kg ha^{-1} (Wilm). The lowest nitrite inputs during 24 June-21 July 2001 with 0.04±0.03 kg ha^{-1} (Excel) and 0.03±0.02 kg ha^{-1} (Wilm).

In LPF, the highest nitrite inputs using Excel and Wilm methods were during 8-31 March 2001 at 1.18±0.20 kg ha^{-1} and 1.31±0.07 kg ha^{-1}, respectively. The lowest input using Excel was during 24 June-21 July 2001 of 0.03±0.02 kg ha^{-1} while using Wilm nitrite inputs were not detected in 10 November-8 December 2000 and 24 June-21 July 2001.

The amount of nitrite in rainfall is not significant differently to LPF throughfall while rainfall and MSF throughfall are significantly different. In contrast, the amount of nitrite in MSF throughfall is not significantly different to LPF throughfall.

Phosphate (Figures 3.2.19.a (Excel) and 3.2.19.b (Wilm))

Peak phosphate input in rainfall occurred during 4 February-7 March 2001 with 1.62±2.23 kg ha^{-1}. Phosphate inputs were low from 8 March to 9 November 2001 with values not more than 0.18 kg ha^{-1} in every 4 weekly period; a minimum phosphate input occurred in 1-28 April 2001 of 0.006±0.013 kg ha^{-1}.

The highest phosphate inputs in MSF throughfall using both Excel and Wilm were during 4 February-7 March 2001 at 2.71±0.34 kg ha^{-1} (Excel) and 2.62±0.18 kg ha^{-1} (Wilm). Lowest inputs were during 24 June-21 July 2001 of 0.03±0.02 kg ha^{-1} (Excel) and 19 August- 15 September 2001 of 0.05±0.55 kg ha^{-1} (Wilm).

The highest LPF phosphate inputs by both Excel and Wilm methods were during 4 February- 7 March 2001 of 3.01±1.07 kg ha^{-1} and 3.04±0.08 kg ha^{-1}, respectively. Low phosphate throughfall inputs were recorded from 8 March to 9 November 2001 with the lowest occurring during 19 August-15 September 2001 of 0.004±0.003 kg ha^{-1} (Excel) and 0.000 kg ha^{-1} (Wilm).

Similarly to sodium, iron, and manganese, the amount of phosphate among rainfall, MSF throughfall, and LPF throughfall during 1 year study period are not significantly different.

<u>Ammonium</u> (Figures 3.2.20.a (Excel) and 3.2.20.b (Wilm)

The highest input of ammonium in precipitation was recorded during 29 April-26 May 2001 of 6.91±0.39 kg ha^{-1}.

The highest inputs of ammonium in MSF throughfall using both Excel and Wilm were during 29 April- 26 May 2001 at 3.16±2.67 kg ha^{-1} (Excel) and 2.88±0.27 kg ha^{-1} (Wilm). Lowest inputs were during 19 August- 15 September 2001 by both methods of 0.13±0.03 kg ha^{-1} (Excel) and 0.44±0.13 kg ha^{-1} (Wilm).

The highest ammonium LPF throughfall inputs were during 29 April- 26 May 2001 of 2.99±0.38 kg ha^{-1} (Excel) and during 4 February- 7 March 2001 of 1.78±0.33 kg ha^{-1} (Wilm). The lowest iron inputs were during 22 July- 18 August 2001 by both methods with 0.000 kg ha^{-1} (Excel) and 0.28±0.35 kg ha^{-1} (Wilm). In this case (Throughfall water in LPF was finished before ammonium analysis could be carried out).

The amount of ammonium in rainfall, MSF throughfall, and LPF throughfall are not significantly different.

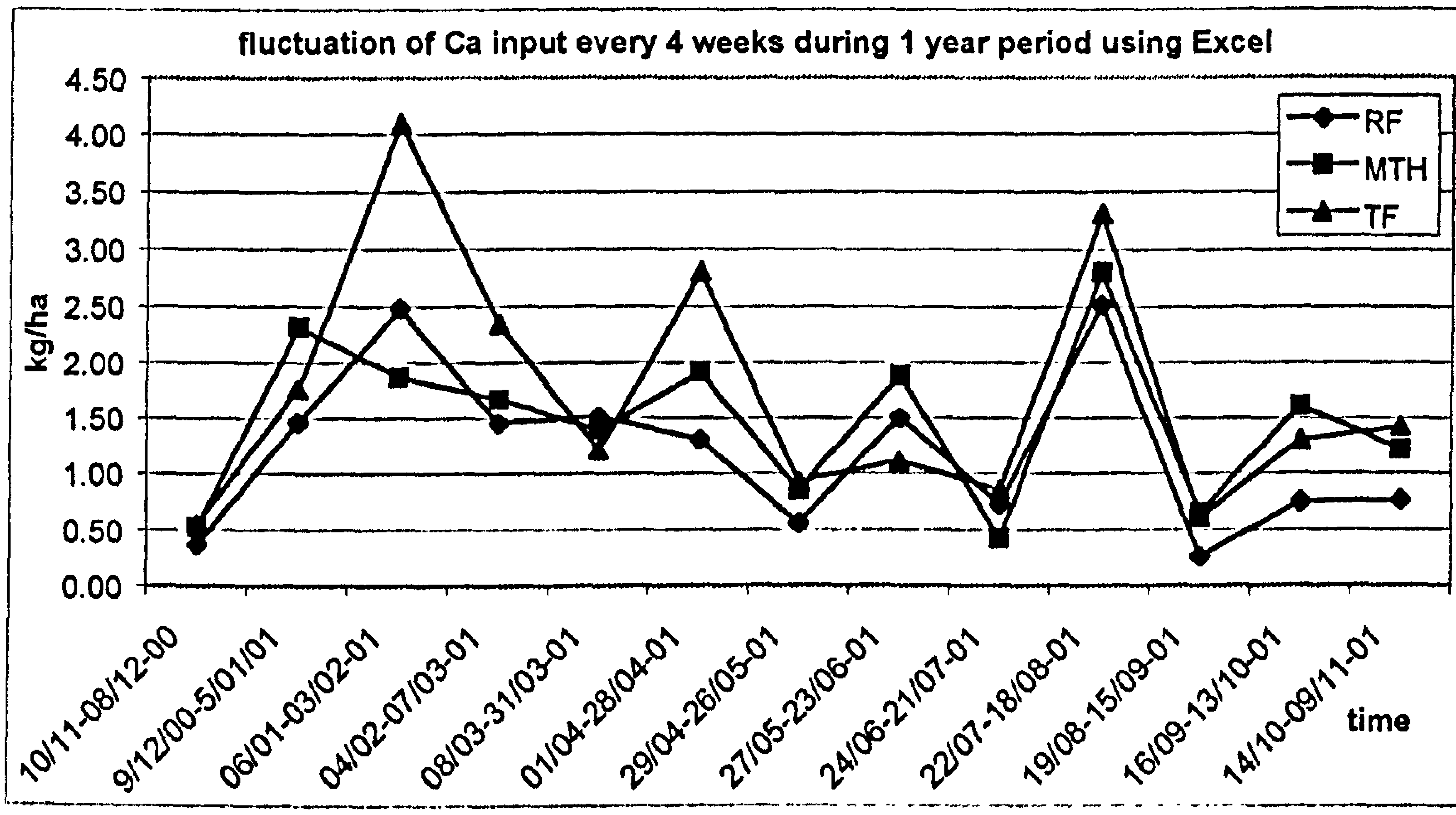


Figure 3.2.12.a: Fluctuation of Ca input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

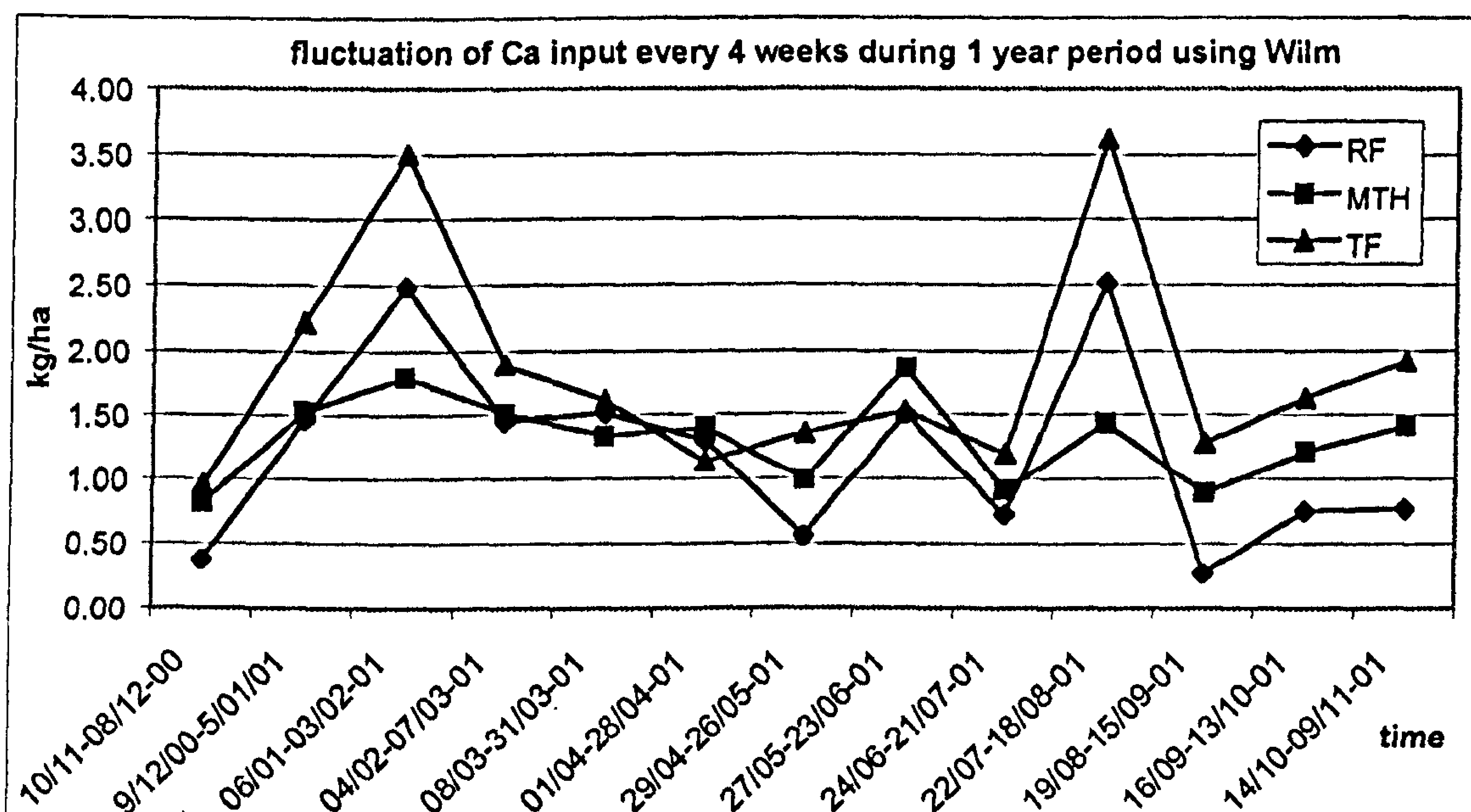


Figure 3.2.12.b: Fluctuation of Ca input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

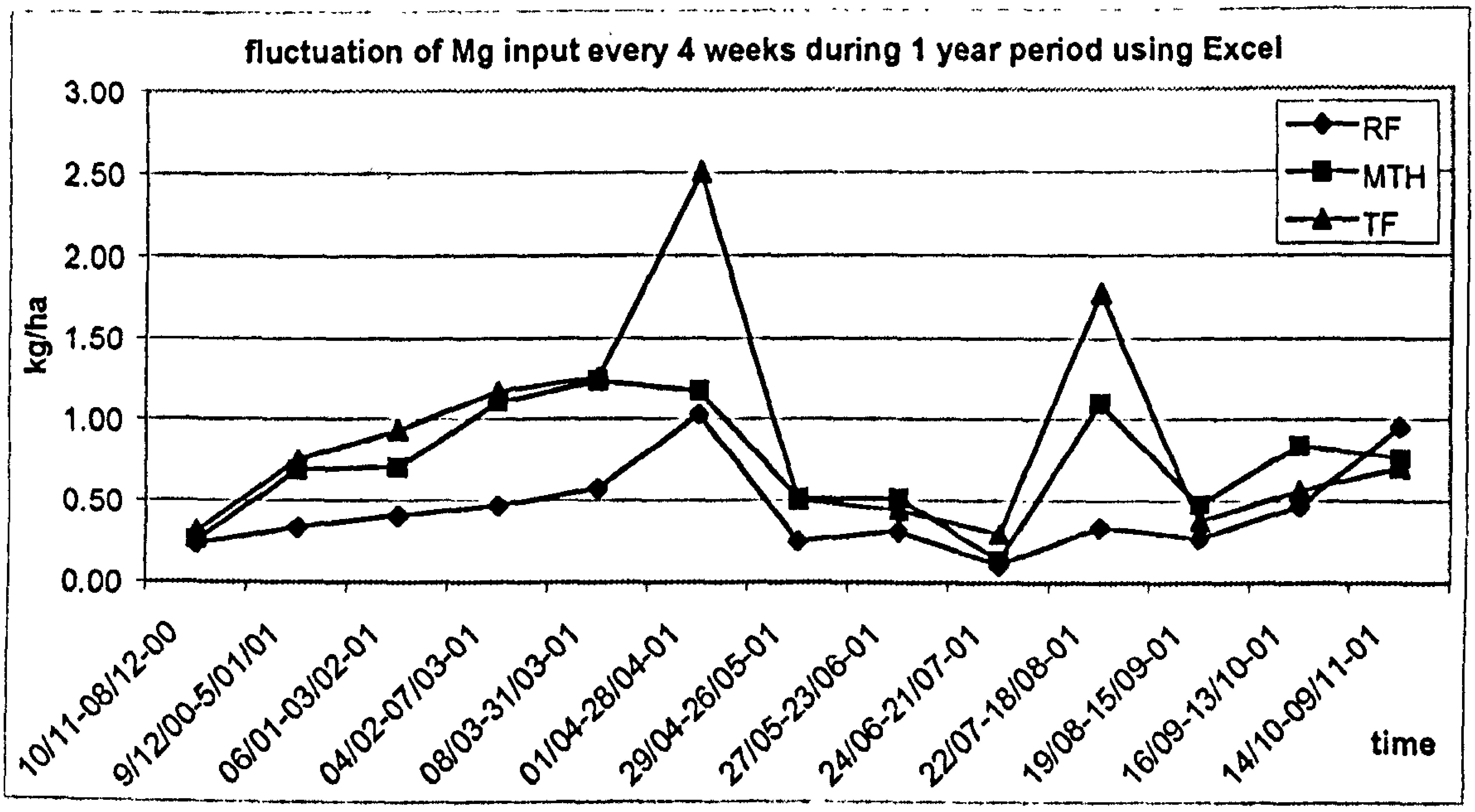


Figure 3.2.13.a: Fluctuation of Mg input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

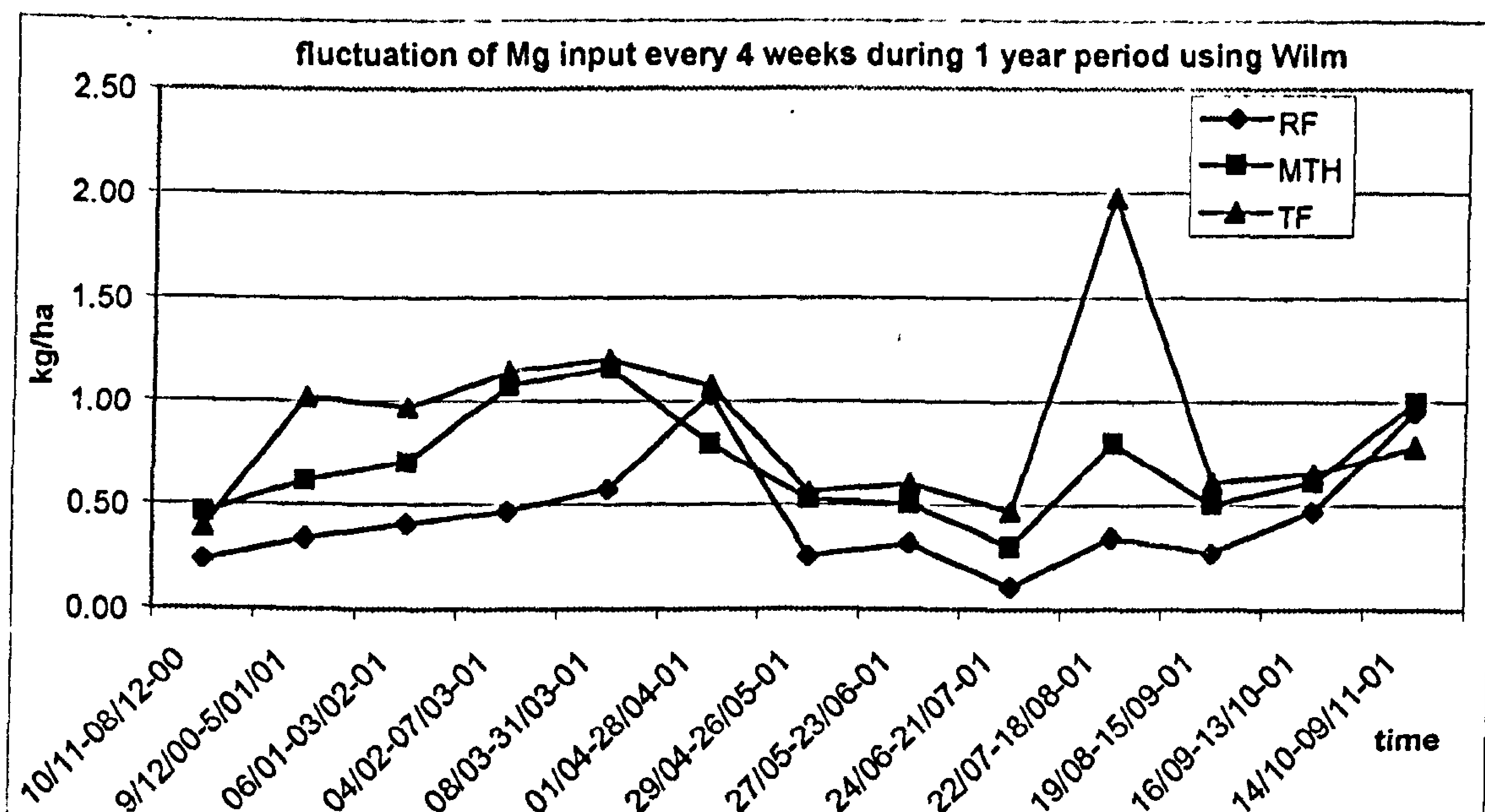


Figure 3.2.13.b: Fluctuation of Mg input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

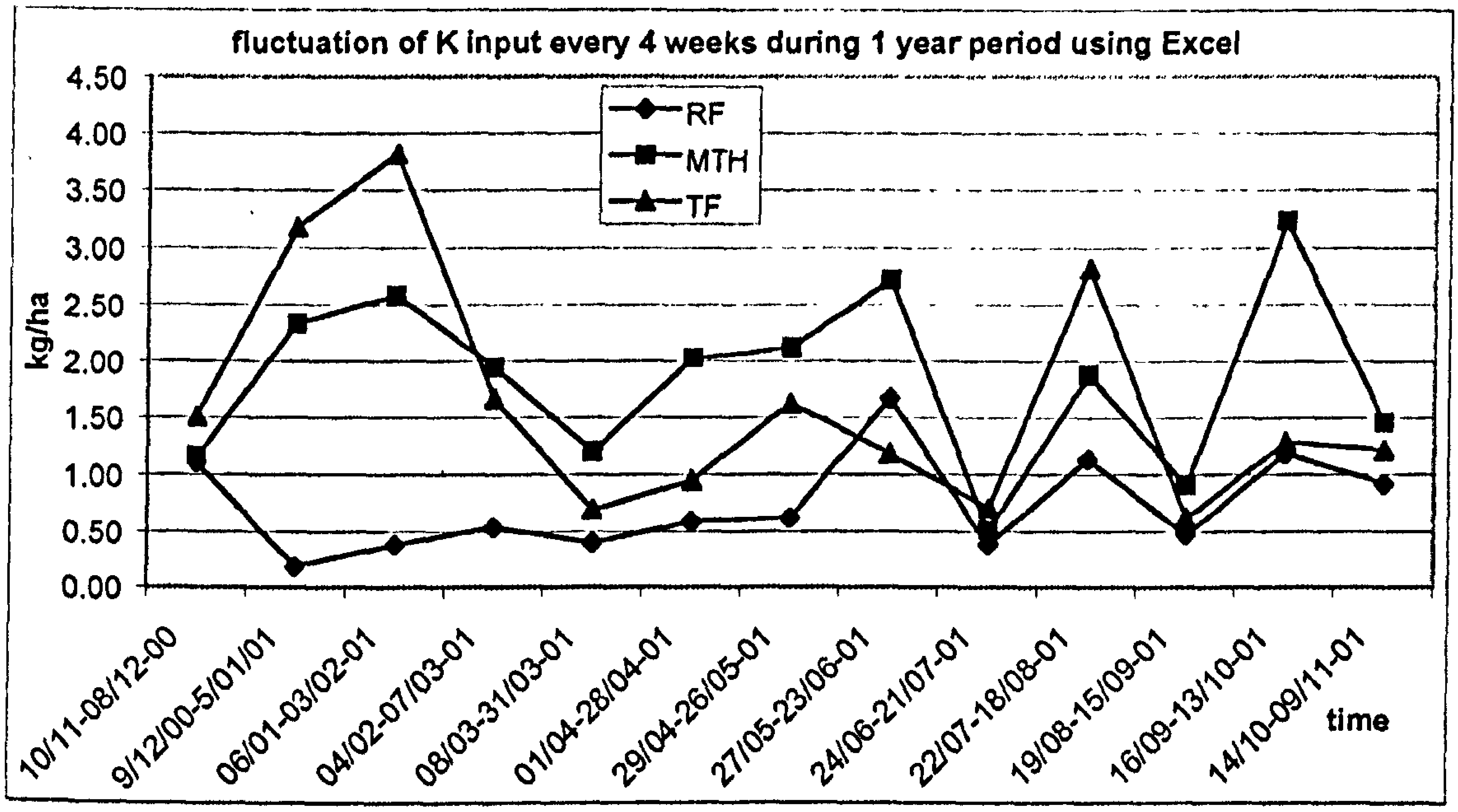


Figure 3.2.14.a: Fluctuation of K input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

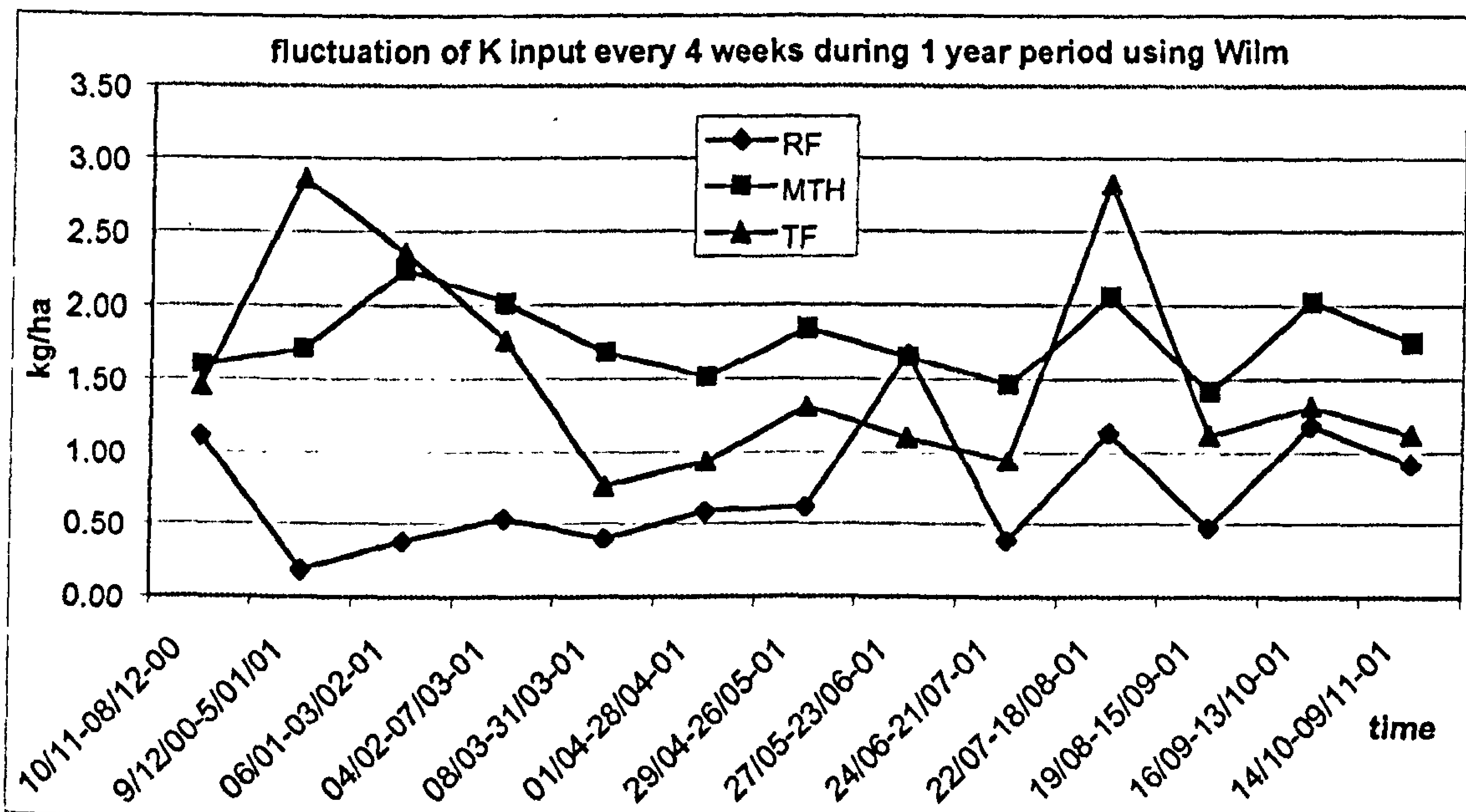


Figure 3.2.14.b: Fluctuation of K input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

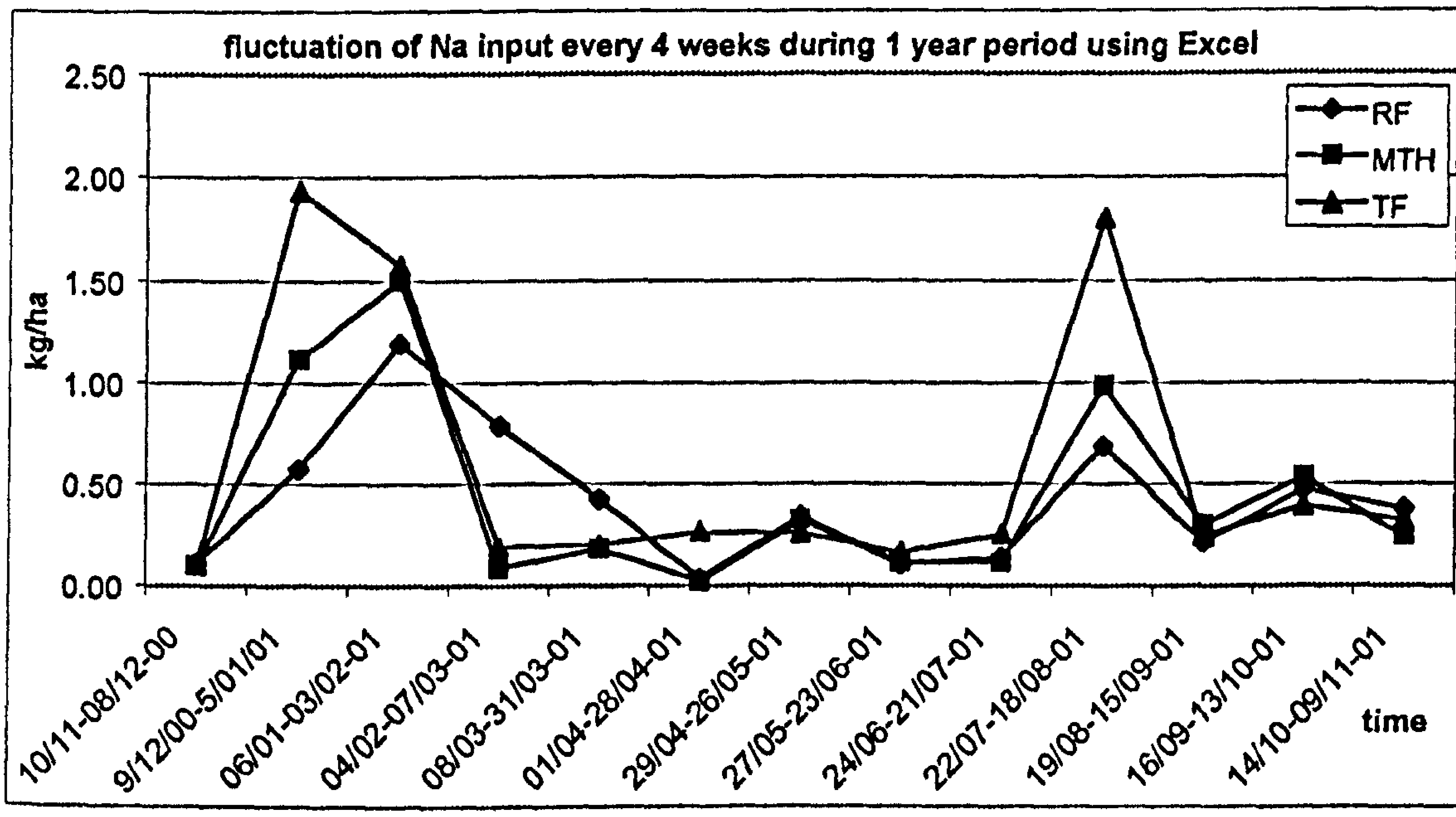


Figure 3.2.15.a: Fluctuation of Na input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

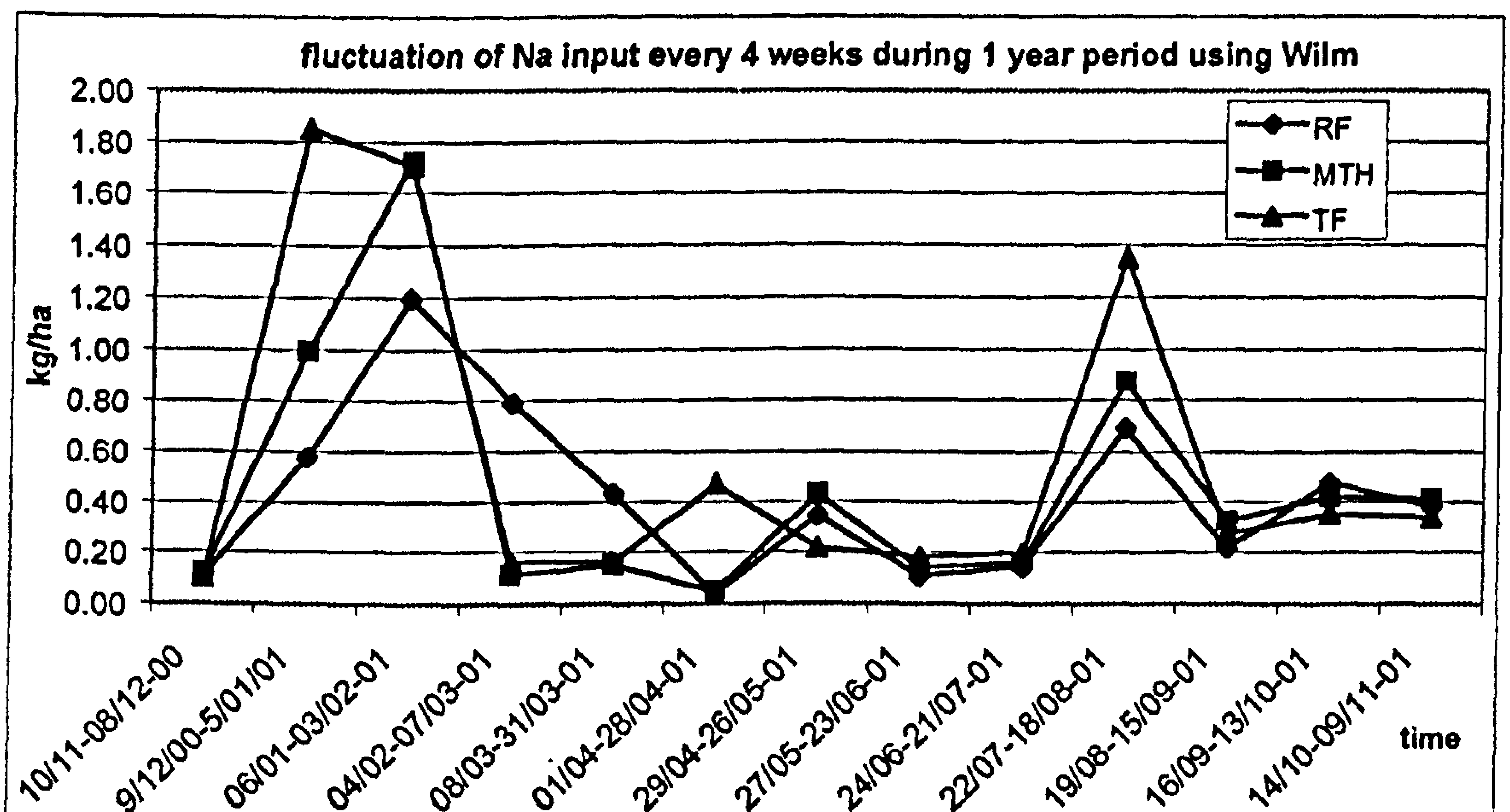


Figure 3.2.15.b: Fluctuation of Na input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

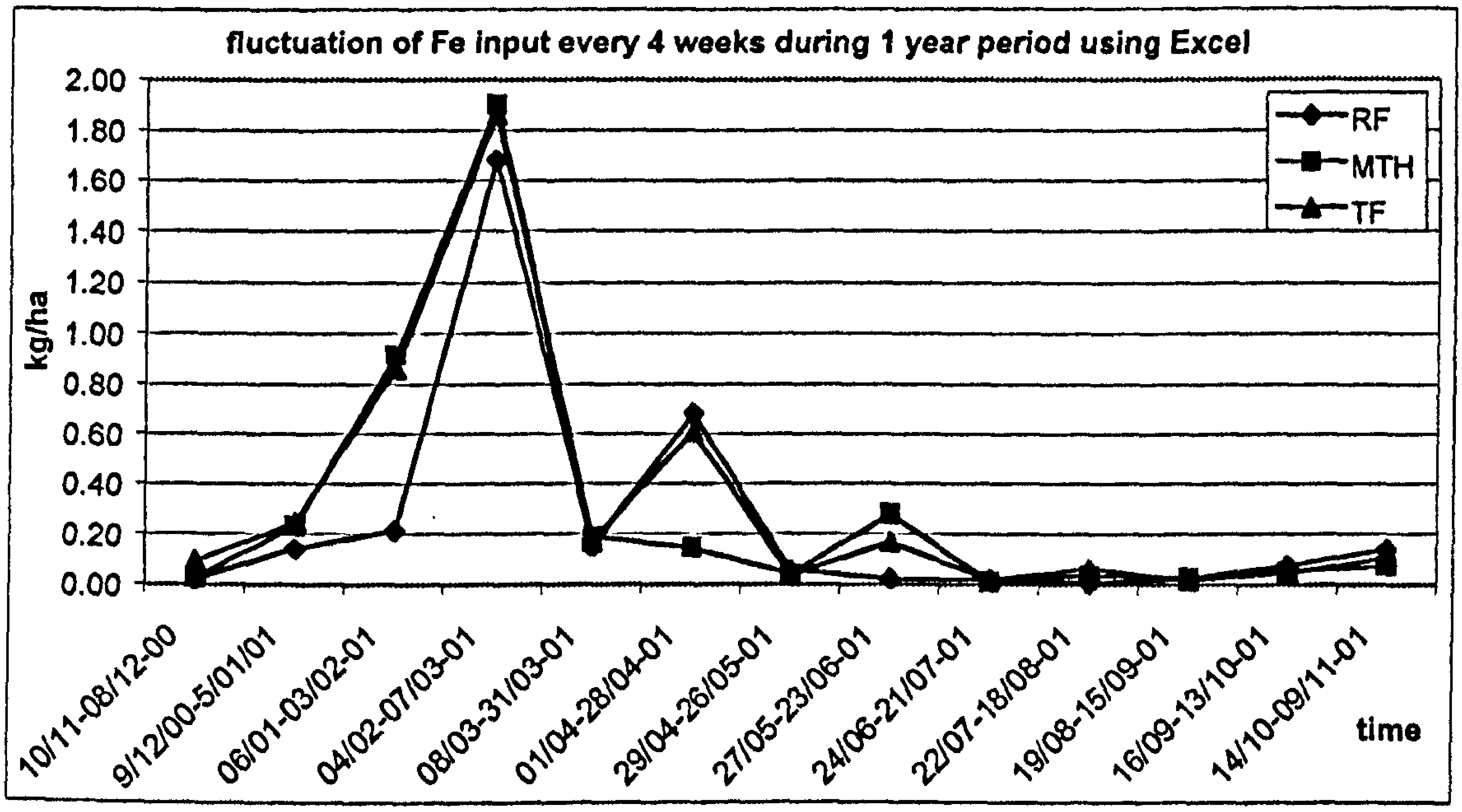


Figure 3.2.16.a: Fluctuation of Fe input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

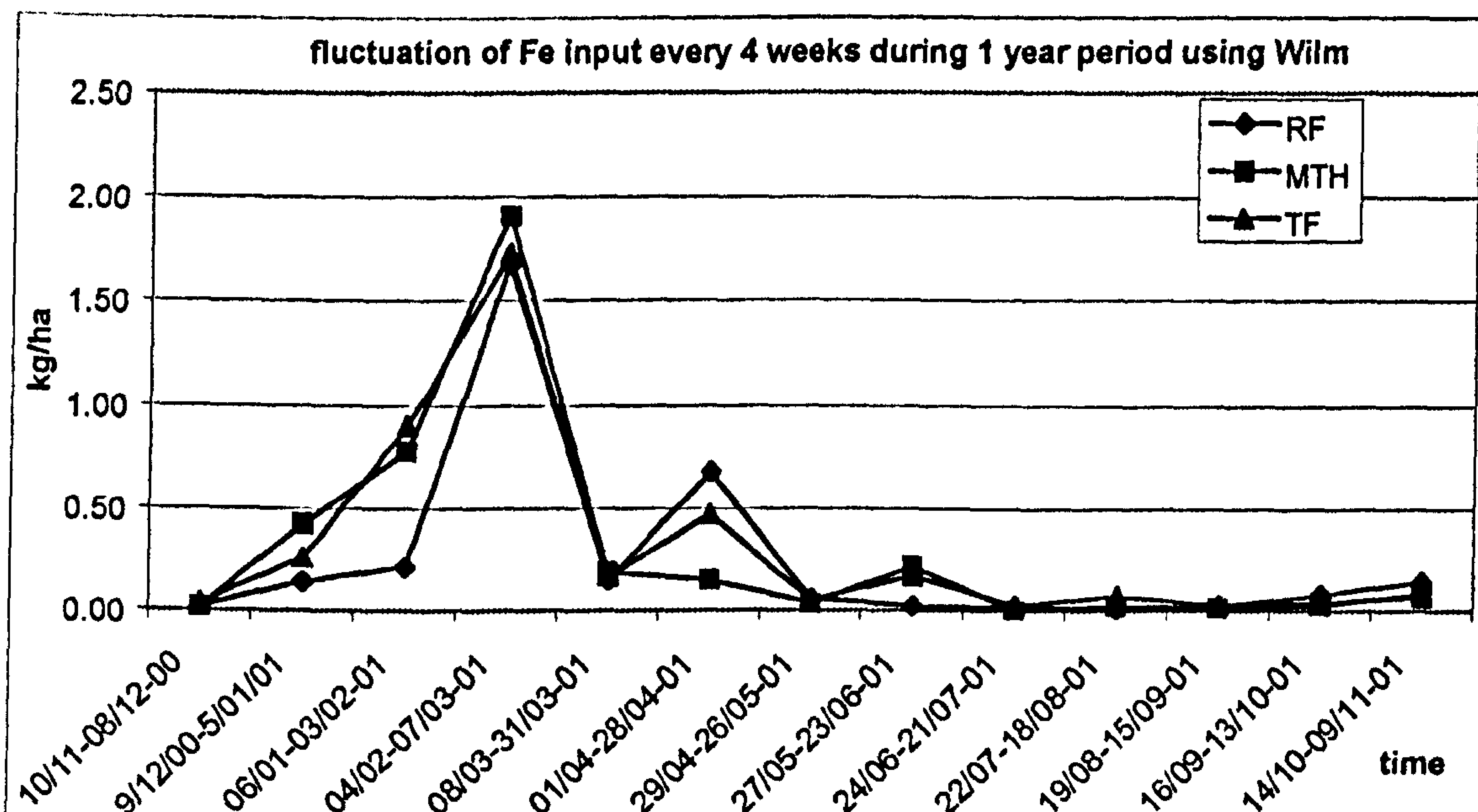


Figure 3.2.16.b: Fluctuation of Fe input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

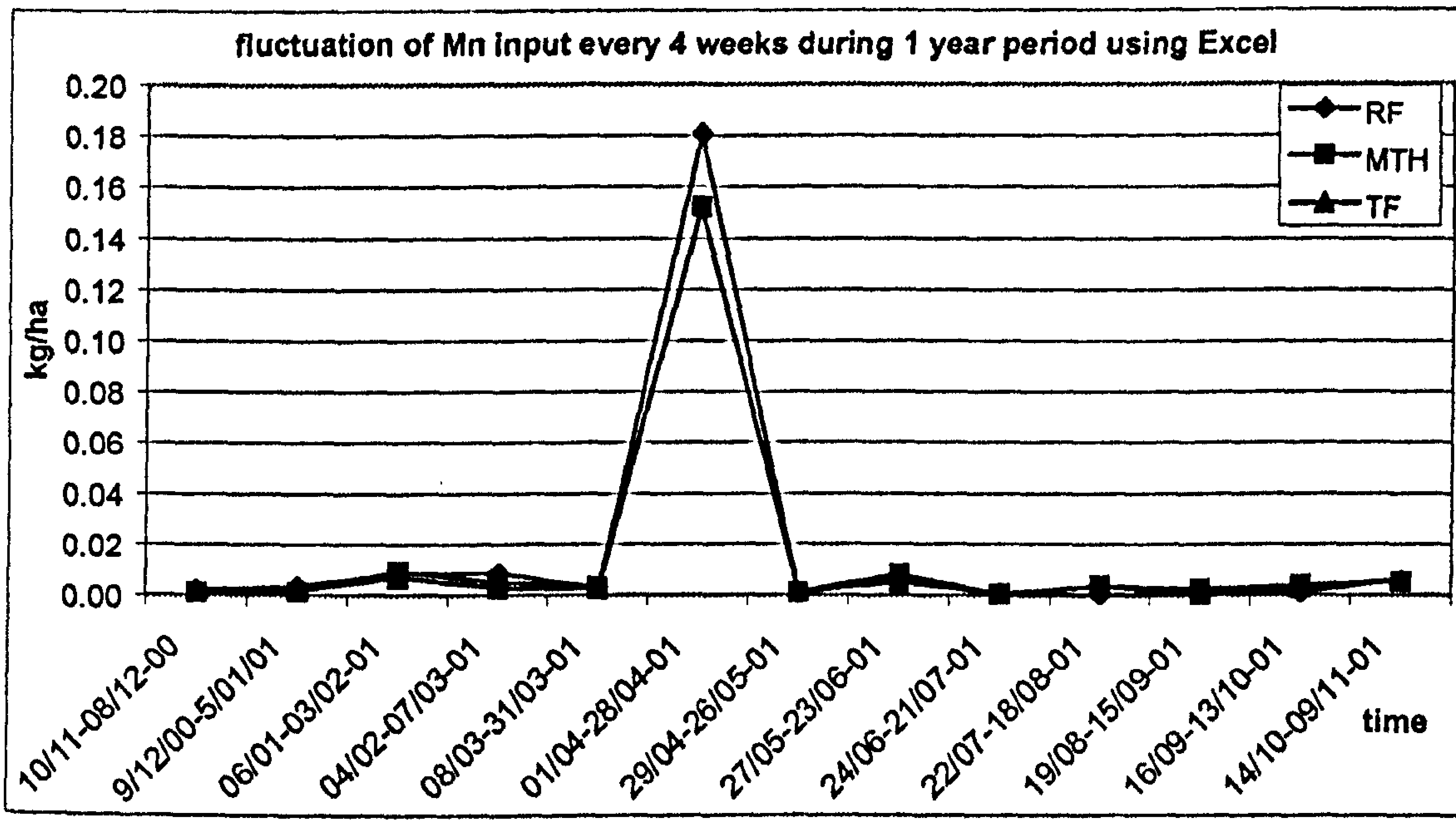


Figure 3.2.17.a: Fluctuation of Mn input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

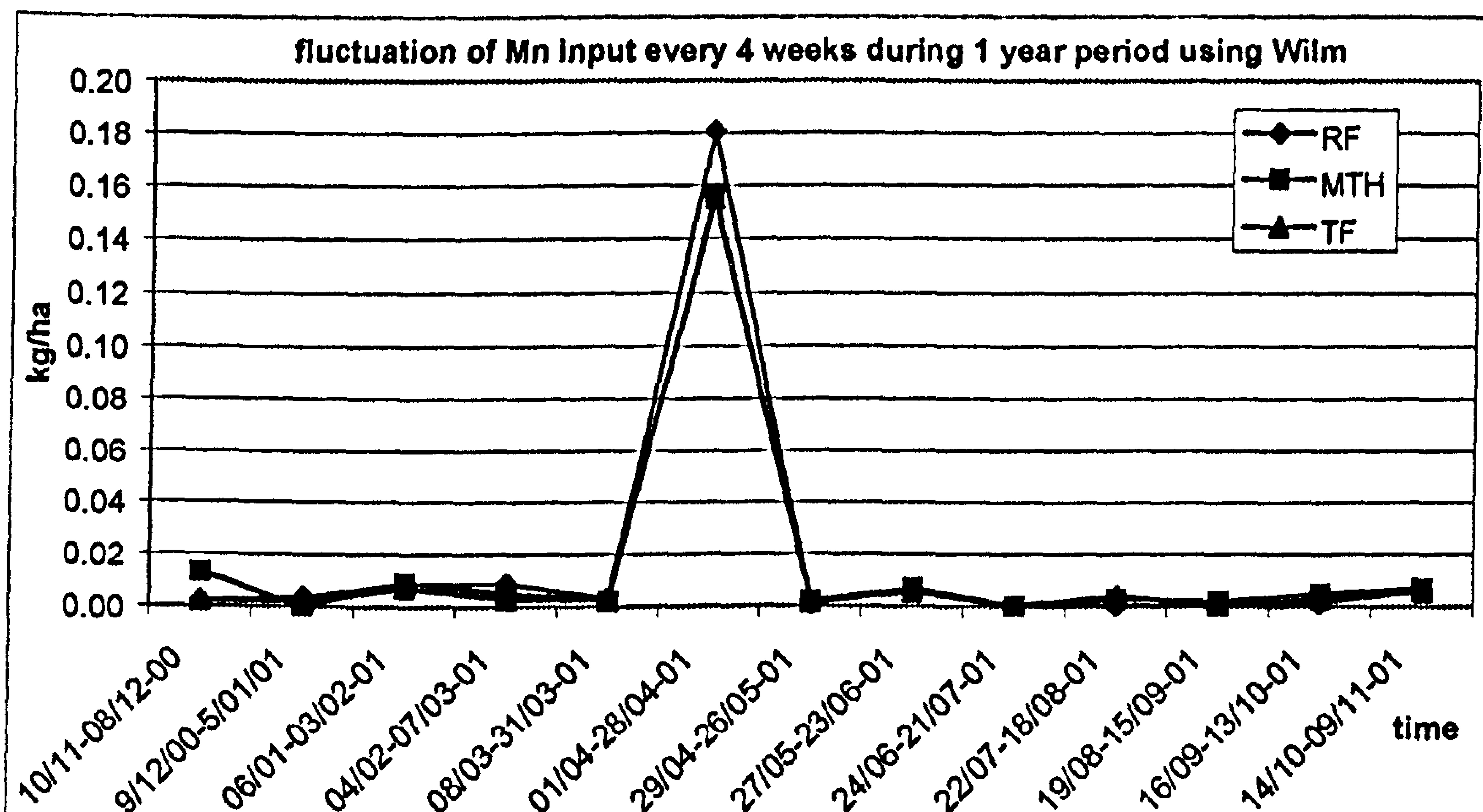


Figure 3.2.17.b: Fluctuation of Mn input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

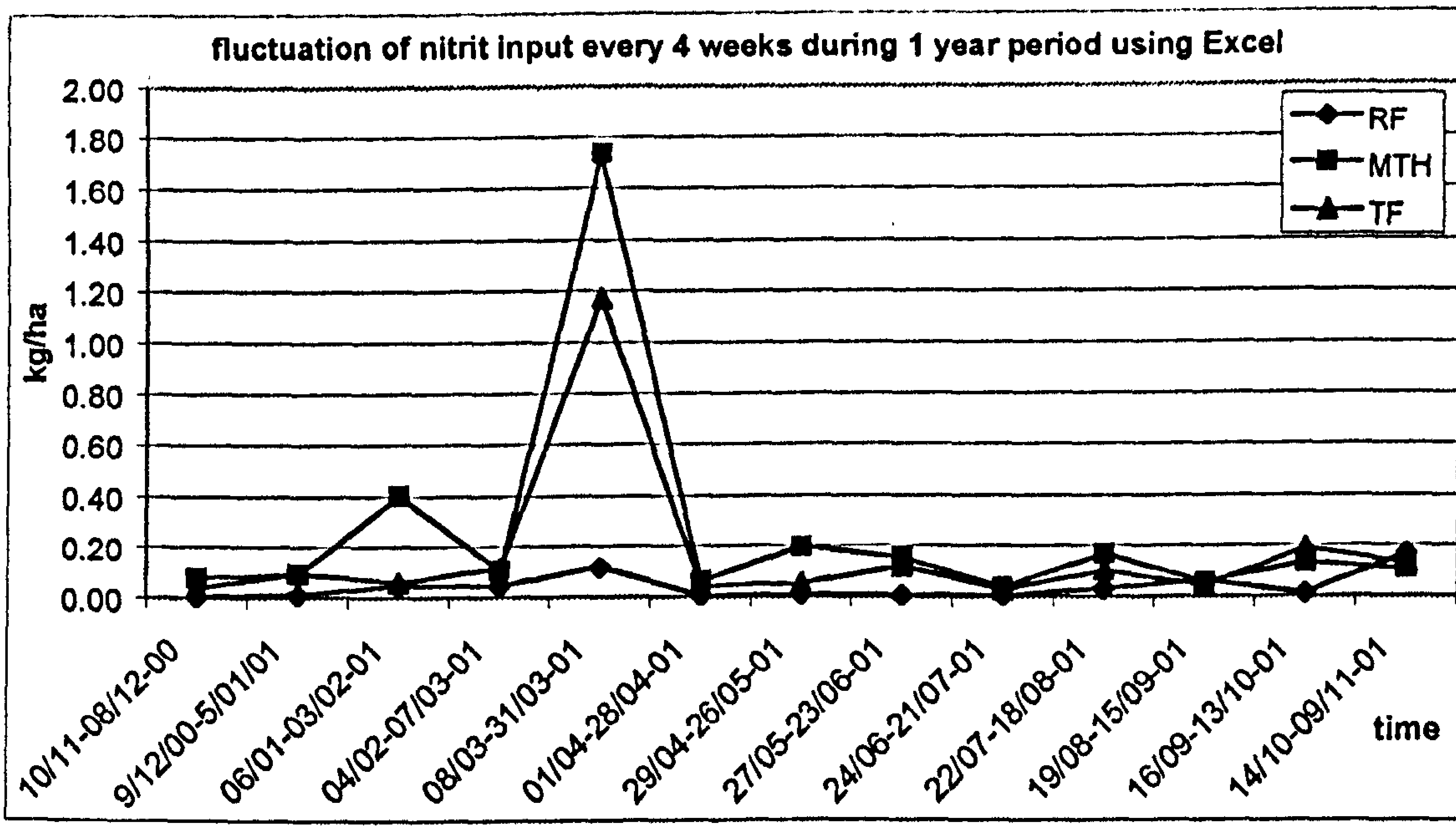


Figure 3.2.18.a: Fluctuation of nitrite input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

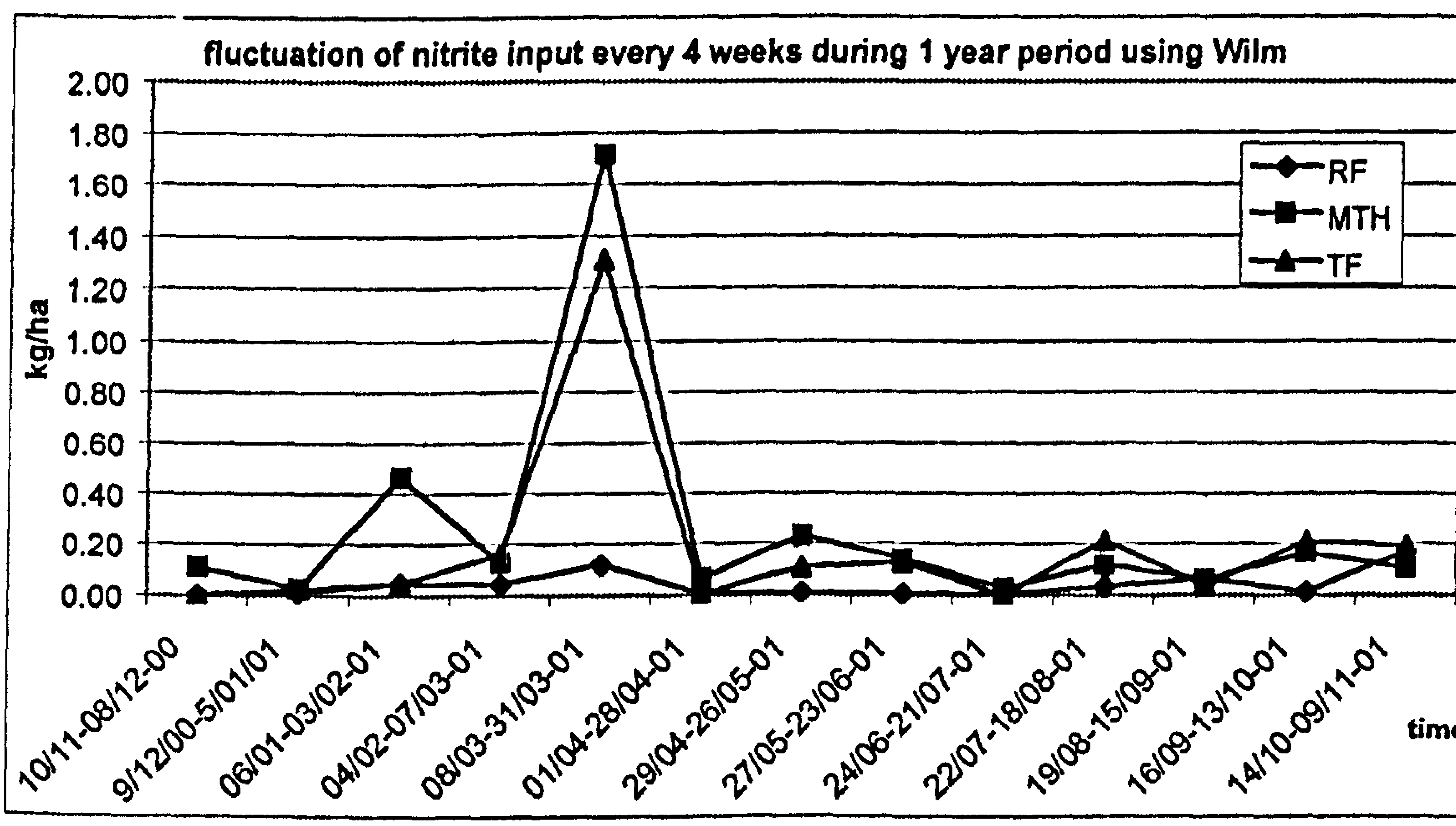


Figure 3.2.18.b: Fluctuation of nitrite input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

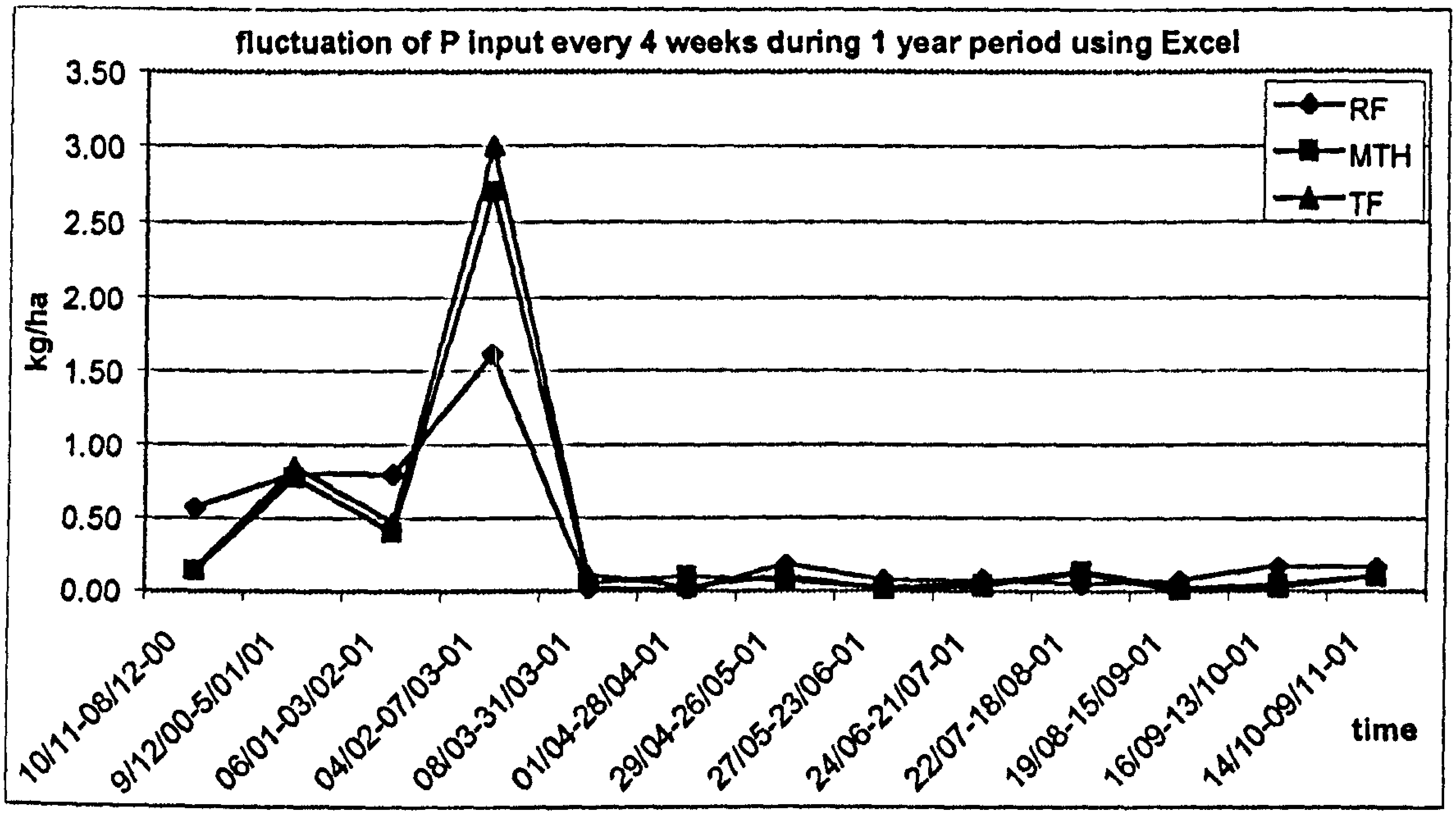


Figure 3.2.19.a: Fluctuation of phosphate input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

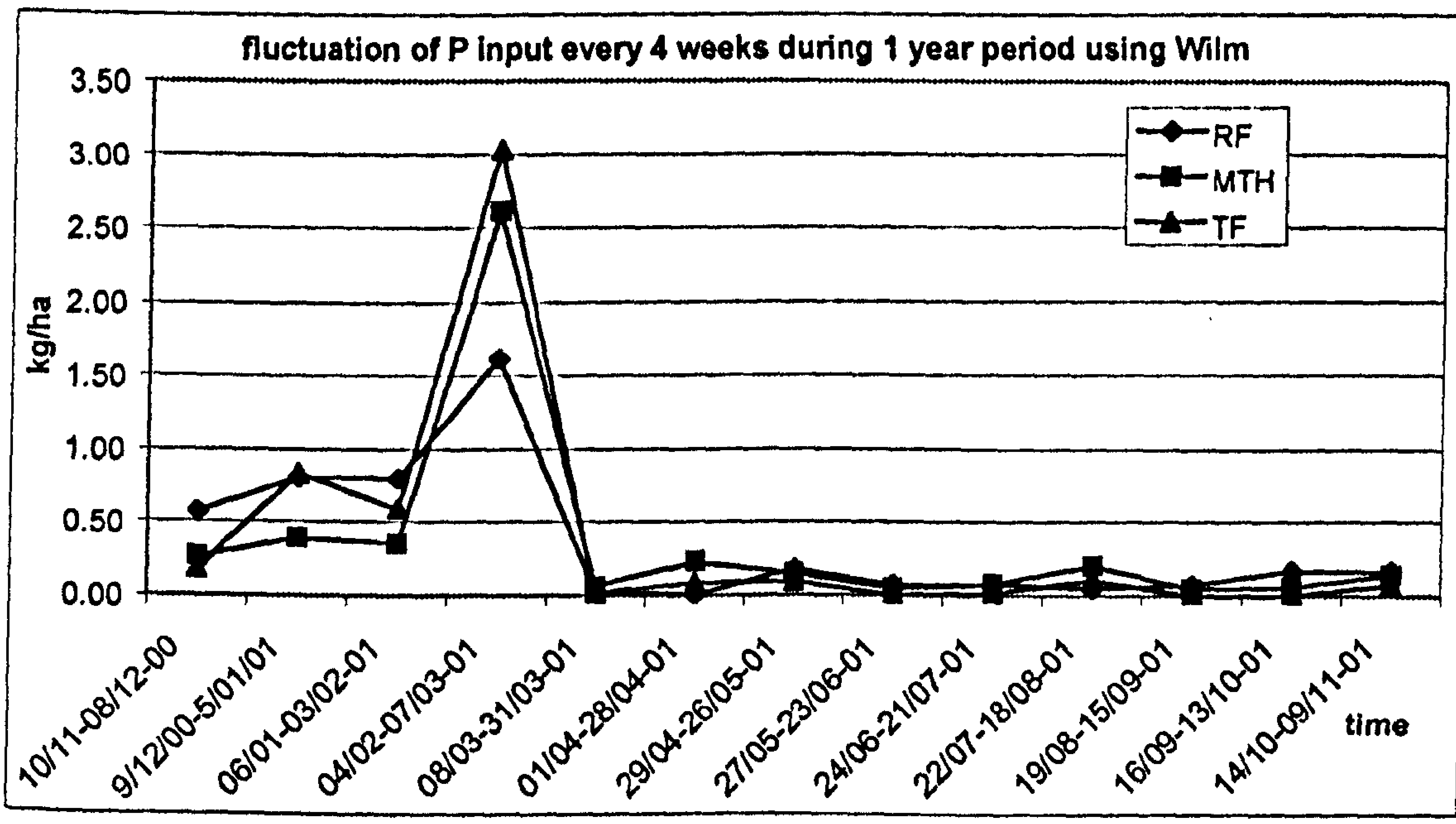


Figure 3.2.19.b: Fluctuation of phosphate input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

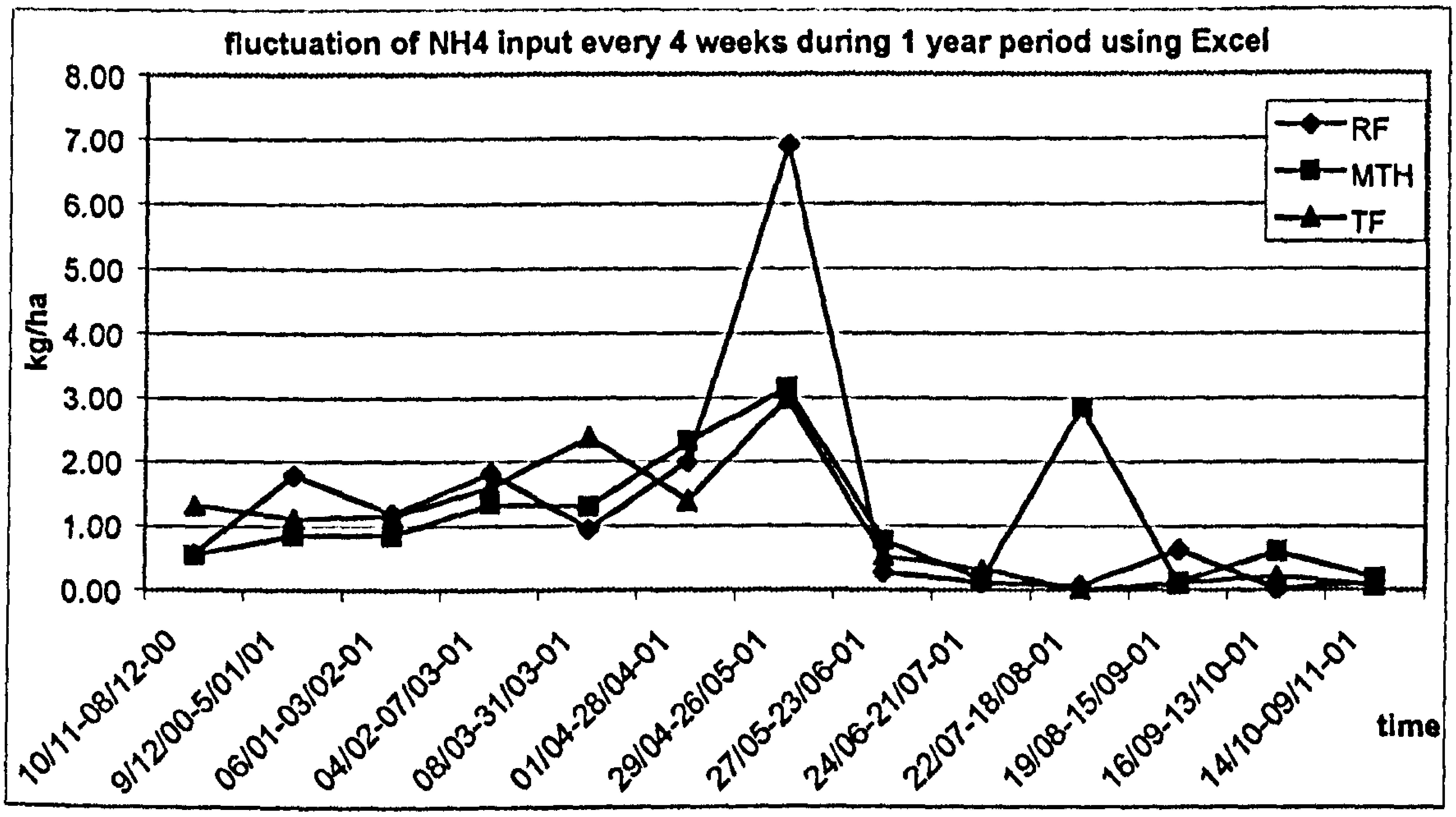


Figure 3.2.20.a: Fluctuation of ammonium input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Excel

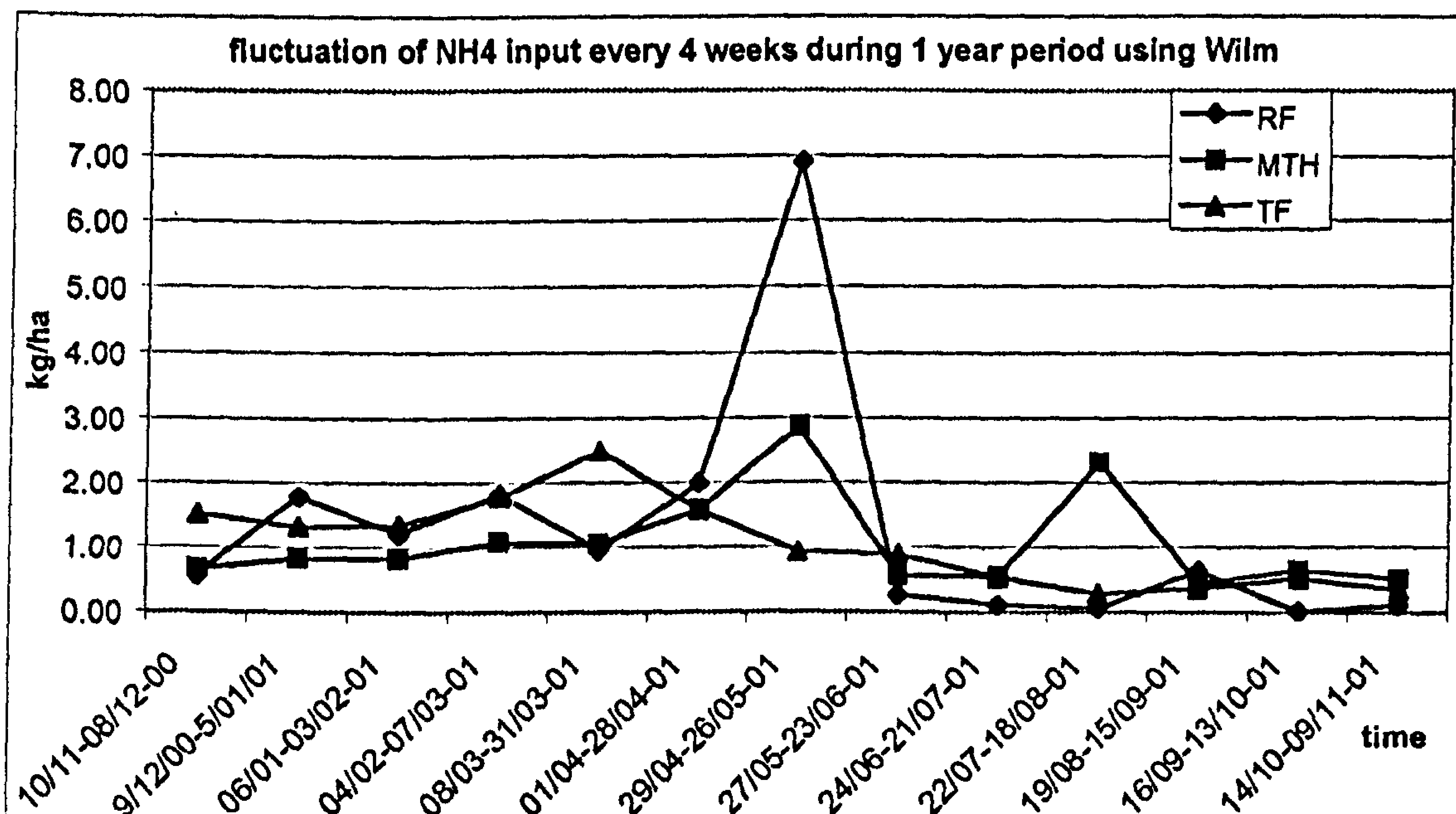


Figure 3.2.20.b: Fluctuation of ammonium input every 4 weeks in rainfall (RF), throughfall in MSF (MTH), and throughfall in LPF (TF) during the 1 year study period using Wilm

3.2.2.3.2. Annual total input of throughfall nutrients to the forest floor

The annual input of chemical ions in throughfall to the forest floor in Central Kalimantan using Excel and Wilm's method are shown in Table 3.2.1. Rainfall is presented as comparison.

Table 3.2.1: Mineral nutrient content of rainfall (RF) and throughfall in MSF (MTH) and LPF (TF) using excel, standard deviation and % standards deviation and using Wilm's method, standards error, and % standards error during the one year period from 10 November 2000 to 9 November 2001 (kg ha^{-1}).

Code	Ca Kg ha^{-1}	Mg kg ha^{-1}	K kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	NO_2-N kg ha^{-1}	PO4 kg ha^{-1}	NH_4-N kg ha^{-1}
Rainfall (RF)	15.72	5.79	9.61	5.52	3.25	0.22	0.54	4.62	16.51
SD rainfall	10.62	3.22	9.54	2.78	0.96	0.06	0.42	4.30	1.93
% SD rainfall	67.54	55.56	99.24	50.31	29.45	26.91	77.67	93.10	11.67
USING EXCEL									
MSF throughfall (MTH)	19.18	9.54	24.13	5.66	3.95	0.20	3.35	4.64	15.12
SD MSF througfall	7.01	1.7	10.48	1.19	0.90	0.02	1.41	1.47	7.40
% SD MSF throughfall	36.56	17.86	43.43	20.95	22.69	11.19	42.14	31.61	48.96
LPF throughfall (TF)	22.34	11.61	21.33	7.75	4.31	0.19	2.20	5.04	13.24
SD LPF througfall	5.97	4.56	10.14	1.85	0.92	0.03	0.73	2.10	2.86
% SD LPF throughfall	26.72	39.30	47.52	23.81	21.23	17.33	33.33	41.78	21.59
USING WILM									
MSF throughfall (MTH)	17.17	9.09	23.05	5.93	3.89	0.21	3.36	4.65	13.97
SE MSF througfall	3.32	1.28	4.10	0.71	0.47	0.01	0.28	0.79	1.74
% SE MSF throughfall	19.34	14.09	17.80	11.98	12.09	3.70	8.41	17.09	12.49
LPF throughfall (TF)	23.90	11.48	19.91	7.39	4.04	0.19	2.44	5.06	13.91
SE LPF througfall	4.79	3.09	2.96	1.02	0.31	0.01	0.32	0.39	4.0
% SE LPF throughfall	20.03	26.92	14.87	13.86	7.62	3.68	13.05	7.66	28.74

Ammonium-N is the predominant cation in rainfall, followed by calcium, potassium, magnesium, sodium, iron, and manganese, the last is present in lowest amount. Of the anions, phosphate is highest (4.62 ± 4.30 kg $ha^{-1}yr^{-1}$) followed by nitrite (0.54 ± 0.42 kg $ha^{-1}yr^{-1}$).

In mixed swamp forest throughfall, potassium is the major cation (24.13 ± 10.48 kg $ha^{-1}yr^{-1}$), followed by calcium, ammonium, magnesium, sodium, iron and manganese; anions follow the same pattern as in rainfall using Excel. Similarly to Excel, using Wilm potassium is the major cation (23.05±4.10 kg $ha^{-1}yr^{-1}$), followed by calcium, ammonium, magnesium, sodium, iron, and manganese; anions phosphate followed by nitrite.

In low pole forest throughfall, using Excel, calcium is the cation present in greatest quantity (22.34±5.97 kg $ha^{-1}yr^{-1}$), followed by potassium, ammonium, magnesium, sodium, iron, and manganese; anions follow the same pattern as in rainfall and mixed swamp forest. Using Wilm, calcium is also the major cation (23.90±4.79 kg $ha^{-1}yr^{-1}$), followed by potassium, ammonium, magnesium, sodium, iron, and manganese; anions follow the same pattern as Excel.

3.2.2.3.3. Correlation between volume, pH and nutrients of throughfall

Correlation of amount of water (mm) between rainfall and throughfall in MSF; rainfall and throughfall in LPF, and throughfall in MSF and throughfall in LPF using excel and Wilm method are the same, that is 0.97, 0.95, and 0.91 respectively.

Correlation coefficients (r) between volumes of rainfall or throughfall (mm), pH and 4 weekly input of cation and anion (kg ha^{-1}) were calculated in order to examine their possible relationships. These values for the throughfall in MSF and LPF are given in Tables 3.2.2. to 3.2.3.

The pH does not show significant correlation with throughfall volume in MSF and LPF (table 3.2.2 to table 3.2.3). Similarly to throughfall volume, pH does not show significant correlation with all of the nutrients in throughfall in both types of forest (MSF and LPF).

There is high correlation between Ca and Mg; Ca and K; Fe and phosphate in both sub-type of forest (MSF and LPF). There is high correlation between amount of water and Fe in MSF and weak correlation in LPF. In contrast, there is weak correlation between Ca and Na in MSF and high correlation in LPF.

Weak correlation between Mg and amount of water was shown in MSF but no correlation in LPF. In contrast, there is high correlation between Mg and Mn in LPF but no correlation in MSF.

Table 3.2.2: Correlation coefficients (r) between quantity (mm), pH and ionic content (kg ha^{-1}) of throughfall in MSF (n = 9) (* p < 0.05; **, P< 0.01, N.S=Not Significant)

	Water	PH	Ca	Mg	K	Na	Fe	Mn	Nitrite	P Total
PH	0.356									
	N.S									
Ca	0.368	-0.076								
	N.S	N.S								
Mg	0.557	0.210	0.662							
	*	N.S	**							
K	0.363	-0.042	0.627	0.310						
	N.S	N.S	**	N.S						
Na	-0.094	-0.197	0.559	0.094	0.426					
	N.S	N.S	*	N.S	N.S					
Fe	0.647	0.373	0.228	0.336	0.220	0.089				
	**	N.S	N.S	N.S	N.S	N.S				
Mn	0.260	0.007	0.215	0.398	0.103	-0.243	-0.058			
	N.S	N.S	N.S	N.S	N.S	N.S	N.S			
Nitrite	0.255	0.188	0.036	0.448	-0.138	-0.012	-0.001	-0.123		
	N.S	N.S	N.S	*	N.S	N.S	N.S	N.S		
P total	0.541	0.271	0.210	0.313	0.117	-0.011	0.915	-0.097	-0.124	
	*	N.S	N.S	N.S	N.S	N.S	**	N.S	N.S	
NH4	0.085	-0.061	0.418	0.470	0.251	0.089	0.012	0.337	0.089	0.038
	N.S	N.S	N.S	*	N.S	N.S	N.S	N.S	N.S	N.S

Table 3.2.3: Correlation coefficients (r) between quantity (mm), pH and ionic content (kg ha $^{-1}$) of throughfall in LPF (* $p < 0.05$; **, $P < 0.01$, N.S = not significant)

	Water	pH	Ca	Mg	K	Na	Fe	Mn	Nitrite	P Total
PH	0.263									
	N.S									
Ca	0.283	-0.257								
	N.S	N.S								
Mg	0.326	-0.124	0.671							
	N.S	N.S	**							
K	0.183	-0.320	0.710	0.130						
	N.S	N.S	**	N.S						
Na	-0.001	-0.362	0.651	0.235	0.888					
	N.S	N.S	**	N.S	**					
Fe	0.563	0.263	0.517	0.348	0.255	0.012				
	*	N.S	*	N.S	N.S	N.S				
Mn	0.196	-0.093	0.323	0.753	-0.182	-0.131	0.170			
	N.S	N.S	N.S	**	N.S	N.S	N.S			
Nitrite	0.343	0.335	-0.126	0.164	-0.266	-0.159	-0.077	-0.124		
	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S		
P total	0.486	0.277	0.268	0.118	0.236	0.049	0.895	-0.129	-0.071	
	*	N.S	N.S	N.S	N.S	N.S	**	N.S	N.S	
NH4	0.341	0.292	-0.049	0.132	0.010	-0.199	0.255	0.113	0.384	0.223
	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

3.3. STEMFLOW

3.3.1. The Quantity of stemflow

During the year 10 November 2000 – 9 November 2001 the total amounts of stemflow were 81.93±4.10 mm in mixed swamp forest (MSF) and 136.02±24.74 mm in low pole forest (LPF). The seasonal pattern of the amounts of stemflow in 4-weekly periods throughout the study period are shown in Figure 3.3.1.

Figure 3.3.1. shows that there is variation in the amount of stemflow falling on the peat swamp forest during the study period. In mixed swamp forest (MSF), the mean 4 weekly amounts of stemflow ranged from 0.04±0.01 mm to 12.06±0.52 mm and the mean over the 1-year period was 6.30±0.32 mm with the highest value obtained between 4 February and 7 March 2001) (12.06±0.52 mm), followed by 13 October to 9 November 2001 (10.92±0.99 mm). In contrast, the lowest amount of stemflow water was collected between 24 June and 21 July 2001 (0.04±0.01 mm).

The highest stemflow volume in low pole forest (LPF) occurred during 8–31 March 2001 (18.78±2.26 mm) while the lowest was in 19 August-15 September 2001 (0.18±0.14 mm). The mean 4 weekly stemflow in LPF over the 1-year period was 10.46±1.90 mm. In general, stemflow as a proportion of rainfall is higher in Low Pole Forest (4.93%) than in Mixed Swamp Forest (2.97%). T-test between stemflow water in MSF and LPF showed them to be significantly different.

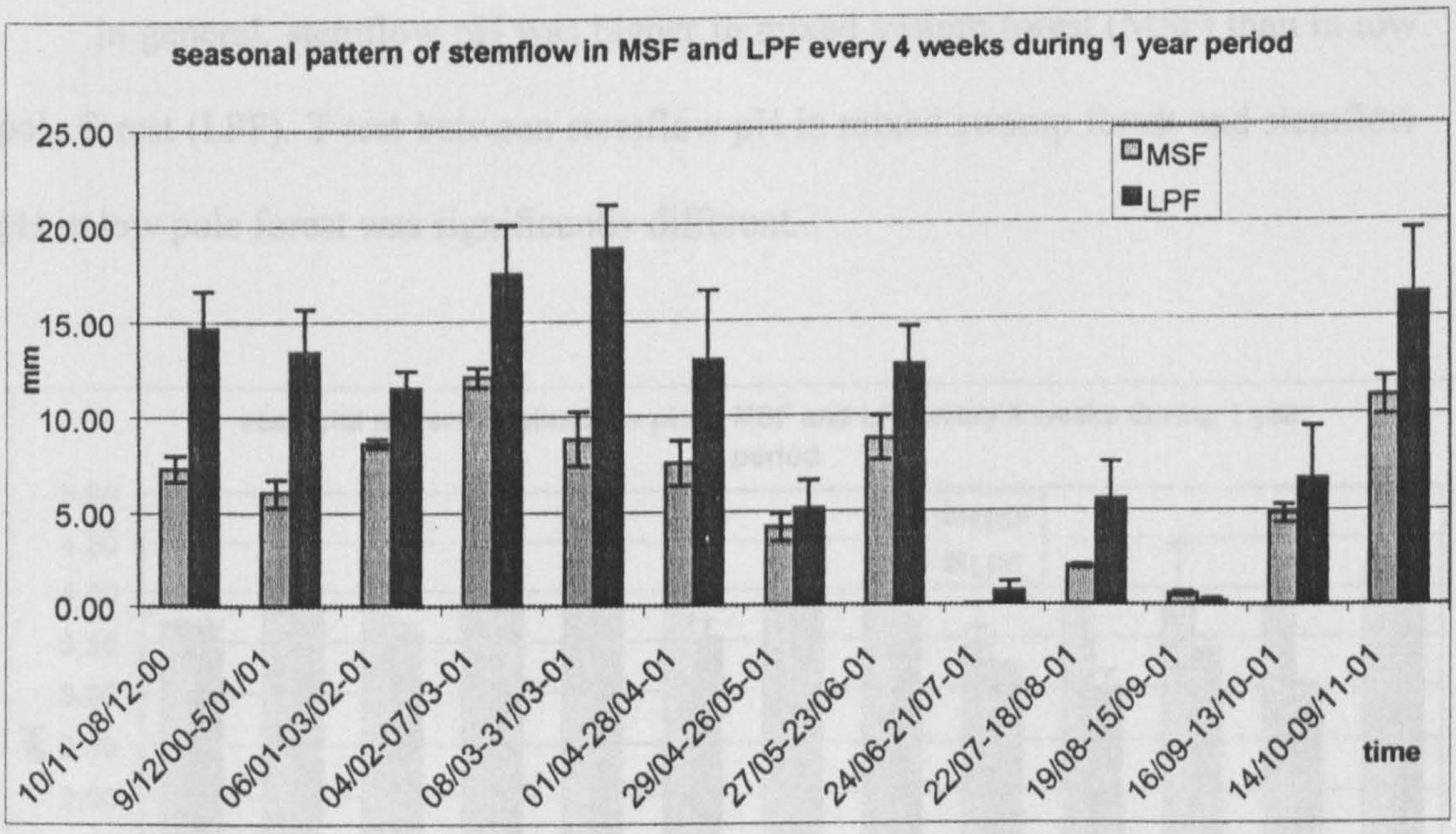


Figure 3.3.1: Seasonal pattern of stemflow in MSF and stemflow in LPF every 4 weeks during 1 year period.

3.3.2. Stemflow chemistry

3.3.2.1. Stemflow pH

The pH of stemflow in MSF and LPF varied throughout the study period (Figure 3.3.2.). In mixed swamp forest, the mean 4 weekly pH – stemflow pH ranged from 3.42±0.19 to 4.43±0.12 and the mean over the 1-year period was 4.03±0.19 with the highest value obtained between 4 February and 7 March 2001 (4.43±0.12). In contrast, the lowest pH of stemflow was obtained between 24 June-21 July 2001 (3.42±0.19).

Similarly to mixed swamp forest, in low pole forest, the highest stemflow pH was during 4 February-7 March 2001 (4.01±0.06) while the lowest was from 16 September–13 October 2001 (2.88±0.16). The mean 4 weekly pH over the 1-year period was 3.57±0.11.

In general, stemflow pH was higher in mixed swamp forest (MSF) than in low pole forest (LPF). T-test between stemflow pH in mixed swamp forest and stemflow pH in low pole forest was significantly different.

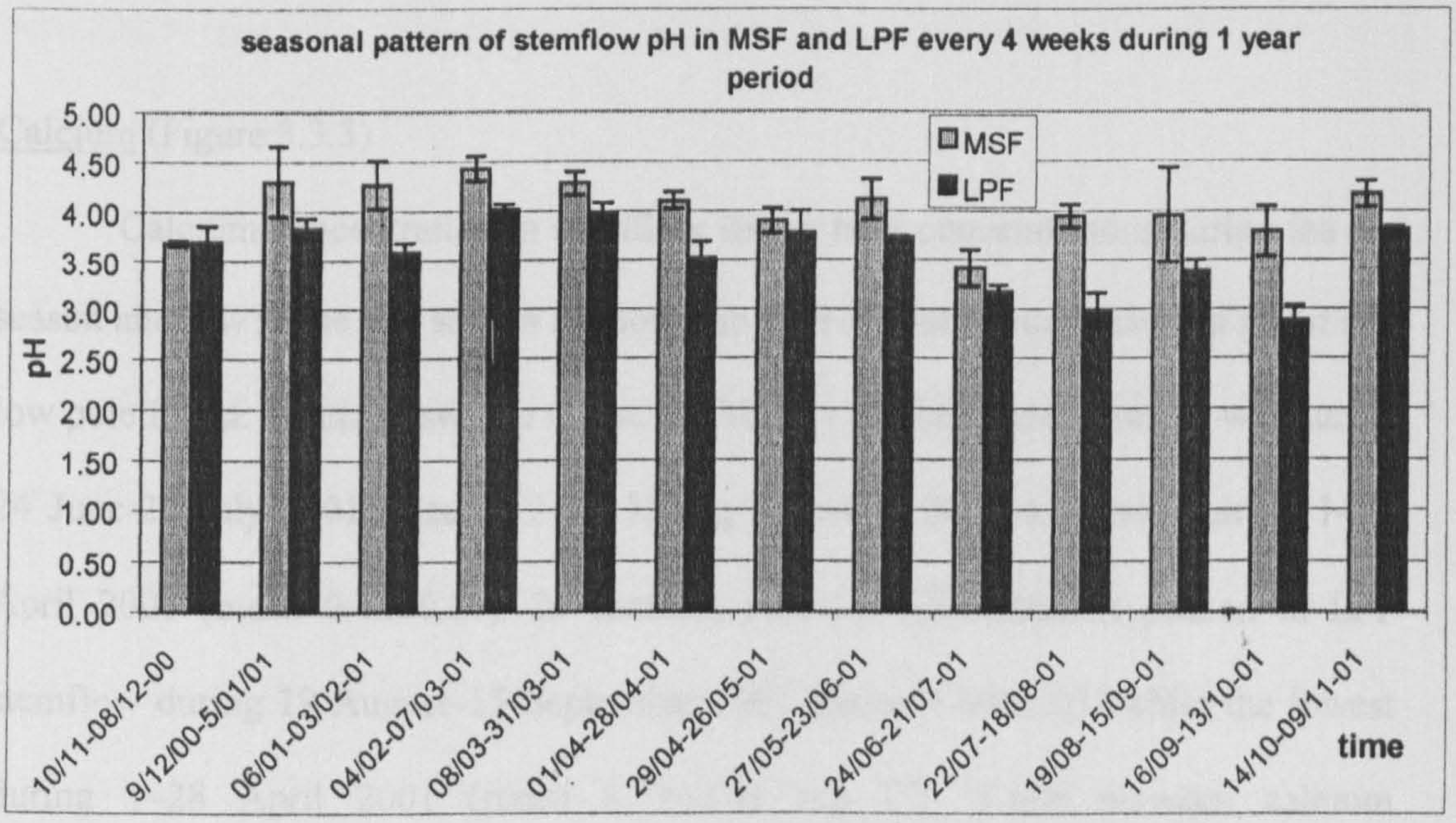


Figure 3.3.2: Seasonal pattern of stemflow pH in MSF and stemflow pH in LPF every 4 weeks during 1 year period.

3.3.2.2. Concentration of chemical elements in stemflow

The 4 weekly concentrations of nutrients (Ca, Mg, K, Na, Fe, Mn, NO_2, P, and NH_4) in stemflow in MSF and LPF during the one-year study period are presented in Figures 3.3.3 to 3.3.11.

Calcium (Figure 3.3.3)

Calcium concentration in stemflow shows high concentrations during the dry season and low in the wet season for both sub-type of forest, mixed swamp forest and low pole forest. In mixed swamp forest, the highest calcium concentration was during 24 June-21 July 2001 (mean 5.16±1.35 mg l^{-1}) while the lowest was during 1–28 April 2001 (mean 0.42±0.26). In contrast, calcium concentration peaked in LPF stemflow during 19 August–15 September 2001 (mean 4.49±1.03) while the lowest during 1–28 April 2001 (mean 0.71±0.41 mg l^{-1}). T-test between calcium concentration in MSF stemflow and LPF stemflow was not significant.

Magnesium (Figures 3.3.4)

Magnesium concentration in stemflow shows a similar pattern to calcium with higher values recorded during the dry than the wet season. In mixed swamp forest, the highest value occurred during 24 June-21 July 2001(mean 01.48 ± 0.36 mg l^{-1}) and the lowest in 4 February–7 March 2001 (mean 0.42± 0.26 mg l^{-1}). The average of magnesium concentration in MSF stemflow during study period was 0.58±0.12 mg l^{-1}.

Magnesium concentration peaked in LPF stemflow during 19 August-15 September 2001 (mean 1.99±0.59 mg l^{-1}) while the lowest was during 10 November-8 December 2000 with a mean of 0.64±0.20. The average of magnesium concentration in LPF stemflow during the study period was 1.21±0.37 mg l^{-1}. T-test between magnesium concentration in MSF stemflow and LPF stemflow was significant.

Potassium (Figures 3.3.5)

Similarly to magnesium, potassium concentration was higher in the dry season than in the wet season. In mixed swamp forest, the highest value of potassium concentration was during 19 August–15 September 2001 (mean 12.03±4.74 mg l^{-1}). The wet season minimum occurred during 1–28 April 2001 (mean 0.36±0.23 mg l^{-1}). The average potassium concentration in MSF stemflow during the 1-year study period was 4.31±2.00 mg l^{-1}.

Similarly to MSF stemflow, potassium concentration peaked in LPF stemflow during 19 August-15 September 2001 with a mean of 18.51±7.22 mg l^{-1}. In contrast, the lowest stemflow potassium concentration in LPF was during 6 January–3 February 2001 with a mean of 0.62±0.04 mg l^{-1}. Similarly to calcium concentration, comparison using T-test between potassium concentration in MSF stemflow and LPF stemflow was not significant.

Sodium (Figures 3.3.6)

Sodium concentration in MSF stemflow was high during 24 June–15 September 2001 and peaked during 19 August–15 September 2001 with a mean of 1.48±0.25 mg l^{-1}. It was lowest during the wet season with a mean of 0.03±0.01 mg l^{-1} during 4 February–7 March 2001. The average concentration of sodium in MSF throughfall during the study period was 0.50±0.08 mg l^{-1}.

Sodium concentration in LPF stemflow peaked in 19 August–15 September 2001 (mean 1.65±0.06 mg l^{-1}). In contrast, the lowest sodium concentration occurred in 1–28 April 2001 with mean of 0.08±0.05 mg l^{-1} . The average of sodium concentration in LPF stemflow duirng the study period was 0.45±0.05 mg l^{-1}. T-test between sodium concentration in MSF stemflow and LPF stemflow was not significant.

Iron (Figures 3.3.7)

Concentration of iron in stemflow for both sub-types of forest is low with the average during the study period of 0.18±0.05 mg l^{-1} (MSF) and 0.15±0.03 mg l^{-1} (LPF).

The highest iron concentration in MSF stemflow was during 1–28 April 2001 with mean of 0.60±0.09 mg l^{-1} while the lowest was during 14 October–9 November 2001 (0.04±0.005 mg l^{-1}). In contrast, the highest iron concentration in LPF stemflow was during 4 February–7 March 2001 (0.63±0.03 mg l^{-1}) while the lowest was during 14 October–9 November 2001 with mean of 0.05±0.007 mg l^{-1}. Comparison between iron concentration in MSF stemflow and LPF stemflow using t-test was not significant.

Manganese (Figures 3.3.8)

The lowest nutrient concentration was manganese. The highest manganese concentration in MSF stemflow was only 0.137±0.097 mg l^{-1} during 1 – 28 April 2001 while the lowest was during 10 November- 8 December 2000 with a mean of 0.00067±0.0011 mg l^{-1}. The average of manganese concentration during the study period was only 0.0129±0.0082 mg l^{-1}.

Similarly to MSF stemflow, the highest manganese concentration in LPF stemflow was during 1–28 April 2001 (mean 0.0761±0.0022 mg l^{-1}) and the lowest was 10 November– 8December 2000 with mean of 0.000± 0.000 mg l^{-1}. The average of manganese concentration in LPF stemflow was also low with 0.008±0.0006 mg l^{-1}. Similarly to iron concentration, comparison using t-test between manganese concentration in MSF stemflow and LPF stemflow was not significant.

Nitrite (Figures 3.3.9)

Similarly to iron, nitrite concentration in stemflow in both sub-types of forest is generally low. In mixed swamp forest, the peak concentration occurred during 22 July-18 August 2001 with a mean of 0.688±0.759 mg l^{-1} and the lowest in 1-28 April with mean of 0.011±0.003 mg l^{-1}. The average nitrite concentration in MSF stemflow during the study period was 0.199±0.160 mg l^{-1}.

Peak nitrite concentrations in LPF stemflow occurred in 19 August–15 September 2001 with means of 0.282±0.055 while the lowest in 10 November–8

December 2000 with mean of 0.009±0.002 mg l^{-1}. The average of nitrite concentration in LPF stemflow during study periods was 0.067±0.027 mg l^{-1}. T-test between nitrite concentration in MSF stemflow and LPF stemflow was significant.

Phosphate (Figures 3.3.10)

There were several peak concentrations of phosphate in MSF stemflow and LPF stemflow, for example in MSF stemflow, during 9 December 2000–5 January 2001 with a mean of 0.77±0.99 mg l^{-1} and 22 July–18 August 2001 with a mean of 0.38±0.10 mg l^{-1}, although there are no clear seasonal trends .

The mean phosphate concentrations in MSF and LPF stemflows during the study period were 0.21±0.13 mg l^{-1} and 0.18±0.07 mg l^{-1}, respectively. Similarly to manganese, there is no significant different between phosphate concentration in MSF stemflow and LPF stemflow.

Ammonium (Figures 3.3.11).

The average ammonium concentration in MSF stemflow and LPF stemflow during the study period was 1.29±0.54 mg l^{-1} and 1.32±0.47 mg l^{-1}, respectively. Ammonium concentration showed a similar seasonal pattern to calcium. The highest concentration in MSF stemflow was recorded during the dry season with a peak during 22 July–18 August 2001 (mean 6.82±1.70 mg l^{-1}) while the lowest during the wet season in 14 October–9 November 2001 with a mean of 0.012±0.010 mg l^{-1}.

Similarly to MSF stemflow, the ammonium concentration peak in LPF stemflow occurred during 22 July-18 August 2001 with mean of 7.11±3.51 mg l^{-1}

and the lowest during 14 October–9 November 2001 with a mean of 0.035±0.037 mg l^{-1}. Similarly to manganese and phosphate concentration, ammonium concentration are not significant different between MSF stemflow and LPF stemflow.

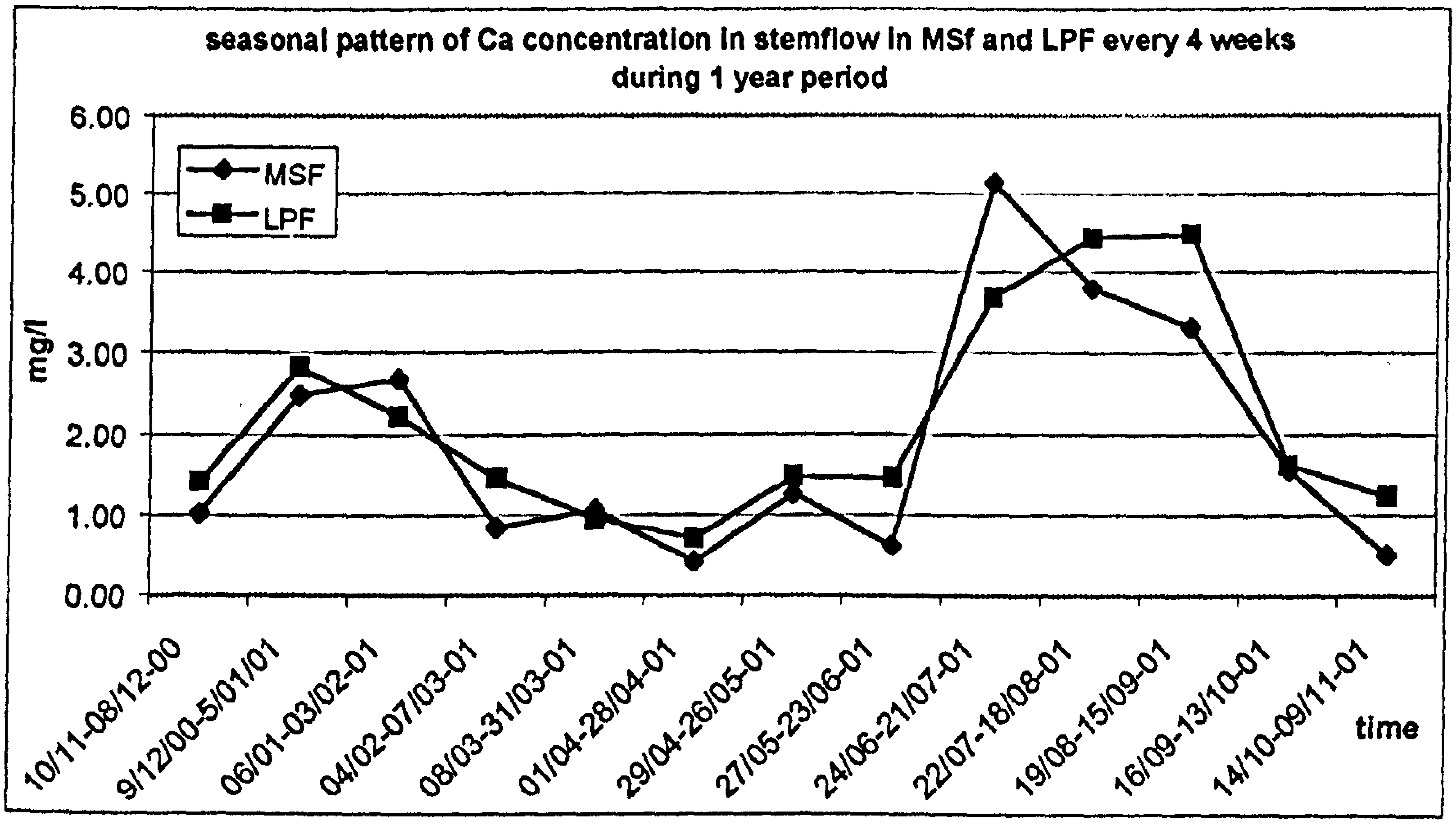


Figure 3.3.3: Seasonal pattern of Ca concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period

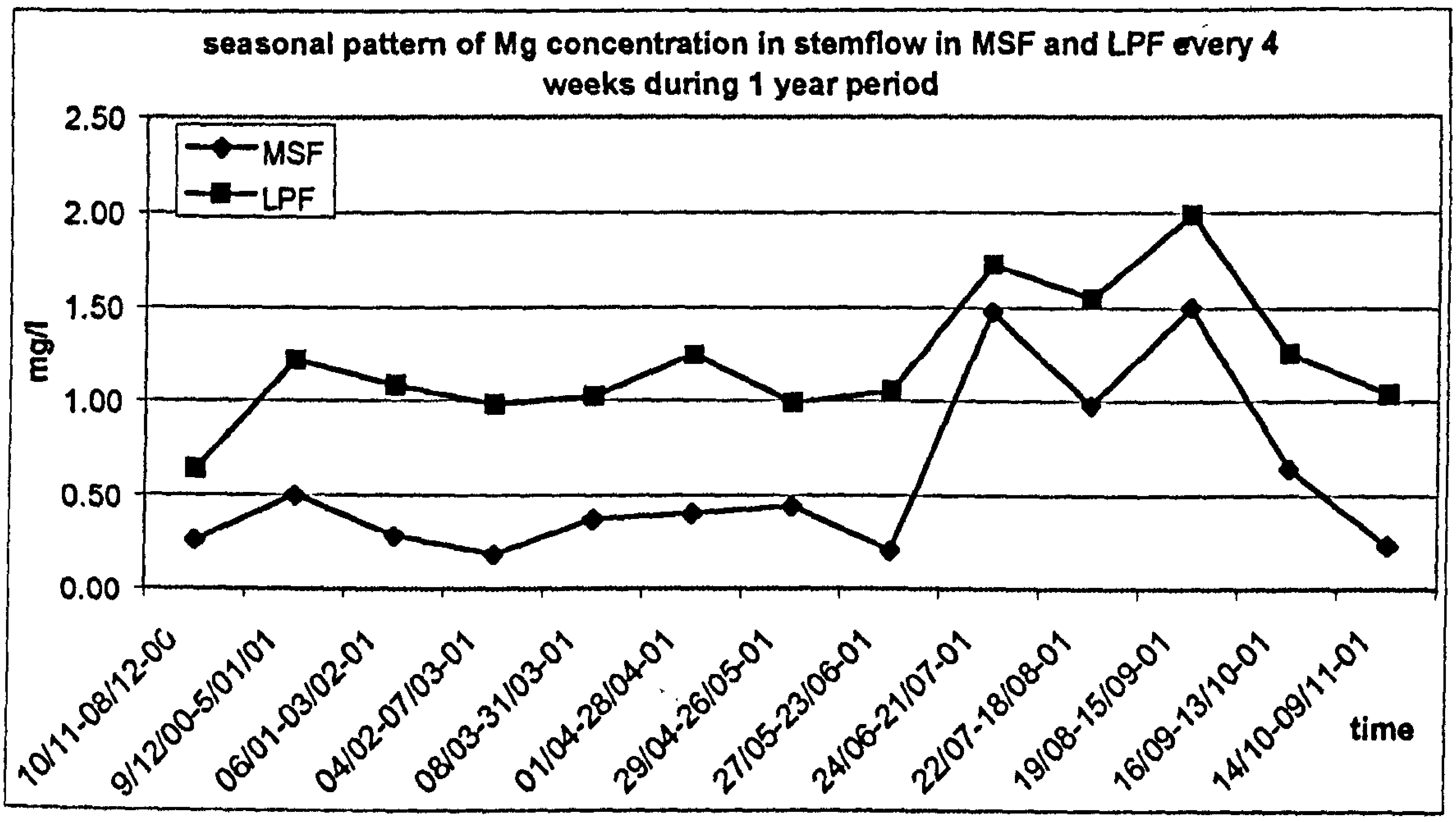


Figure 3.3.4: Seasonal pattern of Mg concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period

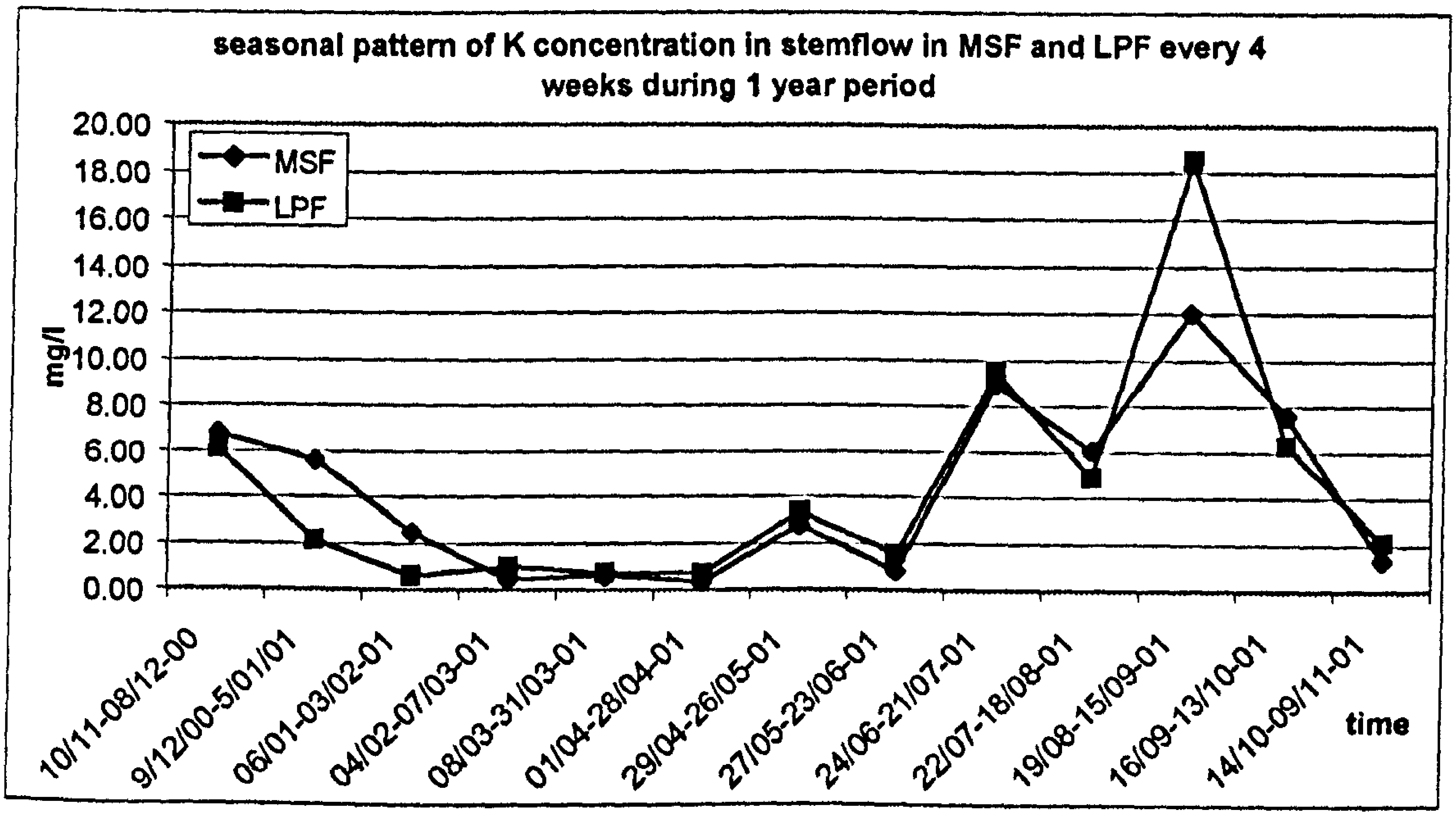


Figure 3.3.5: Seasonal pattern of K concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period

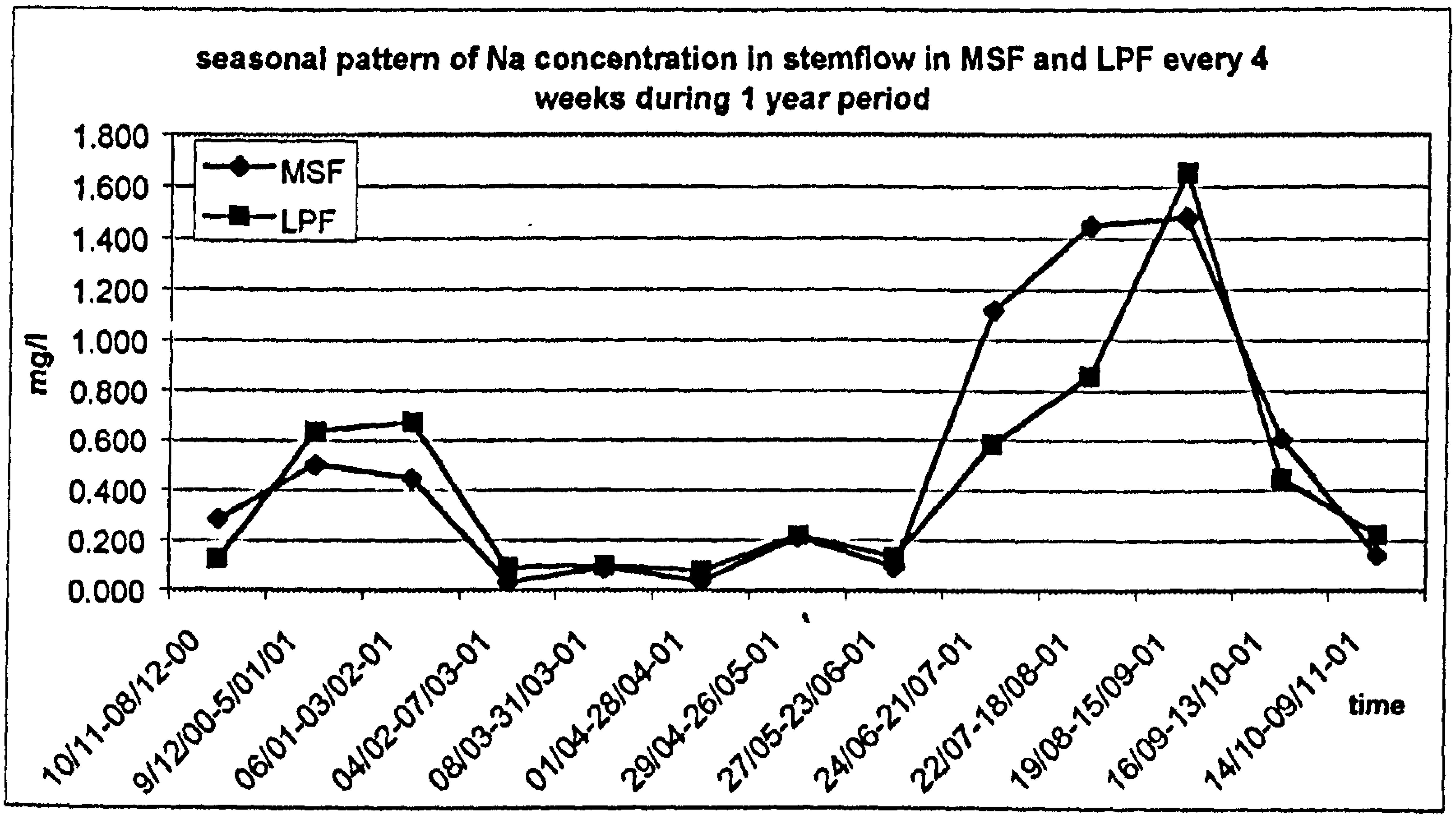


Figure 3.3.6: Seasonal pattern of Na concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period

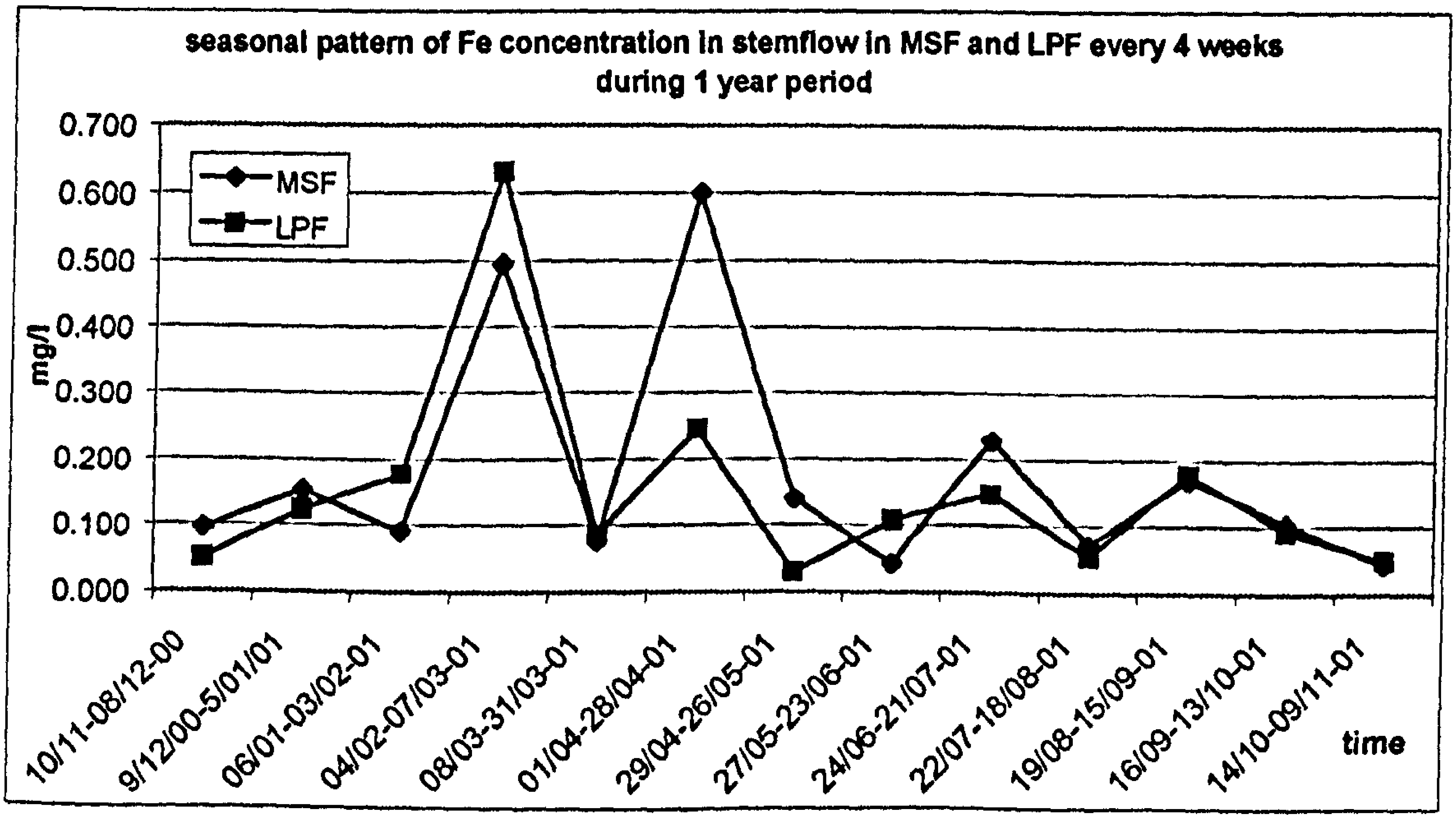


Figure 3.3.7: Seasonal pattern of Fe concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period

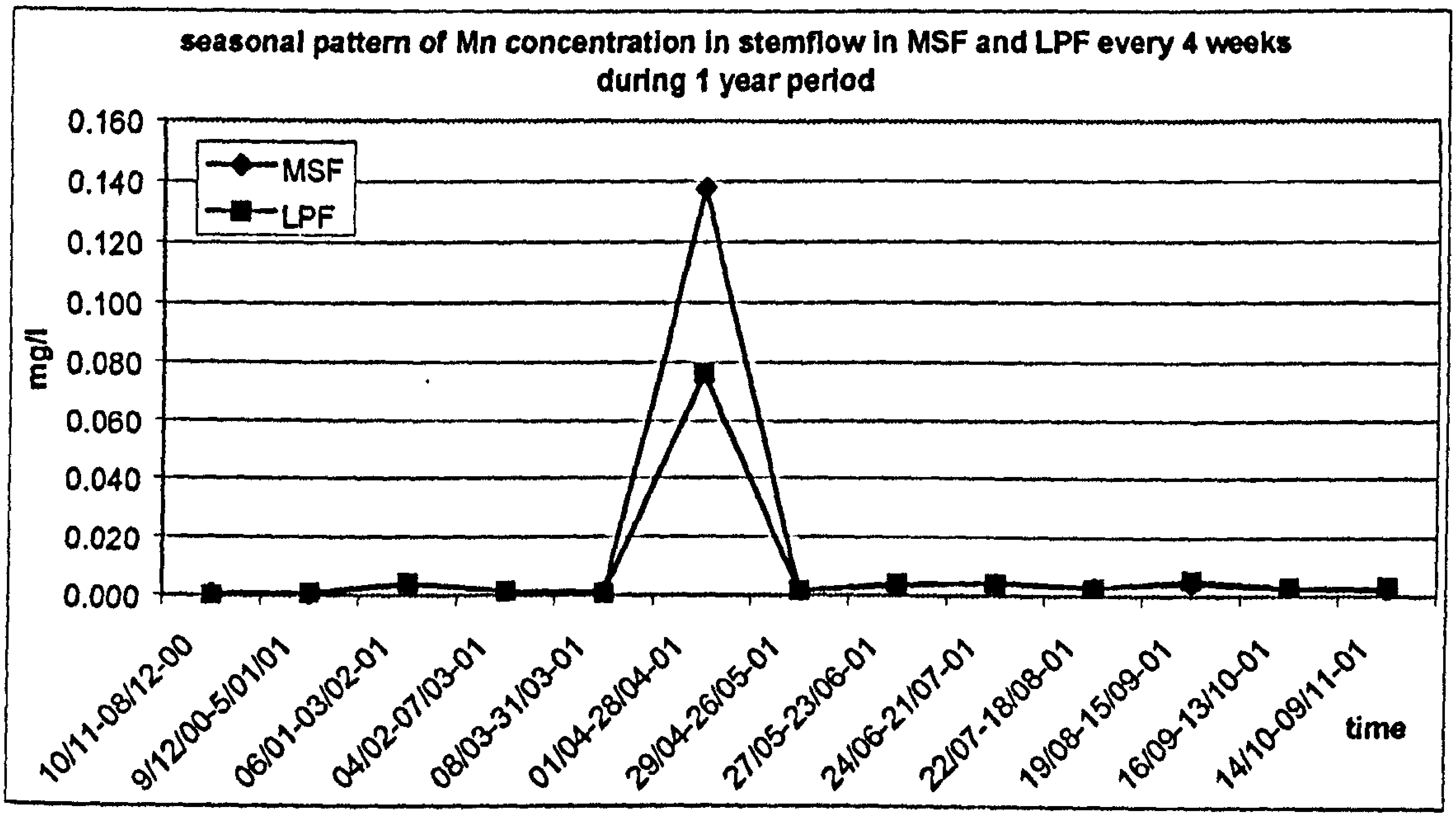


Figure 3.3.8: Seasonal pattern of Mn concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period.

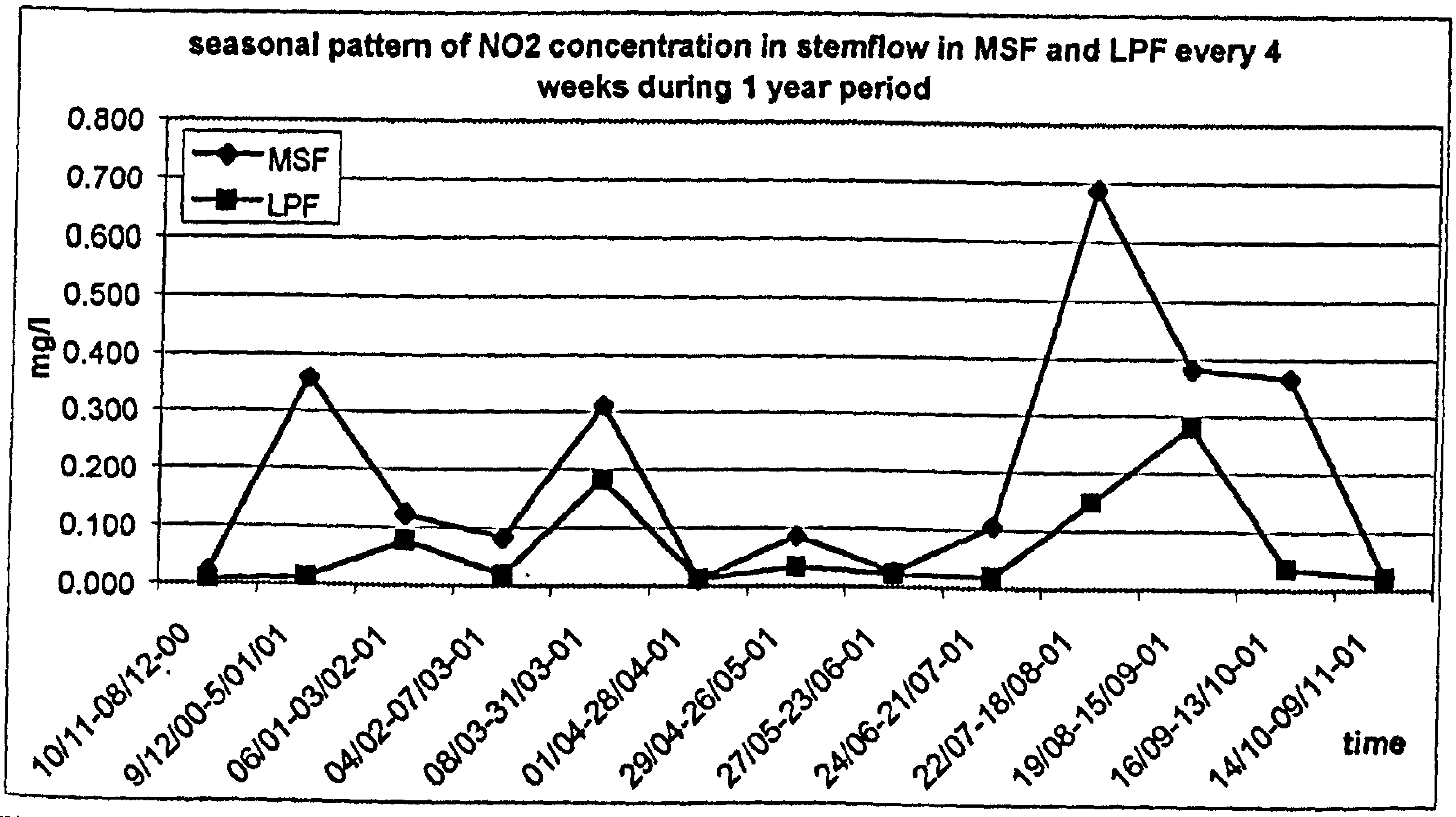


Figure 3.3.9: Seasonal pattern of nitrite concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period

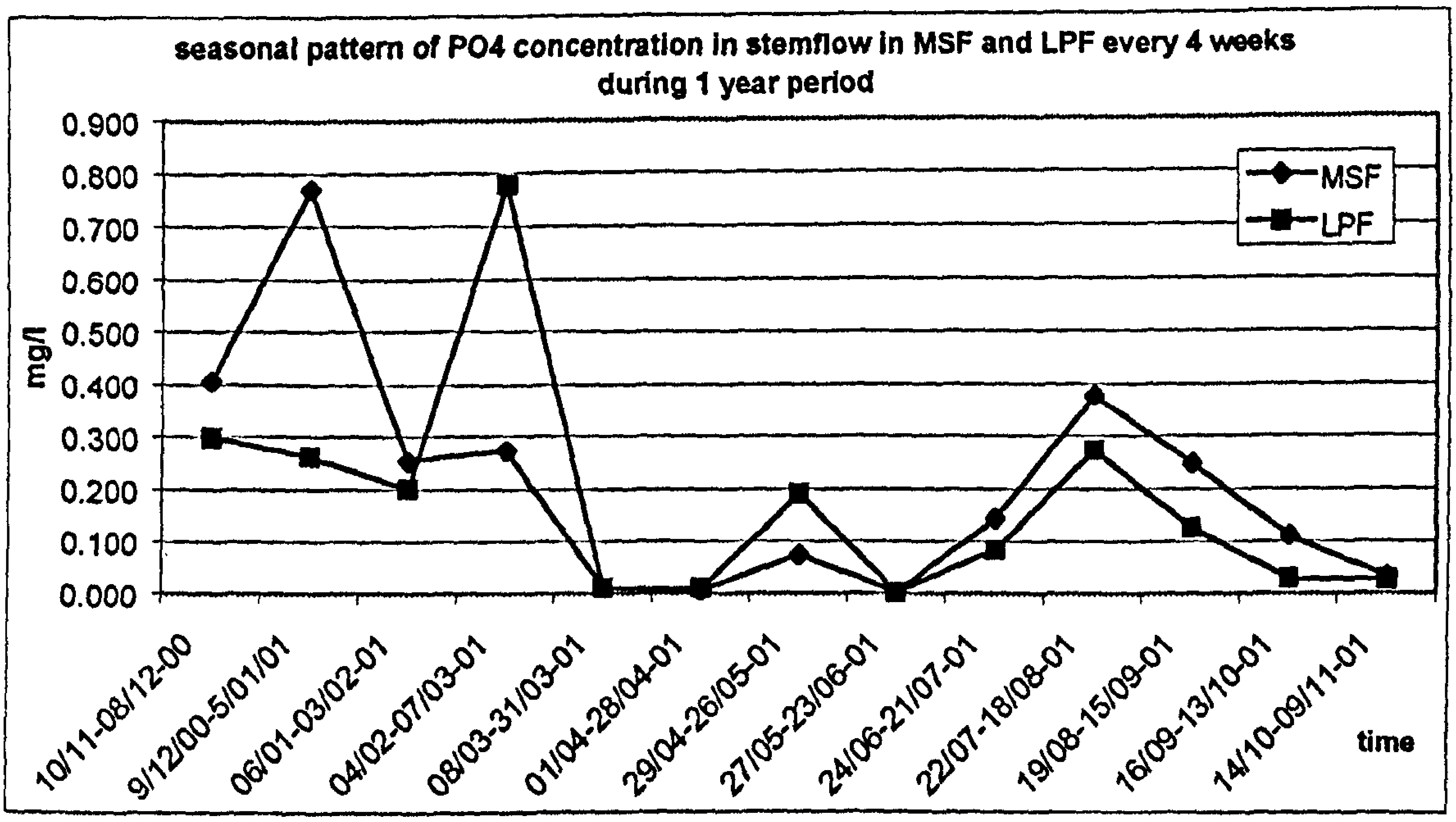


Figure 3.3.10: Seasonal pattern of phosphate concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period.

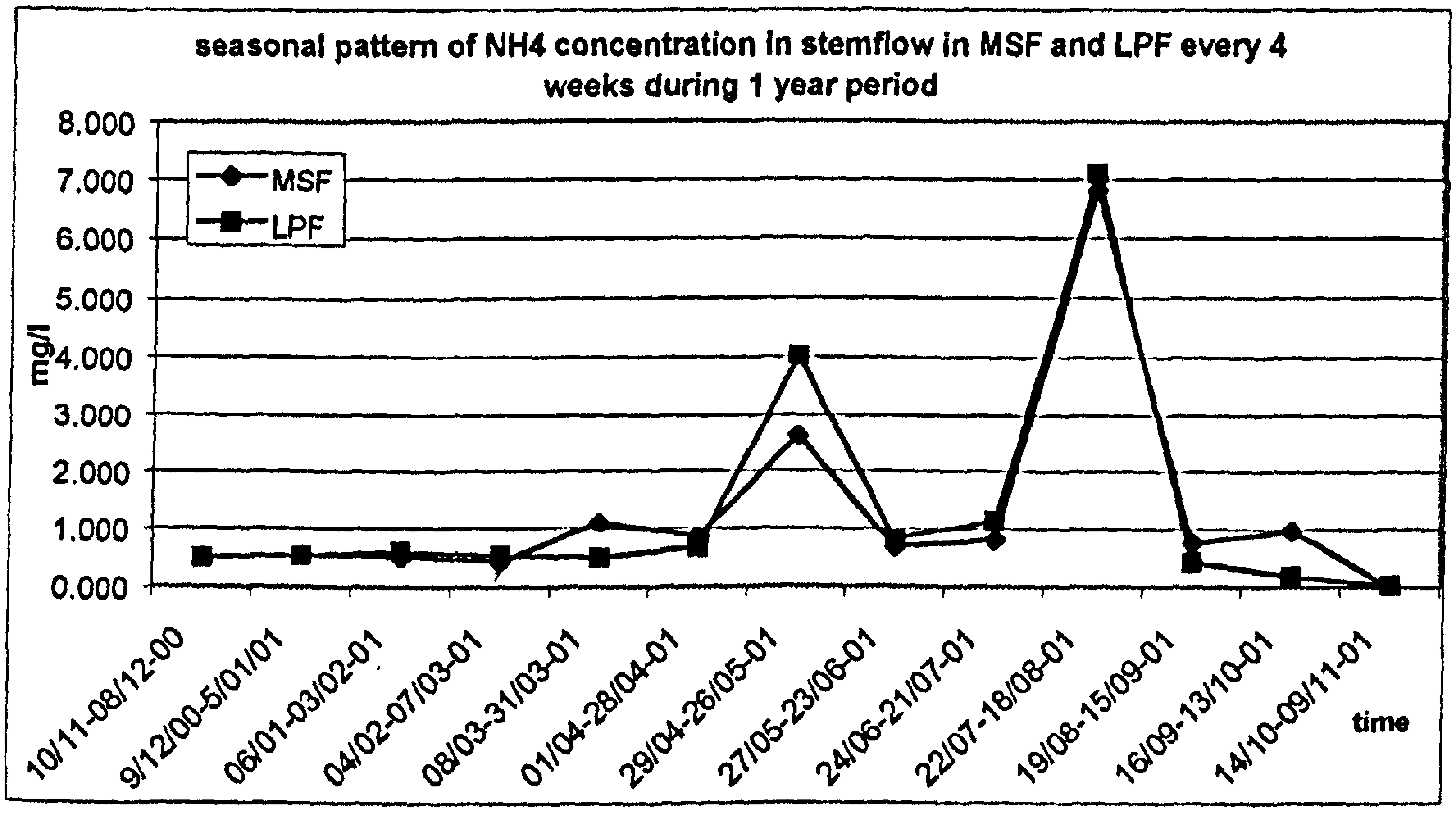


Figure 3.3.11: Seasonal pattern of ammonium concentration in stemflow in MSF and stemflow in LPF every 4 weeks during the 1 year study period

3.3.2.3. Nutrient inputs in stemflow

Similarly to rainfall and throughfall, stemflow nutrient inputs to the forest floor were obtained by multiplying the 4-weekly periodical totals of stemflow by the corresponding nutrient concentrations. These are expressed in kilogram per hectare (kg ha^{-1}). Four-weekly means of each element are presented in Figures 3.3.12. to 3.3.20 for the one year study period (13 mean values for every element).

Calcium (Figures 3.3.12)

In MSF stemflow, the highest calcium mean input was 0.23±0.17 kg ha^{-1} during 6 January–3 February 2001. The lowest mean of 0.002±0.0001 was obtained in 24 June-21 July 20001. The total input to forest floor through stemflow was 1.01±0.51 kg ha^{-1} yr^{-1}.

The highest stemflow input in LPF was 0.378±0.054 kg ha^{-1} during 9 December 2000–5 January 2001 while the lowest was 0.009±0.009 kg ha^{-1} in 19 August–15 September 2001. The total input in LPF stemflow during the study period was 2.23±0.61 kg ha^{-1}. T-test between nutrient input in MSF stemflow and LPF stemflow was significantly different.

Magnesium (Figure 3.3.13)

In the mixed swamp forest (MSF), stemflow magnesium content showed a marked peak input during 8-31 March 2001 of 0.033±0.003 kg ha^{-1}. The lowest input was during 24 June-21 July 2001 with a mean of 0.001±0.0001 kg ha^{-1}. The average 4 weekly during the 1-year period was 0.022±0.005 kg ha^{-1}.

Stemflow magnesium content in LPF was high from 9 December 2000 to 28 April and 14 October–9 November 2001 with a marked peak 0.191±0.041 kg ha^{-1} in 8-31 March 2001. The lowest inputs of 0.014±0.014 kg ha^{-1} occurred in 24 June-21 July 2001. The average 4 weekly during the 1-year period was 0.114±0.049 kg ha^{-1}. Amounts of magnesium in MSF stemflow and LPF stemflow are significantly different.

Potassium (Figures 3.3.14)

In the mixed swamp forest (MSF), stemflow potassium content was high during 10 November 2000–3 February 2001 and 16 September–13 October 2001. The highest input of 0.499±0.103 kg ha^{-1} occurred during 10 November–8 December 2000 while the lowest input was during 24 June–21 July 2001 of 0.003±0.002 kg ha^{-1}. The total potassium input to the forest floor in MSF was 2.082±1.089 kg ha^{-1} yr^{-1}.

In LPF, potassium input was high during 10 November 2000–5 January 2001 and 16 September–9 November with a peak of 0.906±0.179 kg ha^{-1} in 10 November–8 December 2000. The lowest input was during 19 August–15 September 2001 with a mean of 0.028±0.012 kg ha^{-1}. The total input of potassium through stemflow in LPF during the study period was 3.018±1.266 kg ha^{-1} yr^{-1}. Similarly to magnesium, amount of potassium in stemflow was significantly different between MSF and LPF stemflow.

Sodium (Figures 3.3.15)

Lowest sodium stemflow input in MSF was during 24 June–21 July 2001 with mean of 0.0004±0.00004 kg ha^{-1}. In contrast, the highest sodium inputs occurred during 6 January-3 February 2001 of 0.039±0.006 kg ha^{-1}. The average 4 weekly during the 1-year study period was 0.016±0.003 kg ha^{-1}.

In the low pole forest (LPF), the highest nutrient input occurred during 9 December 2000-5 January 2001 at 0.085±0.012 kg ha^{-1} while the lowest in 19 August–15 September 2001 with a mean of 0.003±0.002 kg ha^{-1}. The average 4 weekly during the 1-year study period was 0.029±0.005 kg ha^{-1}. T- test between the amount of sodium in MSF stemflow and LPF stemflow was significantly different.

Iron (Figures 3.3.16)

The peak in iron reaching the forest floor in MSF stemflow took place in 4 February-7 March 2001 with 0.059±0.0014 kg ha^{-1}. Lowest iron input occurred during 24 June–21 July 2001 with a mean of 0.0001±0.00002 kg ha^{-1}. The total iron input through stemflow in MSF was 0.702±0.301 kg ha^{-1} yr^{-1}.

The highest iron 4 weekly inputs in the LPF stemflow was detected in 22 July–18 August 2001 of 0.441±0.366 kg ha^{-1}. Lowest inputs was in 19 August–15 September 2001 of 0.0007±0.0003 kg ha^{-1}. The total iron input to the forest floor through stemflow in LPF was 1.29±0.66 kg ha^{-1} yr^{-1}. Comparison using t-test between amount of iron content in MSF stemflow and LPF stemflow was significant.

Manganese (Figures 3.3.17)

Manganese was the smallest nutrient studied in both MSF and LPF stemflow. In MSF, the highest manganese content just reached 0.0097±0.0051 kg ha^{-1} during 1-28 April 2001 while for the rest of the year it was less than 0.0003 kg ha^{-1} in every 4 weekly sampling period. The total manganese content during the 1-year study period was only 0.011±0.006 kg ha^{-1} yr^{-1}.

Similarly to MSF stemflow, the highest manganese inputs in stemflow in LPF was during 1-28 April 2001 with 0.0099±0.0031 kg ha^{-1} while for the rest of the year it was less than 0.0005 kg ha^{-1} in every 4 weeks sampling period. The amount of manganese during the 1-year study period was only 0.013 kg ha^{-1} yr^{-1}. T-test between manganese content in MSF stemflow and LPF stemflow was not significant.

Nitrite (Figures 3.3.18)

Similarly to iron, nitrite content in MSF stemflow and LPF stemflow during the one-year study period was low. In MSF, the highest input was only 0.0275±0.0043 kg ha^{-1} during 8–31 March 2001. In contrast, the lowest nitrite input to forest floor through stemflow was in 24 June–21 July 2001 with a mean of 0.00004±0.00002 kg ha^{-1}.

Similarly to MSF stemflow, the highest nitrite content in LPF stemflow occurred during 8-31 March 2001 with a mean of 0.0331±0.016 kg ha^{-1} and the lowest during 24 June-21 July 2001 with a mean of 0.00013±0.00007 kg ha^{-1}. Comparison between the amount of nitrite in MSF stemflow and LPF stemflow was not significant.

Phosphate (Figures 3.3.19)

Peak phosphate input in MSF stemflow occurred during 9 December 2000–5 January 2001 with a mean of 0.0423±0.0523 kg ha^{-1} while the lowest was during 24 June–21 July 2001 of 0.00005±0.00002 kg ha^{-1}. The total phosphate input to forest floor through stemflow in MSF was only 0.150±0.096 kg ha^{-1} yr^{-1}.

The highest phosphate input in LPF stemflow was during 4 February-7 March 2001 at 0.134±0.006 kg ha^{-1}. Lowest input was during 19 August–15 September 2001 with a mean of 0.0001±0.00008 kg ha^{-1}. The total phosphate input through stemflow in LPF was higher than MSF stemflow. Comparison using t-test was not significant.

Ammonium (Figures 3.3.20)

The highest input of ammonium in MSF stemflow was during 22 July–18 August 2001 at 0.1397±0.037 kg ha^{-1}. In contrast, the lowest inputs was during 22 July – 18 August 2001 with mean of 0.0003±0.00058 kg ha^{-1}. The amount of ammonium in MSF stemflow during the study period was 0.702±0.301 kg ha^{-1} yr^{-1}.

Similarly to MSF stemflow, the highest ammonium LPF stemflow inputs was during 22 July–18 August 2001 with mean of 0.441±0.366 kg ha^{-1}. In contrast, the lowest was during 19 August – 15 September 2001 with a mean of 0.0007±0.0003 kg ha^{-1}. The amount of ammonium in MSF stemflow during the study period was 1.291±0.661 kg ha^{-1} yr^{-1}. Comparison using t-test between ammonium content in MSF stemflow and LPF stemflow was significant.

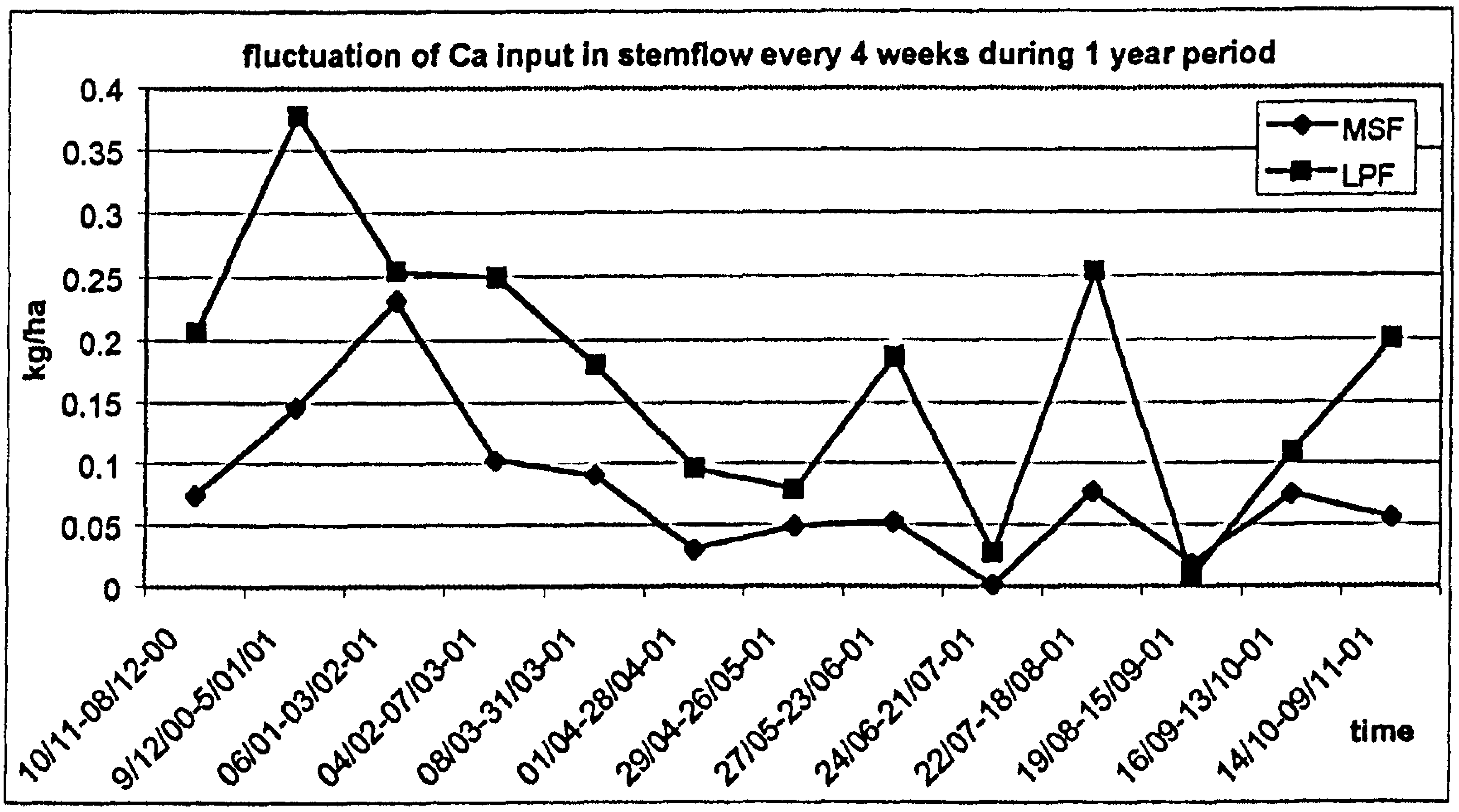


Figure 3.3.12: Fluctuation of Ca input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

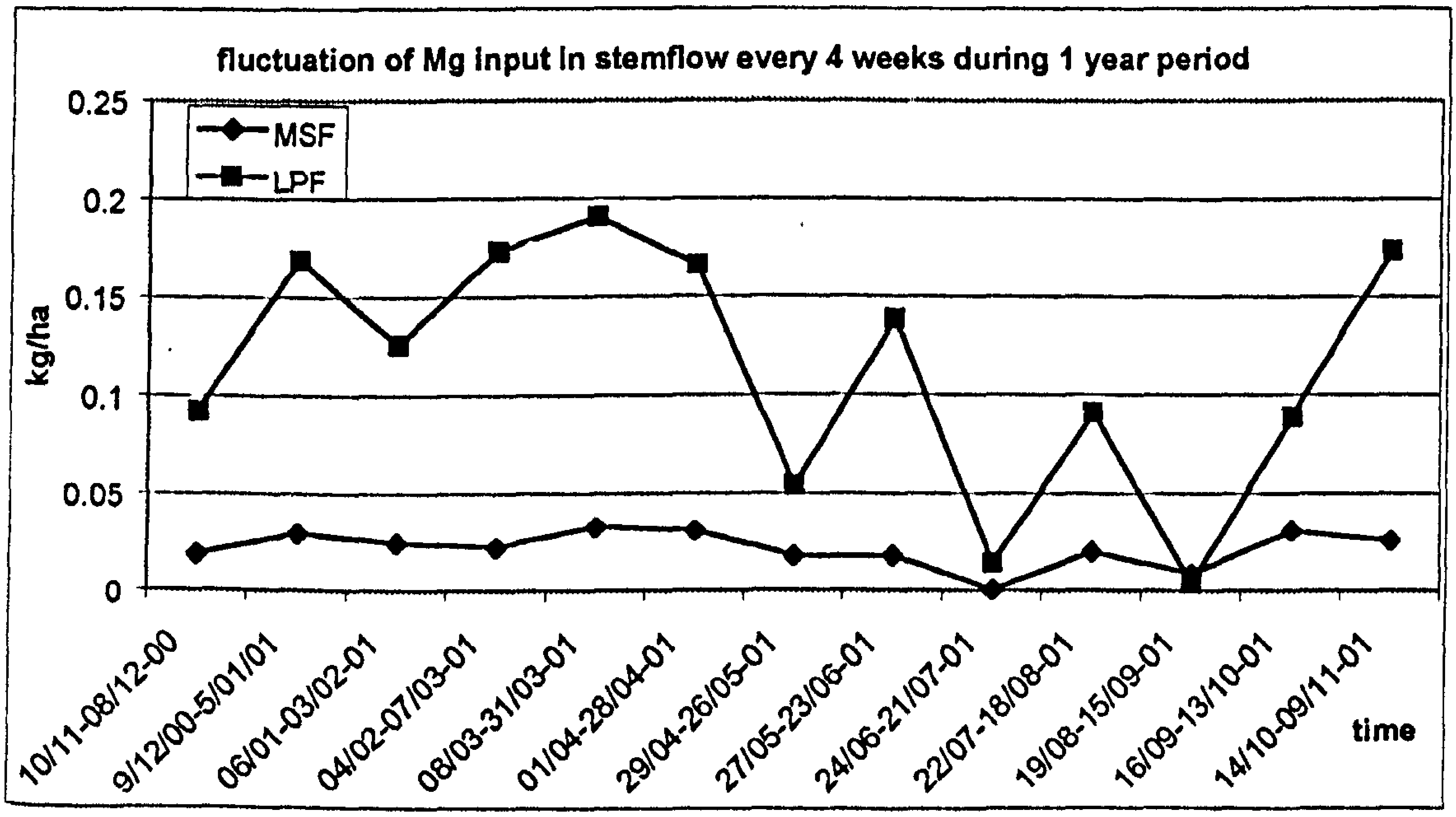


Figure 3.3.13: Fluctuation of Mg input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

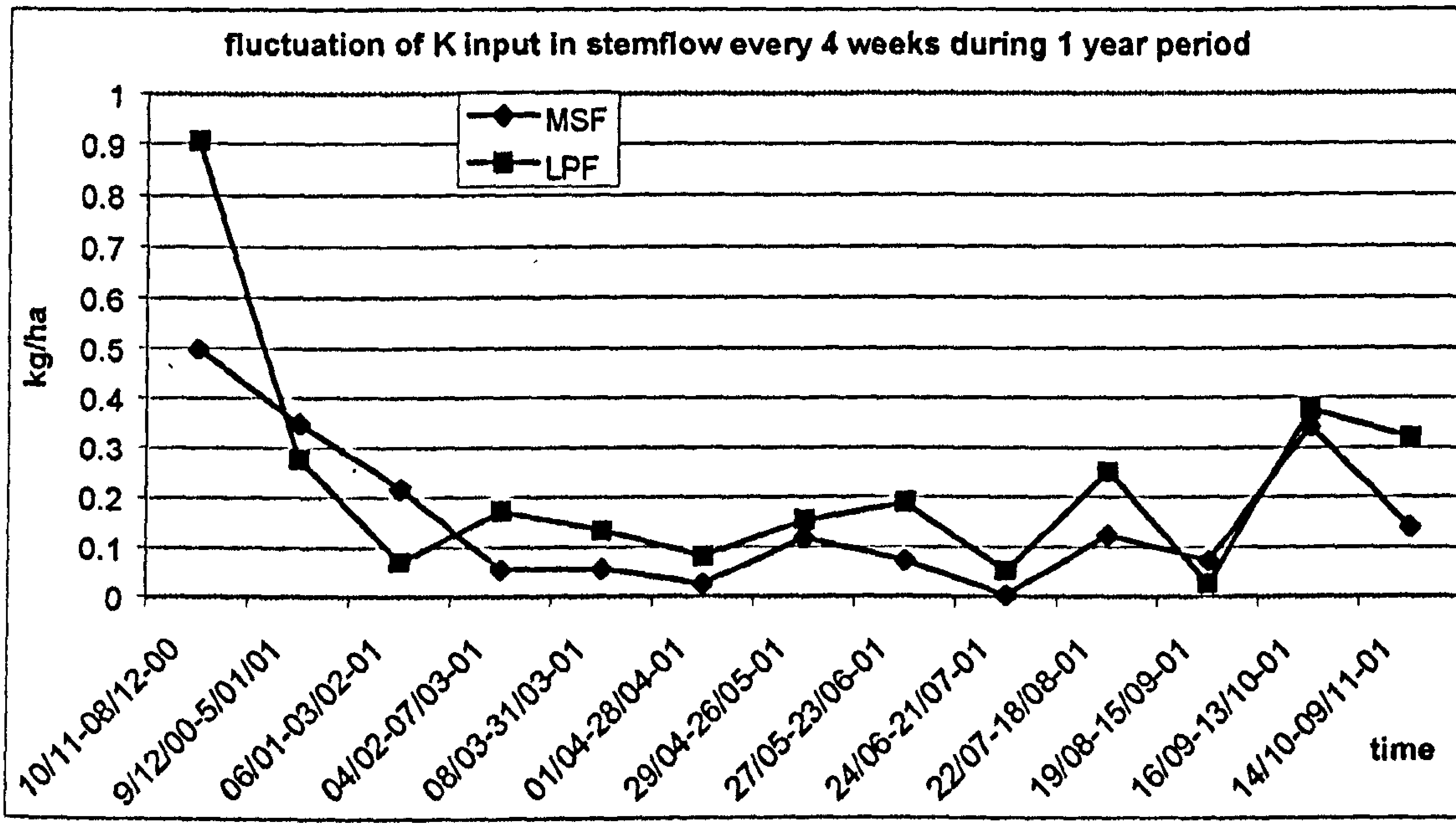


Figure 3.3.14: Fluctuation of K input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

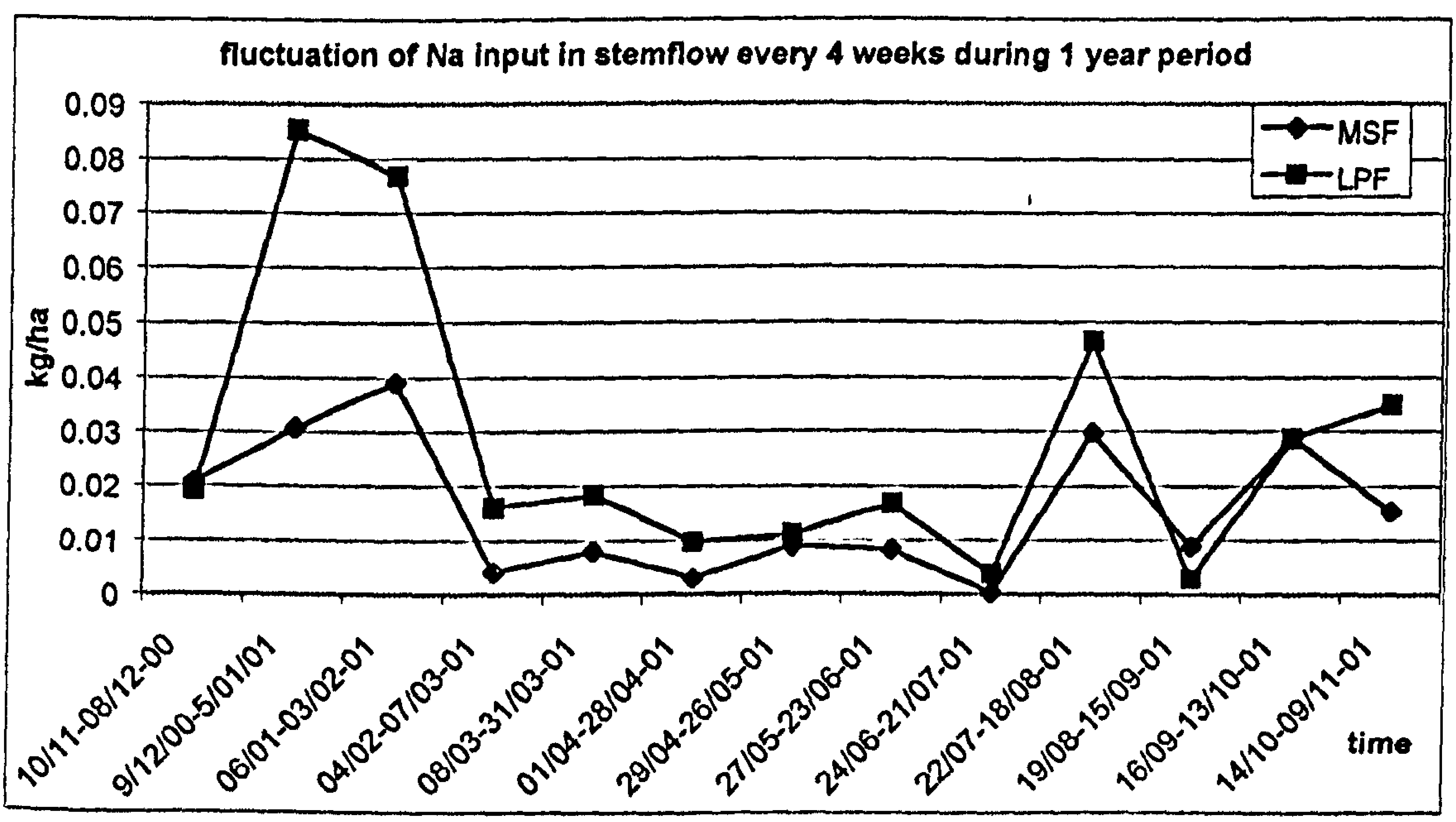


Figure 3.3.15: Fluctuation of Na input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

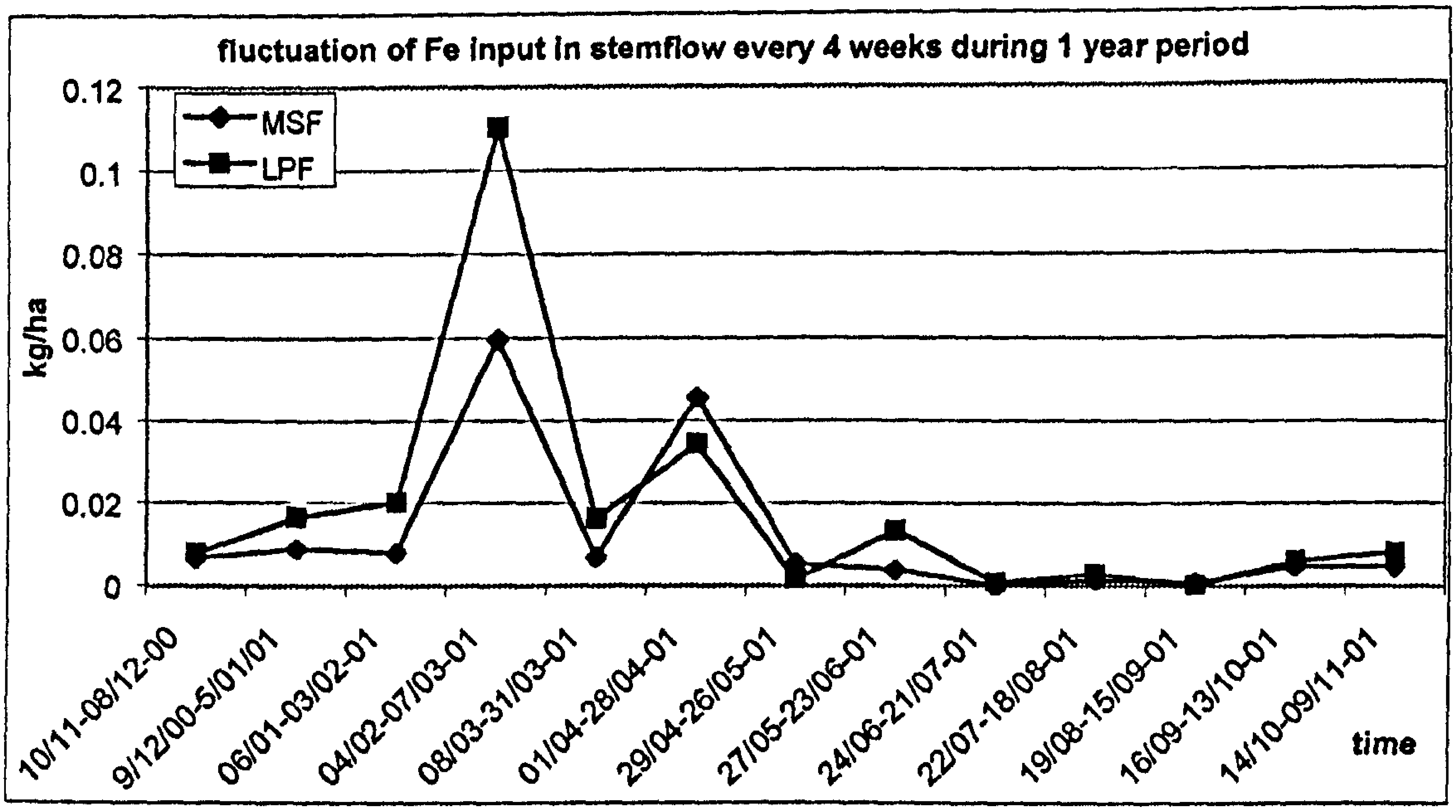


Figure 3.3.16: Fluctuation of Fe input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

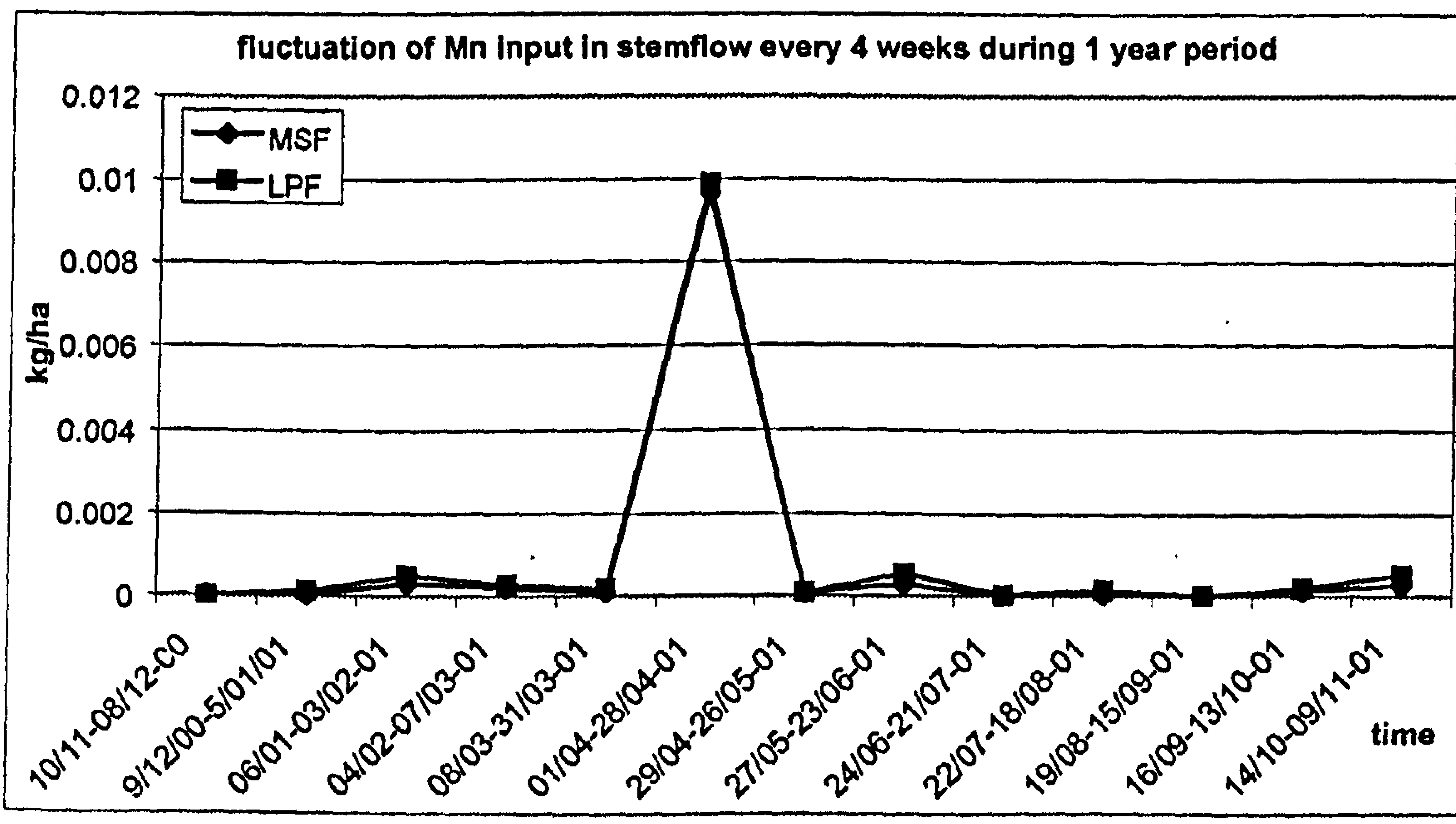


Figure 3.3.17: Fluctuation of Mn input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

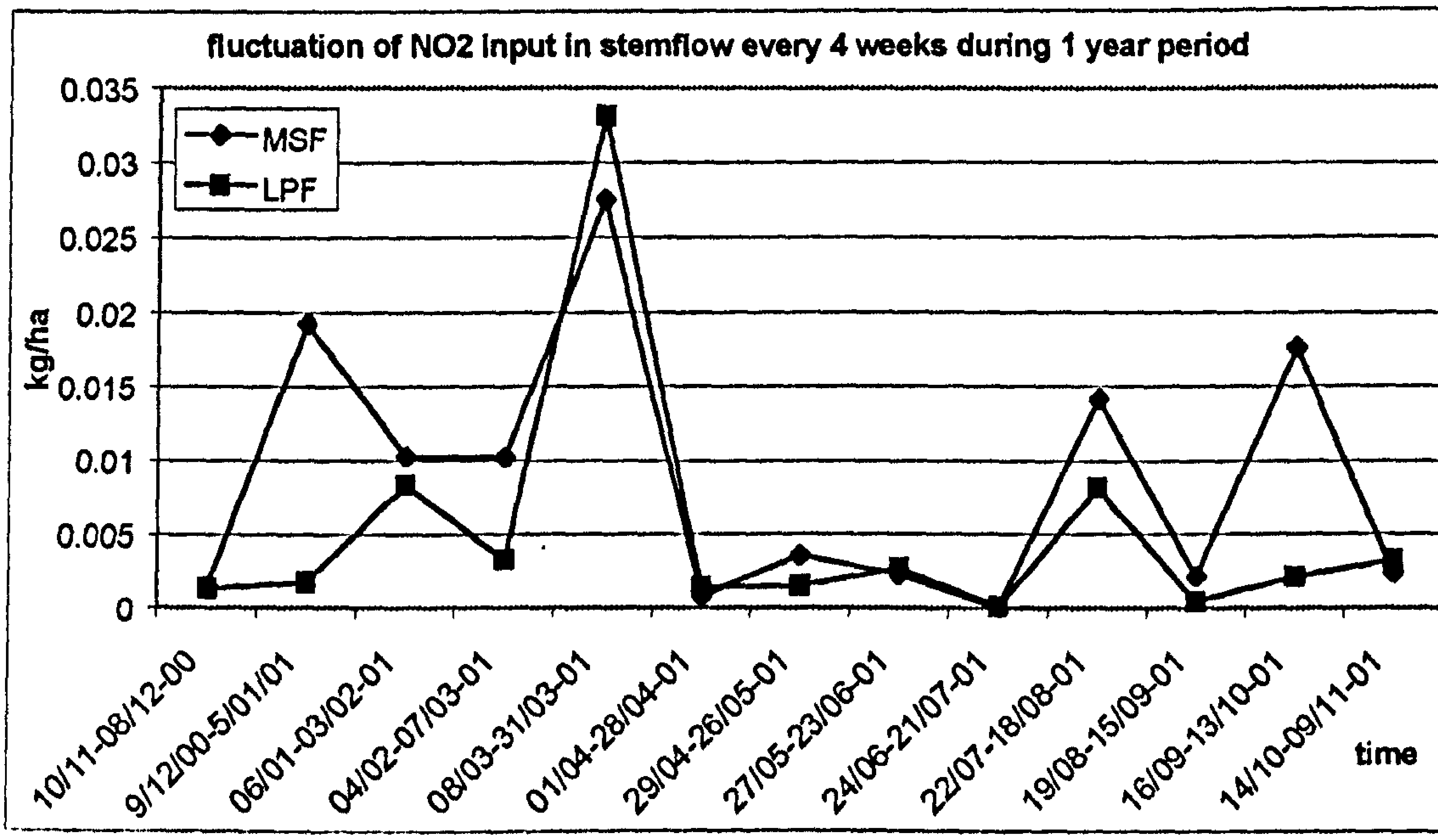


Figure 3.3.18: Fluctuation of nitrite input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

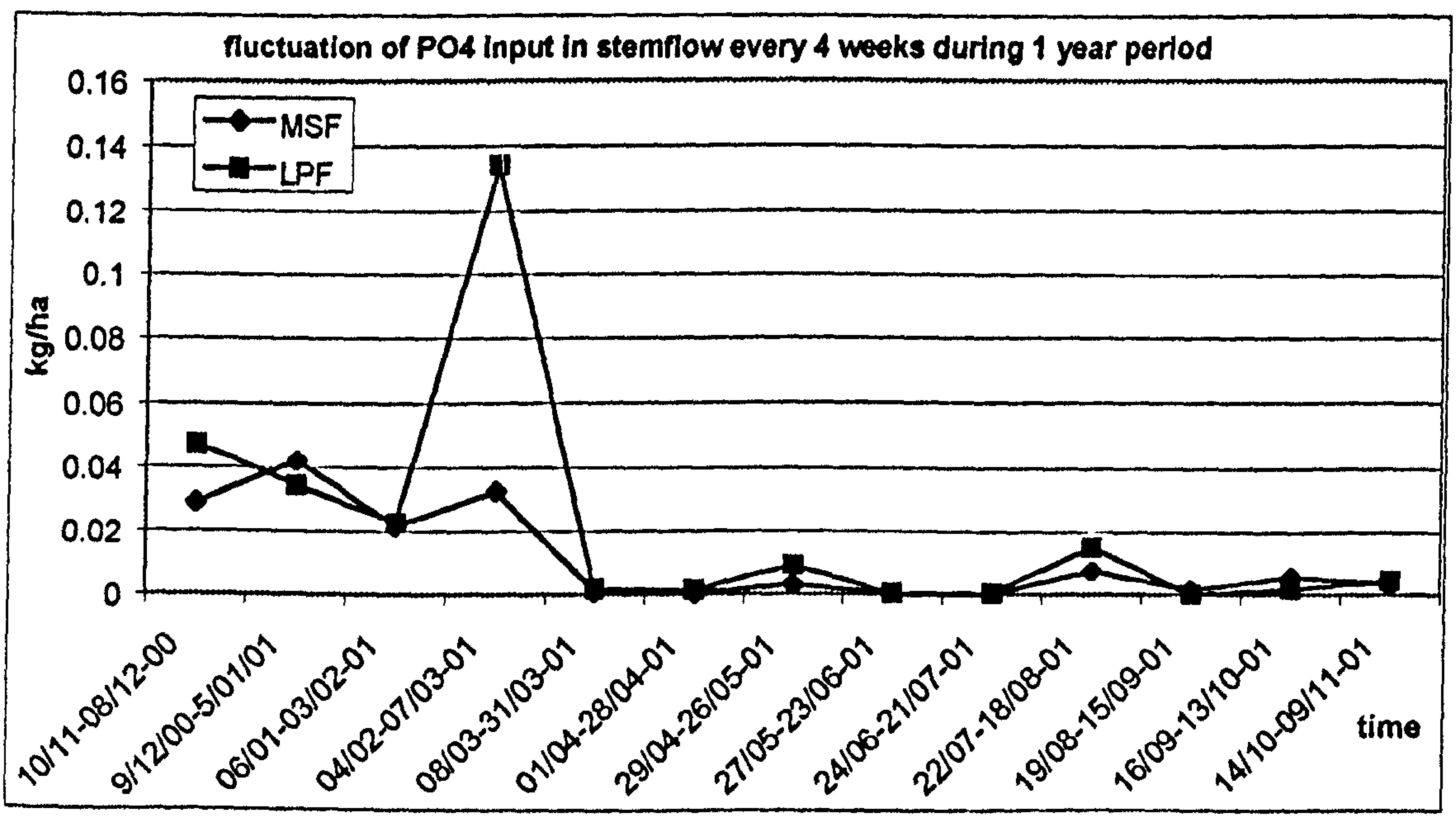


Figure 3.3.19: Fluctuation of phosphate input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

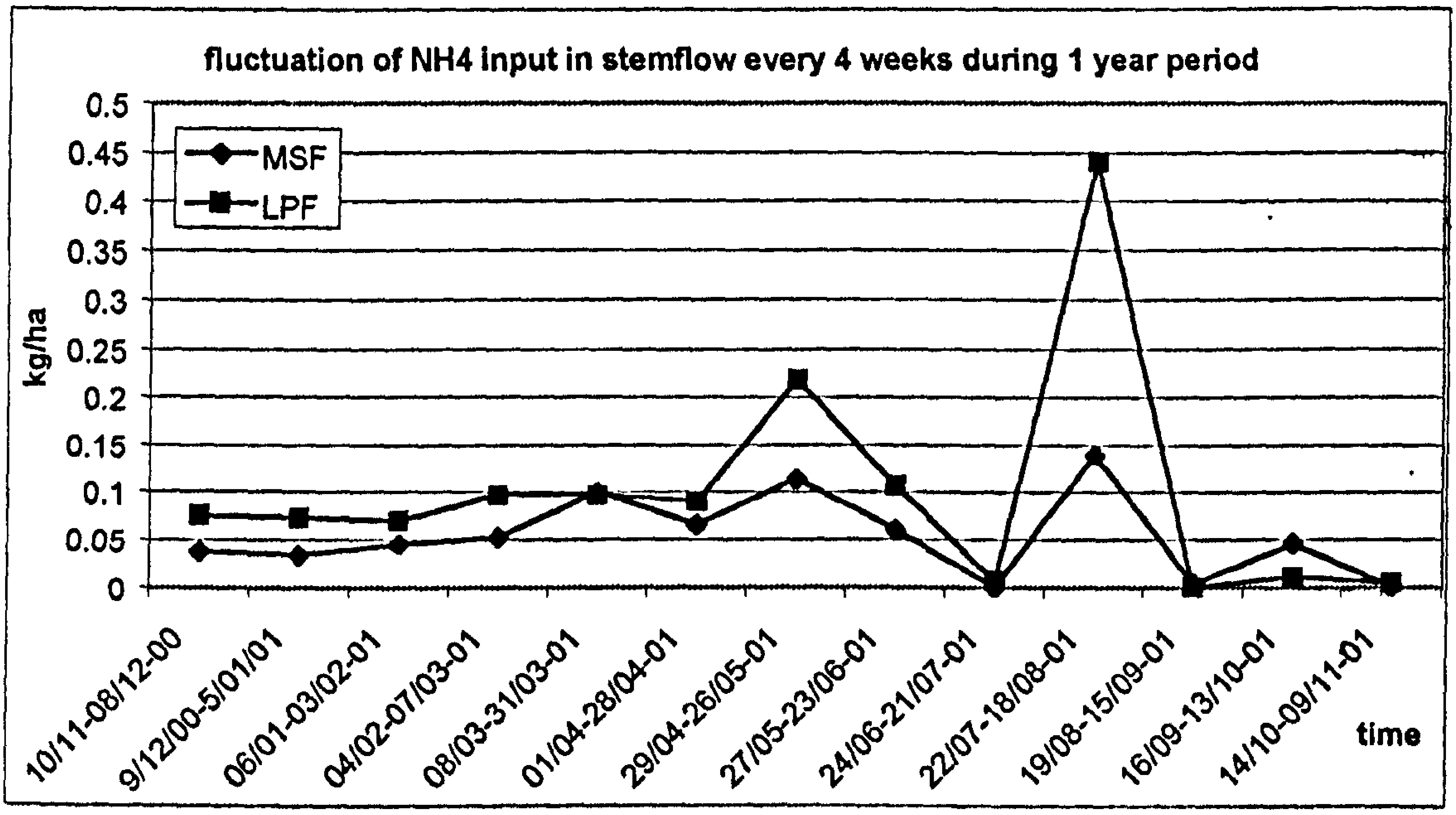


Figure 3.3.20: Fluctuation of ammonium input every 4 weeks in stemflow in MSF and stemflow in LPF during the 1 year study period

3.4. LITTERFALL

3.4.1. Litter production

Dry weight, and percentage of the different fractions of litterfall from 10 November 2000 to 9 November 2001 for Mixed Swamp Forest (MSF) and Low Pole Forest (LPF) using both conventional statistics (Excel) and a co-variance method (Wilm) are summarized in Table 3.4.1 and Table 3.4.2, respectively.

The forest sub-type with the greater litter production was MSF with 8410.7±2095.0 kg ha^{-1} (Excel) and 8153.3±846.8 kg ha^{-1} (Wilm) compared to LPF with 6534.3±547.0 kg ha^{-1} (Excel) and 6368.8±325.3 kg ha^{-1} (Wilm). The average 4-weekly litterfall for the two forest sub-types using Excel were 646.9±161.2 kg ha^{-1} (MSF) and 502.6±119.0 kg ha^{-1} (LPF) and using Wilm 627.2±37.4 kg ha^{-1} (MSF) and 489.9±20.1 kg ha^{-1} (LPF).

In the mixed swamp forest (MSF) leaf litter contributed 74% of the annual total litterfall calculated by both Excel and Wilm, followed by branches 15% (Excel) and 17% (Wilm); reproductive parts 5% (Excel) and 3% (Wilm); and other debris 6% (Excel) and 6% (Wilm) (Table 3.4.1).

Leaf litter contributed 74% and 77% to the annual total litterfall in the LPF by Excel and Wilm, respectively, followed by branches 19% (Excel) and 17% (Wilm); reproductive parts 3% (Excel) and 2% (Wilm), other debris 4% (Excel) and 4% (Wilm) (Table 3.4.2).

Table 3.4.1: Total production of the different litter fractions in Mixed Swamp Forest using Excel and Wilm methods (10 November 2000 to 9 November 2001)

Litter Components	Excel				Wilm method			
	Dry weight (kg ha^{-1})	Std. dev	% Std. Dev	% of total litter	Dry weight (kg ha^{-1})	Std. error	% Std. Error	% of total litter
Leaves	6215.6	1103.9	17.8	74	6058.1	712.4	11.8	74
Branches	1245.9	854.9	68.6	15	1396.2	371.1	26.6	17
Reproductive	459.9	522.2	113.6	5	266.0	93.8	35.2	3
Others	489.4	167.3	34.2	6	438.0	50.9	11.6	5
Total	8410.7	2095.4	24.9	100	8153.3	846.8	10.4	100

Table 3.4.2: Total production of the different litter fractions in Low Pole Forest using Excel and Wilm methods (10 November 2000 to 9 November 2001)

Litter Components	Excel				Wilm method			
	Dry weight (kg ha^{-1})	Std. Dev	% Std. Dev	% of total litter	Dry weight (kg ha^{-1})	Std. error	% Std. Error	% of total litter
Leaves	4863.8	951.4	19.6	74	4919.1	332.9	6.8	77
Branches	1250.7	842.9	67.4	19	1078.4	209.1	19.4	17
Reproductive	169.0	170.9	101.1	3	104.6	38.9	37.2	2
Others	250.9	94.7	37.7	4	267.0	34.4	12.9	4
Total	6534.4	1547.1	23.7	100	6368.8	325.3	5.1	100

3.4.2. Pattern and seasonality of litterfall

The seasonal pattern of total litterfall in the two sub-types of forest, mixed swamp forest and low pole forest at 4 weekly intervals during the one-year study period using Excel and Wilm methods are given in Figures 3.3.1 and 3.3.2.

In MSF, there is a marked seasonal trend with the highest peak litterfall occurring during 19 August- 15 September 2001 with 1124.3±75.4 kg ha^{-1} (Excel). When using Wilm, however, the peak period appears to be during 4 February-7 March 2001 with 820.3±103.4 kg ha^{-1}. The lowest litterfall was during 24 June-21

July 2001 with 423.5±148.1 kg ha^{-1} (Excel) and 27 May-23 June 2001 with 478.9±85.0 kg ha^{-1} (Wilm).

In LPF, the highest peak litterfall occurred during 4 February-7 March 2001 with 1213.4±406.3 kg ha^{-1} (Excel) and 1074.3±65.5 kg ha^{-1} (Wilm). The lowest amounts obtained by both statistical methods were 269.3±37.6 kg ha^{-1} and 33.78±2.54 kg ha^{-1}, during 24 June-21 July 2001.

The seasonal pattern of litterfall in both forest types, mixed swamp forest and low pole forest, was generally similar with marked bimodal peaks. The first peak was in 4 February-7 March 2001, associated with the high rainfall period from January to March, and the second peak was in August-September, towards the end of the dry season (August-September) when rainfall was very low. The correlation between rainfall and litterfall in each sub type of forest, MSF and LPF, and average of them, was examined. The results indicated that none of the relationships proved significant, with an r value 0.01 for MSF, 0.59 for LPF, and an average of 0.35.

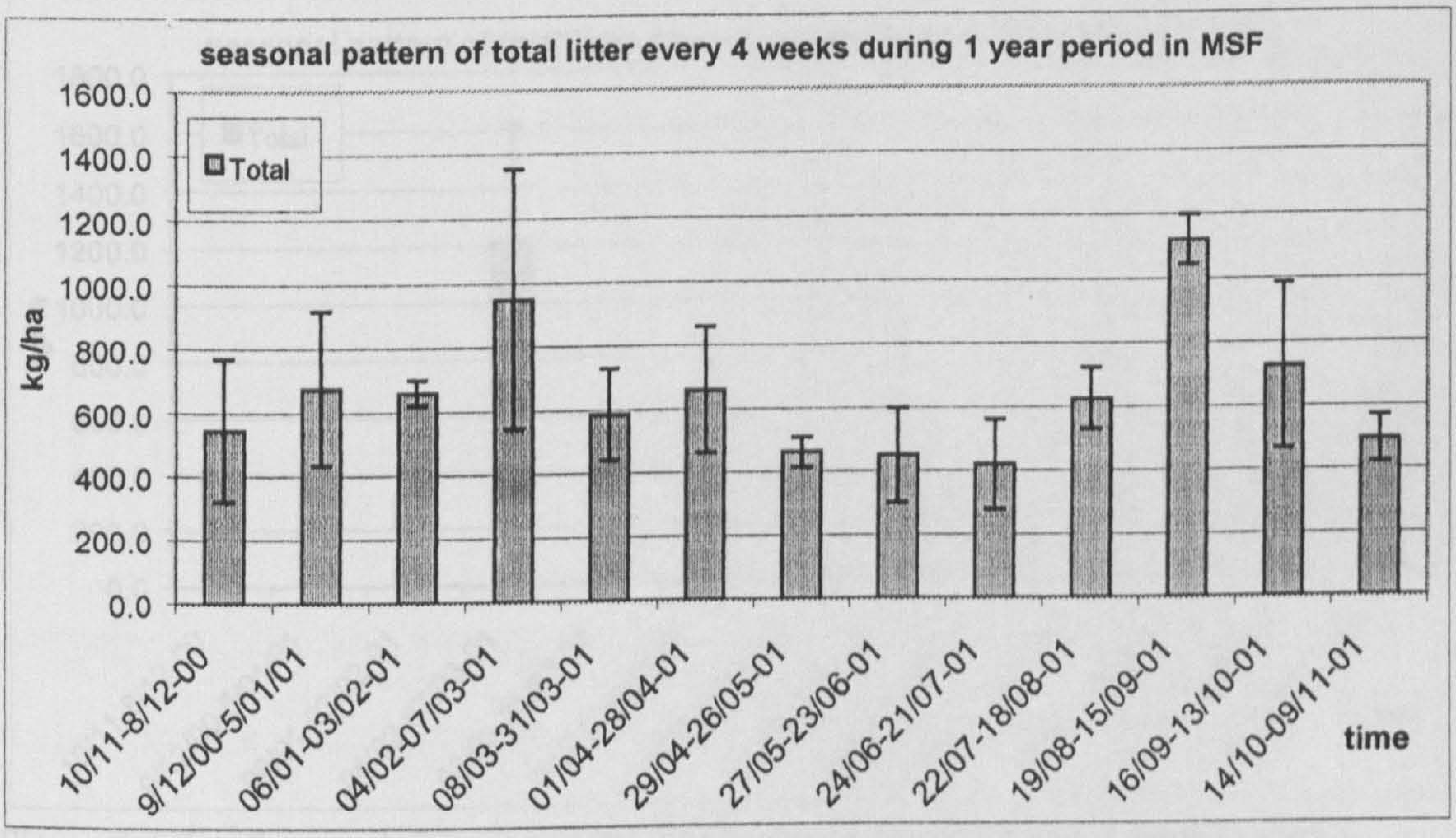


Figure 3.4.1.a: Seasonal pattern of total litter every 4 weeks during 1 year period in MSF using Excel

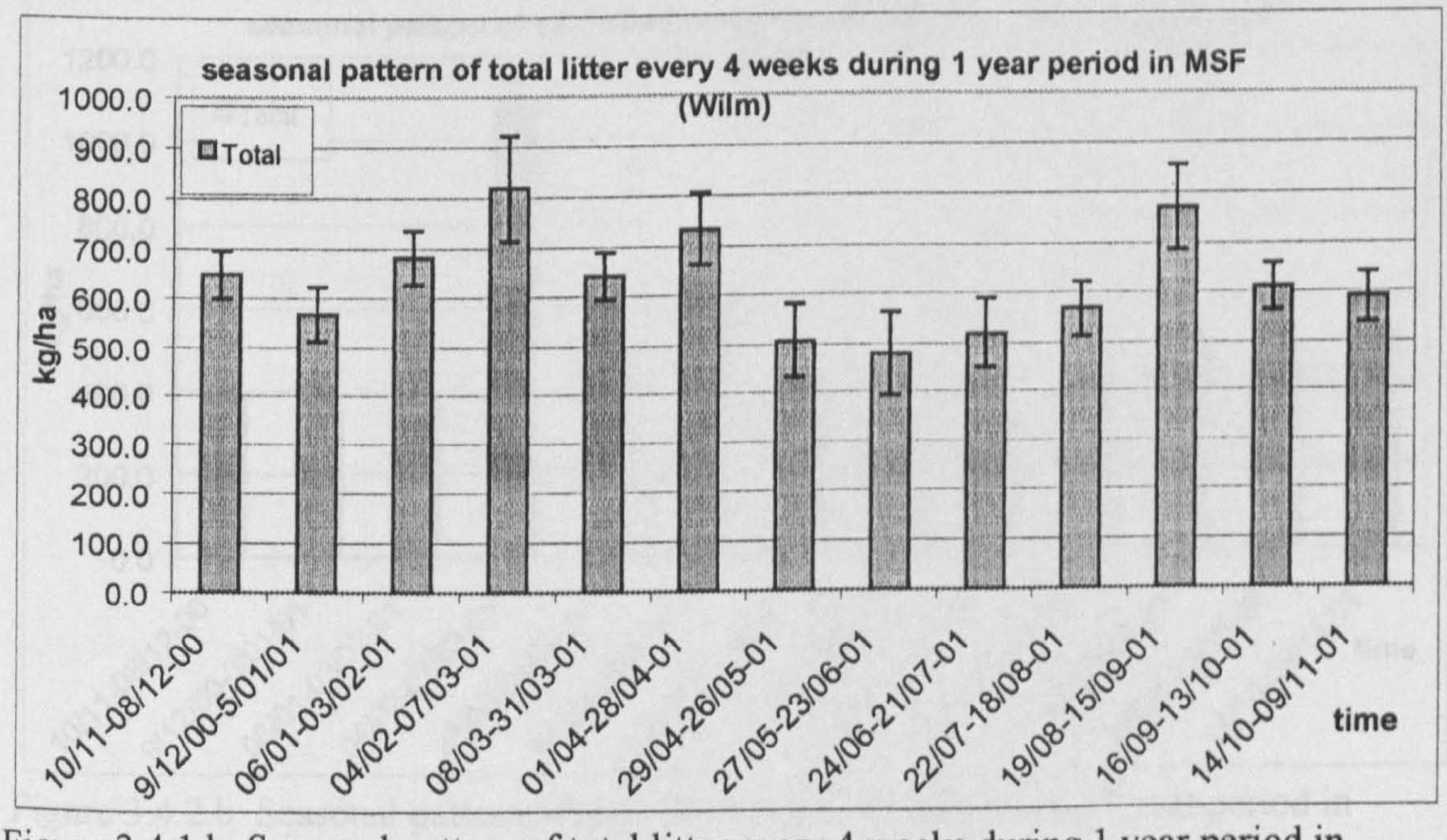


Figure 3.4.1.b: Seasonal pattern of total litter every 4 weeks during 1 year period in MSF using WILM method

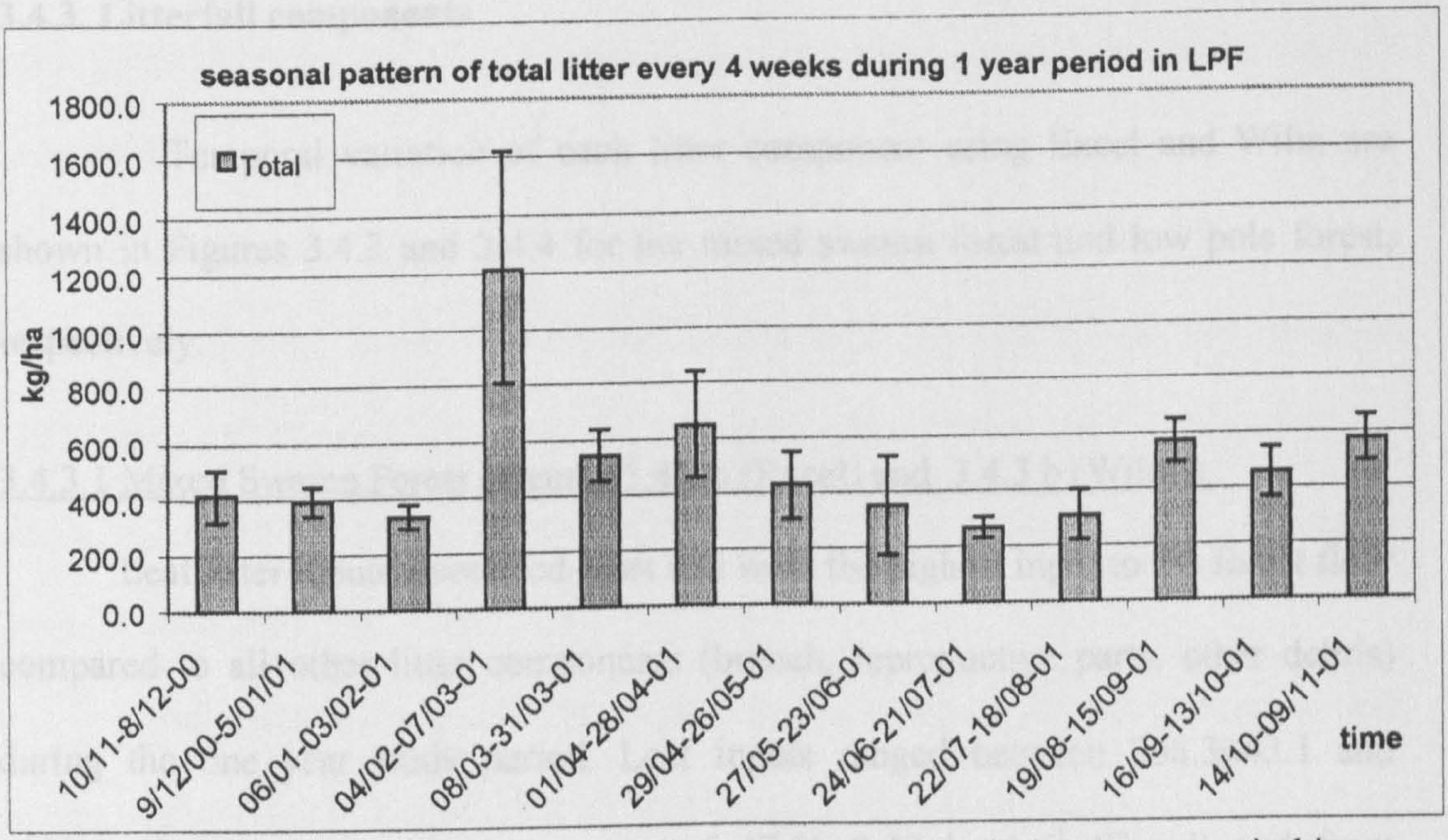


Figure 3.4.2.a: Seasonal pattern of total litter every 4 weeks during 1 year period in LPF using Excel

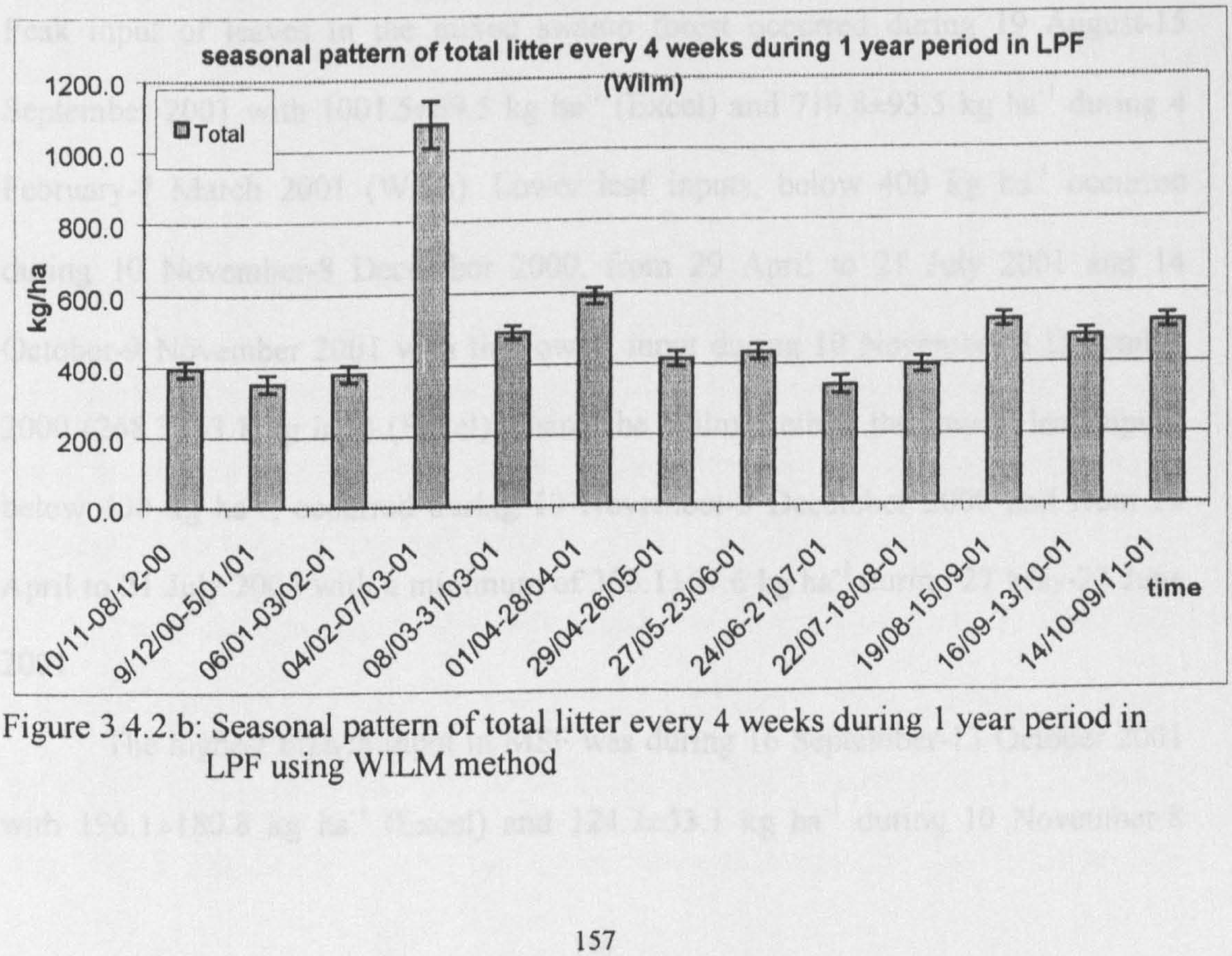


Figure 3.4.2.b: Seasonal pattern of total litter every 4 weeks during 1 year period in LPF using WILM method

3.4.3. Litterfall components

Temporal variation of each litter component using Excel and Wilm are shown in Figures 3.4.3 and 3.4.4 for the mixed swamp forest and low pole forest, respectively.

3.4.3.1 Mixed Swamp Forest (Figures 3.4.3.a (Excel) and 3.4.3.b (Wilm)).

Leaf litter inputs fluctuated most and were the highest input to the forest floor compared to all other litter components (branch, reproductive parts, other debris) during the one year study period. Leaf inputs ranged between 268.3±43.1 and 1001.5±69.5 kg ha^{-1} with an average of 47.81±8.49 kg ha^{-1} (Excel) and from 303.1±67.6 to 719.6±93.5 kg ha^{-1} with an average of 466.0±23.5 kg ha^{-1} (Wilm). Peak input of leaves in the mixed swamp forest occurred during 19 August-15 September 2001 with 1001.5±69.5 kg ha^{-1} (Excel) and 719.8±93.5 kg ha^{-1} during 4 February-7 March 2001 (Wilm). Lower leaf inputs, below 400 kg ha^{-1} occurred during 10 November-8 December 2000, from 29 April to 21 July 2001 and 14 October-9 November 2001 with the lowest input during 10 November-8 December 2000 (268.3±43.1 kg ha^{-1}) (Excel). Using the Wilm method the lowest leaf inputs, below 400 kg ha^{-1}, occurred during 10 November-8 December 2000 and from 29 April to 21 July 2002 with a minimum of 303.1±67.6 kg ha^{-1} during 27 May-23 June 2001.

The highest branch input in MSF was during 16 September-13 October 2001 with 196.1±180.8 kg ha^{-1} (Excel) and 124.3±53.1 kg ha^{-1} during 10 November-8

December 2000 (Wilm). The lowest branch inputs were during 24 June-21 July 2001 with 19.6±180.8 kg ha^{-1} (Excel) and 97.5±35.6 kg ha^{-1} (Wilm) during 22 July–18 August 2001.

Reproductive parts contributed very little inputs to the forest floor with a maximum of only 121.7±161.7 kg ha^{-1} during 1-28 April 2001 and the lowest of 2.5±2.0 kg ha^{-1} (Excel) in 24 June-21 July 2001. Using Wilm the highest input was 26.0±17.5 kg ha^{-1} during 1-28 April 2001 and the lowest 19.2±6.7 kg ha^{-1} during 27 May-23 June 2001.

Similarly to reproductive parts, the input of unclassified debris (others) was small, reaching only 58.8±44.2 kg ha^{-1} during 10 November-8 December 2000 with a minimum of 21.9±0.9 kg ha^{-1} (Excel) during 24 June-21 July 2001. Wilm method showed a different result with the highest input of 41.8±8.3 kg ha^{-1} during 10 November-8 December 2000 and the lowest of 30.4±4.3 kg ha^{-1} during 1-28 April 2001.

3.4.3.2. Low Pole Forest (Figures 3.4.4.a (Excel) and 3.4.4.b (Wilm)).

Similarly to the mixed swamp forest, leaf litter was the highest and the most variable input to the forest floor with an average 4 weekly value of 374.1±73.2 kg ha^{-1} (Excel) and 378.4±15.7 kg ha^{-1} (Wilm).

Peak leaf input in the low pole forest was during 4 February-7 March 2001 with 835.2±206.0 kg ha^{-1} (Excel) and 777.4±51.3 kg ha^{-1} (Wilm). Lower leaf inputs, below 300 kg ha^{-1} occurred from 10 November 2000 to 3 February 2001 and from 27 May to 18 August 2001 with the lowest amount during 27 May-23 June 2001

(166.7±77.0 kg ha^{-1}) (Excel). Using Wilm the lower leaf inputs, below 300 kg ha^{-1} occurred from 10 November 2000 to 3 February 2001 and from 27 May to 21 July 2001 with the lowest of 199.0±28.6 kg ha^{-1} during 24 June-21 July 2001.

The second largest input to the forest floor comes from branches with highest input in LPF during 4 February-7 March 2001 with 319.3 ±241.5 kg ha^{-1} (Excel) and 135.5±44.5 kg ha^{-1} during 4 February-7 March 2001 (Wilm). The lowest input of branch material occurred during 22 July-18 August 2001 with 29.0±18.3 kg ha^{-1} (Excel) and 74.3± 14.6 kg ha^{-1} during 22 July – 18 August 2001 (Wilm).

Reproductive parts contribute little to inputs to the forest floor with the highest amount of only 47.7±50.8 kg ha^{-1} during 27 May-23 June 2001 and the lowest input during 22 July-18 August 2001 with 0.8±0.6 kg ha^{-1} (Excel). According to Wilm the highest input was 12.9±7.3 kg ha^{-1} during 27 May-23 June 2001 and the lowest of 6.9±2.8 kg ha^{-1} during 16 September-13 October 2001.

The unclassified debris (others) only provided small amounts to the total litterfall with the highest of 35.1±13.5 kg ha^{-1} during 29 April-26 May 2001 and the lowest 7.7±0.5 kg ha^{-1} during 22 July-18 August 2001 (Excel). The Wilm method showed that the highest debris input was only 30.6±3.4 kg ha^{-1} during 29 April-26 May 2001 and the lowest 10.6±3.4 kg ha^{-1} during 22 July-18 August 2001.

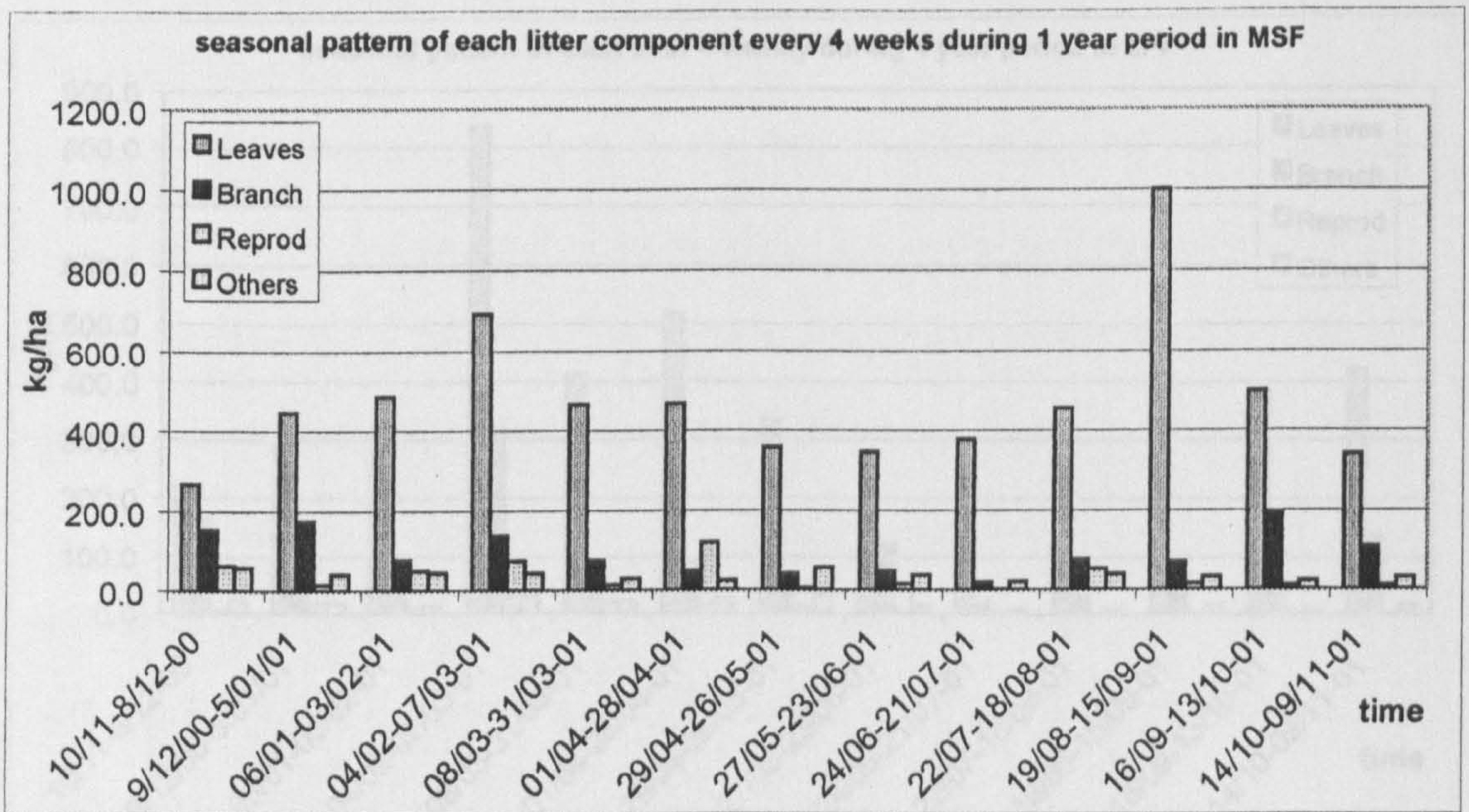


Figure 3.4.3.a: Seasonal pattern of each litter component every 4 weeks during 1 year period in MSF using Excel

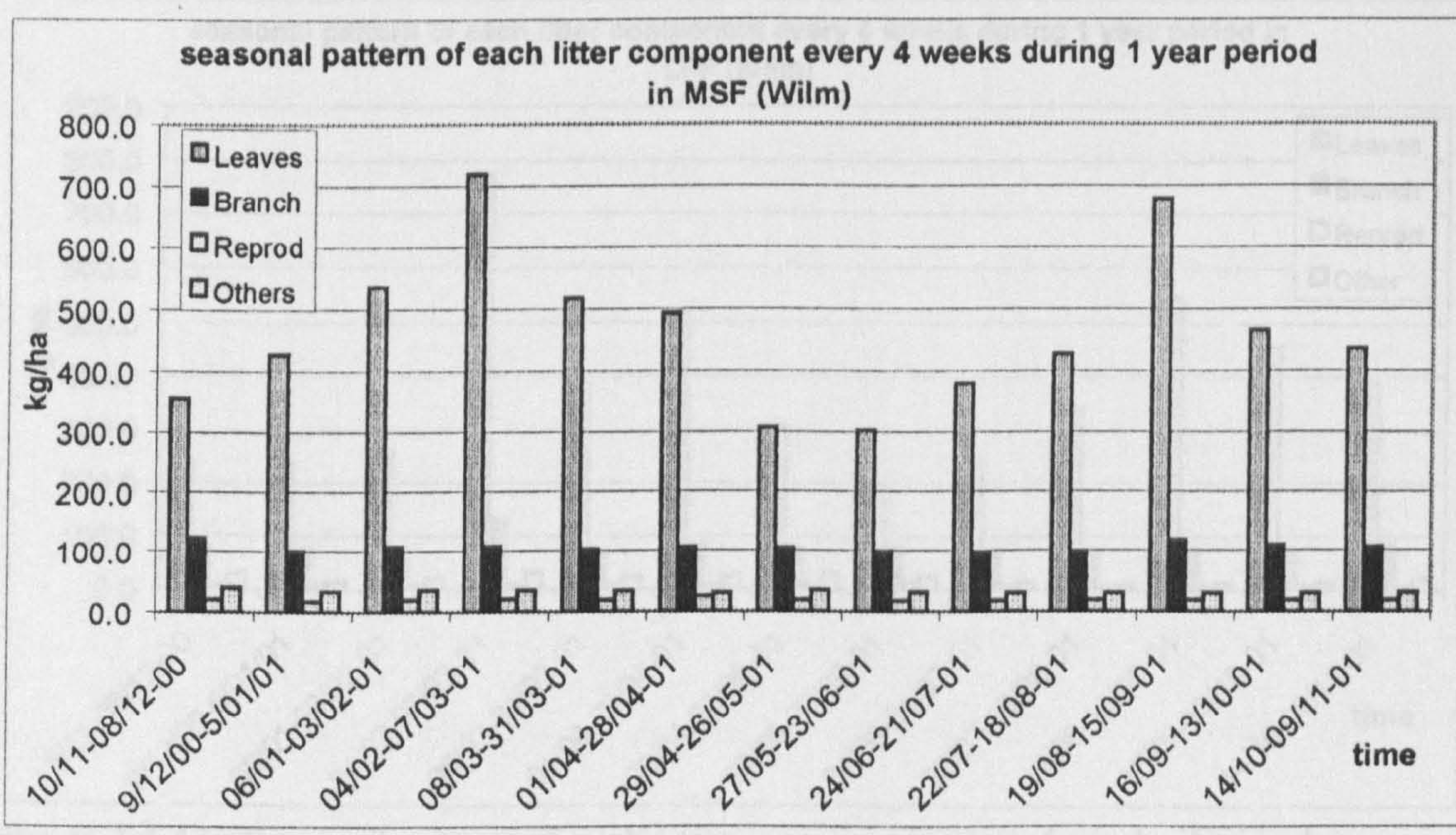


Figure 3.4.3.b: Seasonal pattern of each litter component every 4 weeks during 1 year period in MSF using WILM method

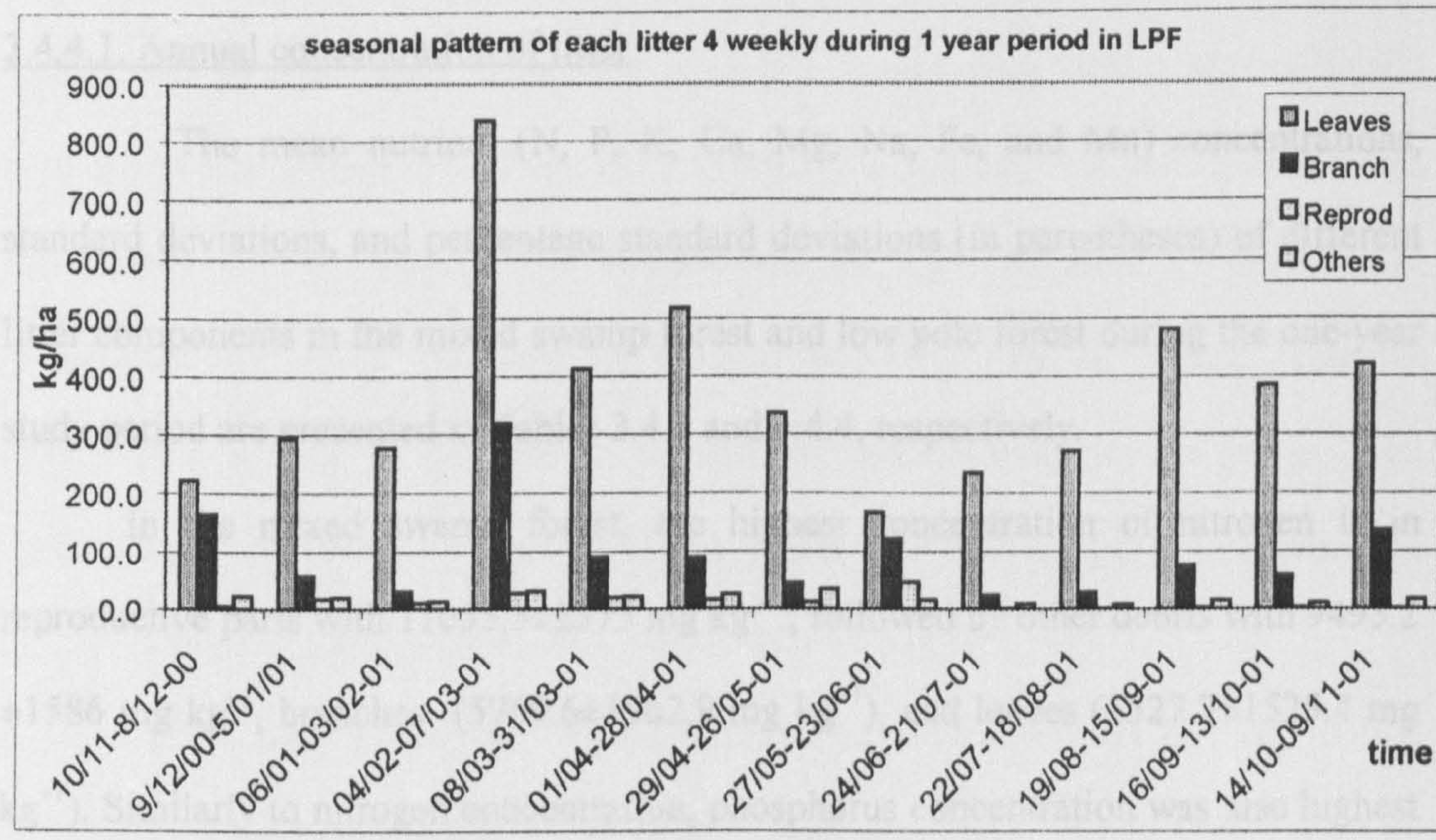


Figure 3.4.4.a: Seasonal pattern of each litter component every 4 weeks during 1 year period in LPF using Excel

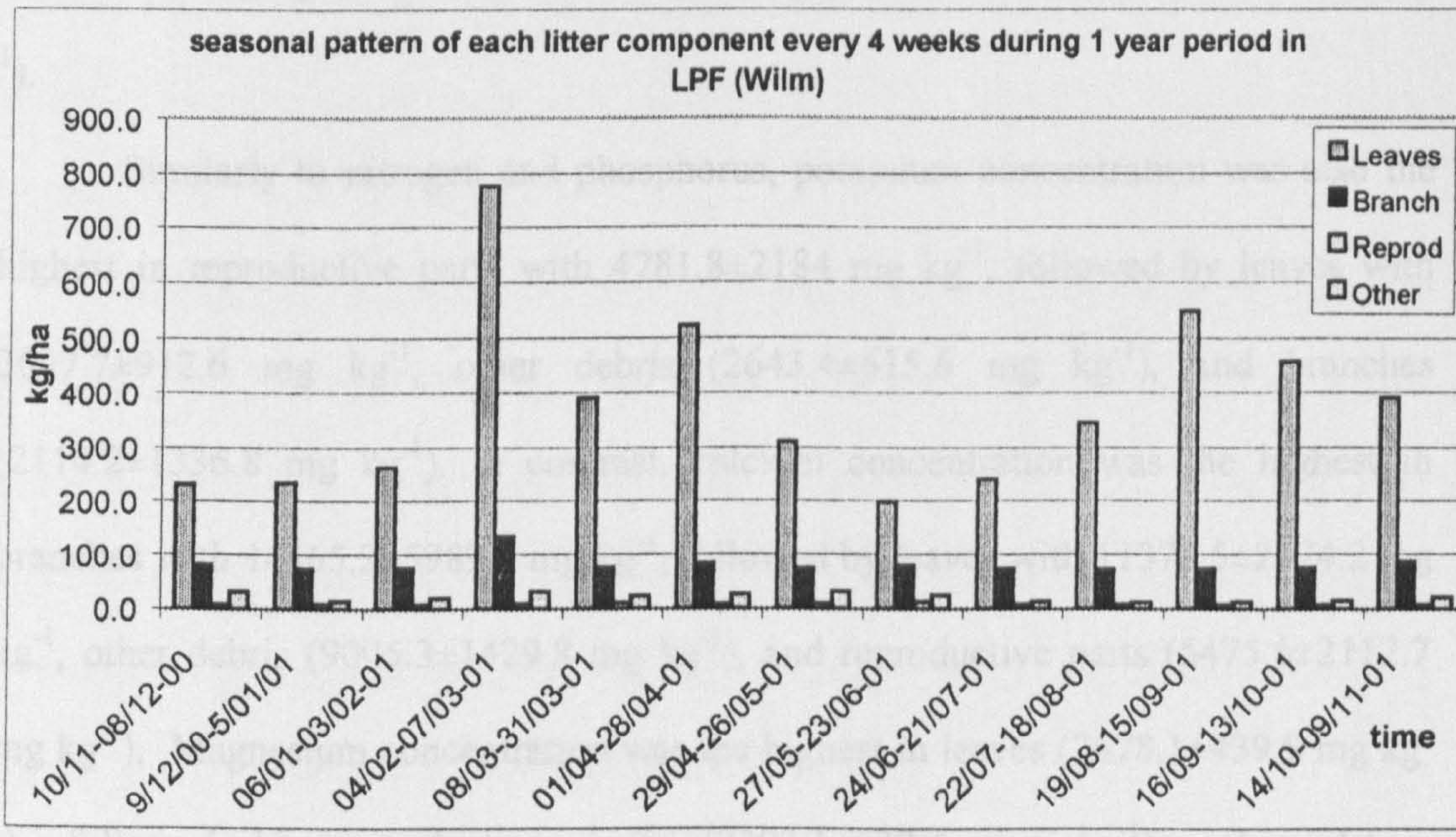


Figure 3.4.4.b: Seasonal pattern of each litter component every 4 weeks during 1 year period in LPF using WILM method

3.4.4. Litter nutrient concentration

3.4.4.1. Annual concentration of litter

The mean nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentrations, standard deviations, and percentage standard deviations (in parentheses) of different litter components in the mixed swamp forest and low pole forest during the one-year study period are presented in Tables 3.4.3 and 3.4.4, respectively.

In the mixed swamp forest, the highest concentration of nitrogen is in reproductive parts with 11055.3±2375 mg kg^{-1}, followed by other debris with 9493.2 ±1586 mg kg^{-1}, branches (5769.6±1562.9 mg kg^{-1}), and leaves (5527.7±1525.4 mg kg^{-1}). Similarly to nitrogen concentration, phosphorus concentration was also highest in reproductive parts with 392.1± 79.2 mg kg^{-1}, followed by other debris with 313.7±61.2 mg kg^{-1}, leaves (121.4±32.7 mg kg^{-1}), and branches (120.0±57.6 mg kg^{-1}).

Similarly to nitrogen and phosphorus, potassium concentration was also the highest in reproductive parts with 4781.8±2184 mg kg^{-1}, followed by leaves with 3097.7±912.6 mg kg^{-1}, other debris (2643.4±615.6 mg kg^{-1}), and branches (2114.2±1336.8 mg kg^{-1}). In contrast, calcium concentration was the highest in branches with 14465.2±5989.9 mg kg^{-1}, followed by leaves with 11378.5±2074.2 mg kg^{-1}, other debris (9005.3±1429.8 mg kg^{-1}), and reproductive parts (5475.6±2112.7 mg kg^{-1}). Magnesium concentration was the highest in leaves (2678.1±439.9 mg kg^{-1}), followed by reproductive parts (2303.1±537.4 mg kg^{-1}), other debris (2025.8±323.7 mg kg^{-1}), and branches (1899.1±891.5 mg kg^{-1}).

Sodium concentration was the highest in other debris with 364.2±62.9 mg kg^{-1}, followed by branches (327.3±82.6 mg kg^{-1}), leaves (309.5±91.8 mg kg^{-1}), and reproductive parts (305.0±93.1 mg kg^{-1}). Similarly to sodium, iron concentration was the highest in other debris with 406.4±378.2 mg kg^{-1}, followed by leaves with 150.4±96.5 mg kg^{-1}), reproductive parts (144.1±60.3 mg kg^{-1}), and branches (139.5±59.5 mg kg^{-1}). The highest manganese concentration was in leaves with 17.8±6.0 mg kg^{-1} only, followed by other debris with 13.3±5.1 mg kg^{-1}, branches (11.5±6.2 mg kg^{-1}), and reproductive parts (10.5±6.6 mg kg^{-1}).

In low pole forest, the highest nitrogen concentration was in reproductive parts with 7874.7±1024.0 mg kg^{-1}, followed by others debris 7737.6±1746.5 mg kg^{-1}; branches 4076.5±1140.7 mg kg^{-1}; and leaves litter with 3426.1±917.2 mg kg^{-1}. Phosphorus concentration was the highest in other debris with 262.5±104.0 mg kg^{-1}, followed by reproductive parts with 242.4±74.6 mg kg^{-1}, branches (88.8±49.6 mg kg^{-1}), and leaves (79.0±31.6 mg kg^{-1}).

Similarly to nitrogen, potassium concentration was highest in reproductive parts with 3629.0±1284.9 mg kg^{-1}, followed by leaves with 1789.0±574.1 mg kg^{-1}, other debris (1658.4±526.3 mg kg^{-1}), and branches (1375.6±882.2 mg kg^{-1}). In contrast, calcium concentration was the highest in leaves with 9523.9±2476.6 mg kg^{-1}, followed by branches with 9207.7±3661.3 mg kg^{-1}, other debris (8618.0±2418.3 mg kg^{-1}), and reproductive parts (5443.2±1881.4 mg kg^{-1}).

The highest magnesium concentration was in leaves with 2505.9±536.3 mg kg^{-1}, followed by reproductive parts with 1919.1±457.3 mg kg^{-1}, other debris (1787.5±371.4 mg kg^{-1}), and branches (1611.5±628.0 mg kg^{-1}). In contrast, sodium concentration was the highest in other debris (322.8±59.7 mg kg^{-1}), followed by leaves with 298.0±110.5 mg kg^{-1}, branches (295.2±123.2 mg kg^{-1}), and reproductive parts (247.0±74.2 mg kg^{-1}).

Similarly to sodium, iron concentration was the highest in other debris with 307.1±224.0 mg kg^{-1}, followed by branches with 123.2±55.0 mg kg^{-1}, leaves (122.7±62.4 mg kg^{-1}), and reproductive parts (90.3±19.5 mg kg^{-1}). Manganese concentration was the highest in leaves with 9.4±3.7 mg kg^{-1} only, followed by other debris (7.9±3.0 mg kg^{-1}), branches (5.8±3.4 mg kg^{-1}), and reproductive parts (3.7±1.7 mg kg^{-1}).

Table 3.4.3: The mean nutrient concentrations, standard deviations, and percentage standard deviations of different litter components in mixed swamp forest using Excel.

Excel	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}
Leaves	5527.7	121.4	3097.7	11378.5	2678.1	309.5	150.4	17.8
SD leaves	1525.4	32.7	912.6	2074.2	439.9	91.8	96.5	6.0
% SD leaves	*27.9*	*26.6*	*29.9*	*18.0*	*17.0*	*29.1*	*55.3*	*34.0*
Branch	5769.6	120.0	2114.2	14465.2	1899.1	327.3	139.5	11.5
SD branch	1562.9	57.6	1336.8	5989.9	891.5	82.6	59.5	6.2
% SD branch	*27.4*	*47.8*	*62.8*	*39.5*	*48.1*	*24.4*	*42.8*	*55.7*
Reproductive	11055.3	392.1	4781.8	5475.6	2303.1	305.0	144.1	10.5
SD reprod	2375.0	79.2	2184.4	2112.7	537.4	93.1	60.3	6.6
% SD reprod	*23.0*	*22.2*	*44.6*	*39.8*	*24.3*	*29.0*	*39.6*	*59.2*
Others	9493.2	313.7	2643.4	9005.3	2025.8	364.2	406.4	13.3
SD others	1586.2	61.2	615.6	1429.8	323.7	62.9	378.2	5.1
% SD others	*18.2*	*18.8*	*23.3*	*15.2*	*15.9*	*17.7*	*48.6*	*40.8*

Table 3.4.4: The mean nutrient concentrations, standard deviations, and percentage standard deviations of different litter components in low pole forest.

Excel	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}
Leaves	3426.1	79.0	1789.0	9523.9	2505.9	298.0	122.7	9.4
SD leaves	917.2	31.6	574.1	2476.6	536.3	110.5	62.4	3.7
% SD leaves	*22.0*	*37.9*	*32.5*	*26.4*	*21.8*	*33.3*	*40.7*	*39.9*
Branch	4076.5	88.8	1375.6	9207.7	1611.5	295.2	123.2	5.8
SD branch	1140.7	49.6	882.2	3661.3	628.0	123.2	55.00	3.4
% SD branch	*29.3*	*49.8*	*69.4*	*37.9*	*41.9*	*27.7*	*42.1*	*58.0*
Reproductive	7874.7	242.4	3629.0	5443.2	1919.1	247.0	90.3	3.7
SD reprod	1024.0	74.6	1284.9	1881.4	457.3	74.2	19.5	1.7
% SD reprod	*15.1*	*33.2*	*35.6*	*32.3*	*22.0*	*30.0*	*23.3*	*51.1*
Others	7737.6	262.5	1658.4	8618.0	1787.5	322.8	307.1	7.9
SD others	1746.5	104.0	526.3	2418.3	371.4	59.7	224.0	3.0
% SD others	*22.3*	*37.2*	*32.2*	*26.2*	*30.3*	*18.7*	*57.9*	*36.9*

3.4.4.2. Temporal variation of nutrient concentration in litterfall

The 4-weekly concentrations of nutrients (N, P, K, Ca, Mg, Na, Fe, and Mn) during the one-year study period in each different component of litterfall are presented in Figures 3.4.5.a to 3.4.12.a (MSF) and Figures 3.4.5.b. to 3.4.12.b. (LPF).

Nitrogen (Figures 3.4.5.a. in MSF and 3.4.5.b. in LPF).

In mixed swamp forest (MSF), nitrogen concentration variation in leaves is quite large ranging between 3184.57±781.08 and 7153.56±7153.56 mg kg $^{-1}$ with mean of 5527.68±1525.36 mg kg^{-1}. Similarly to leaves, nitrogen concentration of branches is also quite large with a range from 4389.88±2382.85 to 8209.12±3121.77 mg kg^{-1} and mean of 5769.57±1525.36 mg kg^{-1}. The highest and most variable values of nitrogen concentration occur in reproductive parts with a range between 6206.33±1152.25 and 20365.51±0.00 mg kg $^{-1}$ (only one sample available) and mean of 11055.31±2375.05 mg kg^{-1}. The mean of nitrogen concentration in reproductive parts is nearly twice that of leaves. The nitrogen content of other debris ranges from 6931.90±5299.39 to 11636.16±68.05 mg kg-1 with a mean of 9493.20±1586.19 mg kg^{-1}. The highest value occurred during the period 14 October-9 November 2001 and the lowest during 22 July-18 August 2001.

Similarly to the mixed swamp forest (MSF), in low pole forest (LPF) nitrogen concentration range in leaves is relatively large from 1465.71±192.91 to 6604.70±5397.88 mg kg^{-1} and mean 3426.15±917.16 mg kg^{-1}. Similarly to leaves, nitrogen concentration of branches is also relatively large ranging from 1267.69±369.56 to 5803.48±885.30 mg kg^{-1} with a mean of 4076.49±1140.74 mg kg^{-1}. Similar to MSF, LPF also shows most fluctuation and highest nitrogen values in reproductive parts within the range 5330.06±1774.89 to 11877.15±1507.15 mg kg^{-1} and mean 7874.70±1024.02 mg kg^{-1}. The highest nitrogen concentration in reproductive parts occurred during 6 January-3 February 2001 with mean of 11877.15±1507.15 mg kg^{-1} while the lowest was obtained in 9 December 2000-5 January 2001 with mean 5330.06±1774.89 mg kg^{-1}. The lowest nitrogen concentration fluctuation was obtained for other debris with a range between 5282.03±1948.43 to 10322.43±3478.15 mg kg^{-1} and mean of 7737.62±1746.51 mg kg^{-1}. The highest nitrogen concentration of other debris occurred during 22 July-18 August 2001 with mean of 10322.43±3478.15 mg kg^{-1}. In contrast, the lowest nitrogen concentration was during 24 June-21 July 2001 with 5282.03±1948.43 mg kg^{-1}.

In general, nitrogen concentration of each litter component in MSF was higher than in LPF. Student 't' test (Appendix 4) between nitrogen concentration in leaves, branches, reproductive parts, and other debris between MSF and LPF shows significant differences.

Phosphorus (Figures 3.4.6.a. in MSF and 3.4.6.b. in LPF).

In mixed swamp forest (MSF), similarly to nitrogen concentration, phosphorus concentration variations between 4-weekly sampling periods during the 1-year study period in leaves are relatively large ranging between 62.70±5.61 and 207.98±48.15 mg kg^{-1} with mean of 121.38±32.71 mg kg^{-1}. Phosphorus concentration of branches is also relatively large ranging from 72.42±88.68 to 184.36±148.41 mg kg^{-1} with mean of 120.02±57.64 mg kg^{-1}. The highest and the most variable values of phosphorus concentration occur in reproductive parts with a range between 212.82±37.69 and 633.82±0.00 mg kg^{-1} (only one sample available) and mean of 392.15±79.24 mg kg^{-1}. The phosphorus concentration of other debris ranges from 242.47±41.52 to 394.98±148.24 mg kg^{-1} with a mean 313.74±61.23 mg kg^{-1}. The highest phosphorus concentration occurred during 24 June- 21 July 2001 and the lowest during 8-31 March 2001.

In low pole forest (LPF), phosphorus concentration in leaves is large ranging between 35.88±9.68 and 172.57±104.06 mg kg^{-1} with a mean of 79.04±31.62 mg kg^{-1}. Similarly to leaves, phosphorus concentration of branches is also large ranging from 34.79±8.87 to 211.19±126.19 mg kg^{-1} with a mean of 88.77±49.63 mg kg^{-1}. The most fluctuating and highest phosphorus value occurred in reproductive part with a range from 107.10±50.06 to 635.90±267.38 mg kg $^{-1}$ and mean of 242.42±74.61 mg kg^{-1}. The highest phosphorus concentration in reproductive parts occurred during 1-28 April 2001 with mean of 635.90±267.38 mg kg $^{-1}$, while the lowest was obtained during 10 November- 8 December 2000 with mean of 107.10±50.06 mg kg^{-1}. The lowest phosphorus concentration fluctuation was obtained for others debris with a range between 168.89±54.19 to 425.90±294.95 mg kg^{-1} and mean of 262.48±103.98 mg kg^{-1}. The highest nutrient concentration of others debris occurred during 14 October- 9 November 2001 with mean of 425.90±294.95 mg kg^{-1}. In contrast, the lowest phosphorus concentration of 168.89±54.19 mg kg^{-1}occurred during 27 May-23 June 2001.

Similarly to nitrogen concentration, phosphorus in litter from MSF is higher than that from LPF in each litter component. Student 't' test showed these differences to be significant for leaves, reproductive parts, and other debris but not for branches.

<u>Potassium </u>(Figures 3.4.7.a. in MSF and 3.4.7.b. in LPF).

In mixed swamp forest (MSF), potassium concentration in leaves during the 1-year study periodsranged from 1873.73±923.51 to 4292.50±1263.35 mg kg $^{-1}$ with mean of 3097.72±912.63 mg kg^{-1}. Potassium concentration of branches ranged from 1146.60±1528.31 to 3686.32±2088.82 mg kg^{-1} with mean of 2114.22±1336.83 mg kg^{-1}. Potassium concentration in reproductive parts is higher than in all other litter components and ranged between 2697.26±893.02 and 6234.52±3108.20 mg kg^{-1} with a mean of 4781.76±2184.36 mg kg^{-1}. Potassium un unclassified debris (other debris) ranged between 1897.33±191.25 and 4501.01±923.50 mg kg^{-1} with a mean of

2643.36±615.61 mg kg^{-1}. The highest potassium concentration in other occurreds during 19 August-15 September 2001 with mean of 4501.01±923.50 mg kg^{-1}. In contrast, the lowest potassium concentration occurred during 6 January- 3 February 2001 with mean of 1897.33±191.25 mg kg^{-1}.

In low pole forest (LPF), potassium concentration for leaves ranged between 1046.83±158.03 and 2429.13±602.68 mg kg^{-1} with mean of 1789.00±574.08 mg kg^{-1}. Other debris ranged from 938.30±334.56 to 2851.73±437.90 mg kg^{-1} with mean of 1658.36±526.32 mg kg^{-1}. Potassium concentration in branches was ranged widely from 658.13±501.15 to 3182.27±2526.27 mg kg^{-1} with mean of 1375.59±882.18 mg kg^{-1}. The greatest fluctuation and highest potassium value occurred in reproductive parts with a range between 1520.00±0.00 and 6576.50±0.00 mg kg $^{-1}$(only one sample available) with mean of 3629.05±1284.90 mg kg^{-1}. The highest potassium concentration of reproductive parts occurred during 24 June-21 July 2001 with mean of 6576.50±0.00 mg kg^{-1} (only one sample available), while the lowest was during 14 October- 9 November 2001 with mean of 1520.00±0.00 mg kg^{-1} (only one sample available).

Similarly to nitrogen and phosphorus concentration, potassium concentration in MSF generally was higher than in LPF. 'T' test between leaves, branch, reproductive part and other debris categories in MSF and LPF showed these differences to be significantly different.

Calcium (Figures 3.4.8.a. in MSF and 3.4.8.b. in LPF).

In mixed swamp forest (MSF), calcium concentration in leaves is relatively stable compared to branches during study periods with a range between 9371.39±631.10 and 13979.65±2258.43 mg kg^{-1} and mean of 11378.49±2074.18 mg kg^{-1}. Calcium concentration in branches is the most fluctuating with a range from 8648.18±2974.83 to 20224.76±20451.47 mg kg^{-1} and mean of 14465.22±5989.86 mg kg^{-1}. The lowest calcium concentration in branches occurred during 10 November-8 December 2000 with mean of 8648.18±2974.83 mg kg^{-1}. In contrast, the highest calcium concentration was during 29 April- 26 May 2001 with 20224.76±20451.47 mg kg^{-1}. Calcium concentration in other debris ranged from 6762.77±1108.84 to 11686.00±3365.40 mg kg^{-1} with mean of 9005.28±1429.79 mg kg^{-1}. The mean calcium concentration in reproductive parts was lower than other debris at 5475.56±2112.68 mg kg^{-1}.

In low pole forest (LPF), calcium concentration from leaves ranged between 7656.59±1444.60 and 11972.55±1682.86 mg kg^{-1} with mean of 9523.88±2476.61 mg kg^{-1}. Calcium concentration from branches fluctuated more than leaves ranging from 4737.47±1744.15 to 13266.37±8647.75 mg kg^{-1} with mean of 9207.72±3661.33 mg kg^{-1}. The greatest fluctuation of calcium concentration was in reproductive parts with a range between 1510.00±0.00 and 9989.47±2745.10 mg kg^{-1} with mean of 5443.24±1881.37 mg kg^{-1}. The highest calcium concentration in reproductive parts was detected during 9 December 2000-5 January 2001 with mean of 9989.47±4351.85 mg kg^{-1} while the lowest was during 24 June-21 July 2001 with mean of 1510.00±0.00 mg kg^{-1} (one sample only). Calcium concentration for other debris ranged between 7134.89±928.00 and 12697.29±8203.44 mg kg^{-1} with mean of 8618.02±2418.30 mg kg^{-1}. The highest calcium concentration in other debris occurred during 14 October-9 November 2001 with mean of 12697.29±8203.44 mg kg^{-1}. In contrast, the lowest calcium concentration was during 19 August-15 September 2001 with mean of 7134.89±928.00 mg kg^{-1}. In order of abundance, the calcium concentration in LPF are as follows:

leaves> branches> other debris>reproductive parts.

Similarly to nitrogen, phosphorus, and potassium concentration, calcium concentration in MSF all litter components were higher than in LPF. 'T' test showed that these differences were significant betweenbetween leaves and branches in MSF and LPF but not for reproductive parts and other debris.

Magnesium (Figures 3.4.9.a. in MSF and 3.4.9.b. in LPF).

In mixed swamp forest (MSF), magnesium concentration in leaves is the highest compared to other litter component during the 4-week study periods with a range between 1984.90±472.23 and 3217.45±403.48 mg kg^{-1} and mean of 2678.06±439.95 mg kg^{-1}. Magnesium concentration of branches was the smallest ranging from 1400.45±1123.15 to 2531.28±731.91 mg kg^{-1} and mean of 1899.11±891.47 mg kg^{-1}. The lowest magnesium concentration in branches was found during 24 June-21 July 2001 with mean of 1400.45±1123.15 mg kg^{-1}. In contrast, the highest magnesium concentration occurred during 6 January-3 February 2001 with mean of 2531.28±731.91 mg kg^{-1}. Magnesium concentration of reproductive parts ranged between 1651.05±468.36 and 3626.46±0.00 mg kg^{-1} (only one sample available) with mean of 2303.08±537.36 mg kg^{-1}. The highest magnesium concentration of 3626.46±0.00 mg kg^{-1} occurred during 4 February-7 March 2001 (one sample available) while the lowest was during 16 September-13 October 2001 at 1651.05±468.36 mg kg^{-1}. Magnesium concentration in other debris is relatively stable compared to other litter component and ranged from 1727.27±101.73 to 2584.59±488.88 mg kg^{-1} with mean of 2025.80±323.70 mg kg^{-1}.

In low pole forest (LPF), magnesium concentration in leaves ranged between 1918.88±448.03 and 3182.89±999.66 mg kg^{-1} with mean of 2505.93±536.27 mg kg^{-1}. Magnesium concentration of branches fluctuated more than leaves ranging from 995.23±703.64 to 2533.77±313.08 mg kg^{-1} with mean of 1611.50±628.04 mg kg^{-1}. Magnesium concentration in reproductive parts ranged between 1044.50±0.00 (one sample) and 2745.10±1340.07 mg kg^{-1} with mean of 1919.14±457.32 mg kg^{-1}. The mean of magnesium concentration in other debris was nearly the same as that in branches at 1787.54±371.38 mg kg^{-1}. In order of abundance, the magnesium concentration in LPF are as follows:

leaves>reproductive parts > other debris > branches

Similarly to calcium, magnesium litter concentration in MSF was higher than that in LPF in each litter component. 'T' test showed that magnesium concentration in reproductive parts and other debris were significantly different between MSF and LPF while leaves and branches are not.

Sodium (Figures 3.4.10.a. in MSF and 3.4.10.b. in LPF).

In mixed swamp forest (MSF), the range of sodium concentration in leaves was between 191.66±46.81 and 478.34±61.57 mg kg^{-1} with mean of 309.48±91.83 mg kg^{-1}. Reproductive parts ranged from 141.62±10.13 to 517.50±97.02 mg kg^{-1} with mean of 305.01±93.08 mg kg^{-1}. Sodium concentration in branches was relatively higher than in reproductive parts with a range from 169.48±56.99 to 551.84±59.44 mg kg^{-1} and mean of 327.26±82.57 mg kg^{-1}. The highest sodium concentration was in other debris with a range between 185.56±26.45 and 567.07 mg kg^{-1} with mean 364.21±62.90 mg kg^{-1}. The highest value occurred during 19 August-15 September 2001 and the lowest during 9 December 2000- 5 January 2001. In order of abundance, the sodium concentration in MSF are as follows:

other debris> branches> leaves> reproductive parts

Similarly to mixed swamp forest, the highest mean value for sodium concentration in low pole forest (LPF) was in other debris with a range from 169.91±44.82 to 499.01±92.08 mg kg^{-1} and mean of 322.83±59.67. In contrast, reproductive parts had the lowest sodium concentration with mean of 246.98±74.20 mg kg^{-1}. The higher sodium concentration in reproductive parts occurred during 22 July-18 August 2001 with mean of 499.01±92.08 mg kg^{-1} while the lowest value was during 4 February-7 March 2001 with mean of 169.91±44.82 mg kg^{-1}. Sodium concentration in branches ranged between 129.29±15.98 and 847.87±907.71 mg kg^{-1} with mean of 295.23±123.19 mg kg^{-1}. Leaves exhibited less fluctuation from 146.49±34.11 to 495.89±190.51 mg kg^{-1} with mean of 297.97±110.51 mg kg^{-1}.

In general, sodium concentration in each litter component in MSF was higher than in LPF. Comparison between sodium in reproductive parts in MSF and LPF are significantly different . In contrast, sodium concentrations in leaves, branches, and other debris were not significantly different between MSF and LPF.

Iron (Figures 3.4.11.a. in MSF and 3.4.11.b. in LPF).

In mixed swamp forest (MSF), iron concentrations in each litter component were relatively low with mean values less than 500 mg kg^{-1}. Iron concentration in leaves during the 1-year study period ranged from 29.27±10.72 to 311.59±440.42 mg kg^{-1} with mean of 150.38±96.54 mg kg^{-1}. Iron concentration in branches was the lowest compared to the other litter components with mean of 139.51±59.50 mg kg^{-1}. In contrast, the highest iron concentration was obtained in other debris with a range from 122.45±37.26 to 2296.63±3698.42 mg kg^{-1} and mean of 406.43±378.18 mg kg^{-1}. The highest value was during 29 April – 26 May 2001 and the lowest during 4 February – 7 March 2001.

In low pole forest (LPF), iron concentration in leaves ranged between 37.71±9.60 and 282.60±324.79 mg kg^{-1} with mean of 122.67±62.45 mg kg^{-1}. Iron concentration of branches ranged from 35.60±42.40 to 262.03±202.18 mg kg^{-1} with mean of 123.23±54.99 mg kg^{-1}. Similarly to MSF, the greatest fluctuation of iron concentrations in LPF was in other debris with a range between 112.72±41.26 and 979.44±1186.92 mg kg^{-1} and mean of 307.09±223.98 mg kg^{-1}.

Comparison of iron concentration of leaves, branch and other debris showed that these were not significantly different between MSF and LPF but that reproductive parts values were.

Manganese (Figures 3.4.12.a. in MSF and 3.4.12.b. in LPF).

In general, manganese concentration in both sub-types of forest, MSF and LPF are low with mean values less than 20 mg kg^{-1}. In mixed swamp forest (MSF), manganese concentration variation in leaves is quite small with the range between 12.26±1.74 and 23.00±7.99 mg kg^{-1} and mean of 17.80±6.04 mg kg^{-1}. Similarly to leaves, manganese concentration in branches is also quite small with a range from 5.05±3.35 to 16.17±5.13 mg kg^{-1} and mean of 11.46±6.24 mg kg^{-1}. Manganese concentration in other debris ranged between 7.60±3.10 and 20.66±2.76 mg kg^{-1} and mean of 13.29±5.07 mg kg^{-1}. The manganese content of reproductive parts was less, with a range from 5.80±1.14 to 14.37±13.59 mg kg^{-1} and mean of 10.50±6.58 mg kg^{-1}. The highest value occurred during 29 April-26 May 2001 and the lowest during 14 October –9 November 2001.

Similarly to the mixed swamp forest (MSF), manganese concentration range in leaves is small in low pole forest (LPF) from 5.38±2.02 to 13.27±5.07 mg kg^{-1} and mean of 9.42±3.69 mg kg^{-1}. Similarly to leaves, manganese concentration in branches is also small ranging from 2.76±0.26 to 9.86±2.72 mg kg^{-1} with a mean of 5.81±3.36 mg kg^{-1}. Manganese concentration values in reproductive parts lay within the range 1.51±0.71 to 8.31±2.20 mg kg^{-1} and mean of 3.68±1.74 mg kg^{-1}. The highest manganese concentration in reproductive parts occurred during 4 February-7 March

2001 with 8.31±2.20 mg kg^{-1} while the lowest was obtained in 8-31 March 2001 with 1.51±0.71 mg kg^{-1} only. Manganese concentration in other debris ranged between 3.34±1.59 and 14.82±11.84 mg kg^{-1} and mean of 7.87±3.02 mg kg^{-1}. The highest manganese concentration of other debris occurred during 6 January – 3 February 2001 with 14.82±11.84 mg kg^{-1}. In contrast, the lowest manganese concentration was during 9 December 2000 – 5 January 2001 with 3.34±1.59 mg kg^{-1}.

'T' tests of manganese concentration in leaves, branch, reproductive part, and other debris between MSF and LPF showed them all to be significantly different.

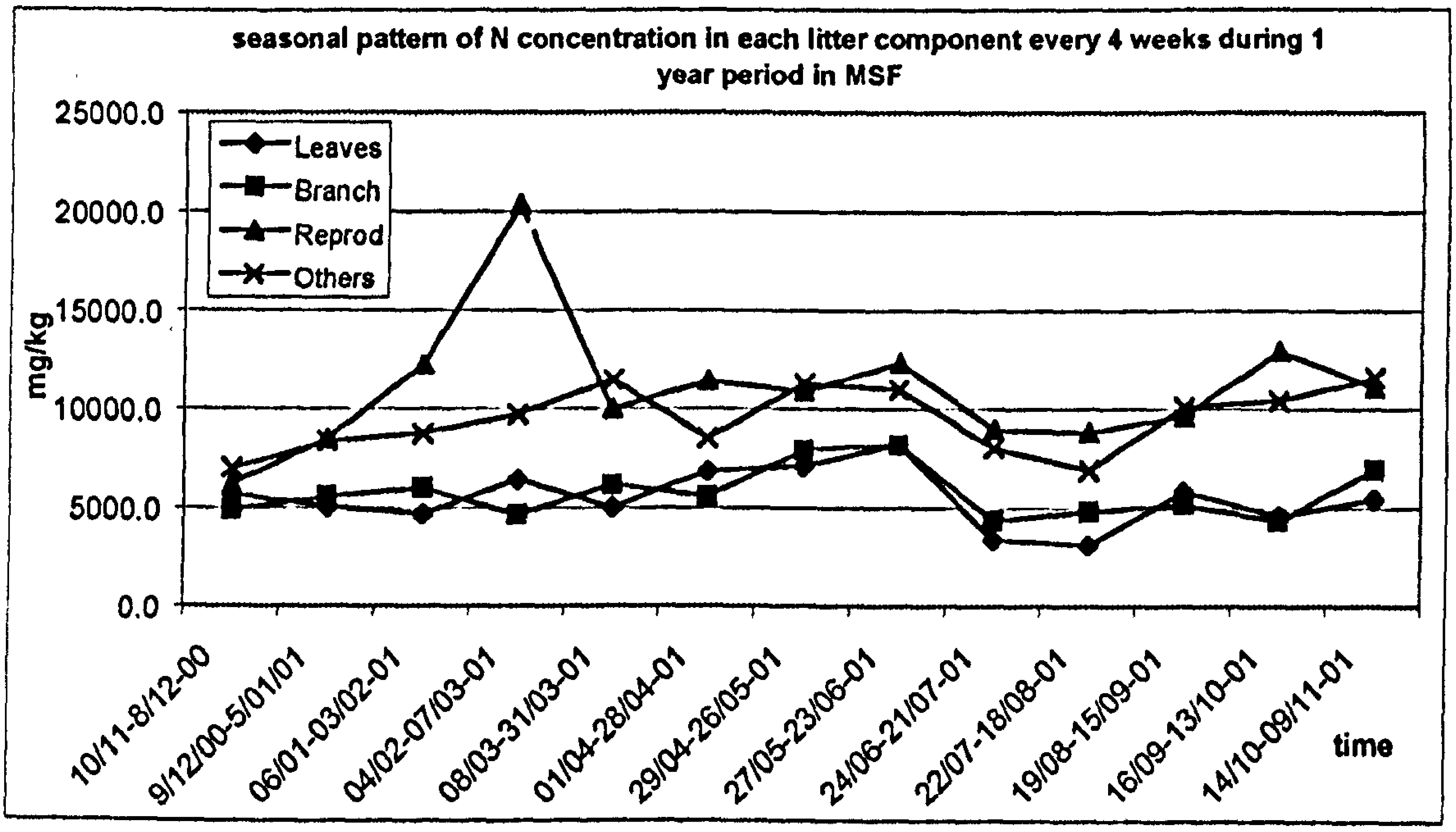


Figure 3.4.5.a.: Seasonal pattern of N concentration in each litter component every 4 weeks during 1 year period in MSF

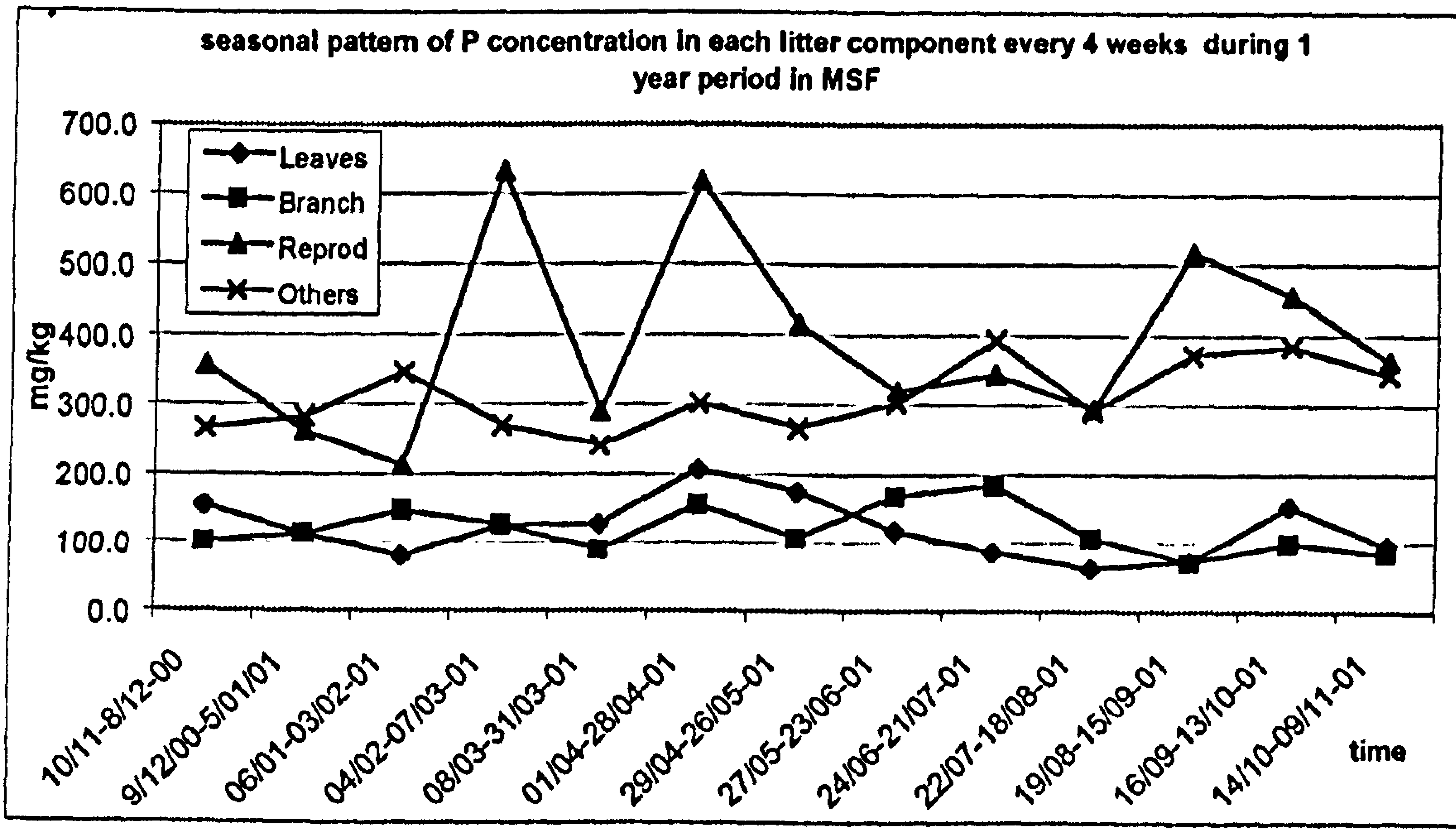


Figure 3.4.6.a.: Seasonal pattern of P concentration in each litter component every 4 weeks during 1 year period in MSF

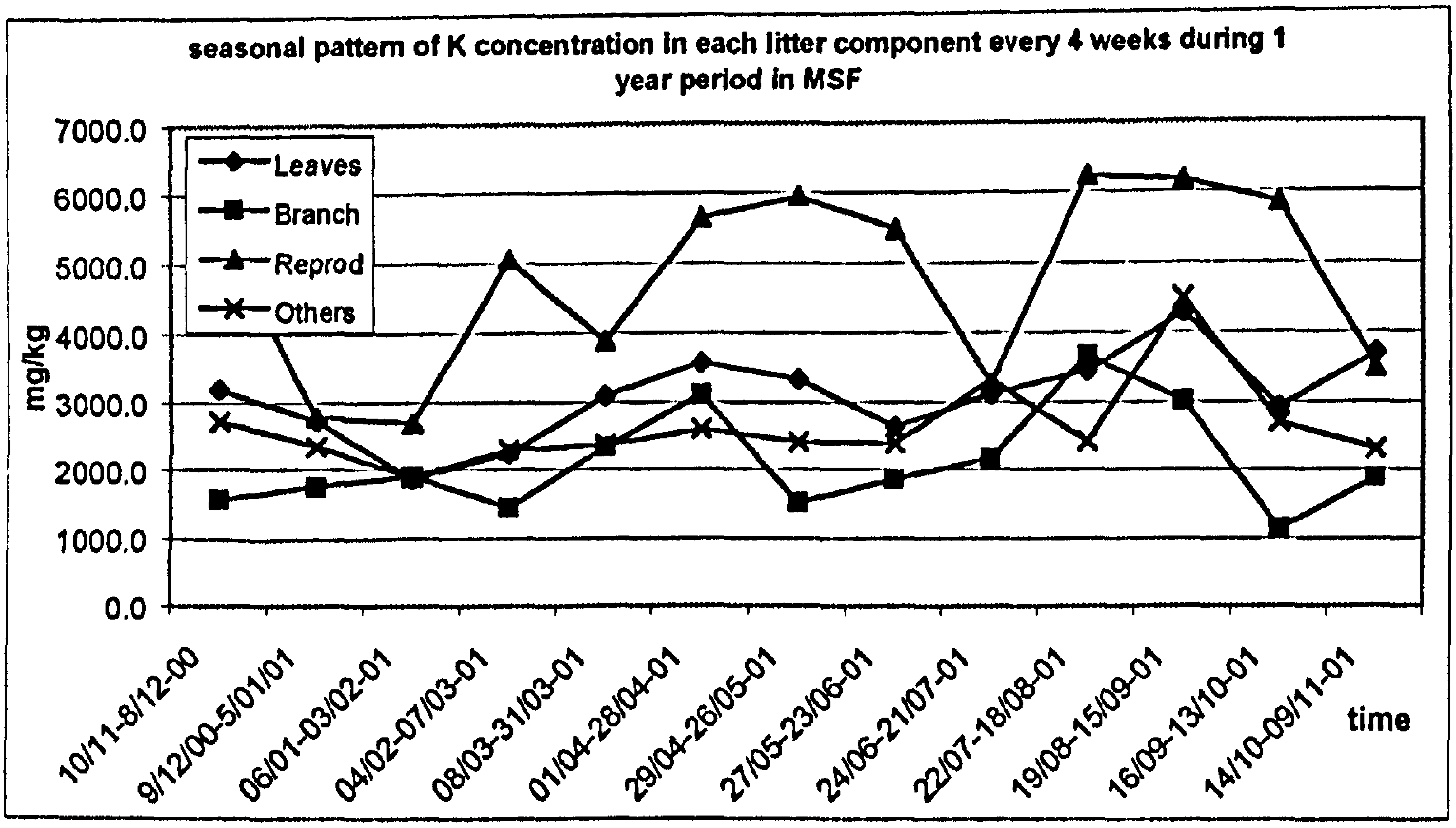


Figure 3.4.7.a.: Seasonal pattern of K concentration in each litter component every 4 weeks during 1 year period in MSF

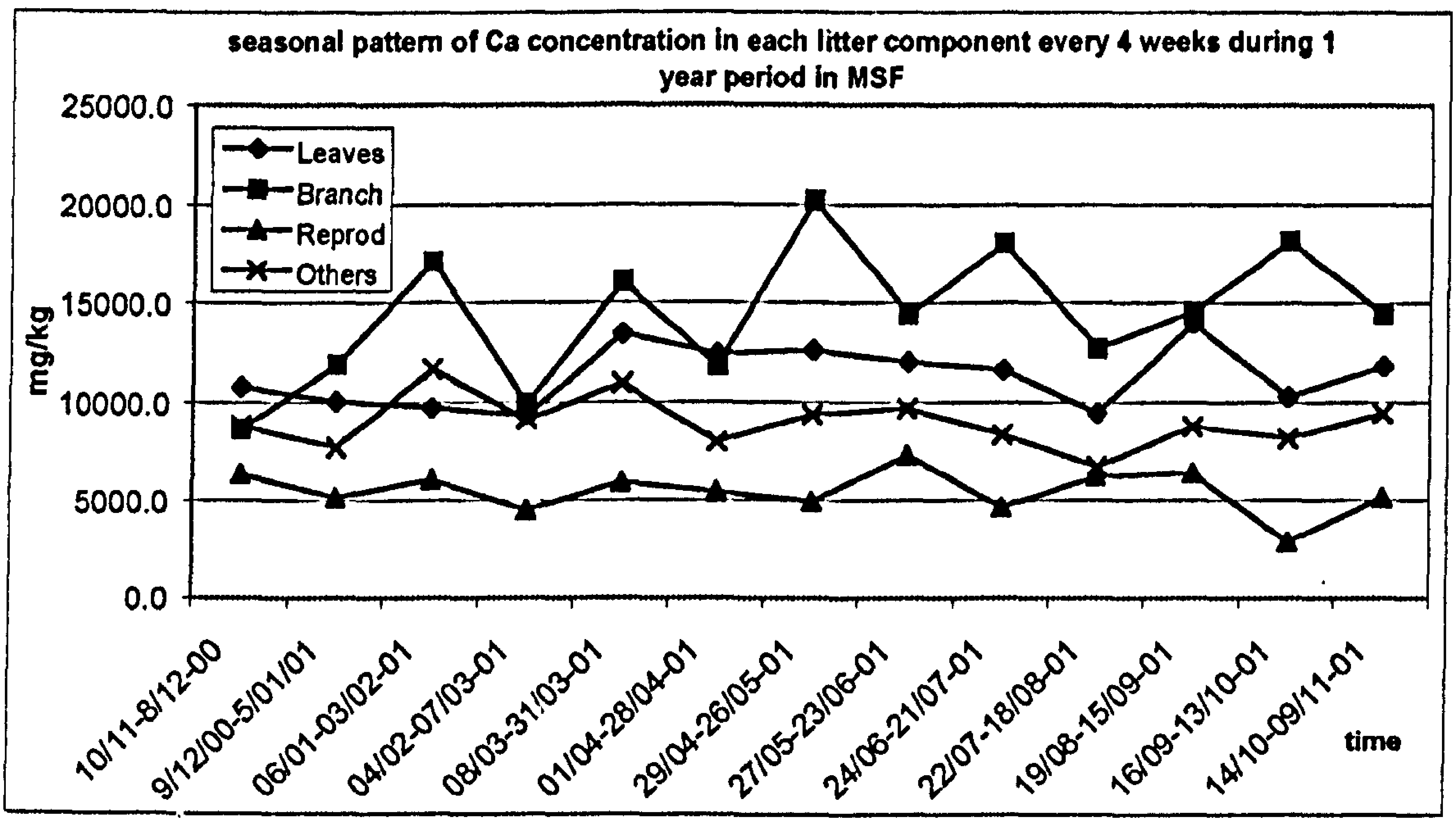


Figure 3.4.8.a.: Seasonal pattern of Ca concentration in each litter component every 4 weeks during 1 year period in MSF

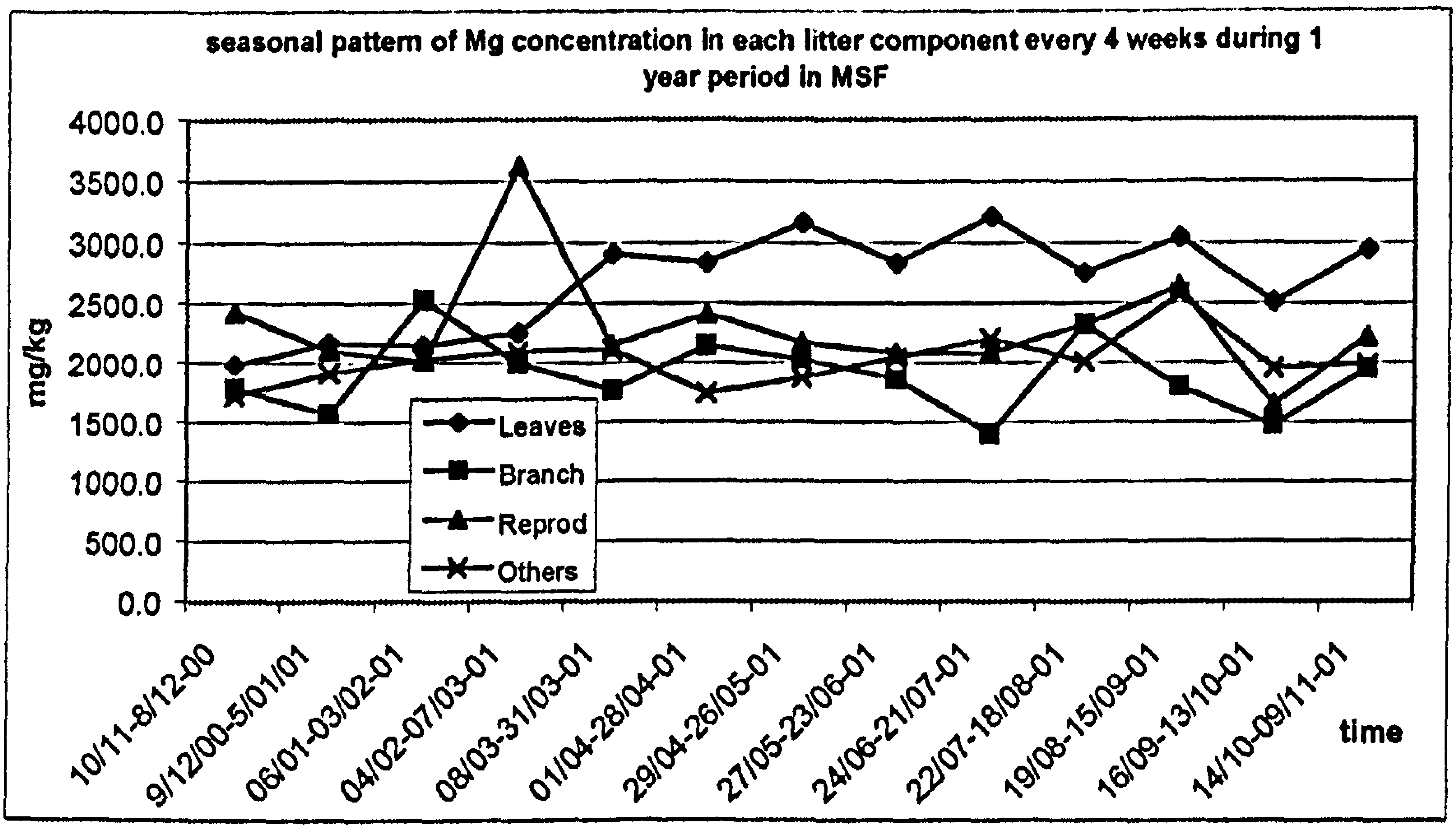


Figure 3.4.9.a.: Seasonal pattern of Mg concentration in each litter component every 4 weeks during 1 year period in MSF

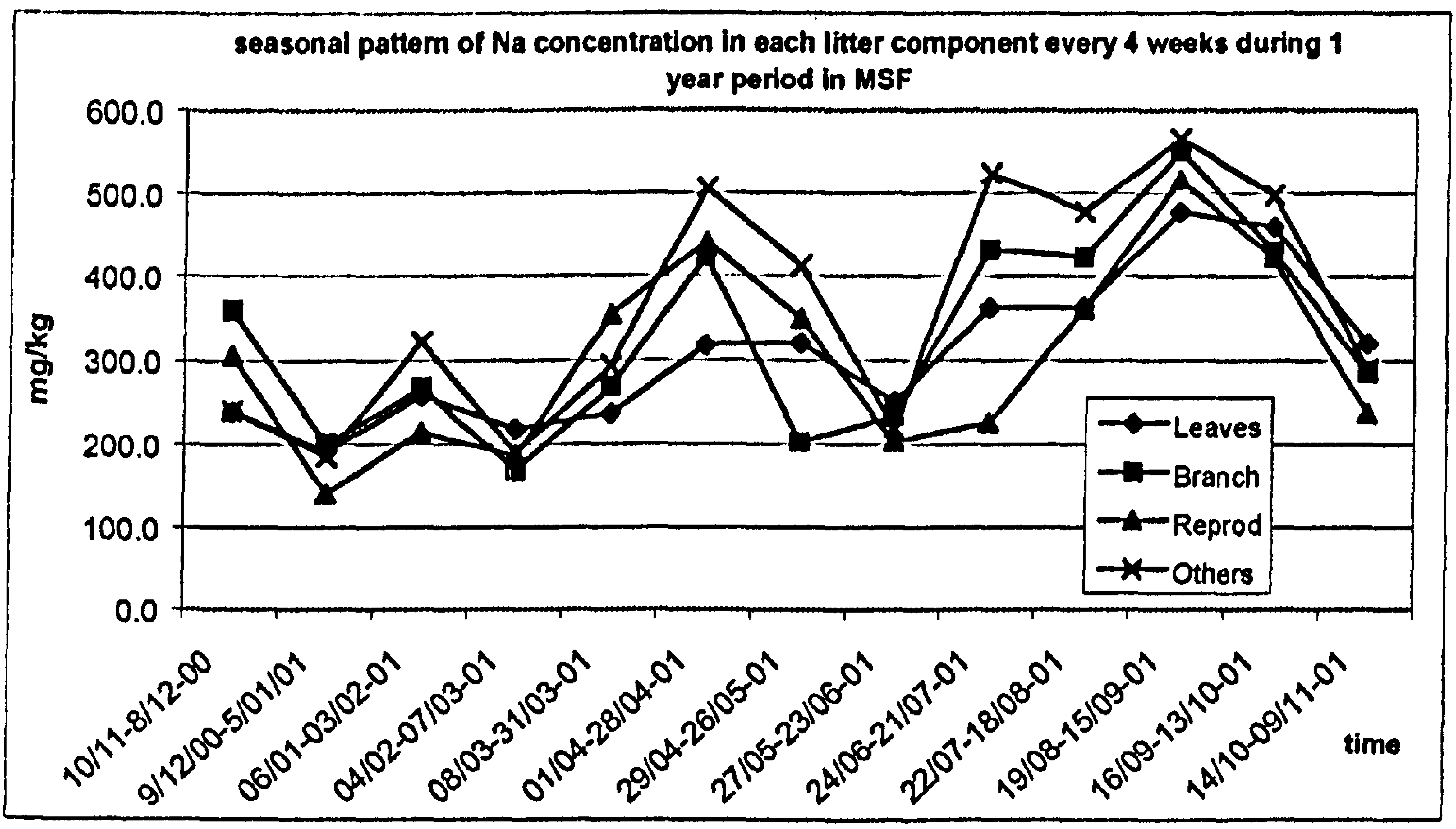


Figure 3.4.10.a.: Seasonal pattern of Na concentration in each litter component every 4 weeks during 1 year period in MSF

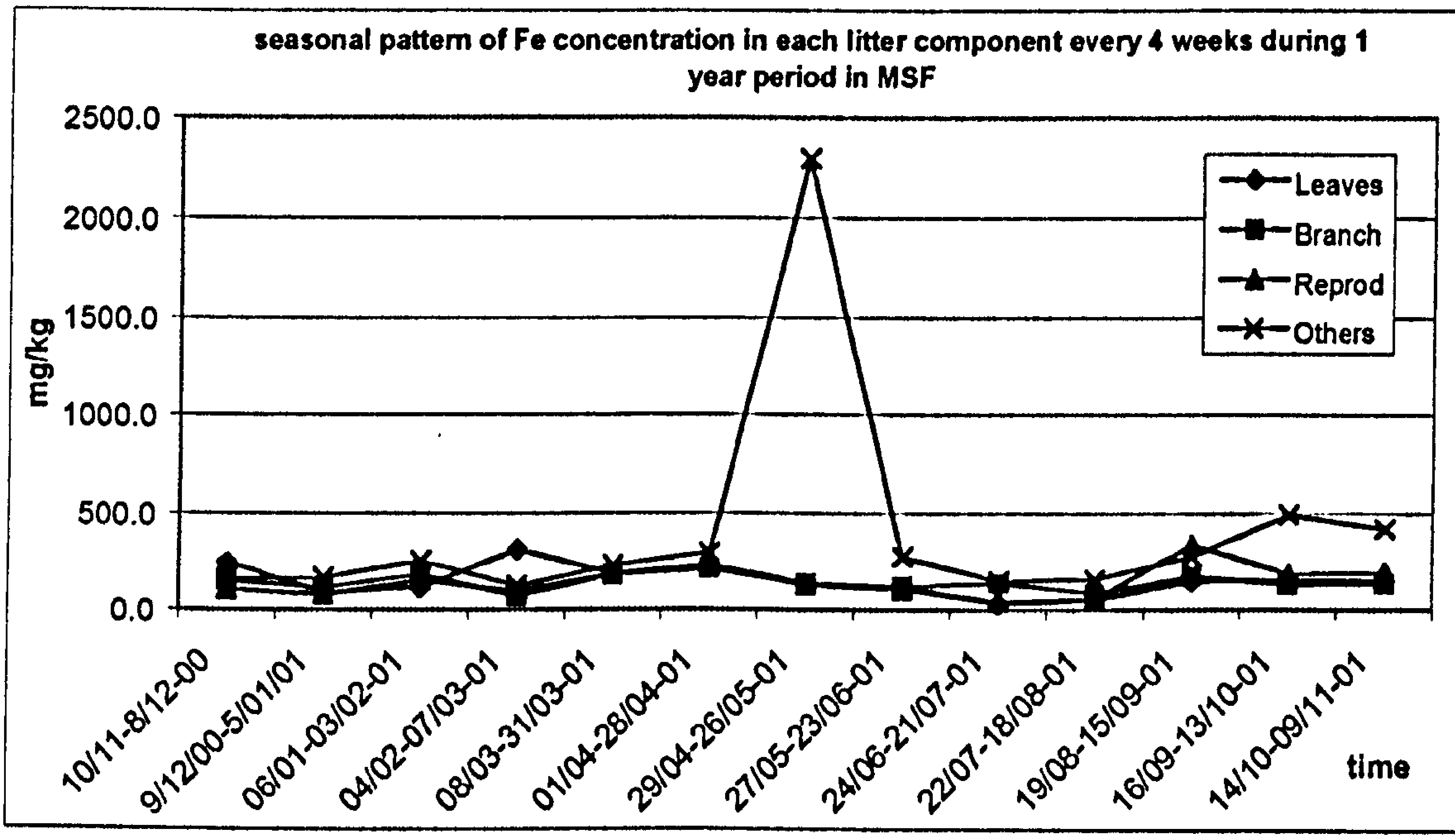


Figure 3.4.11.a.: Seasonal pattern of Fe concentration in each litter component every 4 weeks during 1 year period in MSF

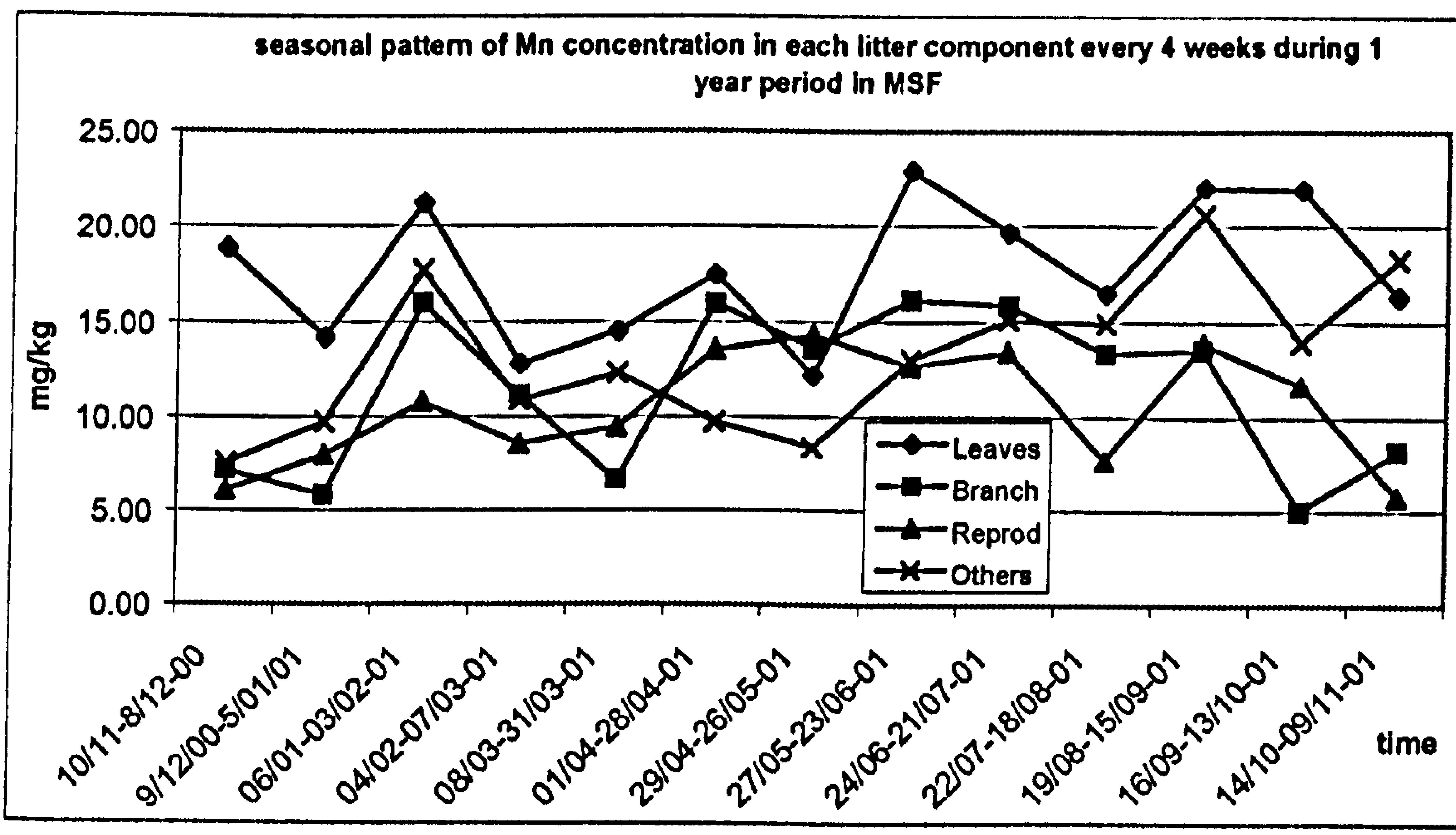


Figure 3.4.12.a.: Seasonal pattern of Mn concentration in each litter component every 4 weeks during 1 year period in MSF

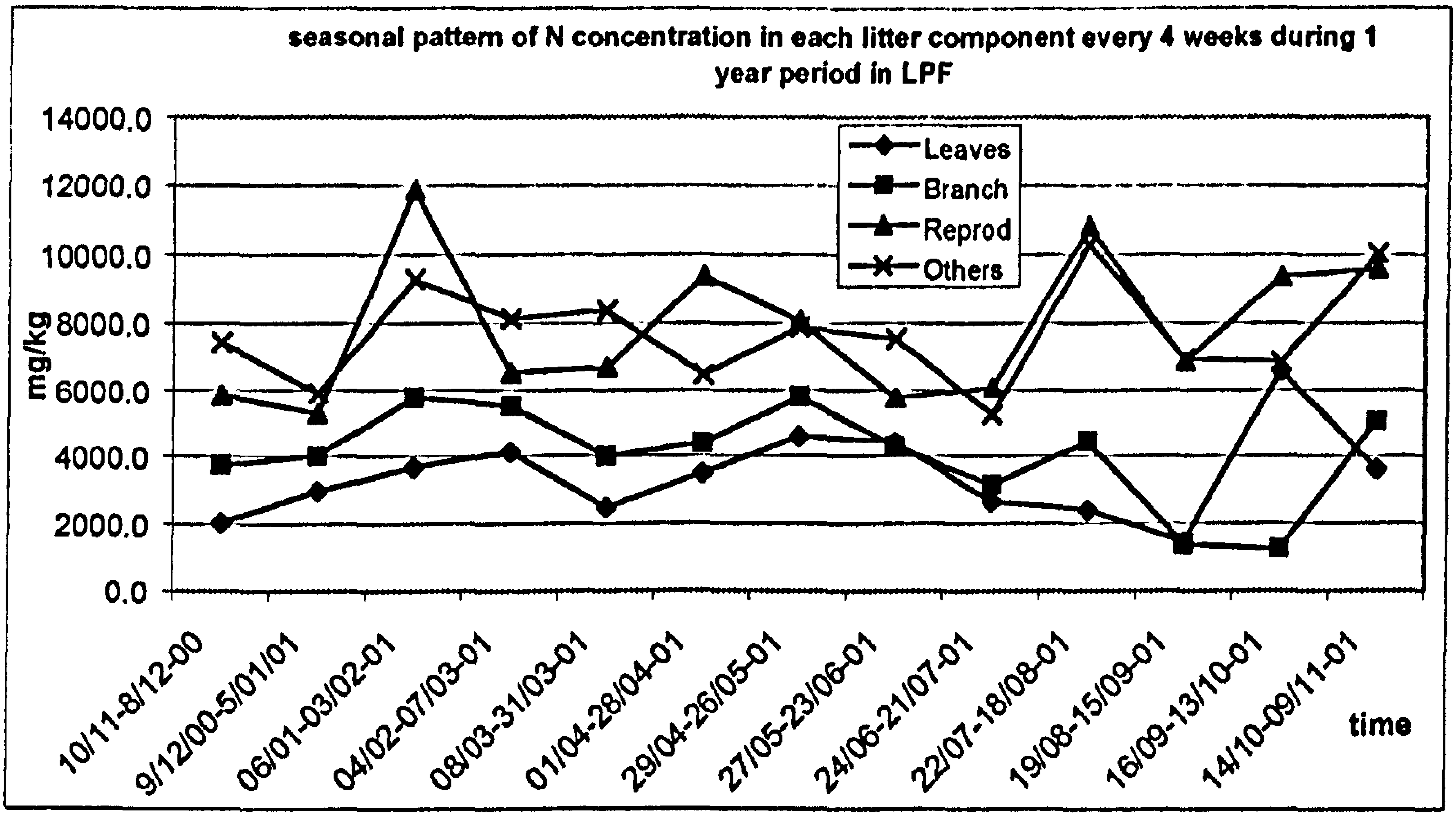


Figure 3.4.5.b.: Seasonal pattern of N concentration in each litter component every 4 weeks during 1 year period in LPF

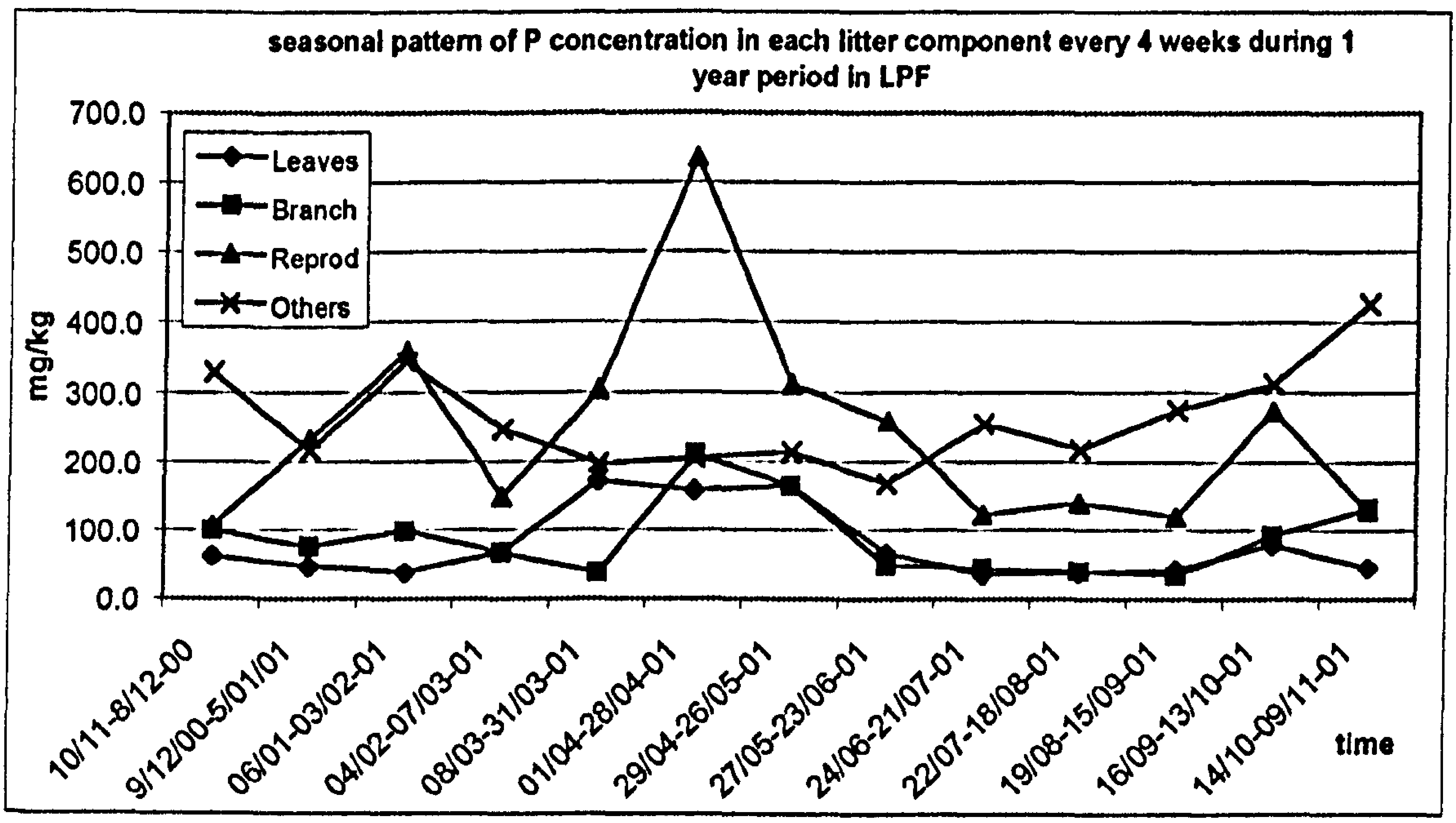


Figure 3.4.6.b.: Seasonal pattern of P concentration in each litter component every 4 weeks during 1 year period in LPF

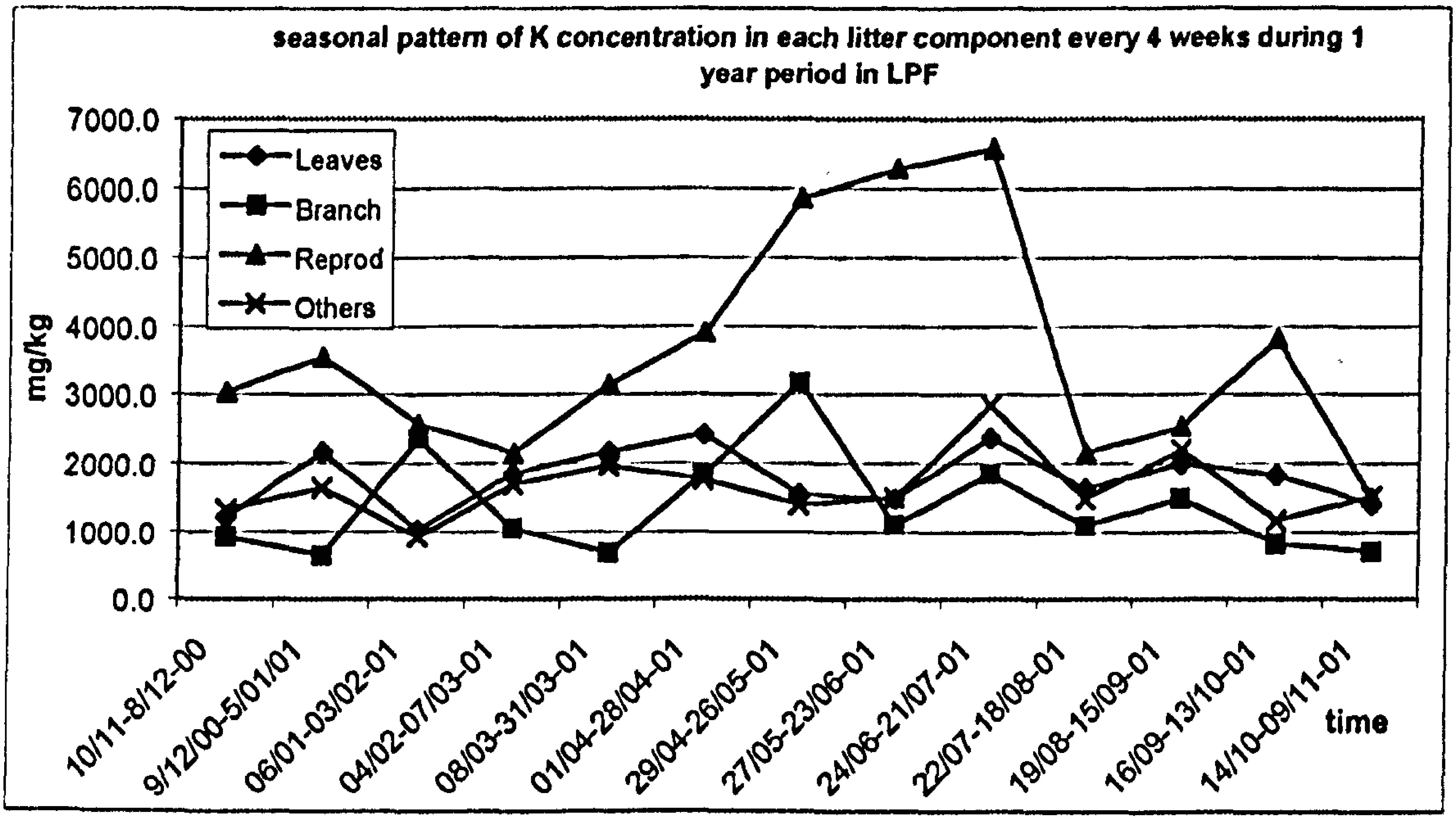


Figure 3.4.7.b: Seasonal pattern of K concentration in each litter component every 4 weeks during 1 year period in LPF

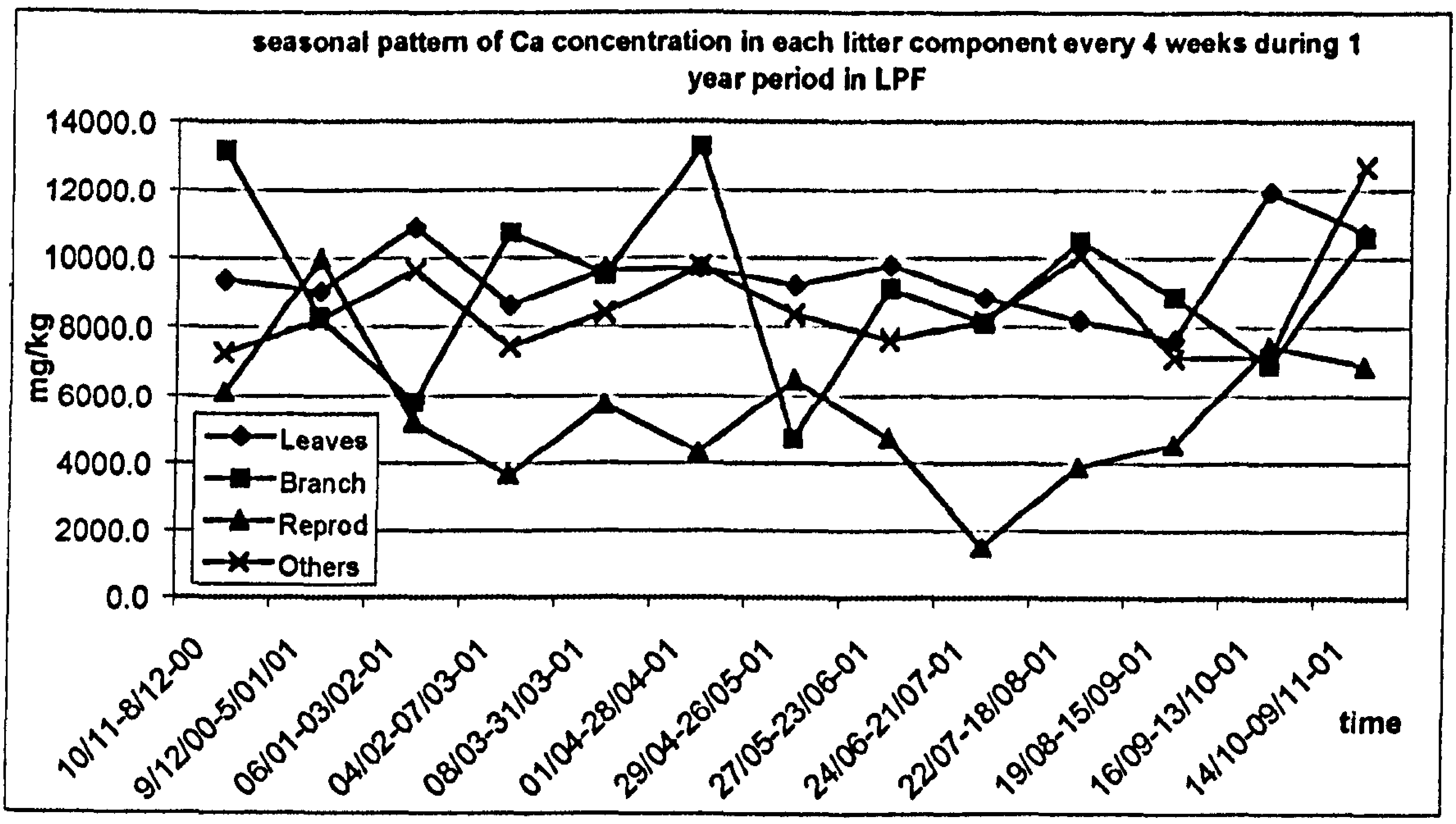


Figure 3.4.8.b: Seasonal pattern of Ca concentration in each litter component every 4 weeks during 1 year period in LPF

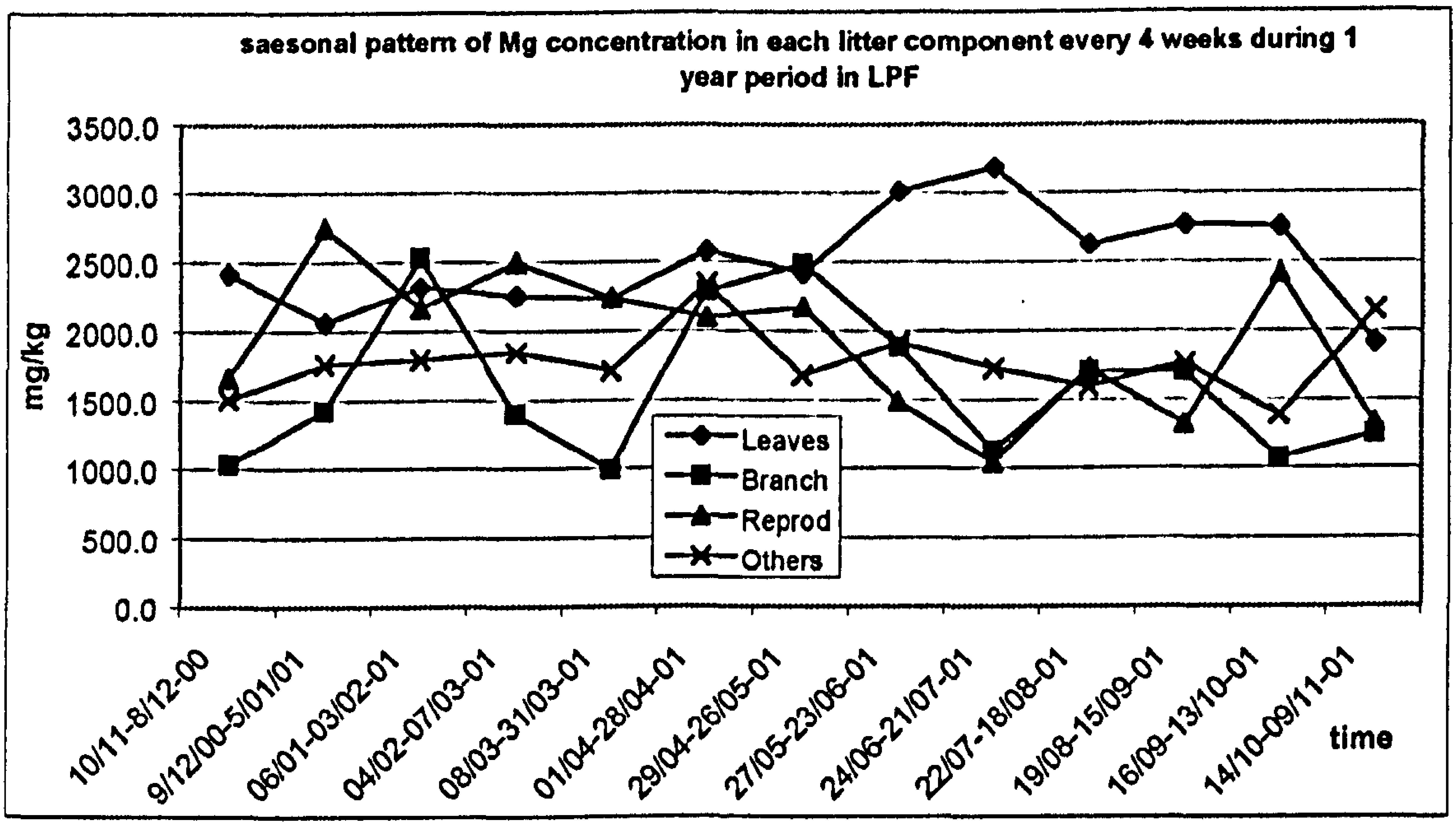


Figure 3.4.9.b.: Seasonal pattern of Mg concentration in each litter component every weeks during 1 year period in LPF

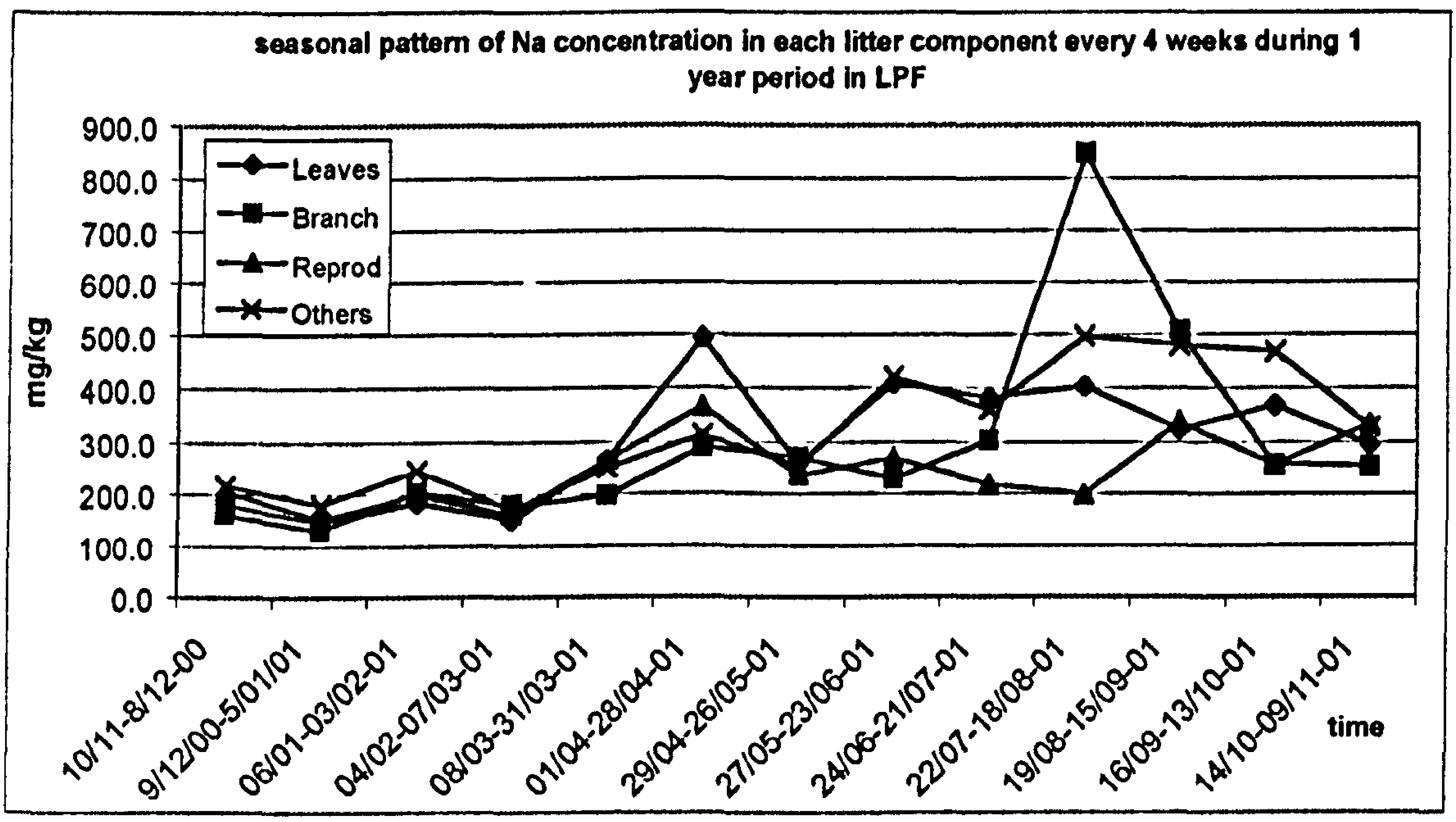


Figure 3.4.10.b.: Seasonal pattern of Na concentration in each litter component every 4 weeks during 1 year period in LPF

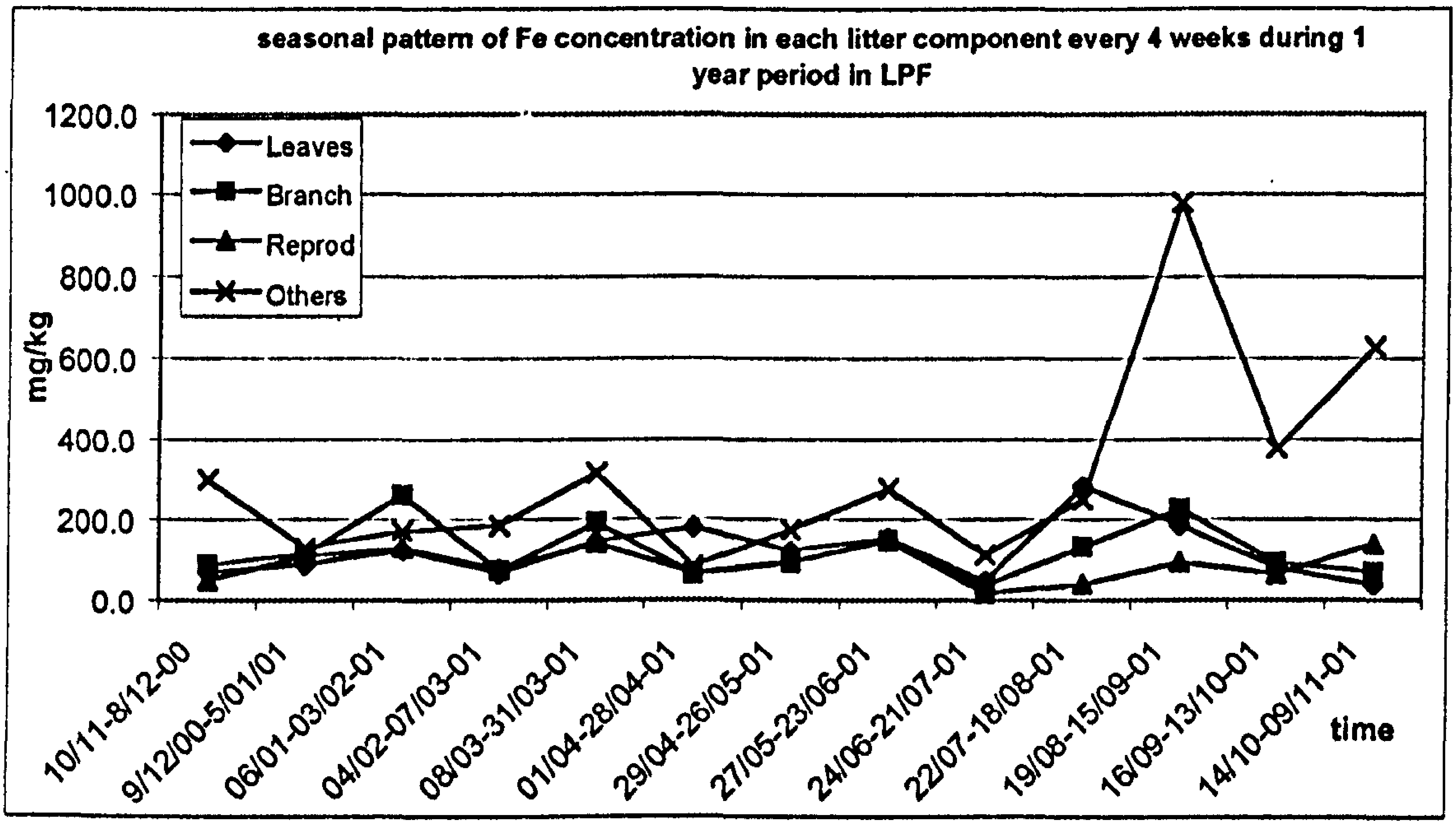


Figure 3.4.11.b.: Seasonal pattern of Fe concentration in each litter component every 4 weeks during 1 year period in LPF

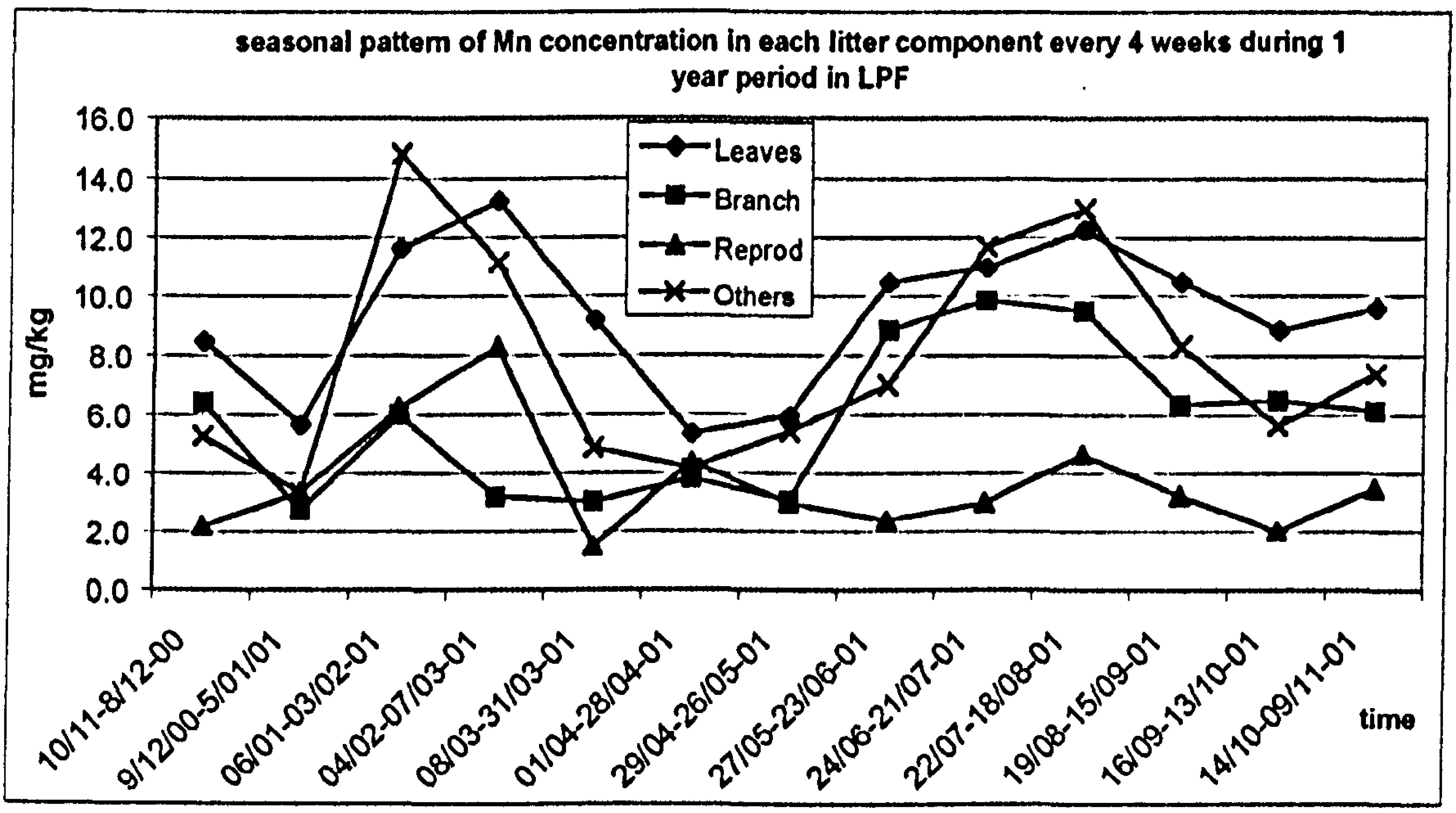


Figure 3.4.12.b.: Seasonal pattern of Mn concentration in each litter component every 4 weeks during 1 year period in LPF

3.4.5. Litter mineral nutrient content

3.4.5. 1. Annual nutrient input in litterfall.

Annual inputs, standard deviations and percentage standard deviations of nitrogen, phosphate, potassium, calcium, magnesium, sodium, iron, and manganese in different litter fractions and total litterfall in the two sub-types of forest are given in Tables 3.4.5. and 3.4.6.

In the mixed swamp forest (Table 3.4.5), annual input in litterfall for all the nutrient elements studied was 197.956±60.44 kg ha^{-1} yr^{-1} with the highest transfer being calcium at 95.326±24.486 kg ha^{-1} yr^{-1}, followed by nitrogen with 50.263±16.913 kg ha^{-1} yr^{-1}. The third place was potassium at 26.125±11.256 kg ha^{-1} yr^{-1}, followed by magnesium (20.830±5.456 kg ha^{-1} yr^{-1}), sodium (2.714±0.912 kg ha^{-1} yr^{-1}), iron (1.351±0.840 kg ha^{-1} yr^{-1}), phosphorus (1.213±0.531 kg ha^{-1} yr^{-1}), and the lowest was manganese contributing only 0.134±0.046 kg ha^{-1} yr^{-1}.

Similarly to total litterfall, calcium was the greatest element in leaf litter with 70.774±14.598 kg ha^{-1} yr^{-1}, followed by nitrogen (34.058±10.510 kg ha^{-1} yr^{-1}), potassium (19.565±7.071 kg ha^{-1} yr^{-1}). The fourth place was magnesium with 16.515±3.704 kg ha^{-1} yr^{-1}, followed by sodium (2.011±0.645 kg ha^{-1} yr^{-1}), iron (0.893±0.534 kg ha^{-1} yr^{-1}), phosphorus (0.722±0.240 kg ha^{-1} yr^{-1}), and manganese (0.110±0.036 kg ha^{-1} yr^{-1}).

Calcium in branches was also the highest nutrient with 17.448±12.402 kg ha^{-1} yr^{-1}, followed by nitrogen with 6.263±3.458 kg ha^{-1} yr^{-1}. Potassium was the third with 2.297±1.901 kg ha^{-1} yr^{-1}, followed by magnesium (2.156±1.385 kg ha^{-1} yr^{-1}), sodium

(0.395±0.285 kg ha^{-1} yr^{-1}), iron (0.164±0.122 kg ha^{-1} yr^{-1}), phosphorus (0.129±0.093 kg ha^{-1} yr^{-1}), and manganese (0.012±0.009 kg ha^{-1} yr^{-1}). In contrast, nitrogen was the highest nutrient in reproductive parts with 5.429±6.720 kg ha^{-1} yr^{-1}, followed by potassium with 2.984±4.245 kg ha^{-1} yr^{-1}, calcium (2.676±3.168 kg ha^{-1} yr^{-1}), magnesium (1.186±1.481 kg ha^{-1} yr^{-1}). After magnesium was phosphorus with 0.211±0.275 kg ha^{-1} yr^{-1}, followed by sodium (0.138±0.154 kg ha^{-1} yr^{-1}), iron (0.058±0.063 kg ha^{-1} yr^{-1}), and manganese (0.006±0.008 kg ha^{-1} yr^{-1}).

Similarly to reproductive parts, nitrogen in other debris was the highest with 4.513±1.607 kg ha^{-1} yr^{-1}, followed by calcium (4.428±1.689 kg ha^{-1} yr^{-1}). The third place was potassium with 1.279±0.564 kg ha^{-1} yr^{-1}, followed by magnesium (0.973±0.334 kg ha^{-1} yr^{-1}), iron (0.235±0.268 kg ha^{-1} yr^{-1}), sodium (0.170±0.059 kg ha^{-1} yr^{-1}), phosphorus (0.151±0.063 kg ha^{-1} yr^{-1}), and manganese (0.006±0.004 kg ha^{-1} yr^{-1}).

Total nutrient elements in different litter components was greatest in leaf litter (144.649±37.338 kg ha^{-1} yr^{-1}), followed by branches (28.865±19.655 kg ha^{-1} yr^{-1}), reproductive parts (12.687±16.114 kg ha^{-1} yr^{-1}) and other debris (11.755±4.588 kg ha^{-1} yr^{-1}).

In the LPF (Table 3.4.6), annual input in litterfall for all the elements studied was 115.715±40.072 kg ha^{-1} yr^{-1} with the highest transfer being calcium at 61.914±22.788 kg ha^{-1} yr^{-1}, followed by nitrogen (25.086±8.172 kg ha^{-1} yr^{-1}). Magnesium was the third with 14.238±3.929 kg ha^{-1} yr^{-1}, followed by potassium (11.194±3.817 kg ha^{-1} yr^{-1}), sodium (1.817±0.764 kg ha^{-1} yr^{-1}), iron (0.809±0.394 kg ha^{-1} yr^{-1}), phosphorus (0.600±0.181 kg ha^{-1} yr^{-1}), and the lowest was manganese contributing only 0.056±0.027 kg ha^{-1} yr^{-1}.

Similarly to total litterfall, calcium was the greatest element in leaf litter with 45.643±14.660 kg ha^{-1} yr^{-1}, followed by nitrogen (16.783±5.635 kg ha^{-1} yr^{-1}), magnesium (11.855±3.106 kg ha^{-1} yr^{-1}). The fourth place was potassium at 8.892±2.931 kg ha^{-1} yr^{-1}, followed by sodium (1.425±0.622 kg ha^{-1} yr^{-1}), iron (0.601±0.329 kg ha^{-1} yr^{-1}), phosphorus (0.401±0.146 kg ha^{-1} yr^{-1}), and manganese (0.048±0.025 kg ha^{-1} yr^{-1}).

Similarly to total litterfall and leaf litter, calcium in branches was also the highest nutrient with 13.234±10.562 kg ha^{-1} yr^{-1}, followed by nitrogen with 5.282±3.427 kg ha^{-1} yr^{-1}. Magnesium was the third highest with 1.552±0.866 kg ha^{-1} yr^{-1}, followed by potassium (1.136±0.696 kg ha^{-1} yr^{-1}), sodium (0.283±0.191 kg ha^{-1} yr^{-1}), iron (0.121±0.068 kg ha^{-1} yr^{-1}), phosphorus (0.090±0.043 kg ha^{-1} yr^{-1}), and manganese (0.006±0.006 kg ha^{-1} yr^{-1}). In contrast, nitrogen was the highest nutrient in reproductive parts with 1.119±1.245 kg ha^{-1} yr^{-1}, followed by calcium with 0.845±0.798 kg ha^{-1} yr^{-1}, potassium (0.759±0.895 kg ha^{-1} yr^{-1}), magnesium (0.382±0.435 kg ha^{-1} yr^{-1}). After magnesium was phosphorus with 0.048±0.0.050 kg ha^{-1} yr^{-1}, followed by sodium (0.037±0.036 kg ha^{-1} yr^{-1}), iron (0.018±0.018 kg ha^{-1} yr^{-1}), and manganese (0.001±0.001 kg ha^{-1} yr^{-1}).

Calcium was the major element in other debris with 2.192±1.116 kg ha^{-1} yr^{-1}, followed by nitrogen with 1.902±0.655 kg ha^{-1} yr^{-1}. In third place was magnesium with 0.449±0.181 kg ha^{-1} yr^{-1}, followed by potassium (0.407±0.190 kg ha^{-1} yr^{-1}), sodium (0.072±0.028 kg ha^{-1} yr^{-1}), iron (0.069±0.051 kg ha^{-1} yr^{-1}), phosphorus (0.061±0.026 kg ha^{-1} yr^{-1}), and manganese (0.002±0.001 kg ha^{-1} yr^{-1}).

Total nutrient elements in different litter components was greatest in leaf litter (85.648±27.454 kg ha^{-1} yr^{-1}), followed by branches (21.704±15.859 kg ha^{-1} yr^{-1}), other debris (5.154±2.248 kg ha^{-1} yr^{-1}), and reproductive parts (3.209±3.478 kg ha^{-1} yr^{-1}).

Table 3.4.5. : The annual nutrient input (kg ha^{-1}), standard deviation, and percentage of standard deviation of different litter components in the mixed swamp forest.

EXCEL	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Total kg ha^{-1}
Leaves	34.058	0.722	19.565	70.774	16.515	2.011	0.893	0.110	144.649
SD leaves	10.510	0.240	7.071	14.598	3.704	0.645	0.534	0.036	37.338
% SD leaves	30.9	33.3	36.1	20.6	22.4	32.1	59.8	33.0	25.8
Branch	6.263	0.129	2.297	17.448	2.156	0.395	0.164	0.012	28.865
SD branch	3.458	0.093	1.901	12.402	1.385	0.285	0.122	0.009	19.655
% SD branch	55.2	72.1	82.8	71.1	64.2	72.2	74.4	78.3	68.09
Reproductive	5.429	0.211	2.984	2.676	1.186	0.138	0.058	0.006	12.687
SD reprod	6.720	0.275	4.245	3.168	1.481	0.154	0.063	0.008	16.114
% SD reprod	123.8	130.5	142.3	118.4	124.8	111.5	107.2	132.	127.01
Others	4.513	0.151	1.279	4.428	0.973	0.170	0.235	0.006	11.755
SD others	1.607	0.063	0.564	1.689	0.334	0.059	0.268	0.004	4.588
% SD others	35.6	41.8	44.1	38.1	34.3	34.5	113.9	55.7	39.03
Total	50.263	1.213	26.125	95.326	20.830	2.714	1.351	0.138	197.956
SD total	16.913	0.531	11.256	24.486	5.456	0.912	0.840	0.046	60.44
% SD total	33.6	43.8	43.1	25.7	26.2	33.6	62.2	34.1	30.53

Table 3.4.6: The annual nutrient input (kg ha^{-1}), standard deviation, and percentage of standard deviation of different litter components in the low pole forest.

Excel	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Total kg ha^{-1}
Leaves	16.783	0.401	8.892	45.643	11.855	1.425	0.601	0.048	85.648
SD leaves	5.635	0.146	2.931	14.660	3.106	0.622	0.329	0.025	27.454
% SD leaves	33.6	36.3	33.0	32.1	26.2	43.6	54.8	52.9	32.1
Branch	5.282	0.090	1.136	13.234	1.552	0.283	0.121	0.006	21.704
SD branch	3.427	0.043	0.696	10.562	0.866	0.191	0.068	0.006	15.859
% SD branch	64.9	47.0	61.3	79.8	55.8	67.4	56.0	86.8	73.1
Reproductive	1.119	0.048	0.759	0.845	0.382	0.037	0.018	0.001	3.209
SD reprod	1.245	0.050	0.895	0.798	0.435	0.036	0.018	0.001	3.478
% SD reprod	111.2	104.2	117.9	94.4	113.9	98.2	100.0	91.7	108.4
Others	1.902	0.061	0.407	2.192	0.449	0.072	0.069	0.002	5.154
SD others	0.655	0.026	0.190	1.116	0.181	0.028	0.051	0.001	2.248
% SD others	34.4	42.3	46.8	50.9	40.4	38.6	73.6	49.9	43.6
Total	25.086	0.600	11.194	61.914	14.238	1.817	0.809	0.056	115.715
SD total	8.172	0.181	3.817	22.788	3.929	0.764	0.394	0.027	40.072
% SD total	32.6	30.2	34.1	36.8	27.6	42.0	48.7	48.1	34.6

3.4.5.2. Temporal variation of nutrient inputs.

Temporal variation of inputs of nitrogen, phosphorus, potassium, calcium, magnesium, sodium, iron, and manganese with total litterfall in both sub-type of forest, mixed swamp forest and low pole forest, are given in figures 3.4.13a to 3.4.20a and 3.4.13b to 3.4.20b, respectively.

Nitrogen (Figures 3.4.13.a. in MSF and 3.4.13.b. in LPF).

In mixed swamp forest (MSF), the total nitrogen input during the 1-year study period was 50.2628±16.9130 kg ha^{-1} year^{-1}. Nitrogen input in leaves was low during 10 November-8 December 2000 and from 24 June to 18 August 2001 with the lowest during 24 June-21 July 2001 at 1.38097±0.86515 kg ha^{-1} while the highest input occurred from 19 August-15 September with 5.97179 ±4.21230 kg ha^{-1}. Nitrogen input in leaves is the highest compared to all other litter components. In contrast, other debris was the lowest with the total only 4.51312±1.60711 kg ha^{-1} year $^{-1}$. Nitrogen input in other debris was relatively low throughout a year with the highest at 0.63806±0.16892 kg ha^{-1} during 29 April-26 May 2001 and the lowest during 24 June-21 July 2001 with 0.17752±0.02934 kg ha^{-1}. Total nitrogen input in litter was low during 24 June-21 July 2001 and 22 July-18 August 2001 with the lowest during 24 June-21 July 2001 at 1.67262±0.93269 kg ha^{-1}. From 6 January to 26 May 2001 and during 19 August-15 September 2001 nitrogen input was relatively high with the highest during 4 February-7 March 2001 with 6.85762±3.59352 kg ha^{-1}.

Similarly to the mixed swamp forest (MSF), in low pole forest (LPF) nitrogen input in leaves was the highest compared to other litter categories. Low inputs occurred during 10 November-8 December 2000, and from 27 May to 15 September 2001 with the lowest during 10 November-8 December 2000 at 0.45479±0.06344 g ha^{-1}. In contrast the highest nitrogen input in leaves was during 4 February-7 March 2001 at 3.56417±1.64223 kg ha^{-1}. Nitrogen input in reproductive part was the lowest compare to other litter categories with total input during study period only at 1.11942± 1.24525 kg ha^{-1} year $^{-1}$. The lowest input occurred during 14 October-9 November 2001 at only 0.00113±0.00196 kg ha^{-1} while the highest was during 27 May-23 June 2001 at 0.28870±0.33141 kg ha^{-1}. Total nitrogen input for all litter categories was low from 24 June to 15 September 2001 with the lowest during 24 June-21 July 2001 at 0.71783±0.01505 kg ha^{-1}. In contrast, from 6 January to 23 June

2001 and from 16 September to 9 November 2001 nitrogen input was relatively high with the highest during 4 February-7 March 2001 with 5.65391±2.18879 kg ha^{-1}.

In general, nitrogen input to the forest floor in MSF was higher than in LPF, total input in MSF was 50.26280±16.91302 kg ha^{-1} year $^{-1}$, while in LPF was 25.08599±8.17155 kg ha^{-1} year $^{-1}$. 'T' tests (Appendix 4) on nitrogen totals in litterfall between MSF and LPF were significantly different.

Phosphorus (Figures 3.4.14.a. in MSF and 3.4.14.b. in LPF).

In the mixed swamp forest, phosphorus input was low throughout the 1-year study period with a total input of only 1.21295±0.53116 kg ha^{-1} $year^{-1}$. The highest value of phosphorus input was recorded during 1-28 April 2001 with 0.19858±0.14823 kg ha^{-1}. The lowest input was obtained during 24 June-21 July 2001 of 0.046.82±0.01708 kg ha^{-1}.

Similarly to the mixed swamp forest, phosphorus input through litterfall in the low pole forest was also low throughout the study period with the total input only 0.60032±0.18140 kg ha^{-1} $year^{-1}$. The highest value of phosphorus input in LPF was during 1-28 April 2001 of 0.10933±0.01625 kg ha^{-1}. In contrast, the lowest value was recorded during 24 June-21 July 2001 at 0.01163±0.00243 kg ha^{-1}.

Similarly to nitrogen, the amount of total phosphorus in litterfall was significantly different between MSF and LPF.

Potassium (Figures 3.4.15.a. in MSF and 3.4.15.b. in LPF).

In the mixed swamp forest, 19 August-15 September 2001 was the period of maximum input for potassium with 4.81764±1.78408 kg ha^{-1} while the minimum input was during 27 May-23 June 2001 at 1.09623±0.26075 kg ha^{-1}.

Potassium input through litterfall in the low pole forest was low from 9 December 2000 to 5 January 2001 then increased sharply to a peak during 4 February-7 March 2001 (1.87967±0.45817 kg ha^{-1}) then it reduced gradually until 22 July-18 August 2001. The minimum input was 0.44009±0.13852 kg ha^{-1} during 10 November-8 December 2000.

Similarly to nitrogen and phosphorus input, potassium input in MSF was higher than in LPF, total input in MSF was 26.12492±11.25566 kg ha^{-1} $year^{-1}$, while in LPF was 11.19355±3.81745 kg ha^{-1} $year^{-1}$. 'T' tests between them were significantly different.

Calcium (Figures 3.4.16.a. in MSF and 3.4.16.b. in LPF).

In the mixed swamp forest, 19 August-15 September 2001 was the period of maximum input with 15.35590±2.13601 kg ha^{-1}. Low input occurred during 10 November-8 December 2000 and from 27 May to 18 August 2001 with a minimum during 24 June-21 July 2001 of 4.65361±1.42023 kg ha^{-1}.

Calcium input in the low pole forest was low from 10 December 2000 to 3 February 2001, then it increased sharply to a peak during 4 February-7 March 2001 of 11.47546±4.87129 kg ha^{-1}. Subsequently, it decreased gradually until the minimum during 24 June-21 July 2001 at 2.37287±0.57484 kg ha^{-1}. From 22 July-18 August 2001 it increased gradually till 14 October-9 November 2001 when it reached 6.42224±2.34422 kg ha^{-1}.

The total amount of calcium in litterfall in mixed swamp forest was higher than that in low pole forest And this was confirmed by 'T' tests between them.

Magnesium (Figures 3.4.17.a. in MSF and 3.4.17.b. in LPF).

In the mixed swamp forest, the lowest input of magnesium occurred during 10 November- 8 December 2000 at 1.05071±0.58001 kg ha^{-1}, then it increased gradually until 4 February-7 March 2001 period to 2.20806±1.06033 kg ha^{-1} (the first peak). After that it decreased gradually until 27 May-23 June 2001. From 24 June-21 July 2001 to 19 August-15 September 2001 it increased sharply a maximum of 3.32385±0.89140 kg ha^{-1} (second peak) during 19 August-15 September 2001, which was followed by a gradual decrease until 14 October-9 November 2001.

Similarly to the mixed swamp forest, the lowest input of magnesium in low pole forest was during 10 November-8 December 2000 at 0.72067±0.16003 kg ha^{-1} after which it increased steadily until 6 January-3 February. It peaked during 4 February-7 March 2001 at 2.25977±0.56725 kg ha^{-1}. From 1-28 April 2001 period to 22 July-18 August 2001 period it decreased gradually and then increased sharply to reach a second peak at 1.44877±0.35954 kg ha^{-1} during 19 August-15 September 2001.

Similarly to calcium, the total amount of magnesium in litterfall in mixed swamp forest was higher than that in low pole forest. Comparison using T test between them confirmed these differences to be significant.

Sodium (Figures 3.4.18.a. in MSF and 3.4.18.b. in LPF).

Similarly to calcium, sodium input through litterfall in the mixed swamp forest during 19 August-15 September 2001 was the maximum input with 0.54834±0.08569 kg ha^{-1} while the lowest input was during 27 May-23 June 2001 at 0.10853± 0.04920 kg ha^{-1}.

Sodium input in the low pole forest was low from 10 November 2000 to 3 February 2001 after that it fluctuated and then increased sharply to reach the highest input of 0.29522±0.13783 kg ha^{-1} during 1-28 April 2001. From then the input decreased until 24 June- 21 July 2001 followed which it increased gradually again to reach a second, smaller peak of 0.19169±0.05918 kg ha^{-1} during 19 August-15 September 2001.

Total sodium in litterfall in mixed swamp forest was higher than that in low pole forest and comparison between them was significantly different.

Iron (Figures 3.4.19.a. in MSF and 3.4.19.b. in LPF).

In general, iron input in both sub-type of forest, mixed swamp forest and low pole forest, was relatively low. The peak input of iron in litterfall in mixed swamp forest was 187.12±241.08 g ha^{-1} only during 29 April-26 May 2001.

In the low pole forest, iron input increase sharply from 9 December 2000 to 28 April 2001 reach the high peak at 0.11557±0.11226 kg ha^{-1} during 1-28 April 2001 period. From then it decreased until reaching the lowest input at 0.01321±0.00941 kg ha^{-1} during 24 June-21 July 2001. From 19 August-15 September 2001, iron input decrease until 14 October-9 November 2001.

The total amount of iron transferred from the canopy to the forest floor in mixed swamp forest was higher than that in low pole forest. 'T' test, showed, however, thast these differences were not significant.

Manganese (Figures 3.4.20.a. in MSF and 3.4.20.b. in LPF).

Similarly to phosphorus and iron, manganese was low in litterfall during the 1-year study period. In the mixed swamp forest, the total input of manganese was only 0.13387±0.04565 kg ha^{-1} year $^{-1}$. From 10 November 2000 to 18 August 2001 manganese input fluctuated but increased toreach the highest input during 19 August-15 September 2001 of only 0.02449 ±0.00978 kg ha^{-1}.

Similarly to the mixed swamp forest, manganese input in the low pole forest was low and fluctuated with the highest input of only 0.01295±0.00790 kg ha^{-1} during 4 February-7 March 2001. In contrast, the lowest input occurred during 9 December 2000-5 January 2001 with 0.00191±0.00061 kg ha^{-1}. Total input of manganese during the study period was only 0.05614±0.02701 kg ha^{-1} year $^{-1}$.

Similarly to sodium, manganese total in litterfall in mixed swamp forest was higher than that in low pole forest and a 'T' test showed a significant difference between them.

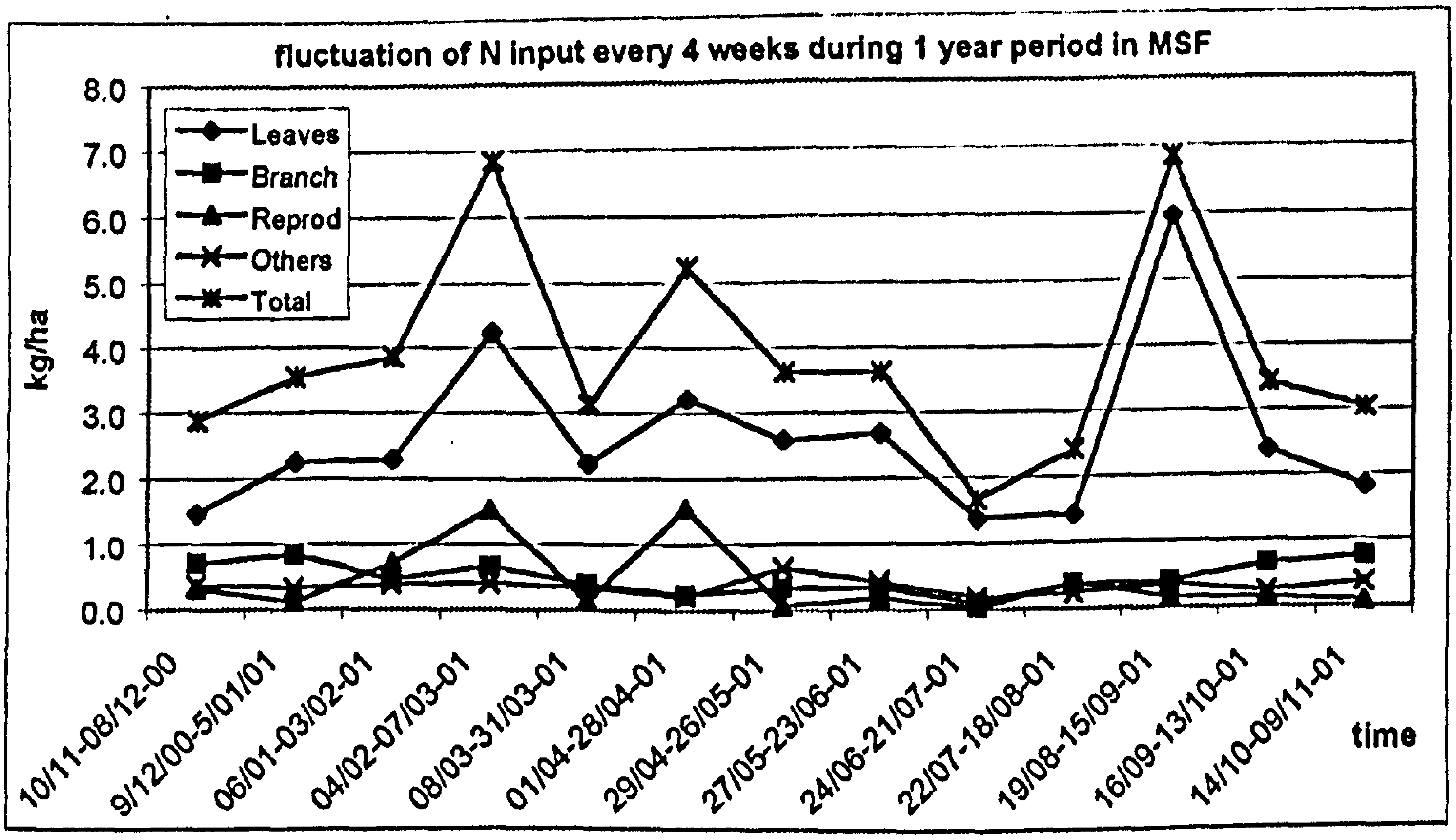


Figure 3.4.13.a.: Fluctuation of N input every 4 weeks during 1 year period in MSF

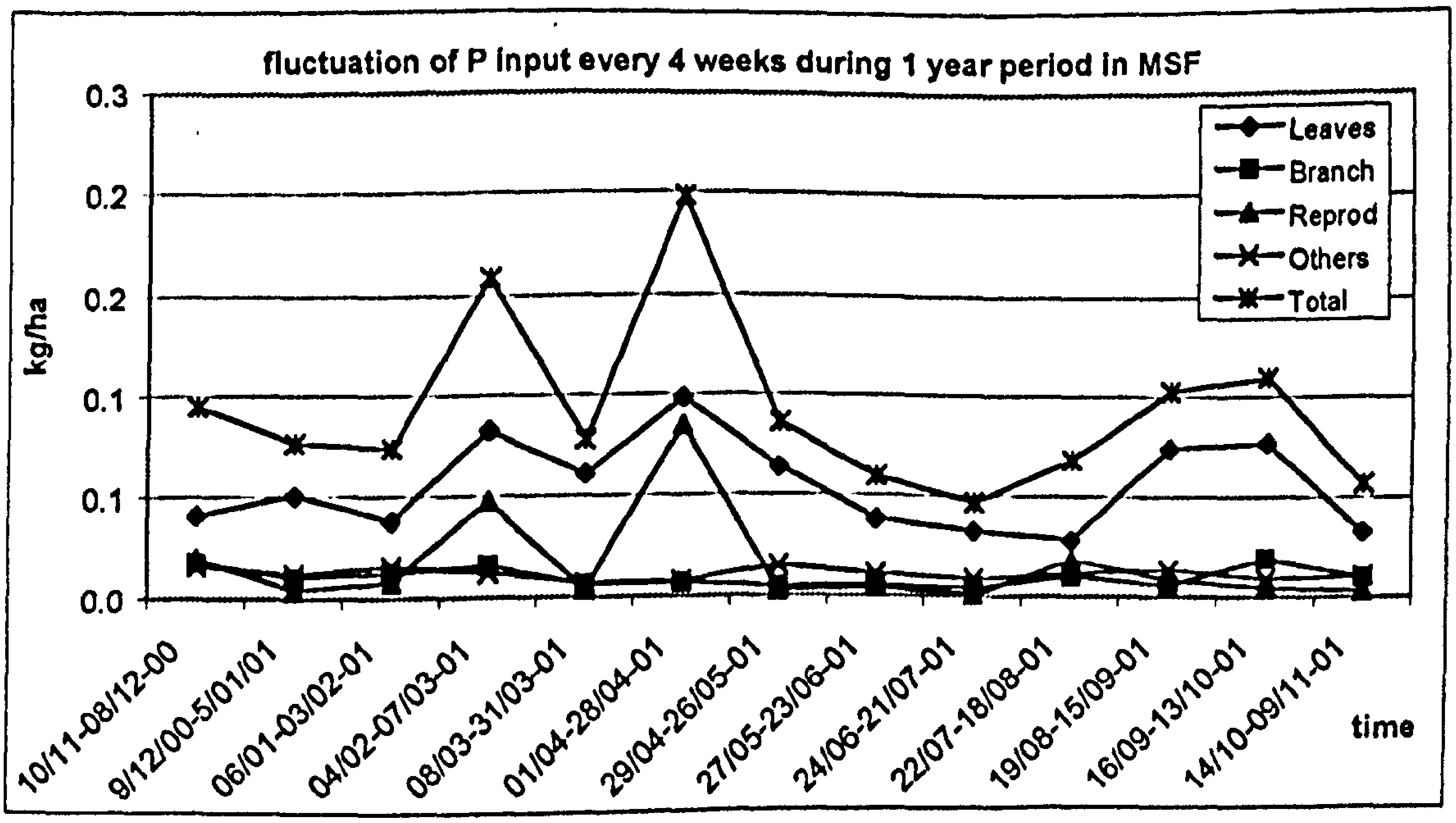


Figure 3.4.14.a.: Fluctuation of P input every 4 weeks during 1 year period in MSF

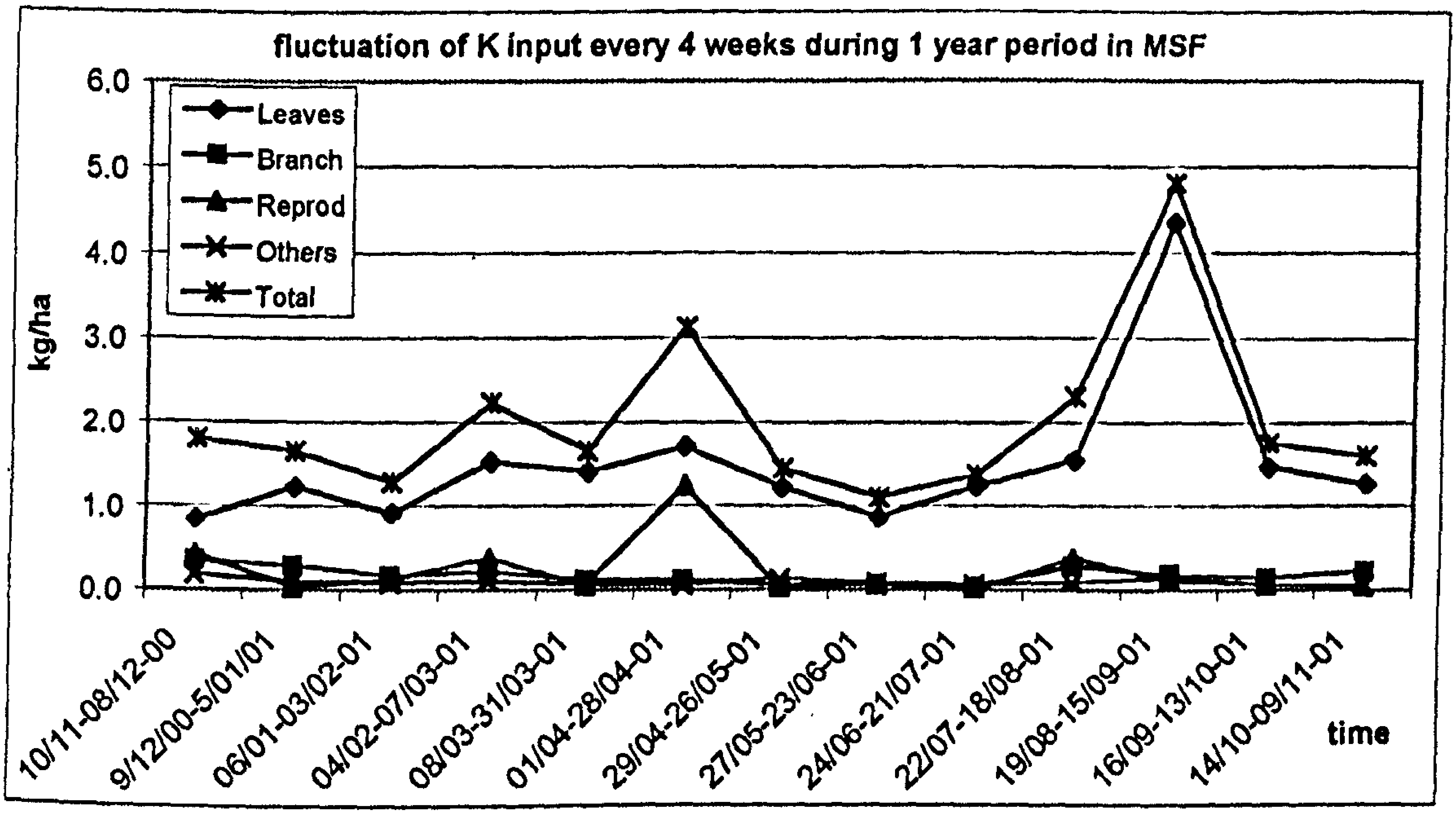


Figure 3.4.15.a.: Fluctuation of K input every 4 weeks during 1 year period in MSF

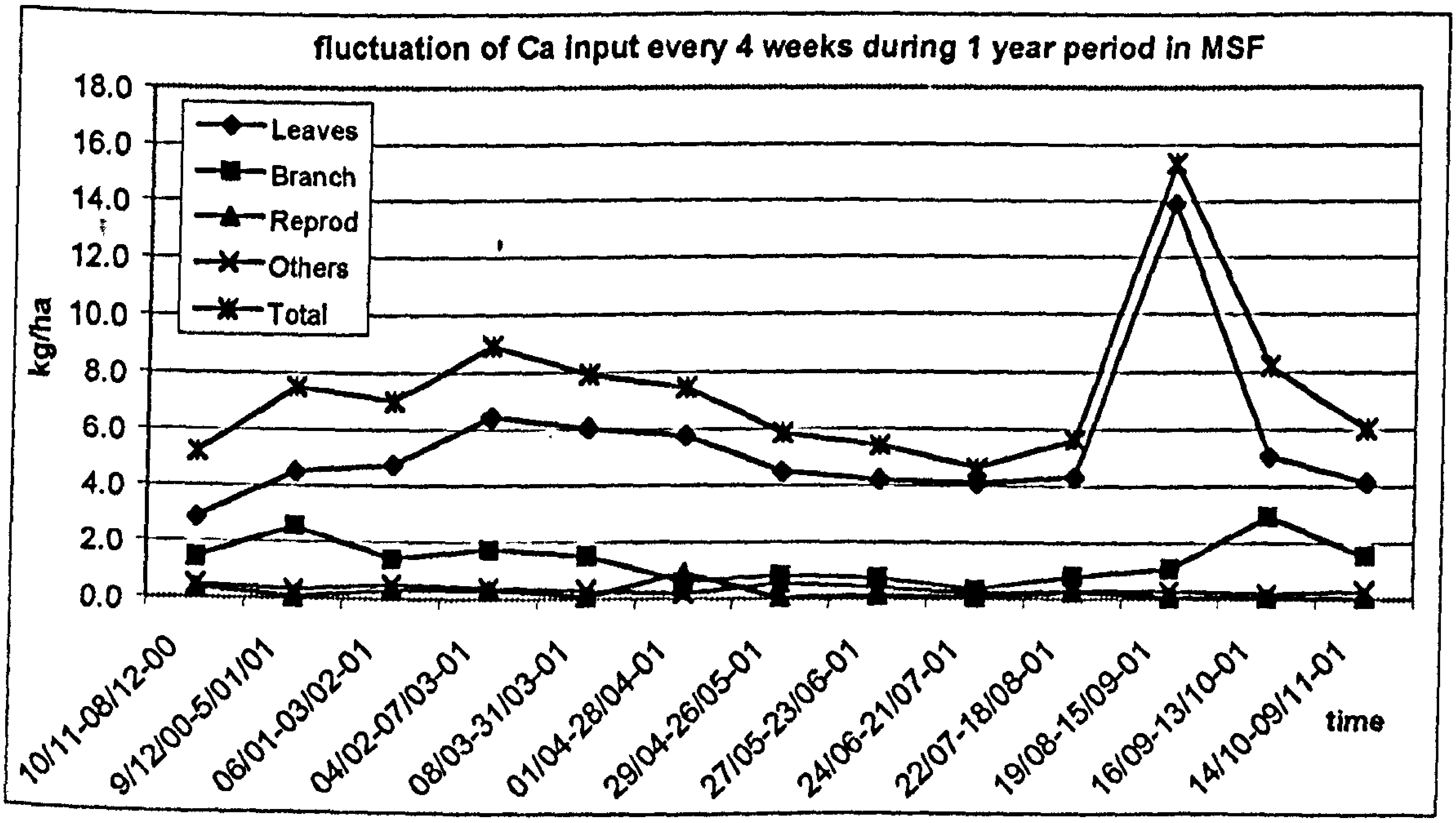


Figure 3.4.16.a.: Fluctuation of Ca input every 4 weeks during 1 year period in MSF

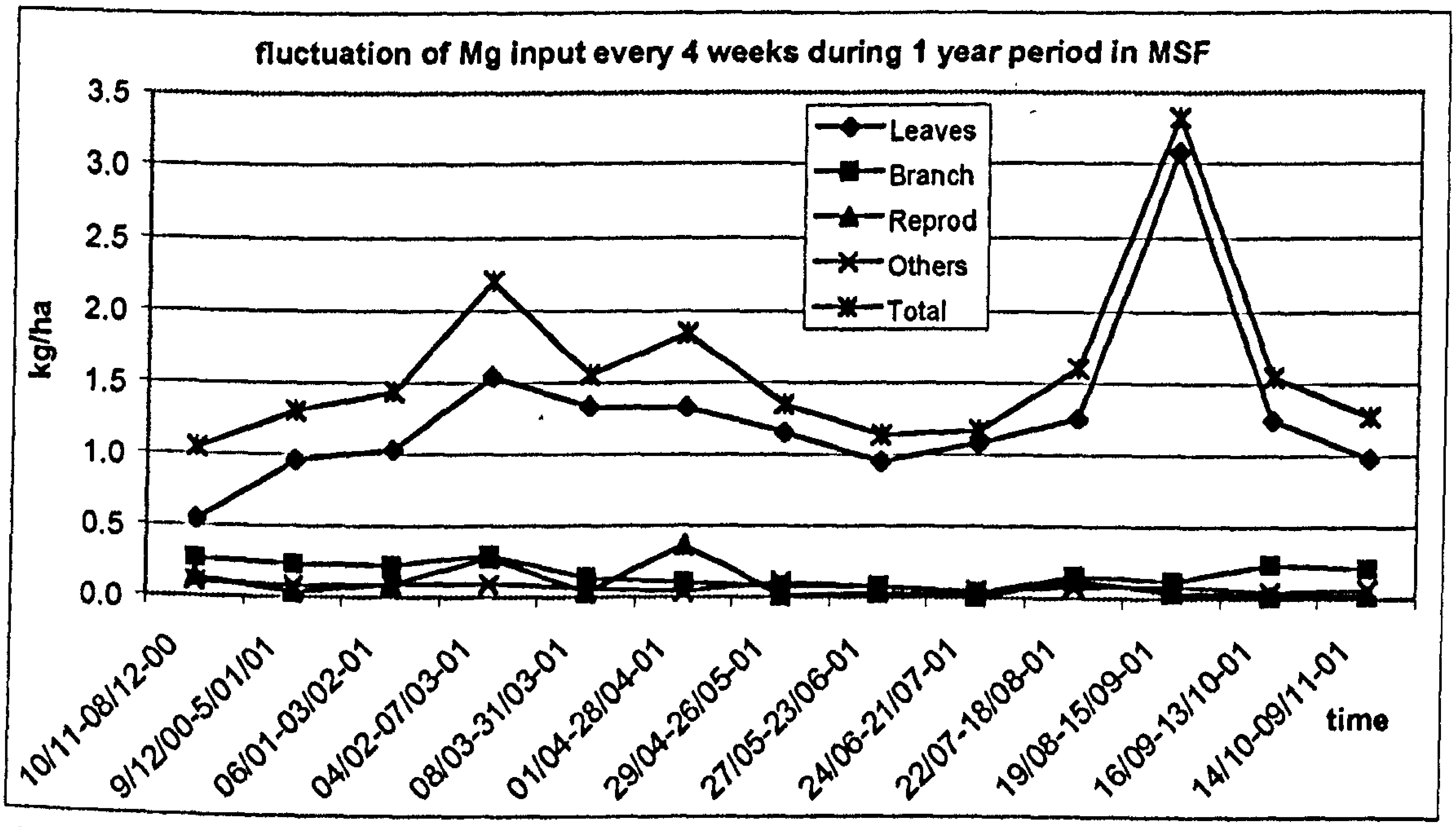


Figure 3.4.17.a.: Fluctuation of Mg input every 4 weeks during 1 year period in MSF

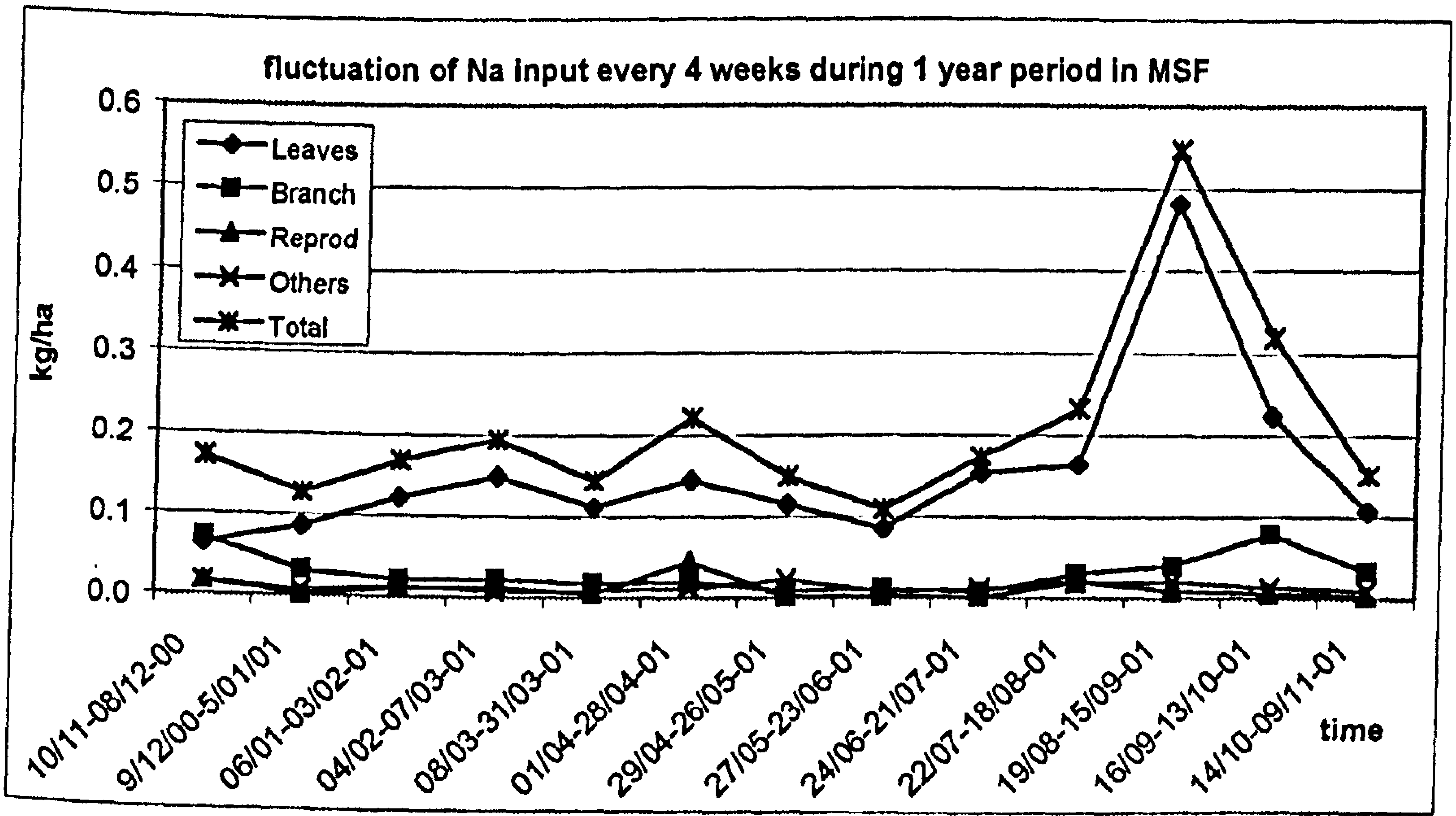


Figure 3.4.18.a.: Fluctuation of Na input every 4 weeks during 1 year period in MSF

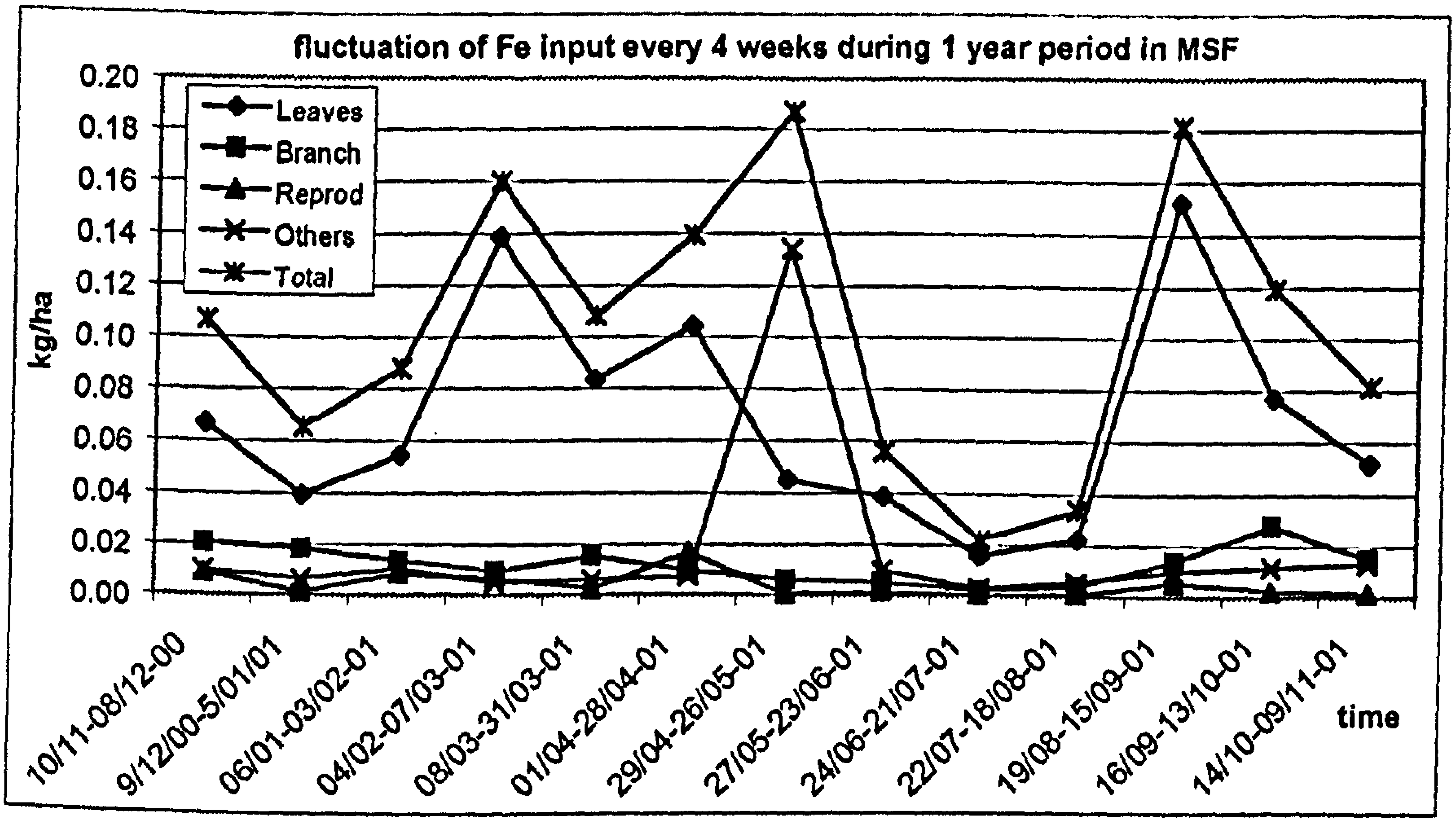


Figure 3.4.19.a.: Fluctuation of Fe input every 4 weeks during 1 year period in MSF

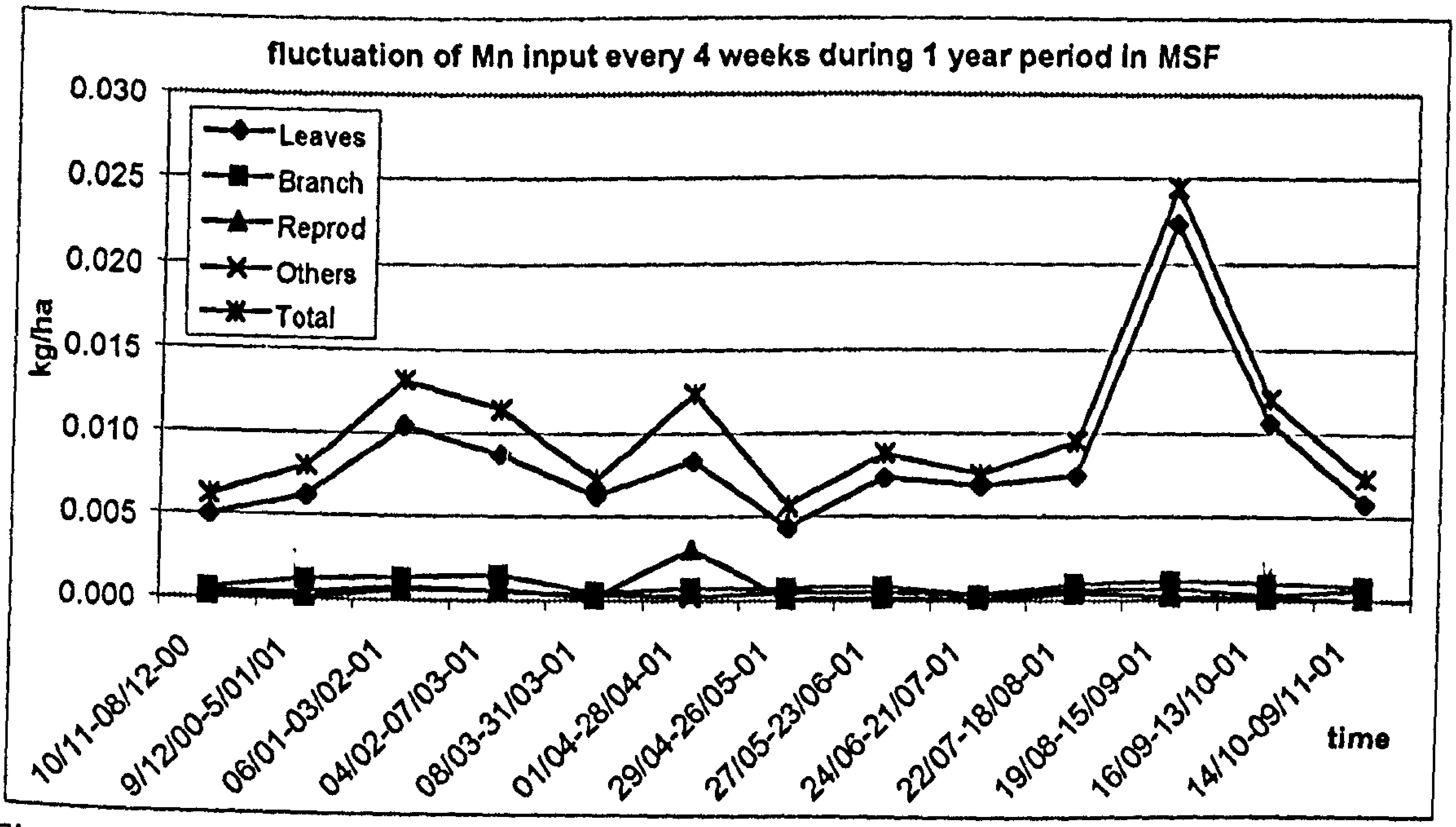


Figure 3.4.20.a.: Fluctuation of Mn input every 4 weeks during 1 year period in MSF

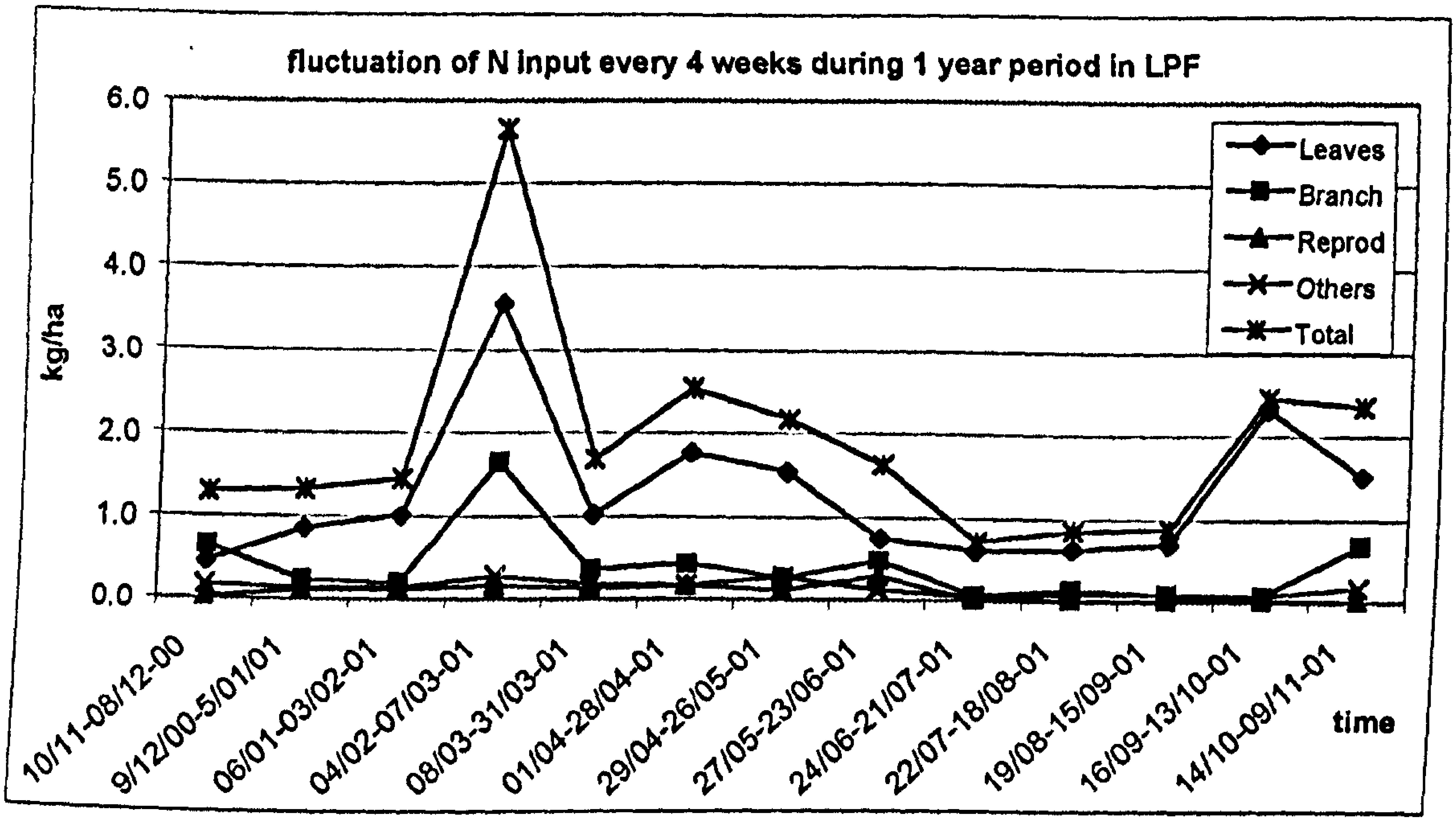


Figure 3.4.13.b.: Fluctuation of N input every 4 weeks during 1 year period in LPF

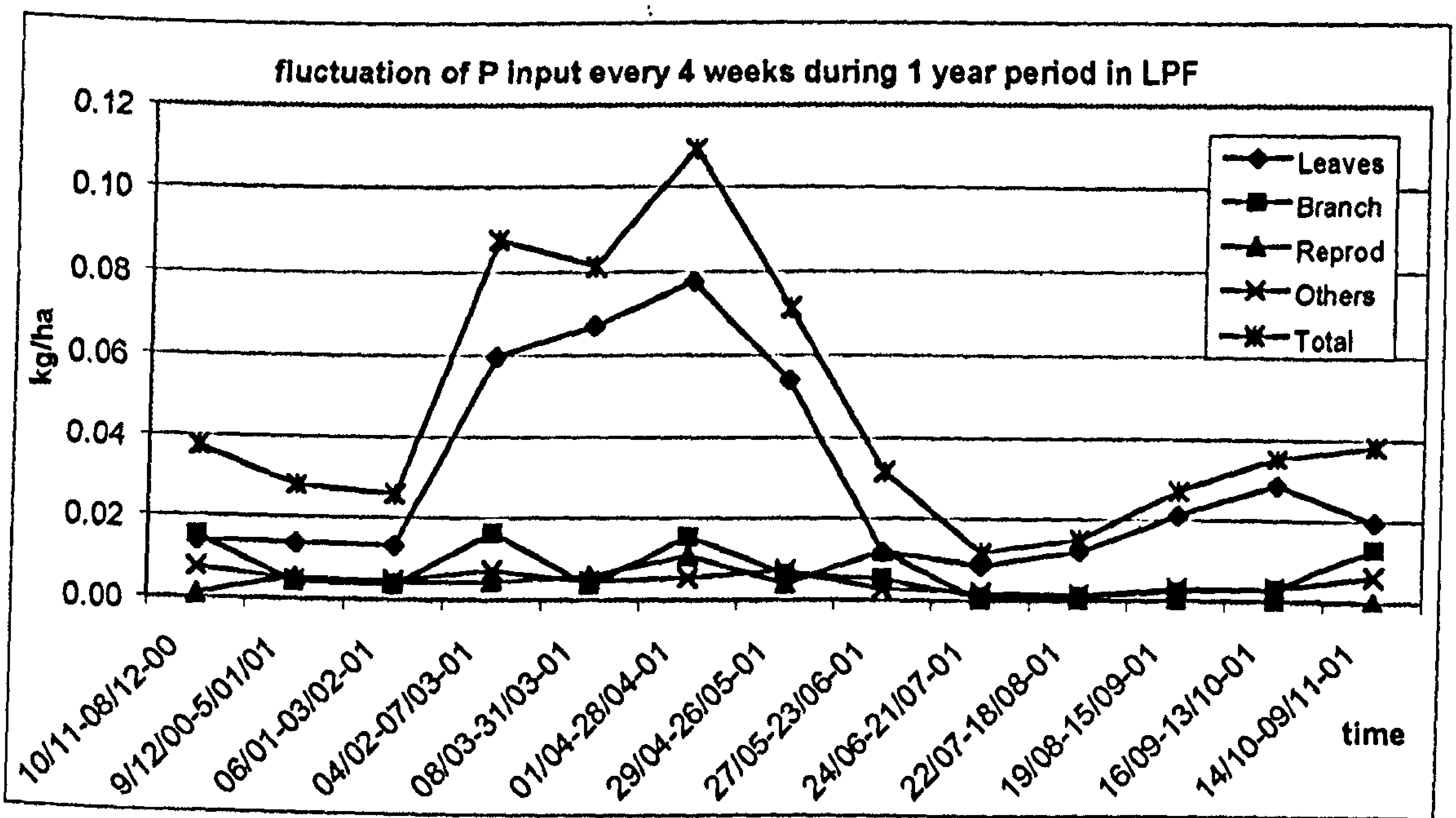


Figure 3.4.14.b.: Fluctuation of P input every 4 weeks during 1 year period in LPF

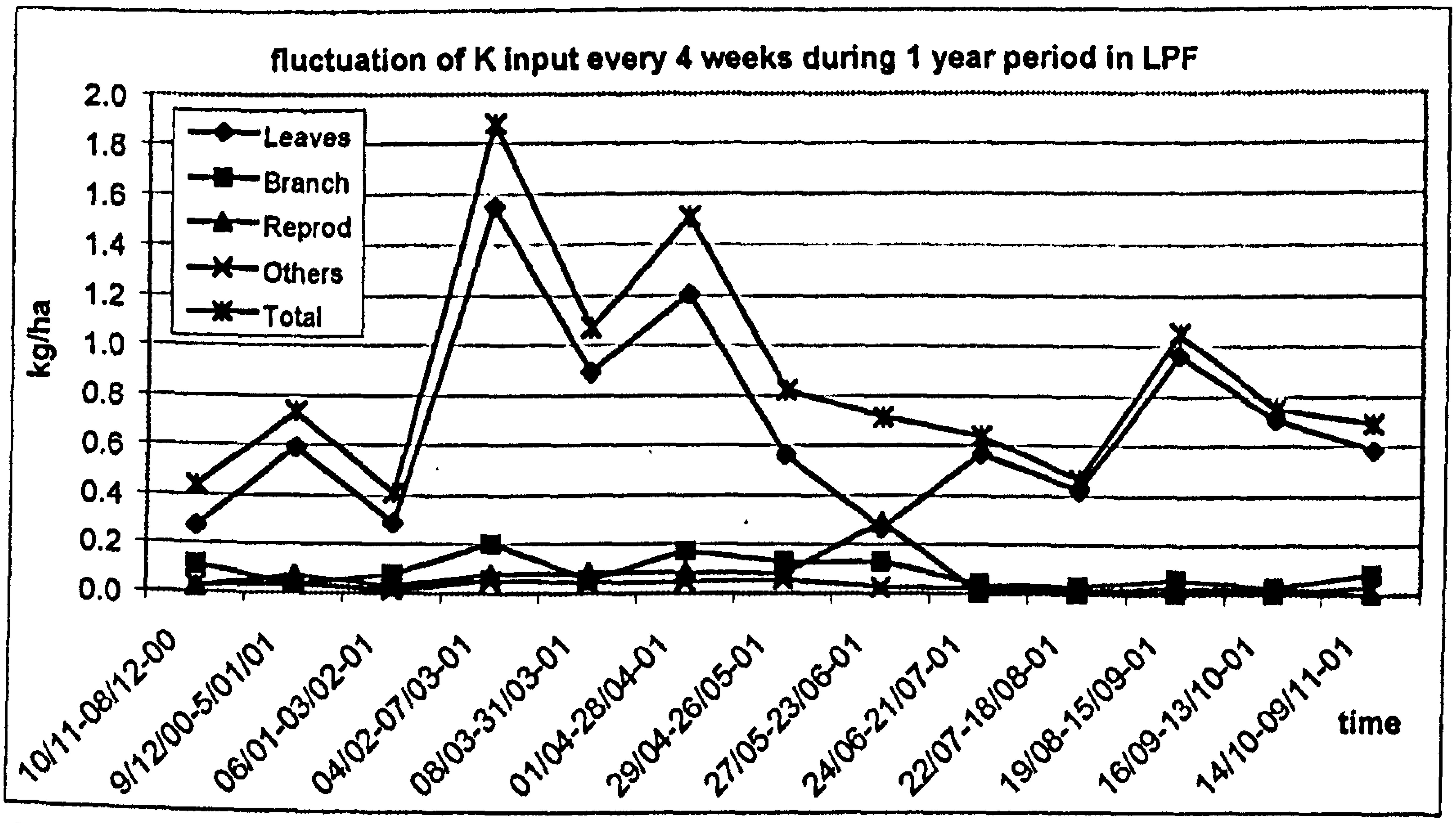


Figure 3.4.15.b.: Fluctuation of K input every 4 weeks during 1 year period in LPF

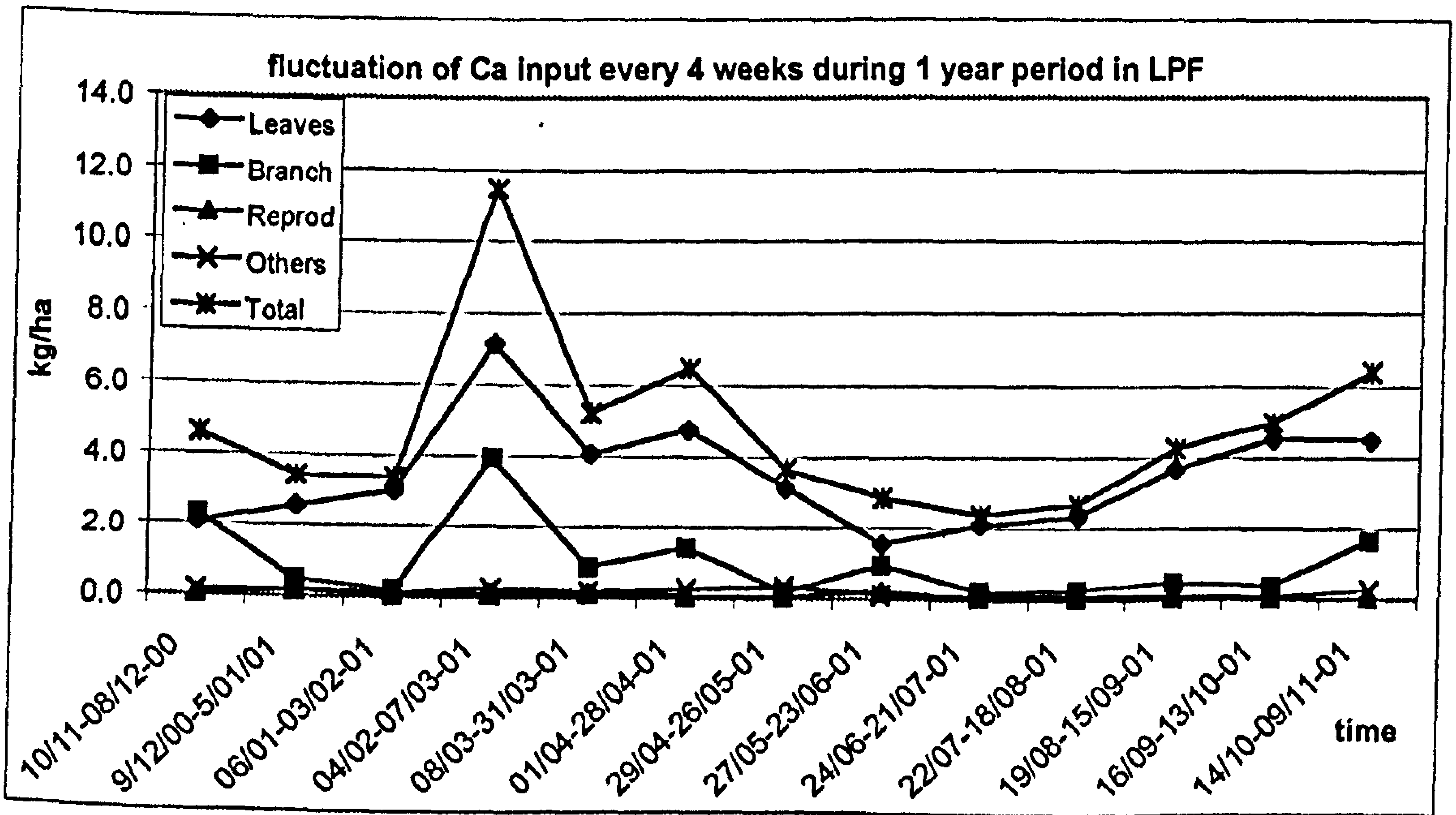


Figure 3.4.16.b.: Fluctuation of Ca input every 4 weeks during 1 year period in LPF

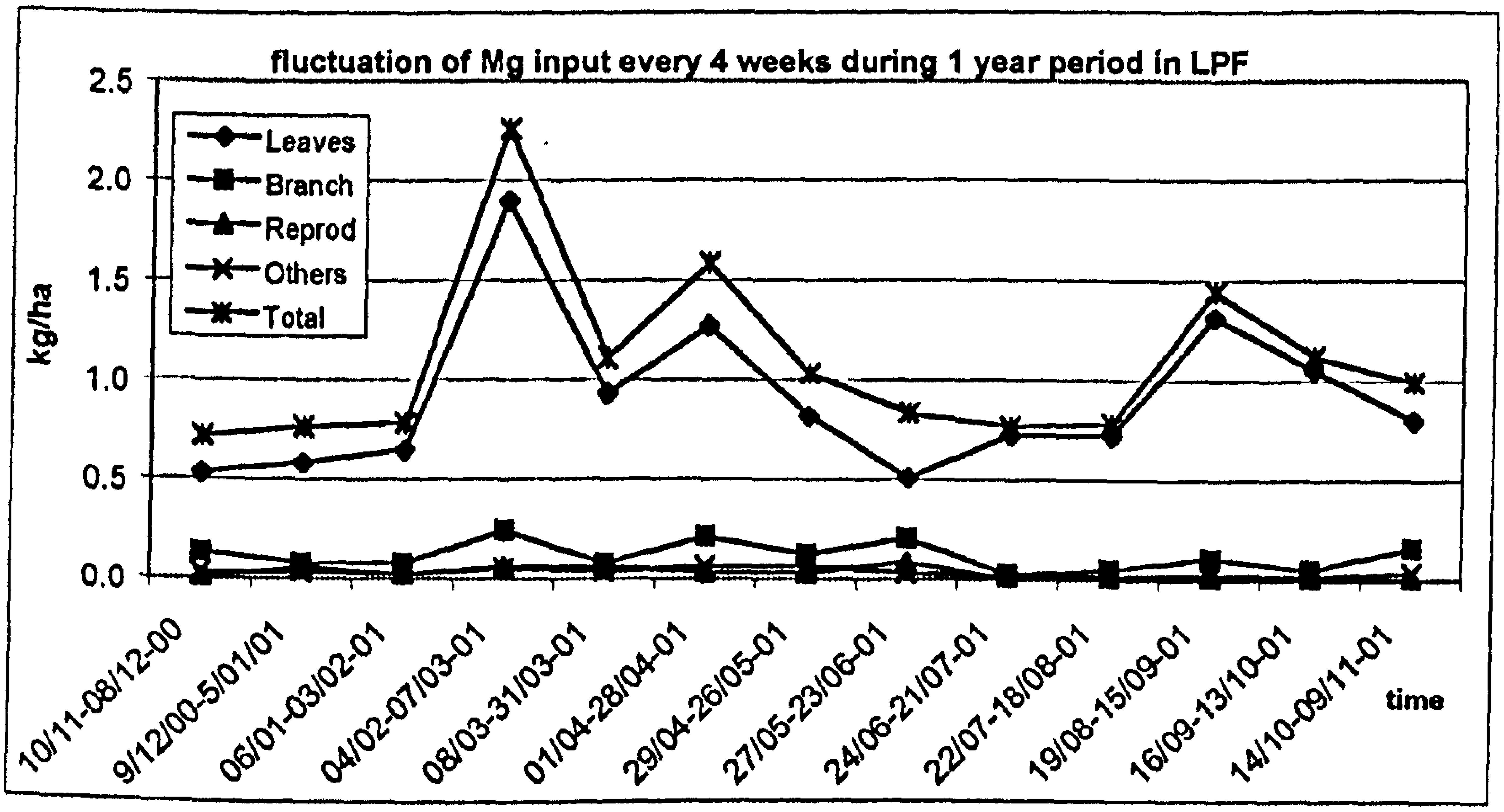


Figure 3.4.17.b.: Fluctuation of Mg input every 4 weeks during 1 year period in LPF

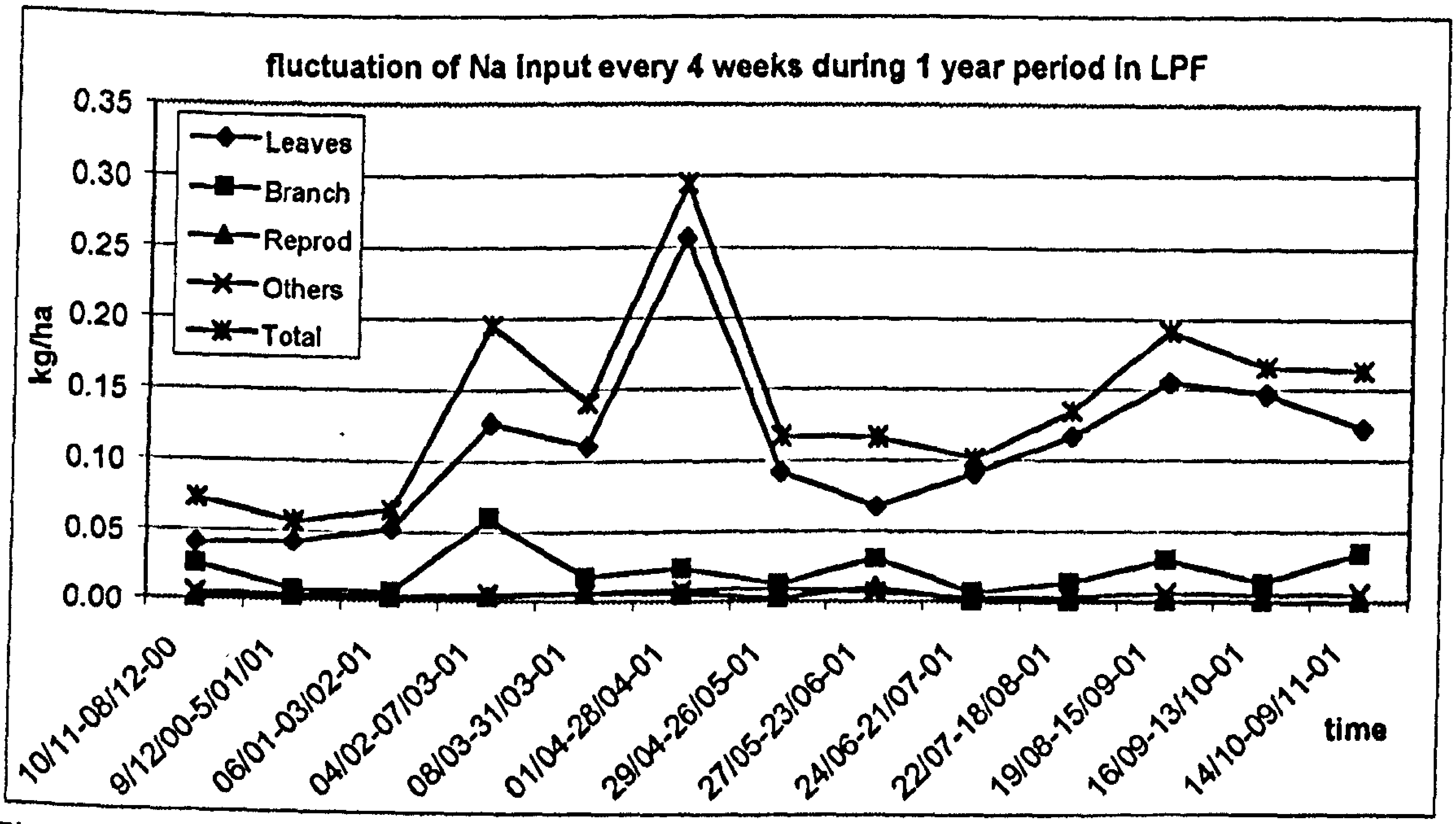


Figure 3.4.18.b.: Fluctuation of Na input every 4 weeks during 1 year period in LPF

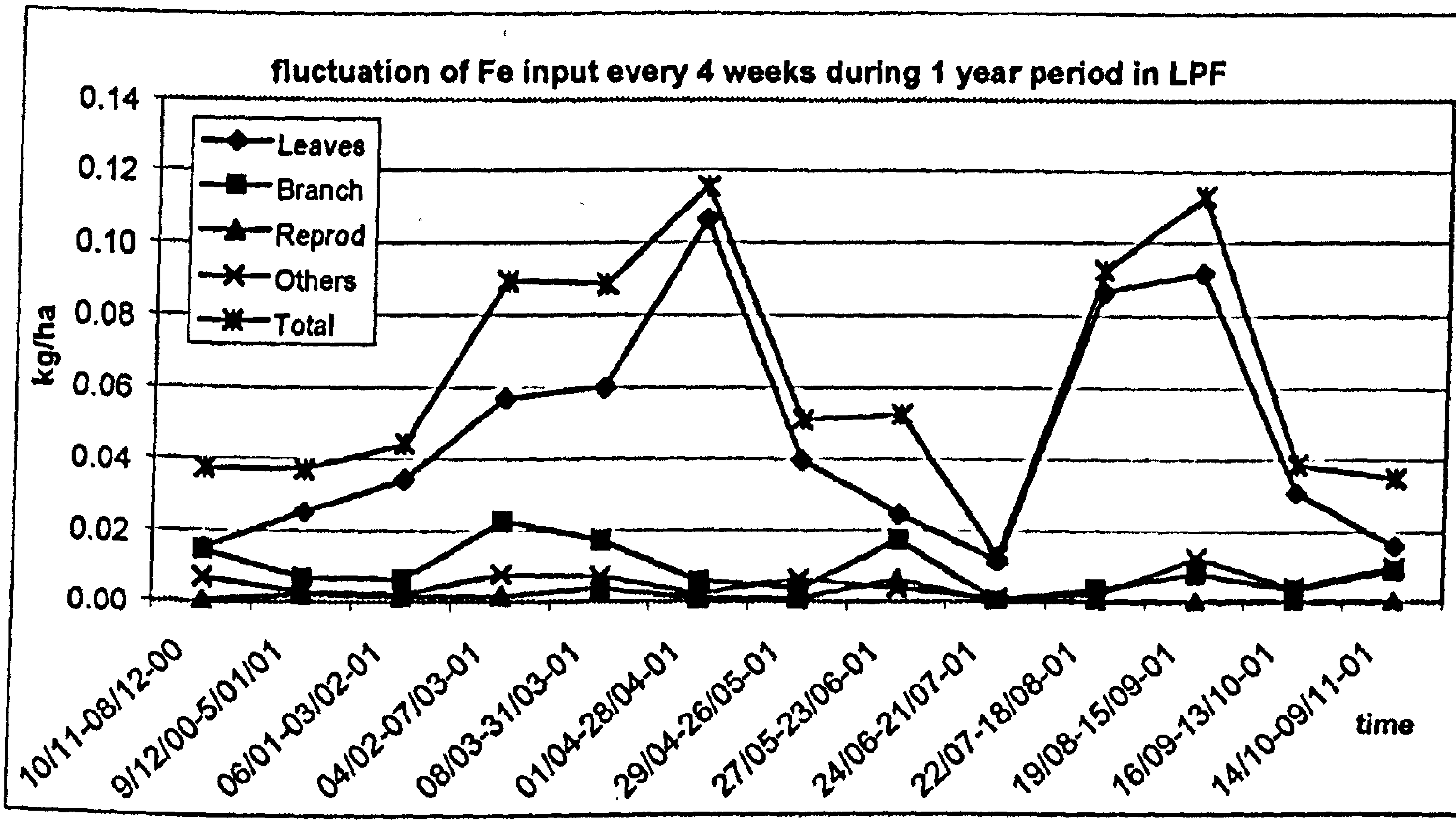


Figure 3.4.19.b.: Fluctuation of Fe input every 4 weeks during 1 year period in LPF

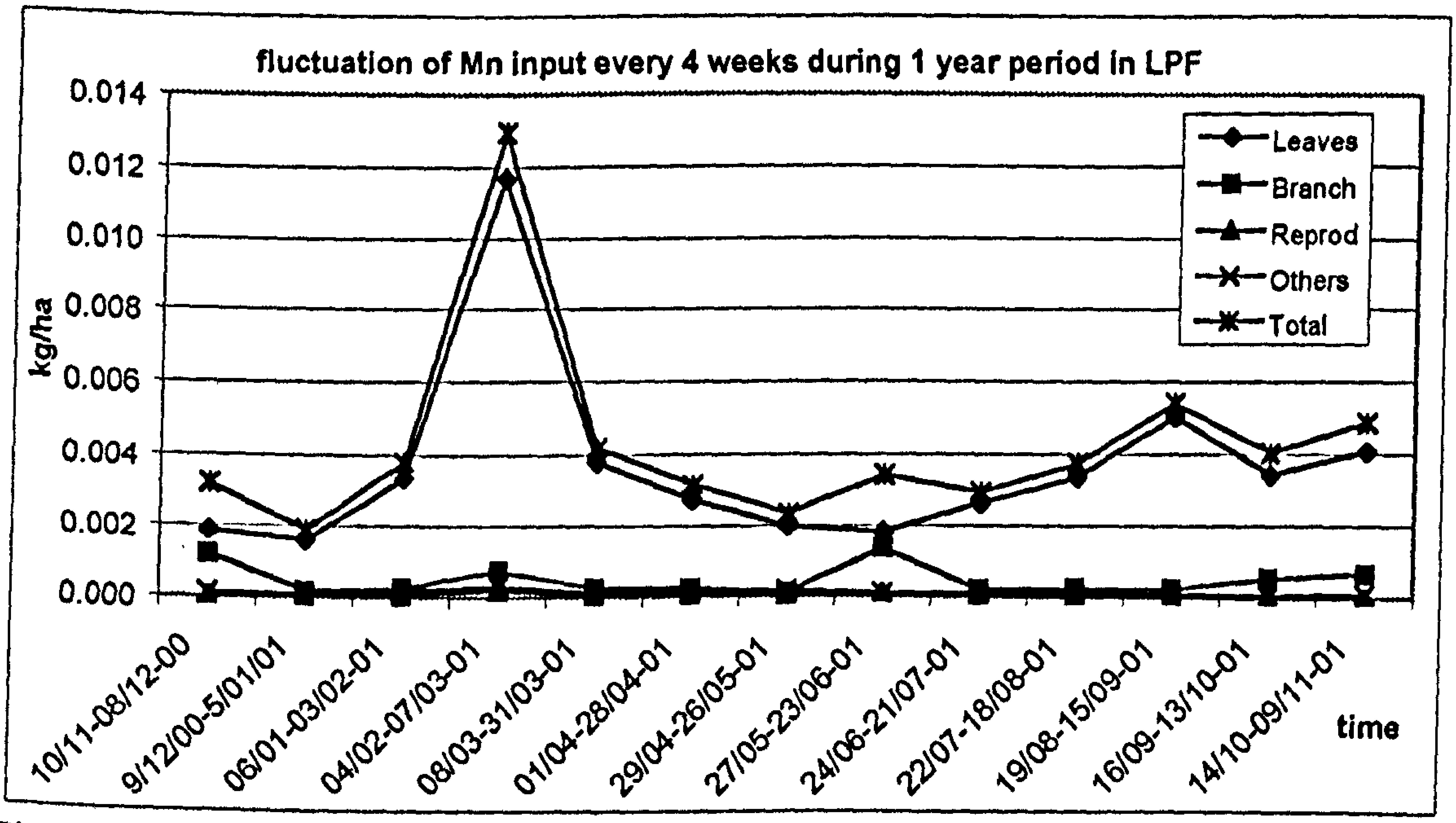


Figure 3.4.20.b: Fluctuation of Mn input every 4 weeks during 1 year period in LPF

3.5. DECOMPOSITION

3.5.1. Weight loss and concentration of nutrients.

Losses in dry weight of the samples of leaves in mixed swamp forest and low pole forest over the 18-months are shown as percent of the original dry weight in Figure 3.5.1. The mean values of dry weight loss, nutrient concentrations in litterbags, standard deviations, and percentage standard deviations of leaves in mixed swamp forest and low pole forest during the 18 months of the decomposition study are shown in Table 3.5.1. and Table 3.5.2.

The pattern of weight loss was similar for both forest sub-types and showed a rapid weight loss during the first 6 months (196 days) with 27.08±11.18 % for MSF and 22.98±0.99% for LPF. In the 12 months (378 days), weight loss was 32.98±11.12 % (MSF) and 25.46±3.99 % (LPF). At the end of 18 months (560 days), the dry weight of organic matter loss was 34.36±13.40 % in MSF and 27.60±2.91 % in LPF.

In mixed swamp forest (MSF), leaf nitrogen concentrations fluctuated widely. It decreased slightly from 0 (15352±2992 mg kg^{-1}) to 6 months (14340±3844 mg kg^{-1}), increased greatly between 6 and 12 months (21782±4110 mg kg^{-1}) and then decreased to its lowest value after 18 months (11739±1993 mg kg^{-1}). Phosphorus concentrations remained low and relatively stable during the 18 month study period at 105±27 mg kg^{-1}, 105±29 mg kg^{-1}, 110±30 mg kg^{-1}, 109±31 mg kg^{-1} after 0, 6, 12 and 18 months, respectively. Potassium concentration decreased steadily from 554±217 mg kg^{-1} (0 months) to 410±409 mg kg^{-1} (6 months), followed by 367±142 mg kg^{-1} (12 months), and 199±68 mg kg^{-1}(18 months). Similarly to nitrogen, calcium also increased and decreased during the study period from 6072±3967 mg kg^{-1} at 0 months, 7032±7123 mg kg^{-1} after 6 months, 6634±4714 mg kg^{-1} at 12 months to 2652±2737 mg kg $^{-1}$ after 18 months. Magnesium showed the same pattern as calcium of 1002±387 mg kg^{-1} at the beginning of the experiment (0 months), 1066±848 mg kg^{-1} after 6 months, 955±489 mg kg^{-1} at 12 months followed by a sharp decrease to 519±180 mg kg^{-1} after 18 months.

Similarly to nitrogen, sodium concentration decreased and increased during the 18 month study period from 234±23 mg kg^{-1} at 0 months, followed by 311±76 mg kg^{-1} (6 months), 135±3 mg kg^{-1} (12 months), and 257±35 mg kg^{-1} (18 months). Iron concentration was 170±20 mg kg^{-1} (0 months), followed by 123±40 mg kg^{-1} (6 months), 216±20 mg kg^{-1} (12 months), and 257±35 mg kg^{-1} (18 months). The element in lowest concentration in this study was manganese with a concentration of only 8±3 mg kg^{-1} (0 months), 8±4 mg kg^{-1} (6 months), 9±4 mg kg^{-1} (12 months), and 7±5 mg kg^{-1}1(18 months).

In low pole forest (LPF), nitrogen concentration also fluctuated up and down during study period. At the commencement of the experiment (0 months) nitrogen concentration was 8036±1907 mg kg^{-1}, followed by 8956±5008 mg kg^{-1} (6 months), 7909±2356 mg kg^{-1} (12 months), and 7787±480 mg kg^{-1} (18 months). Phosphorus concentration was low and relatively stable at 69±6 mg kg^{-1} (0 months), followed by 67±6 mg kg^{-1} (6 months), 67±9 mg kg^{-1} (12 months), and 74±25 mg kg^{-1} (18 months).

Potassium concentration was 331±49 mg kg^{-1}(0 months), 39±17 mg kg^{-1} (6 months), 226±90 mg kg^{-1} (12 months) and 115±52 mg kg^{-1} (18 months). Calcium concentration decreased gradually from 2455±287 mg kg^{-1} (0 months) to 1774±405 mg kg^{-1} (6 months), followed by 1601±1044 mg kg^{-1} (12 months), and 1378±397 mg kg^{-1} (18 months). Similarly to potassium, magnesium concentration fluctuated during the study period. In the control (0 months) it was 454±39 mg kg^{-1}, followed by 269±32 mg kg^{-1} (6 months), 284±61 mg kg^{-1} (12 months), and 300±29 mg kg^{-1} (18 months).

Sodium concentration in the control (0 months) was 184±7 mg kg^{-1}, followed by 242±54 mg kg^{-1} (6 months), 109±18 mg kg^{-1} (12 months), and 196±29 mg kg^{-1} (18 months). Similarly to sodium, iron concentration also varied during the 18 months study period with 131±7 mg kg^{-1} (0 months), followed by 77±40 mg kg^{-1} (6 months), 155±18 mg kg^{-1} (12 months), and 167±37 mg kg^{-1} (18 months). Similarly to mixed swamp forest, manganese concentration in low pole forest was also low with 5±1 mg kg^{-1} (0 months), followed by 3±1 mg kg^{-1} (6 months), 5±1 mg kg^{-1} (12 months), and 4±0 mg kg^{-1} (18 months).

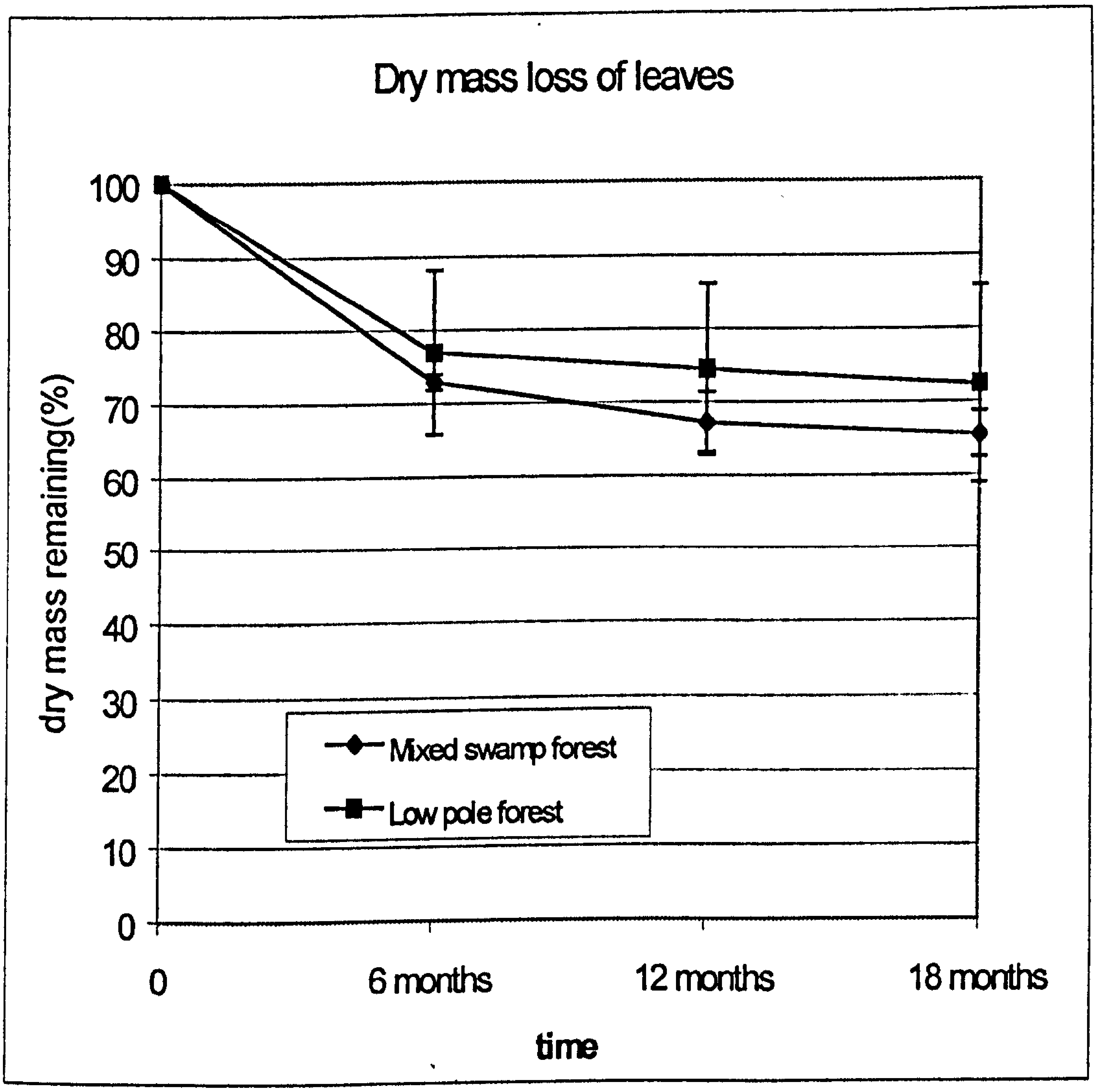


Figure 3.5.1. : Dry mass loss of leaves during the 18 month period of the decomposition experiment, expressed as percentage of the initial dry weight.

Table 3.5.1: Means of dry weight and nutrient concentrations, standard deviations, and percentage standard deviations of leaves in mixed swamp forest during the 18 months of the decomposition study.

MSF	Dry weight (g)	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}
0 month	100.71 a	15352 b	105a	554a	6072a	1002a	234b	170a	8a
SD 0 month	0.15	2992	27	217	3967	387	23	20	3
% SD 0	0.15	19	26	39	65	39	10	12	38
6 months	73.43 b	14340 b	105a	410a	7032a	1066a	311a	123b	8a
SD 6 months	11.19	3844	29	409	7123	848	76	40	4
% SD 6 month	15.24	27	28	100	101	80	24	33	58
12 months	67.48 b	21782a	110a	367a	6634a	955a	135c	216a	9a
SD 12 months	11.13	4110	30	142	4714	489	3	20	4
% SD 12 month	16.49	19	28	39	71	51	2	9	40
18 months	66.10 b	11739b	109a	199a	2652a	519a	257ab	191a	7a
SD 18 months	13.45	1993	31	68	2737	180	35	32	5
% SD 18 month	20.35	17	28	34	103	35	13	17	63

[a] Abbreviation as in Table 3.5.1. indicated value in the same column with different letters are statistically different ($p < 0.05$).

Table 3.5.2: Means of dry weight and nutrient concentrations, standard deviations, and percentage standard deviations of leaves in low pole forest during the 18 months of the decomposition study.

LPF	Dry weight (g)	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}
0 month	100.84a	8036a	69a	331a	2455a	454a	184b	131a	5a
SD 0 month	0.22	1907	6	49	287	39	7	7	1
% SD 0	0.21	24	8	15	12	9	4	5	13
6 months	77.66b	8956a	67a	39c	1774ab	269b	242a	77b	3b
SD 6 months	1.09	5008	6	17	405	32	54	40	1
% SD 6 month	1.41	56	9	45	23	12	22	51	38
12 months	75.17bc	7909a	67a	226b	1601ab	284b	109c	155a	5a
SD 12 months	4.08	2356	9	90	1044	61	18	18	1
% SD 12 month	5.42	30	13	40	65	21	17	12	21
18 months	73.01c	7787a	74a	115c	1378b	300b	196b	167a	4ab
SD 18 months	3.09	480	25	52	397	29	29	37	0
% SD 18 month	4.23	6	33	46	29	10	15	22	10

[a] Abbreviation as in Table 3.5.2. indicated value in the same column with different letters are statistically different ($p < 0.05$).

3.5.2. Nutrient loss

Losses in nitrogen, phosphorus, potassium, calcium, magnesium, sodium, iron and manganese of the samples of leaves in mixed swamp forest and low pole forest over the 18-months, shown as percent of the original dry weight of nutrients, are presented in Figure 3.5.2. to Figure 3.5.5. The mean values of dry weight loss, nutrients remaining (mg) in litterbags, standard deviations, and percentage standard deviations of leaves in mixed swamp forest and low pole forest during the 18 months of the decomposition study are shown in Table 3.5.3. and Table 3.5.4.

In mixed swamp forest, nitrogen loss in the first 6 months was 32.5±10.9 %, although, surprisingly nitrogen losses during the 12 month period appear to be only 4.8±16 %, but reach 49.4±12.2 % after 18 months. Loss of phosphorus was rapid during the first 6 months at 27.3±10.8 % and then levelled off to 30.2±10.0 % after12 months, and 32.2±16.1% by the end of the experiment (18 months) (Figure 3.5.2).

Potassium content of the decomposing leaves changed most quickly in the first 6 months (Figure 3.5.3) with 60.7±29.6 % of this element being released in mixed swamp forest. Similarly to nitrogen losses, potassium losses were 55.2±10.4% during 12 months and 75.8±6.1% after 18 months. Similarly to potassium, calcium loss was also most rapid in the first 6 months at 40.8±34.9 %, but appears to be only 30.3±50.7 % after 12 months but increased to 77.4±12.6 % after 18 months (Figure 3.5.3).

Magnesium loss during the first 6 months was 36.1±24.0%, 37.3±21.7 % after 12 months and 61.5±18.8 % by 18 months. The amount of sodium lost during the first

6 months was only 4.7±18.5 % but was 61.0±8.1 % after 12 months and 28.1±16.3 % at 18 months (Table 3.5.2 and Figure 3.5.4).

Iron losses fluctuated widely during the 18 months study period. In the first 6 months iron decreased by 47.5±17.9 % but, surprisingly over 12 months losses appear to be only 15.3±8.3% and 26.2±18.2% after 18 months (Table 3.5.2. and Figure 3.5.5). Similarly to iron, there was fluctuation in the manganese losses during the 18 month study period. In the first 6 months there was a decrease of 33.9±13.9%, but only 18.6±34.2% at 12 months although this increased to 46.1±8.9 % after 18 months (Table 3.5.2 and Figure 3.5.5).

In low pole forest, nitrogen decreased gradually. In the first 6 months it fell by 17.8±25.0 %, followed by 26.0±19.9 % (12 months), and 28.1±9.1% (18 months). The amount of phosphorus lost from litterbags was 25.7±39.5 % during the first 6 months, 27.0±12.9 % by 12 months and 23.2±21.4 % after 18 months (Figure 3.5.2). Similarly to potassium loss in mixed swamp forest, potassium loss in low pole forest was the fastest compared to other elements. In the first 6 months 91.1±3.8% of potassium was loss from litterbags (Figure 3.5.3) (Table 3.5.2). Unexpectedly, potassium loss appears to be only 50.1±13.6% after 12 months and 75.6±8.8% at 18 months. Similarly to potassium, calcium loss was most rapidly in the first 6 months at 44.6±8.8%, 54.3±21.3% (12 months), and 59.7±8.4% (18 months) (Figure 3.5.3).

Similarly to potassium and calcium, the amount of magnesium decreased sharply in the first 6 months by 54.3±4.8% (Figure 3.5.4) (Table 3.5.2). Unpredictably, magnesium loss was 53.9±3.3 % at 12 months and 52.0±4.9 % by 18 months (Figure 3.5.4). Inexplicably, sodium concentration appears to increase in the first 6 months by 0.9±20.1% increase (Table 3.5.2) but, subsequently, sodium fell by 55.4±9.6% after 12 months and 22.7±14.8 % after 18 months.

The amount of iron lost during the first 6 months was 55.0±20.9 % (Figure 3.5.5) (Table 3.5.2) but, surprisingly, iron losses became 10.5±17.7 % after 12 months and 7.0±20.3 % in 18 months. There was also fluctuation in manganese losses during the 18 month study period. In the first 6 months it was 49.6±13.2% of but only 19.3±9.4% after 12 months, and 41.1±5.5 % by 18 months (Figure 3.5.5).

Table 3.5.3: Means of dry weight and nutrient remaining (mg) in leaves, standard deviations, and percentage standard deviations in mixed swamp forest during the 18 months of the decomposition study.

Mixed Swamp Forest (MSF)	Dry weight (g)	N (mg)	P (mg)	K (mg)	Ca (mg)	Mg (mg)	Na (mg)	Fe (mg)	Mn (mg)
0 month	100.71a	1546.3a	10.6a	55.8a	611.8a	101.0a	23.6a	17.1a	0.8a
SD 0 month	0.15	302.5	2.7	21.9	399.9	39.1	2.3	2.0	0.3
% SD 0	0.15	19.6	25.7	39.2	65.4	38.7	10.0	11.8	37.8
6 months	73.43b	1025.0a	7.5b	26.7b	456.7a	71.2ab	22.8ab	9.2c	0.5a
SD 6 months	11.19	140.6	1.0	25.2	443.7	49.5	6.7	4.1	0.2
% SD 6 month	15.24	13.7	13.1	94.5	97.2	69.5	29.5	44.4	44.3
12 months	67.48b	1436.2b	7.2b	23.6b	415.3a	61.1ab	9.1c	14.6ab	0.6a
SD 12 months	11.13	52.2	0.9	5.7	275.2	24.9	1.6	2.6	0.2
% SD 12 month	16.49	3.6	12.7	24.2	66.3	40.8	17.3	17.8	31.6
18 months	66.10b	757.3c	7.0b	12.5b	155.1a	34.2b	16.9b	12.9ab	0.4a
SD 18 months	13.45	69.3	1.5	1.9	157.5	11.6	3.8	4.5	0.2
% SD 18 month	20.35	9.1	21.2	15.1	101.6	34.0	22.3	35.2	48.5

[a] Abbreviation as in Table 3.5.3. indicated value in the same column with different letters are statistically different ($p < 0.05$).

Table 3.5.4: Means of dry weight and nutrient remaining (mg) in leaves, standard deviations, and percentage standard deviations in low pole forest during the 18 months of the decomposition study.

Low Pole Forest (LPF)	Dry weight (g)	N (mg)	P (mg)	K (mg)	Ca (mg)	Mg (mg)	Na (mg)	Fe (mg)	Mn (mg)
0 month	100.84a	810.7a	7.0a	33.4a	247.5a	45.7a	18.6a	13.2a	0.5a
SD 0 month	0.22	194.2	0.6	4.9	28.6	3.9	0.7	0.7	0.1
% SD 0	0.21	24.0	8.2	14.8	11.6	8.5	3.8	5.0	12.9
6 months	77.66b	696.2a	5.2b	3.0c	137.5b	20.9b	18.8a	6.0b	0.2c
SD 6 months	1.09	391.6	0.4	1.4	29.9	2.2	4.2	3.0	0.1
% SD 6 month	1.41	56.3	8.5	45.1	21.7	10.7	22.5	50.6	37.3
12 months	75.17bc	599.0a	5.1b	16.9b	117.2b	21.2b	8.2c	11.7a	0.4ab
SD 12 months	4.08	200.6	0.6	6.7	68.4	3.2	1.6	1.9	0.1
% SD 12 month	5.42	33.5	12.1	39.8	58.4	15.3	19.4	16.6	23.4
18 months	73.01c	569.6a	5.4ab	8.3c	99.7b	21.8b	14.3b	12.2a	0.3bc
SD 18 months	3.09	58.0	2.0	3.5	24.4	1.4	2.4	2.6	0.0
% SD 18 month	4.23	10.2	36.6	42.6	24.4	6.3	16.5	21.6	7.2

[a] Abbreviation as in Table 3.5.4. indicated value in the same column with different letters are statistically different ($p < 0.05$).

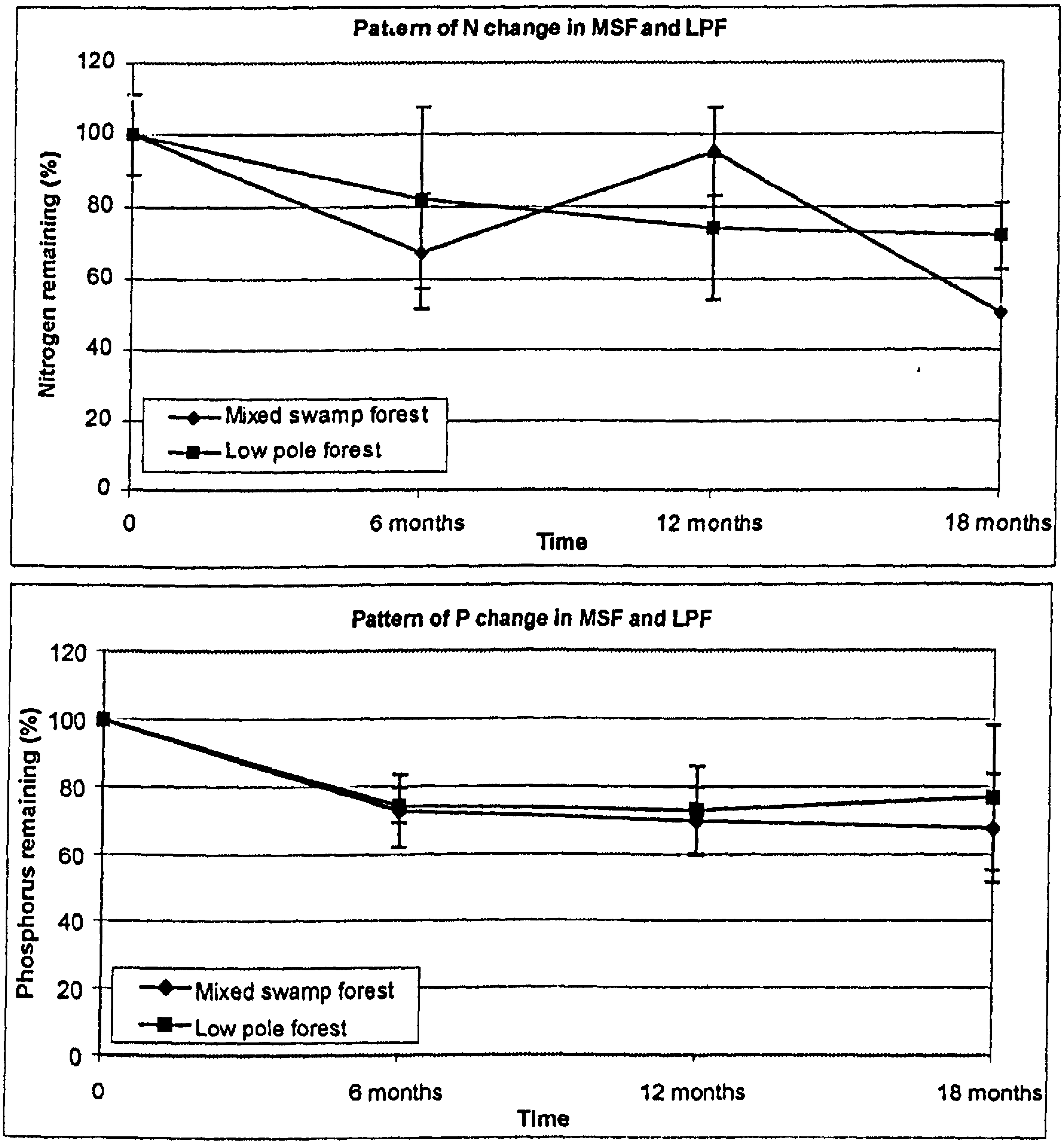


Figure 3.5.2. : Pattern of change in nitrogen and phosphorus in mixed swamp forest and low pole forest during 18 months periods , expressed as percentages of the original amount of nutrient

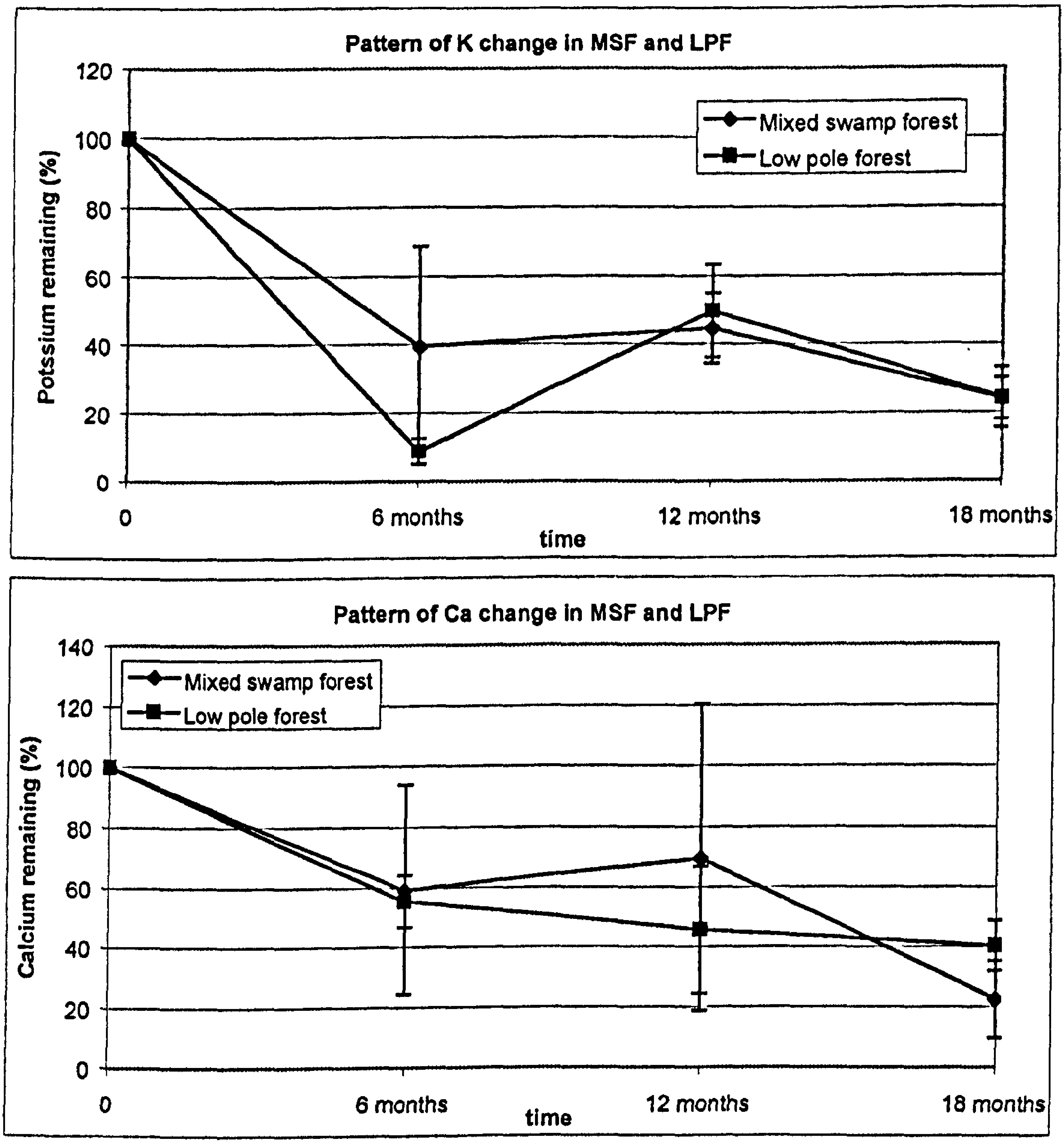


Figure 3.5.3. : Pattern of change in potassium and calcium in mixed swamp forest and low pole forest during 18 months periods , expressed as percentages of the original amount of nutrient

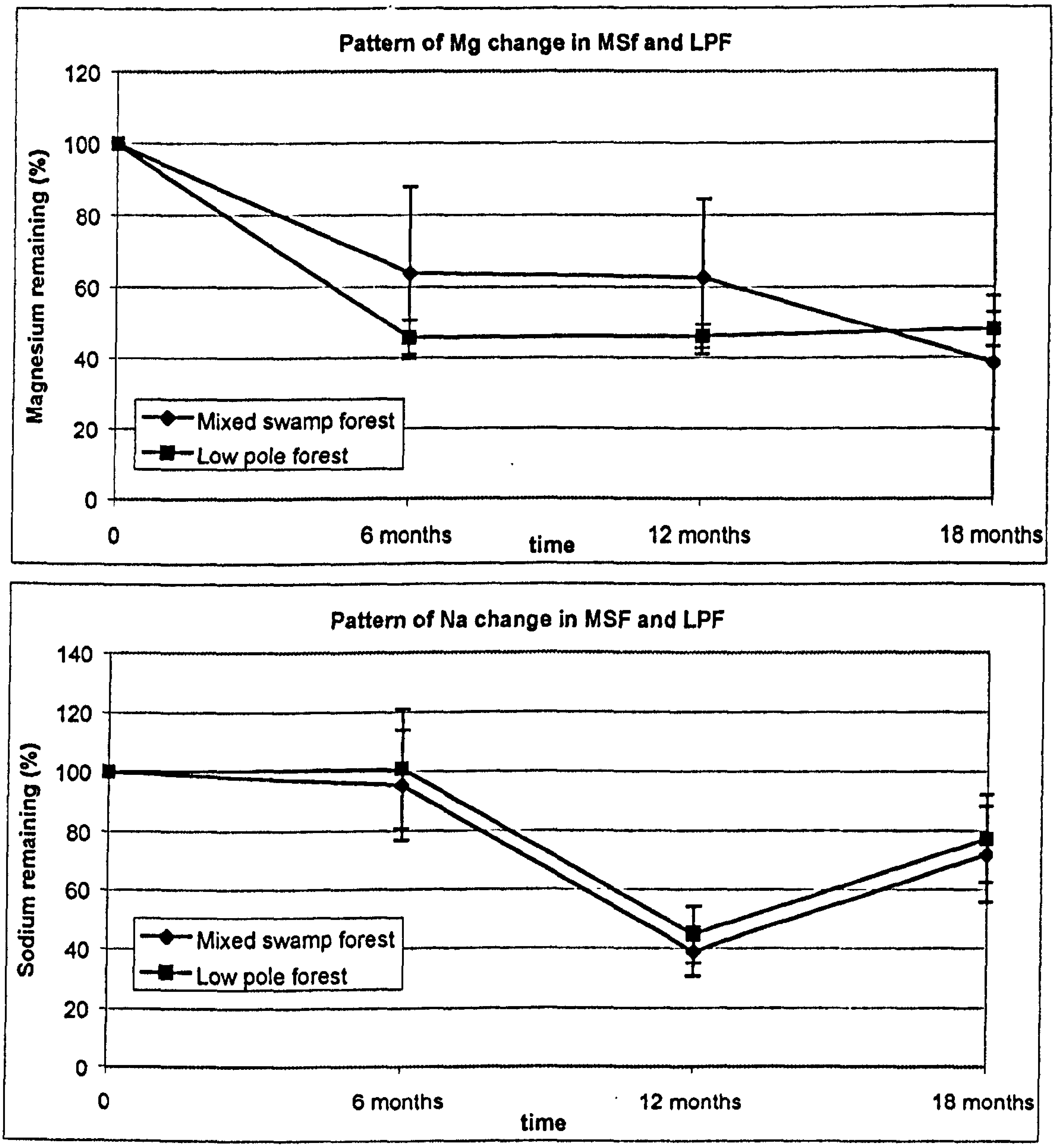
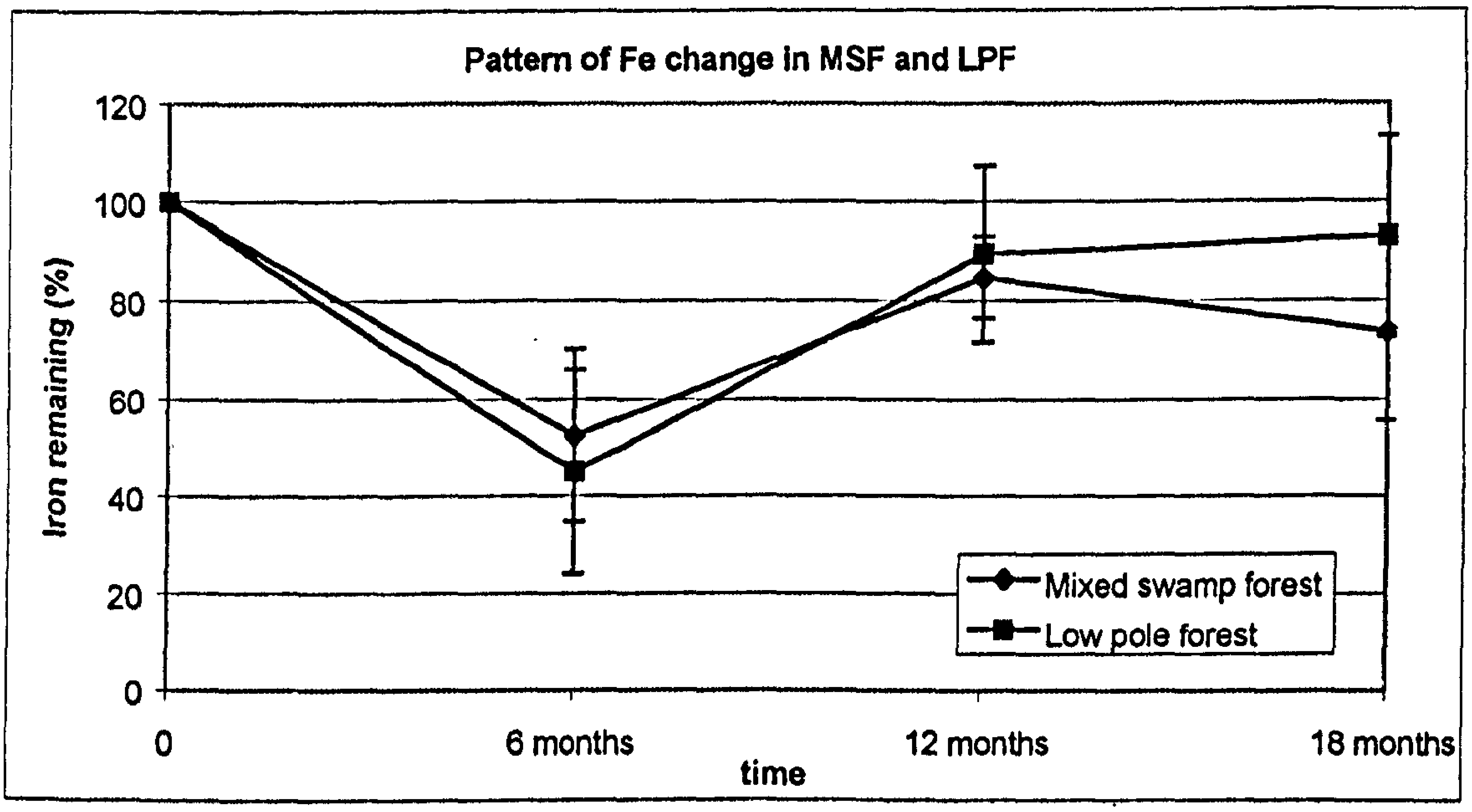


Figure 3.5.4. : Pattern of change in magnesium and sodium in mixed swamp forest and low pole forest during 18 months periods , expressed as percentages of the original amount of nutrient



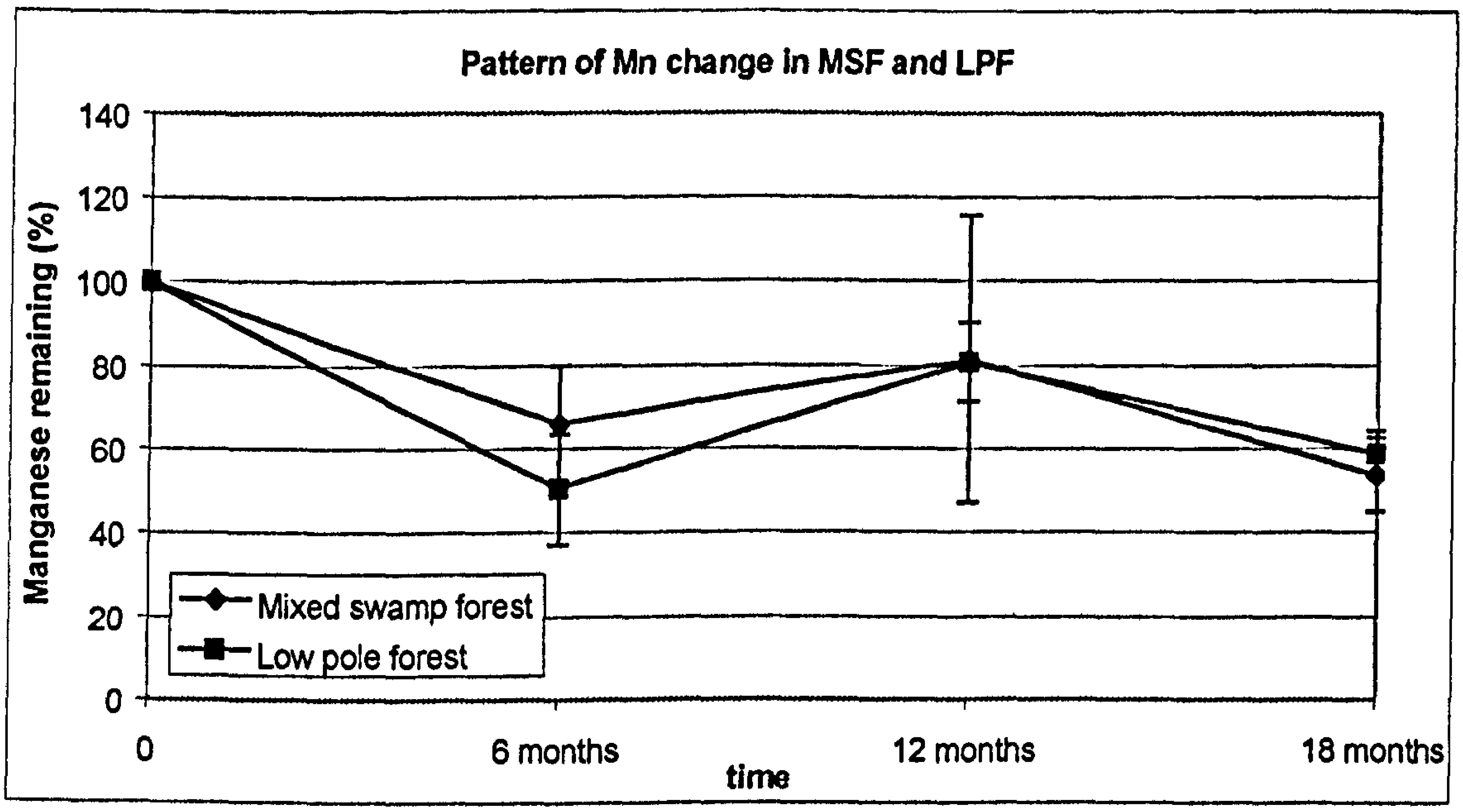


Figure 3.5.5. : Pattern of change in iron and manganese in mixed swamp forest and low pole forest during 18 months periods , expressed as percentages of the original amount of nutrient

3.5.3. Rate of decomposition

In litter decomposition studies, the instantaneous decay constant (*k*) is commonly used to compare litter decomposition rates between species or between various environments. The *k* value of different sub-type of peat swamp forest, mixed swamp forest and low pole forest, in Central Kalimantan, Indonesia during 6, 12, and 18 months periods are presented in table 3.5.5.

Table 3.5.5: The mean rate of decomposition and standard deviation in mixed swamp forest and low pole forest after 6 months, 12 months, and 18 months.

Type of Forest	6 Months (196 days)	12 months (378 days)	18 months (560 days)
Mixed swamp forest	0.605 yr^{-1} a	0.396 yr^{-1} a	0.814 yr^{-1} a
SD	0.288	0.160	0.394
% SD MSF	47.60	40.34	48.39
Low pole forest	0.486 yr^{-1} a	0.285 yr^{-1} a	0.602 yr^{-1} a
SD	0.024	0.053	0.075
% SD LPF	4.91	18.58	12.48

[a] Abbreviation as in Table 3.5.5. indicated value in the same column with different letters are statistically different (T- test, $p < 0.05$).

In general, the decomposition rate in mixed swamp forest was higher than in low pole forest over 6 month, 12 month and 18 month periods, although 't'-tests between MSF and LPF decomposition rates were not significant. The standard deviation in mixed swamp forest was higher than that in low pole forest. This means that the decomposition rate in mixed swamp forest is more variable than that in low pole forest.

In mixed swamp forest, the decomposition rates over 6 months, 12 months, and 18 months were 0.605±0.288; 0.396±0.160; and 0.814±0.394 yr^{-1} respectively while in low pole forest they were 0.486±0.024; 0.285±0.053; and 0.602±0.075 yr^{-1}.

3.6. BIOMASS

3.6.1. Total above ground biomass (TAGB)

3.6.1.1. Nutrient concentration of leaves and branch

Calculation of nutrient concentrations for determination of total nutrients in above ground biomass was carried out through chemical analysis of leaf and branch samples that were bulked prior to analysis for N, P, K, Ca, Mg, Na, Fe, and Mn (see chapter 2.8). The average nutrient concentrations (N, P, K, Ca, Mg, Na, Fe, and Mn) in mixed swamp forest and low pole forest are presented in Tables 3.6.1 and 3.6.2, respectively.

In mixed swamp forest, calcium concentration in leaves was the highest with 12569.6±6630.6 mg kg^{-1}, followed by nitrogen with 11446.9±2202.4 mg kg^{-1}. Potassium concentration was the third with 6235.4±3099.3 mg kg^{-1}, followed by magnesium (3687.0±1918.7 mg kg^{-1}), sodium (343.9±56.5 mg kg^{-1}), phosphorus (217.3±24.5 mg kg^{-1}), iron (185.3±16.1 mg kg^{-1}), and manganese (25.4±17.4 mg kg^{-1}). Similarly to leaves, calcium concentration in branches was also the highest with 17393.2±11804.7 mg kg^{-1}, followed by nitrogen with 7829.9±3732.3 mg kg^{-1}, potassium (5036.8±2227.3 mg kg^{-1}). After potassium was magnesium with 2093.3±897.2 mg kg^{-1}, followed by sodium (257.1±77.0 mg kg^{-1}), phosphorus (220.5±198.0 mg kg^{-1}), iron (191.1±24.8 mg kg^{-1}), and manganese (6.2±3.7 mg kg^{-}). Calcium concentration in *Pandanus* sp was also the highest with 23001.0±16450.5 mg kg^{-1}, followed by potassium with 16284.3±607.5 mg kg^{-1}. The third place was nitrogen with 8702.4±1972.8 mg kg^{-1}, followed by phosphorus with 1144.7±1027 mg kg^{-1}, magnesium (3033.7±263.0 mg kg^{-1}), sodium (290.5±129.5 mg kg^{-1}), iron (180.2±23.5 mg kg^{-1}), and manganese (9.7±5.5 mg kg^{-1}).

In low pole forest, calcium concentration in leaves was also the highest with 11523.2±2191.7 mg kg^{-1}, followed by nitrogen with 7422.7±1101.2 mg kg^{-1}, potassium (6295.3±1230.9 mg kg^{-1}). Magnesium concentration was the fourth with 2869.2±944.7 mg kg^{-1}, followed by sodium (300.6±110.4 mg kg^{-1}), iron (192.2±27.5 mg kg^{-1}), phosphorus (147.2±21.1 mg kg^{-1}), and manganese (9.3±5.6 mg kg^{-1}). Similarly to calcium concentration in branches in mixed swamp forest, calcium in branches from low pole forest was also the highest with 17732.0±3379.0 mg kg^{-1}, followed by potassium with 4941.3±1006.3 mg kg^{-1}, nitrogen (4855.1±1505.9 mg kg^{-1}), magnesium (2522.3±747.8 mg kg^{-1}), sodium (247.6±75.6 mg kg^{-1}), iron (194.0±51.9 mg kg^{-1}), phosphorus (122.9±44.4 mg kg^{-1}), manganese (5.7±3.0 mg kg^{-1}). Since the *Pandanus* spp. from mixed swamp forest and low pole forest were bulked for nutrient analysis the resultant nutrient concentrations (N, P, K, Ca, Mg, Na, Fe, and Mn) presented in Tables 3.6.1 and 3.6.2 are the same.

Table 3.6.1. Nutrient concentrations, standard deviations, and % standard deviations in mixed swamp forest

	N mg kg^{-1}	P Mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}
Leaves *	11446.9	217.3	6235.4	12569.6	3687.0	343.9	185.3	25.4
SD	2202.4	24.5	3099.3	6630.6	1918.7	56.5	16.1	17.4
% SD	19.2	11.3	49.7	52.8	52.0	16.4	8.7	68.5
Branch *	7829.9	220.5	5036.8	17393.2	2093.3	257.1	191.1	6.2
SD	3732.3	198.0	2227.3	11804.7	897.2	77.0	24.8	3.7
% SD	47.7	89.8	44.2	67.9	42.9	29.9	13.0	59.4
Pandanus spp *	8702.4	1144.7	16284.3	23001.0	3033.7	290.5	180.2	9.7
SD	1972.8	1027.4	607.5	16450.5	263.0	129.5	23.5	5.5
% SD	22.7	89.8	3.7	71.5	8.7	44.6	13.0	56.3

* see also chapter 2

Table 3.6.2. Nutrient concentrations, standard deviations, and % standard deviations in low pole forest

	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}
Leaves *	7422.7	. 147.2	6295.3	11523.2	2869.2	300.6	192.2	9.3
SD	1101.2	21.1	1230.9	2191.7	944.7	110.4	27.5	5.6
% SD	14.8	14.3	19.6	19.0	32.9	36.7	14.3	60.3
Branch *	4855.1	122.9	4941.3	17732.0	2522.3	247.6	194.0	5.7
SD	1505.9	44.4	1006.3	3379.0	747.8	75.6	51.9	3.0
% SD	31.0	36.1	20.4	19.1	29.6	30.5	26.8	53.4
Pandanus spp *	8702.4	1144.7	16284.3	23001.0	3033.7	290.5	180.2	9.7
SD	1972.8	1027.4	607.5	16450.5	263.0	129.5	23.5	5.5
% SD	22.7	89.8	3.7	71.5	8.7	44.6	13.0	56.3

* see also chapter 2

3.6.1.2. Biomass and total above ground nutrient contents

The total above ground biomass (TAGB) and its nutrient content were estimated by measuring all tree material above the peat surface (see Section 2.8). TAGB consists of three components namely, trees of diameter equal to or more than 5 cm, trees less than 5 cm diameter and shrubs (especially, *Pandanus* spp). Total above ground biomass in each of these categories and their nutrient element contents

(N, P, K, Ca, Mg, Na, Fe, and Mn) in mixed swamp forest and low pole forest are presented in Tables 3.6.3. and 3.6.4, respectively.

In mixed swamp forest (Table 3.6.3), the TABG in MSF was 313,899 kg ha^{-1} comprising 312,000 kg ha^{-1} (99.40 %) from trees of diameter ≥5 cm , 1,501±126.2 kg ha^{-1} (0.48 %) from trees of diameter <5 cm, and 398±173.2 kg ha^{-1} (0.12 %) from *Pandanus* spp. Most of the biomass is contributed by trees of diameter ≥ 5 cm (Table 3.6.3).

The total nutrient content (N, P, K, Ca, Mg, Na, Fe, and Mn) was 9887.8 kg ha^{-1}. The highest nutrient content in total above ground biomass was calcium with 4576.9±3336.2 kg ha^{-1}, followed by nitrogen with 2643.4±1112.3 kg ha^{-1}. Potassium was the third with 1659.8±977.9 kg ha^{-1}, magnesium (803.9 kg ha^{-1}), sodium (81.8± kg ha^{-1}), phosphorus (64.75±35.1 kg ha^{-1}), iron (52.5±14.8 kg ha^{-1}), and the lowest was manganese contributing only 4.73±3.66 kg ha^{-1}.

Total nutrient content was greatest in trees of diameter ≥5 cm (99.1%) followed by trees of diameter <5 cm (0.5%) and *Pandanus* spp. (0.4 %). The nutrient element content in trees of both diameters decreased in the order: Ca>N>K>Mg>Na>P>Fe>Mn. In the *Pandanus* spp. elements decreased in order: Ca>K>N>Mg>P>Na>Fe>Mn.

In the low pole forest (Table 3.6.4), the total above ground biomass was 252,547.6 kg ha^{-1} comprising 249,000 kg ha^{-1} (98.60%) from trees of diameter ≥5 cm, 2389.2±344.8 kg ha^{-1} (0.95 %) from trees of diameter <5 cm, and 1158.4±296.8 kg ha-

[1] (0.45 %) from *Pandanus* spp. Most of the biomass is concentrated in trees of diameter ≥5 cm.

The total nutrient element content of the above ground biomass in low pole forest is 7585.0 kg ha^{-1} of which calcium contributes most at 3730.5±414.3 kg ha^{-1} while manganese is least at only 1.94±0.29 kg ha^{-1}. The total element content in above ground biomass decreased in the order: Ca>N>K>Mg>Na>Fe>P>Mn. Total element content in different categories was greatest in trees of diameter ≥5 cm (97.5 %) followed by *Pandanus* spp. (1.6 %) and trees of diameter <5 cm (0.9%). The element content in trees of both diameters decreased in the order: Ca>N>K>Mg>Na>Fe>P>Mn. In *Pandanus* spp. element content decreased in order: Ca>K>N>Mg>P>Na>Fe>Mn.

Table 3.6.3. Total above ground biomass, nutrient contents (kg ha^{-1}), standard deviations, and % of total (in italic) in MSF

		Biomass Kg ha^{-1}	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na Kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Total
Tree ≥5 cm	Mean	312000	2624.1	63.7	1639.2	4537.3	797.7	81.2	52.2	4.7	9800.1
	SD	±	1108.9	35.1	974.4	3322.3	320.7	18.5	14.8	3.65	
	% Tot	*99.40*	*99.27*	*98.38*	*98.76*	*99.13*	*99.23*	*99.27*	*99.43*	*99.37*	99.1
Tree <5 cm	Mean	1501	12.4	0.3	7.7	21.3	3.8	0.4	0.2	0.02	46.1
	SD	126.2	4.7	0.16	4.3	15.1	1.3	0.07	0.05	0.017	
	% Tot	*0.48*	*0.47*	*0.46*	*0.46*	*0.47*	*0.47*	*0.49*	*0.38*	*0.42*	0.5
Pandanus sp	Mean	398	6.9	0.75	12.9	18.3	2.4	0.2	0.1	0.01	41.6
	SD	173.2	3.0	0.3	5.6	7.9	1.0	0.1	0.06	0.003	
	% Tot	*0.12*	*0.26*	*1.16*	*0.78*	*0.40*	*0.30*	*0.24*	*0.19*	*0.21*	0.4
Total	Mean	313899	2643.4	64.75	1659.8	4576.9	803.9	81.8	52.5	4.73	9887.8
	SD	293.6	1112.3	35.1	977.9	3336.2	321.5	18.5	14.8	3.66	

Table 3.6.4. Total above ground biomass, nutrient contents (kg ha^{-1}), standard deviations, and % of total (in italic) in LPF

		Biomass .kg ha^{-1}	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na Kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Total
Tree ≥5 cm	Mean	249000	1528.6	33.6	1398.9	3642.3	671.2	68.3	48.1	1.9	7392.9
	SD	± n. a	136.4	3.8	69.8	397.5	137.9	16.3	3.4	0.29	
	% Tot	*98.60*	*97.77*	*93.07*	*96.48*	*97.64*	*98.06*	*98.13*	*98.16*	*97.94*	*97.5*
Tree <5 cm	Mean	2389.2	14.6	0.3	13.4	34.9	6.3	0.6	0.5	0.02	70.6
	SD	344.8	1.9	0.07	2.1	5.9	0.99	0.13	0.07	0.002	
	% Tot	*0.95*	*0.94*	*0.84*	*0.92*	*0.93*	*0.92*	*0.86*	*1.02*	*1.03*	0.9
Pandanus sp	Mean	1158.4	20.2	2.2	37.7	53.3	7.0	0.7	0.4	0.02	121.5
	SD	296.8	5.2	0.6	9.7	13.6	1.8	0.17	0.11	0.006	
	% Tot	*0.45*	*1.29*	*6.09*	*2.6*	*1.43*	*1.02*	*1.01*	*0.82*	*1.03*	*1.6*
Total	Mean	252547.6	1563.4	36.1	1450	3730.5	684.5	69.6	49	1.94	7585.0
	SD	406.4	132.9	3.4	61.1	414.3	137.6	16.6	3.50	0.29	

3.6.2. Total below ground biomass (TBGB)

3.6.2.1. Nutrient concentration of roots

Nutrient concentrations (N, P, K, Ca, Mg, Na, Fe, and Mn) in roots of mixed swamp forest and low pole forest trees are presented in Table 3.6.5.

In mixed swamp forest, nitrogen concentration was the highest with 10688.4±1939.8 mg kg^{-1}, followed by calcium with 6702.0±2741.3 mg kg^{-1}. Potassium concentration was the third with 5717.6±1713.4 mg kg^{-1}, followed by magnesium (2816.7±891.6 mg kg^{-1}), iron (204.1±87.3 mg kg^{-1}), sodium (200.1±122.0 mg kg^{-1}), phosphorus (160.4±46.0 mg kg^{-1}), and manganese (3.5±2.3 mg kg^{-1}).

Similarly to mixed swamp forest, nitrogen concentration of roots was also the highest in low pole forest with 8958.9±1623.8 mg kg^{-1}, followed by calcium with 5308.3±2184.4 mg kg^{-1}, potassium (3096.2±1463.3 mg kg^{-1}). Magnesium concentration was the fourth with 1783.9±591.8 mg kg^{-1}, followed by iron

(202.3±72.9 mg kg^{-1}), sodium (171.6±55.9 mg kg^{-1}), phosphorus (97.4±14.2 mg kg^{-1}), and the lowest was manganese with 1.4±0.9 mg kg^{-1}.

Table 3.6.5. Nutrient concentrationof roots, standard deviation and % standard deviationin mixed swamp forest and low pole forest

Forest sub-type	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}
Mixed swamp forest root	10688.4a	160.4a	5717.6a	6702.0a	2816.7a	200.1a	204.1a	3.5a
SD	1939.8	46.0	1713.4	2741.3	891.6	122.0	87.3	2.3
% SD	18.1	28.7	30.0	40.9	31.7	61.0	42.8	64.3
Low pole forest roots	8958.9b	97.4b	3096.2b	5308.3a	1783.9b	171.6a	202.3a	1.4b
SD	1623.8	14.2	1463.3	2184.4	591.8	55.9	72.9	0.9
% SD	18.1	14.6	47.3	41.2	33.2	32.6	36.0	63.1

[a] Abbreviation as in Table 3.6.5. indicated value in the same column with different letters are statistically different (T- test, $p < 0.05$)

3.6.2.2. Roots biomass and nutrient contents

The total root below ground and nutrient contents were estimated by collecting and weighing all root material from two distances, 0 –25 cm and 25-50 cm, below the peat surface (see Section 2.8). Total root biomass at each depth and its nutrient element content (N, P, K, Ca, Mg, Na, Fe, and Mn) in Mixed Swamp Forest and Low Pole Forest are presented in Tables 3.6.6. and 3.6.7, respectively.

In mixed swamp forest (Table 3.6.6), the total root biomass was 26,533.3 ±13260.1 kg ha^{-1} consisting of 22053.1±10368.5 kg ha^{-1} from 0-25 cm depth (83.1 %) and 4480.3±4028.8 kg ha^{-1} (16.9 %) from 25-50 cm. The highest nutrient content in total root biomass was nitrogen at 287.3±157.8 kg ha^{-1} while the lowest was manganese contributing only 0.08±0.06 kg ha^{-1}.

The total element content in roots decreased in the order: N>Ca>K>Mg>Fe>Na>P>Mn. The element nutrient at 0-25 cm depth decreased in the order: N>Ca>K>Mg>Na>Fe>P>Mn. At 25-50 cm the element content decreased in the order: N>Ca>K>Mg>Fe>Na>P>Mn.

In the low pole forest (Table 3.6.7), the total root biomass was 14,382.7±9,813.8 kg ha^{-1} comprising of 10,678.4±7,705.2 kg ha^{-1} (74.2 %) from 0-25 cm depth and 3,704.3±2,211.6 kg ha^{-1} (25.8 %). Most of the root biomass is concentrated in 0-25 cm depth (74.2%). The total element content in root biomass in low pole forest was 286.8 kg ha^{-1} with the largest contribution from nitrogen at 128.6±95.1 kg ha^{-1} while the lowest is manganese at only 0.02±0.02 kg ha^{-1}.

The total element content in roots, and at both depths, decreases in the order: N>Ca>K>Mg>Fe>Na>P>Mn.

Table 3.6.6. Total below ground biomass (roots), nutrient contents (kg ha^{-1}), standard deviations, and % of total (italic) in MSF

Roots		Biomass kg ha^{-1}	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Total
0-25 cm deep	Mean	22053.1	239.4	3.4	119.1	151.0	62.1	4.9	5.0	0.08	585.0
	Sd	10368.5	126.8	1.8	54.5	101.1	34.4	4.8	4.6	0.06	328.0
	% Tot	*83.1*	*83.3*	*81.7*	*82.4*	*81.8*	*83.3*	*84.9*	*83.5*	*83.0*	*82.7*
25-50 cm deep	Mean	4480.3	47.9	0.8	25.5	33.6	12.5	0.9	1.0	0.02	122.2
	Sd	4028.8	43.1	1.0	27.4	47.7	11.8	0.9	1.1	0.02	133.1
	% Tot	*16.9*	*16.7*	*18.3*	*17.6*	*18.2*	*16.7*	*15.1*	*16.5*	*17.0*	*17.3*
Total	Mean	26533.3	287.3	4.2	144.6	184.6	74.6	5.7	6.0	0.09	707.1
	Sd	13260.1	157.8	2.7	76.3	139.0	42.3	5.6	5.5	0.08	429.2

Table 3.6.7. Total below ground biomass (roots), nutrient contents (kg ha^{-1}), standard deviations, and % of total (italic) in LPF

Roots		Biomass kg ha^{-1}	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Total
0-25 cm deep	Mean	10678.4	95.7	1.1	35.2	56.9	20.3	1.8	2.1	0.01	213.1
	Sd	7705.2	75.2	1.0	36.4	44.9	17.5	1.2	1.3	0.01	177.5
	% Tot	*74.2*	*74.4*	*74.5*	*74.0*	*74.2*	*74.6*	*74.2*	*74.2*	*74.8*	*74.3*
25-50 cm deep	Mean	3704.3	33.0	0.4	12.4	19.8	6.9	0.6	0.7	0.01	73.8
	Sd	2211.6	20.7	0.3	10.5	14.0	5.4	0.4	0.5	0.00	51.7
	% Tot	*25.8*	*25.6*	*25.5*	*26.0*	*25.8*	*25.4*	*25.8*	*25.8*	*25.2*	*25.7*
Total	Mean	14382.7	128.6	1.5	47.5	76.7	27.3	2.4	2.8	0.02	286.8
	Sd	9813.8	95.1	1.3	46.6	58.3	22.7	1.6	1.8	0.02	227.3

3.7. PEAT SOIL

3.7.1. pH and nutrient concentration

The pH value and nutrient concentration (N, P, K, Ca, Mg, Na, Fe, and Mn) in Mixed Swamp Forest and Low Pole Forest peat soils at a 50 cm depth are presented in Table 3.7.1.

The value of pH in mixed swamp forest was lower than pH in low pole forest with 3.30±0.27 and 3.49±0.17, respectively. T-test between soil pH in mixed swamp forest and soil pH in low pole forest was significantly different (Appendix 8). Similarly to soil pH, nitrogen, phosphorus, sodium, and iron concentrations were also significantly different, for example, nitrogen in mixed swamp forest was 28637.3±6586.8 mg kg^{-1} and 21900.9±4642.6 mg kg^{-1} (LPF). Phosphorus concentration in mixed swamp forest was 182.7±42.4 mg kg^{-1} and 139.4±38.9 mg kg^{-1} in low pole forest. In contrast, t-test between potassium, calcium, magnesium and manganese concentration in MSF and LPF showed no significant differences between mixed swamp forest and low pole forest. For example, potassium in mixed swamp forest was 287.9±169.5 mg kg^{-1} and 220.4±146.6 mg kg^{-1} in low pole forest. Calcium in mixed swamp forest was 941.4±357.1 mg kg^{-1} and 889.3±391.6 mg kg^{-1} in LPF. Manganese was the element in lowest concentration in this study with only 3.6±0.9 mg kg^{-1} in mixed swamp forest and 3.6±1.0 mg kg^{-1} in low pole forest.

Table 3.7.1. pH and nutrient concentrations (mg kg^{-1}), standard deviations, % standard deviations in peat soil 50 cm deep in mixed swamp forest (MSF) and low pole forest (LPF).

Roots		pH	N mg kg^{-1}	P mg kg^{-1}	K Mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na Mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}
MSF (Wet period)	Mean	3.30a	28637.3a	182.7a	287.9a	941.4a	709.3a	311.2a	469.2a	3.6a
	SD	0.27	6586.8	42.4	169.5	357.1	209.1	149.1	278.0	0.9
	% SD	*8.21*	*23.0*	*23.2*	*58.9*	*37.9*	*29.5*	*47.9*	*59.3*	*23.7*
LPF (Wet period)	Mean	3.49b	21900.9b	139.4b	220.4a	889.3a	669.1a	139.9b	271.3b	3.6a
	SD	0.17	4642.6	38.9	146.6	391.6	144.1	35.9	54.1	1.0
	% SD	*4.84*	*21.2*	*27.9*	*66.5*	*44.0*	*21.5*	*25.6*	*19.9*	*26.8*

[a] Abbreviation as in Table 3.7.1. indicated value in the same column with different letters are statistically different (T- test, $p < 0.05$)

3.7.2. Nutrient content of peat soil

The calculations of the amount of nutrients (N, P, K, Ca, Mg, Na, Fe, and Mn) in peat soil are based on a 1 hectare area, 50 cm deep and a peat bulk density of 0.15 g cm^{-3}. Nutrient element content of peat soil in mixed swamp forest and low pole forest 50 cm deep are presented in table 3.7.2.

There was no significant difference in several nutrient contents between mixed swamp forest and low pole forest. For example, potassium was 215.9±127.1 kg ha^{-1} in mixed swamp forest and 165.3±109.9 kg ha^{-1} in low pole forest. Calcium was 706.1±267.8 kg ha^{-1} in mixed swamp forest and 666.9±293.7 kg ha^{-1} (LPF). Manganese was 2.7 ±0.6 kg ha^{-1} in mixed swamp forest and 2.7±0.7 kg ha^{-1} in low pole forest. In contrast, nitrogen, phosphorus, sodium, and iron were significantly different between mixed swamp forest and low pole forest, such as, nitrogen was 21478.0±4940.1 kg ha^{-1} in mixed swamp forest and 16425.7±3482.0 kg ha^{-1} in low pole forest. Sodium was 233.4±111.8 kg ha^{-1} in mixed swamp forest but only 105.0±26.9 kg ha^{-1} in low pole forest.

In mixed swamp forest, the element in highest content in peat soil at 50 cm depth was nitrogen at 21478.0±4940.1 kg ha^{-1}, followed by calcium with 706.1±267.8 kg ha^{-1}. The third place was magnesium with 531.9±156.8 kg ha^{-1}, followed by iron with 351.9±208.5 kg ha^{-1}, sodium (233.4±111.8 kg ha^{-1}), potassium (215.9±127.1 kg ha^{-1}), phosphorus (137.0±31.8 kg ha^{-1}) and the lowest was manganese with only 2.7±0.6 kg ha^{-1}.

Similarly to mixed swamp forest, nitrogen in low pole forest was the highest with 16,425.7±3,482.0 kg ha^{-1}, followed by calcium with 666.9±293.7 kg ha^{-1}. The third place of nutrient content in low pole forest was the same as with mixed swamp forest that was magnesium with 501.8±108.1 kg ha^{-1}, followed by iron (203.5±40.6 kg ha^{-1}). After iron was potassium (165.3±109.9 kg ha^{-1}), followed by sodium (105.0±26.9 kg ha^{-1}), phosphorus (104.6±29.2 kg ha^{-1}), and the lowest was manganese with 2.7±0.7 kg ha^{-1}.

Table 3.7.2. Nutrient contents (kg ha^{-1}), standard deviations, % standard deviations in peat soil 50 cm deep in mixed swamp forest (MSF) and low pole forest (LPF).

Roots		N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn Kg ha^{-1}
MSF	Mean	21478.0a	137.0a	215.9a	706.1a	531.9a	233.4a	351.9a	2.7a
(Wet	SD	4940.1	31.8	127.1	267.8	156.8	111.8	208.5	0.6
period)	% SD	23.0	23.2	58.9	37.9	29.5	47.9	59.3	23.7
LPF	Mean	16425.7b	104.6b	165.3a	666.9a	501.8a	105.0b	203.5b	2.7a
(Wet	SD	3482.0	29.2	109.9	293.7	108.1	26.9	40.6	0.7
period)	% SD	21.2	27.9	66.5	44.0	21.5	25.6	19.9	26.8

[a] Abbreviation as in Table 3.7.2. indicated value in the same column with different letters are statistically different (T- test, $p < 0.05$)

3.8. RUNOFF

3.8.1. pH and nutrient concentration of surface water

The pH of runoff water and its nutrient concentration were measured in the wet season when the water table was above the peat surface. The pH values and concentrations of Ca, Mg, K, Na, Fe, Mn, nitrite, and phosphate in runoff water in Mixed Swamp and Low Pole Forests are presented in Table 3.8.1.

The pH of runoff water in both forest sub-types was significantly different with pH 3.13±0.05 in MSF and pH 3.07±0.03 in LPF. Calcium, magnesium, nitrite, and phosphate concentration in both sub type of peat swamp forest were also significantly different while potassium, sodium, iron, manganese were not significantly different, such as, potassium in mixed swamp forest was 0.15±0.29 mg l^{-1} and 0.08±0.06 mg l^{-1} (low pole forest).

Table 3.8.1. pH and nutrient concentrations (mg l^{-1}), standard deviations, % standard deviations in water run off in MSF and LPF

Water		pH	Ca mg l^{-1}	Mg mg l^{-1}	K Mg l^{-1}	Na mg l^{-1}	Fe mg l^{-1}	Mn Mg l^{-1}	Nitrite mg l^{-1}	P Total mg l^{-1}
MSF	Mean	3.13 a	0.53 a	0.16 a	0.15 a	0.32a	0.05a	0.001a	0.017a	0.017a
	SD	0.05	0.12	0.04	0.29	0.06	0.02	0.001	0.002	0.028
	% SD	1.65	22.43	21.85	202.07	19.49	49.69	91.54	10.72	166.37
LPF	Mean	3.07 b	0.47 b	0.15 b	0.08a	0.31a	0.05a	0.001a	0.015b	0.005b
	SD	0.03	0.05	0.02	0.06	0.03	0.02	0.001	0.002	0.004
	% SD	1.01	11.28	13.35	73.36	10.84	49.64	55.93	13.99	86.68

[a] Abbreviation as in Table 3.8.1. indicated value in the same column with different letters are statistically different (T- test, p <0.05)

3.8.2. Nutrient content of runoff water

Nutrient element (Ca, Mg, K, Na, Fe, Mn, nitrite, and phosphate) losses through water runoff in Mixed Swamp Forest and Low Pole Forest are presented in Table 3.8.2. Water runoff was calculated as the difference between annual rainfall (2760.7±387.6 mm) and annual evapotranspiration (1237.6±72.8 mm). The result was 1523.1 mm yr^{-1} equivalent with 15231000 l ha^{-1} yr^{-1} (see appendix 1).
Evapotranspiration (364 x 3.4 mm day^{-1}) was obtained from Takahashi *et al* (2002). The amount of each element lost through run off was calculated by multiplying the amount of run-off by the concentration of each nutrient element.

In mixed swamp forest, the highest nutrient output through runoff during the one-year study period was calcium with 8.15±1.83 kg ha^{-1}, followed by sodium with 4.85±0.94 kg ha^{-1}, magnesium (2.51±0.55 kg ha^{-1}). The fourth was potassium with 2.21±4.47 kg ha^{-1}, followed by iron (0.72±0.36 kg ha^{-1}), nitrite (0.26±0.03 kg ha^{-1}), phosphate (0.26±0.43 kg ha^{-1}), and the lowest was manganese at 0.01±0.01 kg ha^{-1}.

Similarly to the mixed swamp forest, calcium was the highest nutrient lost through run off in low pole forest during the 1-year period with 7.15±0.81 kg ha^{-1}, followed by sodium with 4.69±0.51 kg ha^{-1}. The third place was magnesium with 2.24±0.30 kg ha^{-1}, followed by potassium (1.29±0.94 kg ha^{-1}), iron (0.71±0.35 kg ha^{-1}), nitrite (0.23±0.03 kg ha^{-1}), phosphate (0.07±0.06 kg ha^{-1}), and the lowest was manganese with 0.02±0.01 kg ha^{-1} yr^{-1}.

In general, nutrient losses through run off in mixed swamp forest were higher than in low pole forest. Statistical comparisons using student 't' test indicated that calcium, magnesium, nitrite, and phosphate losses in mixed swamp forest and low pole forest were all significantly different (appendix 9). In contrast, potassium, sodium, iron, and manganese was not significantly different between the two forest sub-types.

Table 3.8.2. Nutrient contents (kg ha^{-1} yr^{-1}), standard deviations, % standard deviations in water run off in MSF anf LPF.

Water		Ca Kg ha^{-1} yr^{-1}	Mg kg ha^{-1} yr^{-1}	K kg ha^{-1} yr^{-1}	Na kg ha^{-1} yr^{-1}	Fe kg ha^{-1} yr^{-1}	Mn kg ha^{-1} yr^{-1}	Nitrite kg ha^{-1} yr^{-1}	P tot kg ha^{-1} yr^{-1}
MSF	Mean	8.15 a	2.51a	2.21 a	4.85 a	0.72 a	0.01 a	0.26 a	0.26 a
	SD	1.83	0.55	4.47	0.94	0.36	0.01	0.03	0.43
	% SD	22.43	21.85	202.07	19.49	49.69	91.54	10.72	166.37
LPF	Mean	7.15 b	2.24 b	1.29 a	4.69 a	0.71 a	0.02 a	0.23 b	0.07 b
	SD	0.81	0.30	0.94	0.51	0.35	0.01	0.03	0.06
	% SD	11.28	13.35	73.36	10.84	49.64	55.93	13.99	86.68

[a] Abbreviation as in Table 3.8.2. indicated value in the same column with different letters are statistically different (T- test, $p < 0.05$)

CHAPTER 4

DISCUSSION

4.1. PRECIPITATION

4.1.1. The Quantity and pH of rainfall

Rainfall data obtained from Cilik Riwut Airport, Palangka Raya, (about 15 km from the study site) for the study period were only slightly different from those in the study area (2760.7 and 2835.4 mm, respectively).

Comparison with other data for several places suggests that the pH value in Central Kalimantan throughout the study period (Table 4.1.1) is near to the top of the range.

Table 4.1.1: The quantity and pH in precipitation in several places in the world.

No	Location	Rain (mm)	.pH	Reference
1	Palangka Raya, Indonesia	2761	5.96±0.35	This study
2	Chartley Moss, England	926.2	4.23	Ahmad-Shah (1984)
3	Selangor, Malaysia	2665	5.77±0.26	Ahmad-Shah *et al.* 1992
4	Kuala Lumpur, Malaysia	3286	4.37	Abas *et al.*, 1992
5	Klosterhede, Denmark	-	4.15	Hansen *et al*, 1994
6	Speuld, Netherlands	-	4.08	Hansen *et al*, 1994
7	Colombia	2115	4.40	Veneklaas (1990)
8	Netherlands	-	4.51	Van Breemen *et al*, 1982
9	Brunei Darussalam	-	5.91	Radojevic & Tan, 2000
10	Posadero, Spain	1426	5.7±0.24	Amezaga *et al*, 1997
11	Manzanal, Spain	1071	5.4±0.19	Amezaga *et al*, 1997
12	Durango, Spain	1303	5.9±0.24	Amezaga *et al*, 1997
13	Orobio, Spain	1583	5.3±0.21	Amezaga *et al*, 1997
14	Yunnan, China	2170	6.42±0.22	Liu *et al*, 2002

The pH of rainwater in the Sg. Sebangau catchment in Central Kalimantan, Indonesia is only slightly acidic (mean 5.92±0.32) compared to that at Chartley Moss, England (mean pH 4.23) (Ahmad-Shah, 1984; Ahmad-Shah & Rieley, 1989). The pH of rainwater in the Sg. Sebangau is higher than Chartley Moss probably because it is far from industrial areas that produce sulphur and nitrous oxides. Neutralization of the weak acidity in the rain falling on the Sebangau catchment could also be caused by atmospheric NH_3 originating in the agriculture area, near to the study plot, where NH_4NO_3 and $(NH_4)_2SO_4$ containing fertilizers are used intensively (Al Momani *et al.*, 1995) and biomass burning produces inorganic N (Clark *et al.*, 1998b) and basic cations such as Ca^{2+}, Mg^{2+} and K^+ (Radojevic & Tan, 2000). In contrast, Chartley Moss, England is close to industrial and urban centres where sulphur and nitrogen oxides are emitted from power stations, space heating and motor vehicles and then converted from gases to H_2SO_4 and HNO_3 causing the precipitation to become acidic (Ruijgrok & Romer, 1993; Kaya & Tuncel, 1997; Heuer, *et al.*, 2000). Similarly, Martin (1979) found that precipitation at the Bowl, New Hampshire, USA, hardwood forest with spruce and fir, was also very acidic, ranging from pH 3.3 to 5.2 with a mean of 4.0. In addition, Galloway (2001) states that most of the atmosphere has more acidic gases (e.g., CO_2, SO_2, NO, HCl, HNO_3) and particles (e.g., H_2SO_4), than basic gases (e.g., NH_3) and particles (e.g., $CaCO_3$).

Moreover, Kaya & Tuncel (1997), suggest that variations in pH may result from differences in distances from industrial areas, which produce emissions of acid precursor gases, particularly SO_2 and NO_3. For example, Amezaga *et al.*, (1997) reported that pH of rain in Manzanal, Spain (close to an industrial centre) was

5.4±0.22, while in Posadero, Spain (farther from industrial centre and close to the coast) the rain pH was 5.7±0.24.

4.1.2. Mineral nutrient concentration of rainfall

Comparison with other data for tropical forests suggests that the concentration of atmospheric input to the forest in Central Kalimantan throughout the study period (Table 4.1.2) is near to the top of the range for calcium and magnesium while sodium and iron are near to the bottom of the range. Potassium, phosphate, and ammonium are in the middle of the range.

Calcium, magnesium, potassium, ammonium, and sodium concentration in rainfall show higher values during the dry than the wet season. Phosphate, nitrite, iron, and manganese do not show any distinct pattern between dry and wet seasons.

These results agree with other workers who also found that the concentration of certain elements in rainfall was higher in the dry than the wet season, for example, magnesium and potassium (Liu *et al.*, 2002b), calcium and sodium (Veneklass *et al.*, 1990) and ammonium (Clark *et al.*, 1998b).

Several reasons have been suggested to explain why nutrient concentrations in precipitation are higher in dry than wet periods, especially, presence in the atmosphere of dust during the dry season originating from soil may contain base cations (e.g. Ca, Mg, K) (Veneklass *et al.*, 1990; Kaya & Tuncel, 1997). Moreover, biomass burning, especially in the end of dry season, may contribute ammonia and several cations to cloud water and precipitation (Clark *et al.*, 1998b).

Several reasons can be suggested to explain why nitrite concentration did not show a seasonal pattern between wet and dry periods. This ion can be produced from soil naturally during both dry and wet seasons (Sanhueza, 1997; Skiba & Smith, 2000) and also from soils used for agriculture (Freney, 1997). It may also be released during the dry season from biomass burning (Radojevic & Tan, 2000) and during the wet season from lightning (Bond *et al.*, 2002). Similarly to nitrite, phosphorus in rainfall can also originate from several sources, including, biomass burning and wind erosion of peat soils bared by tilling (dry season), lightning (wet season) and emission from phosphate mining activities (wet and dry season) (Grimshaw & Dolske, 2002). Iron and manganese occurred in low concentration during the study period, especially, manganese, which could not be detected for much of the time. Iron is a typical soil-related element (Kaya & Tuncel, 1997).

Ca concentrations obtained in this study are lower than data obtained in similar study carried out at Boundary Range, Selangor, Malaysia, while magnesium, potassium, and sodium are higher (Crowther, 1987a). The higher Ca concentration in Malaysia was attributed to limestone quarrying activity.

High sodium concentration in rainfall indicates a seawater effect (Veneklaas, 1990) which does not seem to be the case in this study that reveals a low sodium concentration. Low sodium in this study area may be as a result of the large distance from the coast and direction of winds during study period was not from coast. The origin of elements in precipitation collected in Central Kalimantan during the 1-year study period was likely to be terrestrial, such as atmospheric smoke and dust, rather than marine aerosols (Liu *et al.*, 2002b). Moreover, if sodium originated from terrestrial influences it would be expected to show similar concentration patterns to calcium and potassium (Veneklaas, 1990) that were high during the dry season and lower in the wet season.(See Figure 3.1.3. and 3.1.4 and Table 3.1.2).

Table 4.1.2: Nutrient concentrations in precipitation (R) in several tropical forests.

No	Location	Rain mm	Ca Mg l^{-1}	Mg Mg l^{-1}	K Mg l^{-1}	Na mg l^{-1}	Fe mg l^{-1}	NO_2-N Mg l^{-1}	PO_4-P Mg l^{-1}	NH_4-N Mg l^{-1}	Reference
1	This study	2761	0.89	0.28	0.59	0.30	0.09	0.03	0.17	0.84	This study
2	Selangor, Malaysia	2665	0.78	0.22	0.98	1.26	-	-	-	0.73	Ahmad-Shah *et al.* 1992
3	Kuala Lumpur, Malaysia	3286	0.54	0.30	0.84	1.05	0.3	-	-	1.64	Abas *et al.*, 1992
4	Puerto Rico	3750	0.58	0.13	0.49	1.53	-	-	-	-	Veneklaas (1990)
5	Colombia	2115	0.48	0.15	0.38	1.14	-	-	0.04	0.86	Veneklaas (1990)
6	Boundary Range	2089	1.02	0.09	0.13	0.26	-	-	-	-	Crowther (1987a)
7	Selangor, Malaysia	2441	1.48	0.14	0.15	0.21	-	-	-	-	Crowther (1987a)
8	The Central Cordillera, Panama	3510	0.74	0.14	0.30	1.56	0.13	-	0.7	-	Cavelier *et al*, 1997
9	Monteverde, Costa Rica	2678	0.22	0.16	0.14	1.23	-	-	0.002	0.09	Clark *et al*, 1998

- = no data

4.1.3. Annual flux of mineral nutrients in rainfall

The contribution of nutrient elements in precipitation through wet and dry deposition has been considered as important additions to forest ecosystems (Allen *et al.*, 1968; Marcos & Lancho, 2002). These atmospheric inputs are even more important in poor soils (Veneklass, 1990), especially in ombrotrophic peatlands where efficient use and conservation of nutrients by the vegetation is sufficient to account for sustenance of the bog vegetation (Moore & Bellamy, 1974). Furthermore, under nutrient-limited (oligotrophic) conditions, trees may be able to minimise canopy leaching, and even take up nutrients from precipitation (Brinson *et al.*, 1980; Veneklass, 1990; Rodrigo *et al.*, 2003) as a mechanism to conserve nutrients. In contrast, atmospheric deposition is widely recognised as an important source of trace element contamination for both surficial oceanic water and fresh water (Gelinas *et al.*, 2000).

Comparison with other data for tropical forests suggests that the amount of atmospheric input to the peat swamp forest in Central Kalimantan throughout the study period (Table 4.1.3) is near to the top of the range for calcium and magnesium while sodium is near to the bottom of the range.

Table 4.1.3: Annual fluxes of nutrients in precipitation (R) in several tropical forests.

No	Location	Rain mm	Ca kg ha^{-1}	Mg kg ha^{-1}	K Kg ha^{-1}	Na Kg ha^{-1}	Fe kg ha^{-1}	NO_2-N kg ha^{-1}	PO_4-P kg ha^{-1}	NH_4-N kg ha^{-1}	Reference
1	This study	2761	15.72	5.79	9.61	5.52	3.25	0.54	4.62	16.51	This study
2	Selangor, Malaysia	2665	20.15	5.12	26.36	31.42	-	-	-	18.12	Ahmad-Shah *et al.* 1992
3	Kuala Lumpur, Malaysia	3286	18.2	9.7	27.0	33.7	9.7	-	-	52.0	Abas *et al.*, 1992
4	Puerto Rico	3750	21.8	4.9	18.2	57.2	-	-	-	-	Veneklaas (1990)
5	Colombia	2115	10.1	3.2	7.9	24.1	-	-	0.72	18.28	Veneklaas (1990)
6	Boundary Range	2089	21.3	1.9	2.7	5.4	-	-	-	-	Crowther (1987a)
7	Selangor, Malaysia	2441	36.1	3.4	3.7	5.1	-	-	-	-	Crowther (1987a)
8	The Central Cordillera, Panama	3510	27.87	4.06	13.51	63.51	-	-	0.7	-	Cavelier *et al*, 1997
9	Monteverde, Costa Rica	2678	5.8	2.4	3.0	20.5	-	-	0.05	1.7	Clark *et al*, 1998

Atmospheric pollutants can travel for long distances and may be deposited in remote zones (Gelinas *et al.*, 2000). In contrast, the role of dry deposition decreases with increasing distance from the source (Linberg *et al.*, 1986; Puckett, 1990; Gelinas *et al.*, 2000; Rodrigo *et al.*, 2003).

Biomass burning in the tropics is an important major source of trace gases and particulate matter (including nutrients) to the atmosphere (Prasad *et al.*, 2000; Yamasoe *et al.*, 2000). Furthermore, deforestation (Sanhueza, 1997), intensification of agricultural practices (Freney, 1997; Bremner, 1997, Prasertsak *et al.*, 2001; Goebes *et al.*, 2003), fossil fuel combustion (Skiba *et al.*, 1997) and emision of natural soil ecosystems (Skiba & Smith, 2000) also affect the fluxes of trace gases and particulates to the atmosphere.

Shifting cultivation in India, for example, is one of the major causes of biomass burning (Prasad *et al.*, 2000) while heather burning in the UK releases several elements to the atmosphere, such as, carbon, nitrogen, and sulphur and others that commonly form volatile compounds (Graca, *et al.*, 1999; Muraleedharan, *et al.*, 2000). Nitrogen, for example, was released to the atmosphere at 500° C while potassium was released when the heather burn temperature reached 900° C (Allen, 1964).

The findings of this present study seem to accord with the conclusions of Clark *et al.* (1998) and Prasad *et al.* (2000) who suggest that the majority of elements in rainfall result from biomass burning carried out by farmers near to the study areas every year at the beginning of crop cultivation, mainly during the dry season. Other possibile sources include fertilizer spray and drift, emissions from peat soil and lighting fires.

4.2. THROUGHFALL

4.2.1. The Quantity and pH of throughfall

Table 4.2.1. shows comparison of rainfall pH (R) and throughfall pH (T) in this study using Excel and Wilm's (throughfall only) statistical analyses with other data from several other places. It can be seen that rainfall and throughfall pH in Central Kalimantan throughout the study period are near to the top of the range provided. Rainfall pH is included as a comparison.

Table 4.2.1: The quantity and pH of rainfall and throughfall in several places in the world.

No	Location	Forest type	Rain (mm)	PH	Reference
1	Palangka Raya, Indonesia (R)	Peat swamp forest	2761	5.96±0.35	This study
	MSF throughfall (excel) (T)		1969	4.76±0.33	
	LPF throughfall (excel) (T)		2170	4.37±0.33	
	MSF throughfall (wilm) (T)		1954	4.92±0.05	
	LPF throughfall (wilm) (T)		2110	4.45±0.06	
2	Chartley Moss, England (R)	Peat swamp forest	926.2	4.23	Ahmad-Shah (1984)
	Throughfall (T)		740	3.53	
3	Selangor, Malaysia (R)	Peat swamp forest	2665	5.77±0.26	Ahmad-Shah *et al.* 1992
	Throughfall (T)		1986	5.67±0.40	
4	Kuala Lumpur, Malaysia (R)	Dipterocarp forest	3286	4.37	Abas *et al.*, 1992
	Throughfall (T)		2553	4.71	
5	Klosterhede, Denmark (R)	*Picea abies*	-	4.15	Hansen *et al*, 1994
	Throughfall (T)		-	4.84	
6	Netherlands (R)	*Quercus robur & Betula pendula*	-	4.51	Van Breemen *et al*, 1982
	Throughfall (T)		-	4.54	
7	Manzanal, Spain (R)	*Pinus radiata*	1071	5.4±0.19	Amezaga *et al*, 1997
	Throughfall (T)		749	5.2±0.16	
8	Orobio, Spain (R)	*Quercus rubra*	1583	5.3±0.21	Amezaga *et al*, 1997
	Throughfall (T)		1450.0	5.1±0.17	
9	Yunnan, China (R)	*Lithocarpus & Castanopsis*	2170	6.42±0.22	Liu *et al*, 2002b
	Throughfall (T)		1890	6.20±0.13	

- = no data available

Throughfall was calculated using both Excel and Wilm methods. The differences and advantages/disadvantages between Excel and Wilm can be seen in section 4.9. This study shows that throughfall quantity in Low Pole Forest using Excel and Wilm is higher than in Mixed Swamp Forest with total water a year of 2170±334 mm (78.6% of incident rainfall) and 1969 ±264 mm (71.3% of rainfall), respectively using Excel and 2110±±126 mm (76.4% of rainfall) and 1954±158 mm (70.8 % of rainfall) using Wilm. Differences of forest structure may be the major reason to explain different result between MSF throughfall and LPF throughfall. In MSF, the forest is tall and stratified, with an upper canopy at a height of 35 m, below which there is a closed layer between 15 and 25 m and then a more open layer of smaller trees 7 – 12 m in height (Page *et al.*, 1999). In contrast, LPF has only two canopy layers, the upper of which reaches a maximum height of 20 m and is open while the lower obtains a height of only 12 – 15 m and is more closed (Page *et al.*, 1999).

There are temporal variations throughout the year in both forest sub-types, which are greater in low pole forest than mixed swamp forest (Figure 3.2.1). Differences in throughfall water and their variations reaching the forest floor in both forest sub-types may result from differences in the architecture of tree canopies. Ahmad-Shah (1984) and Ahmad-Shah & Rieley (1989) reported temporal rainwater (precipitation) and throughfall variations in a study of nutrient fluxes in a forested mire at Chartley Moss, England where throughfall ranged from 68% to 80% of precipitation. Henderson *et al.* (1977) obtained a variation from 83% to 89 % in four types of forest - *Pinus, Liriodendron tulipifera, Quercus prinus,* and *mixed Quercus* spp and *Carya* spp, in Tennessee, USA, while Ahmad-Shah *et al.* (1992) reported a range between 55.6 % and 82.7 % in peat swamp forest in Selangor, Malaysia. Ahmad-Shah & Rieley (1989), Loustau *et al.* (1992) and Loescher *et al.* (2002) suggest that variations in the amount of throughfall reaching the forest floor may result from differences in intensity and duration of precipitation, differences in the architecture of tree canopies, tree age and size, density, type of bark and foliage.

The pH of rainwater in the Sg. Sebangau catchment is slightly acidic (mean 5.96±0.35) but the acidity of throughfall is always higher in both MSF and LPF, although the latter is more acid than the former (LPF mean: pH 4.37±0.33; MSF mean: pH 4.76±0.33 (Excel) and LPF mean: pH 4.45±0.05; MSF mean: pH 4.92±0.05 (Wilm)). The acidity of precipitation at Chartley Moss, England was higher than that in Central Kalimantan (mean pH 4.23) and this probably contributed to an even greater acidity in throughfall (mean pH 3.53) (Ahmad-Shah, 1984; Ahmad-Shah & Rieley, 1989). Similarly, Amezaga *et al.* (1997) found that pH of throughfall (pH 5.2) in a *Pinus radiata* plantation at Manzanal, Northern Spain, which is close to an industrial centre, was also more acidic than that in rainfall (pH 5.4). Throughfall pH (pH 5.1) in a *Quercus rubra* plantation at Orobio, Northern Spain, in large forest area, was also more acidic than that in rainfall (pH 5.3) (Amezaga *et al.*, 1997).

Various reasons have been suggested to explain the changes that occur in the pH of precipitation as it passes through a vegetation canopy and temporal variations. Throughfall may contain pollutants leached from the canopy (dry deposits) (Van

Breemen *et al.*, 1982; Novo *et al.*, 1992; Ukonmaanaho, *et al.*, 1998) or organic acids from tree organs (Schroth *et al.*, 2001, Moreno, *et al.*, 2001). Temporal variations may result from differences in intensity and duration of precipitation and variations in the intensity of airborne aerosols and particulates throughout the year (Hansen *et al.*, 1994).

There are a few instances, however, in which throughfall pH is higher than rainfall pH. For example, Abas *et al.* (1992) found that throughfall pH (pH 4.71) at Kuala Lumpur, Malaysia, state forest reserve dominated by members of the Dipterocarpaceae, was higher than that in rainfall (pH 4.37). Similarly, Amezaga *et al.* (1997) reported that at Durango, Northern Spain, in a *Quercus robur* plantation close to a rural area, throughfall pH (pH 6.5) was higher than that of rainfall pH (pH 5.9). The explanation may be higher concentrations of potassium, magnesium, and calcium coming from roads and buildings as urban dust (Takagi *et al.*, 1997), which have a neutralising effect (Ukonmaanaho *et al.*, 1998). There could also be uptake processes taking place in the canopy throughout the rain event that involve H^+ (Rodrigo, 2003). Net retention of H^+ in canopy has been reported by several workers, such as Abas *et al.* (1992), for Dipterocarp forest in urban Kuala Lumpur, Malaysia and Amezaga *et al.* (1997) in *Pinus radiata* plantation in Posadero, northern Spain.

This study showed that throughfall pH in low pole forest (LPF) was significantly lower than throughfall pH in mixed swamp forest (MSF) (LPF mean: pH 4.37±0.33; MSF mean: pH 4.76±0.33 (Excel) and LPF Mean: pH 4.45±0.05; MSF mean: 4.92±0.05 (Wilm)). A major reason for this difference is likely to be the differences in leaf structure (e.g. thin, broad-leaved species in MSF and coriaceous (leathery) leaves with a thicker cuticle in LPF) with the dominant tree community species between MSF and LPF. In MSF the principal tree species are *Aglaia rubiginosa, Calophyllum hosei, C. Lowii, C. scerophyllum, Combretocarpus rotundatus, Cratoxylum glaucum, Dactylocladus stenostachys, Dipterocarpus coriaceus, Dyera costulata, Ganua mottleyana, Gonystylus bancanus, Mezzetia leptopoda, Neoscortechinia kingii, Palaquium cochlearifolium, P. Leiocarpum, Shorea balangeran, S. teymanniana* and *Xylopia fusca* (Page *et al.*, 1999). In contrast, in LPF the typical trees are *Combretocarpus rotundatus, Calophyllum fragrans, C. Hosei, Campnosperma coriaceum, Dactylocladus stenostachys* and *Garcinia cuneifolia.* (Page *et al.*, 1999). Bredemeier, (1988) cited in Ukonmaanaho *et al.* (1998) found that spruce trees have the capability of trapping particles and certain gases. Unfortunately, information on tree species which have the capability to trap certain particles and gases is not available in tropical peat swamp forest. Similar research needs to be carried out in tropical peat swamp forest.

4.2.2. Nutrient concentrations and the amounts of nutrients in throughfall

Table 4.2.2. shows nutrient concentration of throughfall in the study area and several other forests in the tropics. Calcium and Na concentration are near to the bottom of the range while magnesium and ammonium are in the middle of the range. Phosphorus is above the range. Potassium is towards the bottom of the range. Iron and manganese are lower than the findings of Abas *et al.* (1992). There are no data on nitrite for comparison.

Comparison between nutrient concentrations in MSF and LPF throughfall (Table 4.2.2) shows that the concentrations of Ca, Mg, Na, and Fe were higher in LPF than MSF. In contrast, concentrations of K, nitrite, phosphorus, and ammonium were higher in MSF throughfall than LPF throughfall. Manganese concentrations were similar between MSF and LPF throughfall (0.01 mg l^{-1}) but were very low. Analysis of variance of all nutrients showed that the differences between MSF and LPF were not significant with the exception of nitrite (Appendix 2).

Table 4.2.3. shows that the amounts of nutrients in throughfall reaching the forest floor in Central Kalimantan throughout the study period is near to the bottom of the range for calcium, magnesium and sodium while potassium is below the range, phosphorus is above the range and ammonium is in the middle of the range. Iron and manganese are lower than the findings of Abas *et al.* (1992). There are no data on nitrite for comparison.

Comparison between the amount of nutrients in MSF throughfall and LPF throughfall (Table 4.2.3) shows that Ca, Mg, Na, Fe, and phosphorus were higher in LPF than MSF. In contrast, the amounts of K, Mn, nitrite, and ammonium were higher in MSF throughfall than LPF throughfall. Analysis of variance of all nutrients showed that the differences between MSF and LPF were not significant (Appendix 2).

In this study Ca, Mg, and K content in throughfall are higher than in rainfall in agreement with results of previous studies by Ahmad-Shah (1992); Veneklaas (1990); Crowther (1987a); Clark *et al.* (1998) (See table 4.2.2).

It is well known that when water passes over vegetation it is enriched significantly with macronutrients such as Ca, Mg, and K (Carlisle *et al.*, 1966; Potter *et al.*, 1991; Novo *et al.*, 1992; Hansen *et al.*, 1994; Clark, *et al.*, 1998; Moreno *et al.*, 2001; Liu *et al.*, 2002). Comparisons between calcium, magnesium and potassium contents of MSF and LPF throughfall were not significantly different.

Various reasons have been suggested to explain the changes that occur in the chemical composition of precipitation as it passes through a vegetation canopy. Higher nutrient contents in throughfall compared to rainfall may result from the elution of air-borne particles, such as aerosols, dust and pollen grains impacted onto the forest canopy as water passes through and these are then transferred to the forest floor (Potter *et al.*,1991; Hansen *et al.*, 1994; Liu *et al.*, 2002). It has been suggested that high pollen levels in the atmosphere and pollen *in situ* on trees can be washed down in the throughfall leading to increased concentration of K (Carlisle *et al.*, 1966). This may be the case in the Sg. Sebangau study area where reproductive parts, including pollen, in litterfall have the highest concentration of K compared to other components, such as, leaves and branches (Sulistiyanto *et al.*, 2002). Other workers believe that enhanced K, Ca and Mg in throughfall and stemflow derives from foliage leaching (Reiners, 1972; Eaton *et al.*, 1973; Puckett, 1991; Potter et al., 1991; Hansen *et al.*, 1994). Moreover, Ca, Mg and K can be leached easily in the initial stages of wetting (Hansen *et al.*, 1994). In addition, ionic exchanges may take place between rainfall and the internal parts of trees (Jean-Paul *et al.*, 2000).

Na in throughfall was also greater than in rainfall but not as high as Ca, Mg, and K (Hansen *et al.*, 1994; Liu *et al.*, 2002); Fe, and phosphorus were also enhanced (Carlisle *et al.*, 1966; Liu *et al.*, 2002). This study adds to these finding that the amounts of Na, Fe, and phosphorus in throughfall increase slightly compared to rainfall. Analysis of variance among rainfall, MSF throughfall, and LPF throughfall for Na, Fe and phosphorus were not significantly different (Appendix 2).

Several reasons have been suggested to explain slight increases of Na, Fe, phosphorus concentration in throughfall from rainfall. For example, leaching of Na from foliage has been reported to occur (Reiner & Olson, 1984), but normally Na is considered to be conservative, showing only minor canopy exchange (Ulrich, 1983 cit Hansen *et al.*, 1994). In contrast, Beier *et al.* (1992) state that sodium originates solely from dry deposition (no canopy leaching). The explanation for slight increases in iron could be the same as for sodium. Phosphorus in rainfall, in contrast, could be absorbed or adsorbed by well-developed moss and lichen populations in the tree canopy and this could mask any extraction of this element from the rainfall (Carlisle *et al.*, 1966; Schroth *et al.*, 2001).

The higher quantity of nitrite in throughfall than in precipitation may be the result of enrichment of nitrite within the canopy. Leaves and tree trunks are often covered with fungi and these contain nitrogen-fixing organisms (Edwards, 1982) and denitrifying microorganisms (Bremner, 1997) that can produce NO_2-N in the canopy. The increased concentrations of elements in throughfall could also be a result of their release from decomposing dead twigs, branches and bark (Ahmad-Shah *et al.*, 1992). Furthermore, trash fall, such as, bird droppings, and the unclassified part of litterfall (dust and unrecognisable debris) collected in rain gauges may also contribute to the increased level of nutrients in throughfall.

It is well know that plant leaves can extract nutrients from dilute solutions of both organic and inorganic fertilizers by absorption (Thorne, 1955 cit Carlisle *et al.*, 1966). NH_4-N can be absorbed from precipitation by canopies in this way (Carlisle *et al.*, 1966; Potter *et al.*, 1991; Cavelier *et al.*, 1997; Clark *et al.*, 1998; Rodrigo *et al.*, 2003) explaining why lower amounts of (NH_4-N) in throughfall than in rainfall were obtained in the present study. Ahmad-Shah *et al.* (1992) obtained similar results whereby 34.85 mg N m^{-2} $week^{-1}$ (rainfall) was reduced to 33.06 mg N m^{-2} $week^{-1}$ (throughfall). Several reasons have been suggested by many workers to explain why ammonium-N in rainfall is retained by tree canopies (Puckett, 1991; Potter *et al.*, 1991; Cavelier *et al.*, 1997). Firstly, as much as 80% of inorganic N is absorbed by epiphytic bryophytes, vascular epiphytes, litter and humus and this may buffer any "pulse" of inorganic N before it can reach the forest floor; alternatively NH_4 may be transformed to a different form, such as NO_2, by volatilization and nitrification (Clark, 1994 cit Clark *et al.*, 1998). Secondly, under nutrient-limited (oligotrophic) conditions, trees may be able to minimize canopy leaching, and even take up nutrients, such as NH_4-N, from precipitation as a mechanism to conserve chemical elements (Clark *et al.*, 1998; Marcos & Lancho, 2002). Thirdly, Wilson, (1992) cited by Hansen *et al.* (1994) found foliar release of NH_4^+ from Pine shoots and foliar uptake of NH_4^+ from Norway Spruce.

The seasonal pattern of nutrients in throughfall during the one year study period was similar to rainfall because throughfall water came from rainfall.

Correlation between rainfall and throughfall in MSF and rainfall and throughfall in LPF are 0.97 and 0.95 respectively. For example, Ca, Mg, K, Na, and ammonium concentration in rainfall was higher during the dry than the wet season, Ca, Mg, K, Na, and ammonium in MSF and LPF throughfall were also higher during the dry than the wet season. Phosphate, nitrite, iron, and manganese do not show any pattern between dry and wet season.

Nutrient concentrations in throughfall obtained in this study are similar to those of several workers that show dry season concentrations of magnesium, potassium (Pucket, 1990; Liu *et al.*, 2002), calcium and sodium (Veneklass *et al.*, 1990) and ammonium (Clark *et al.*, 1998) are higher than in the wet season. Moreover, element concentrations in precipitation are generally higher in dry periods than in wet ones (Veneklaas, 1990; Kaya & Tuncel, 1997), resulting in higher concentrations in throughfall.

A similar reason can be given to explain the seasonal pattern of nutrients in throughfall and rainfall because throughfall results from rainfall. Nutrient concentrations in throughfall were higher in dry than in wet periods for several reasons, including, presence of more dust in the atmosphere during the dry season and larger amounts of base cations (e.g. Ca, Mg, K) from soil sources (Veneklass *et al.*, 1990; Kaya & Tuncel, 1997) that fall on and are retained by the canopy. When there is some rain during the dry season it leaches impacted substances from the surface of the leaves and this leads to a higher nutrient concentration in throughfall. The contents of calcium, magnesium, potassium, and sodium in throughfall in both MSF and LPF were significantly higher than in rainfall. Comparison of the same elements between MSF and LPF throughfalls, however, did not reveal significant differences.

Similarly to Ca, Mg, and K, ammonium concentrations in throughfall in both sub-types of forest, MSF and LPF, were higher during the dry season than the wet season. Ammonium concentration in rainfall was higher than ammonium concentration in LPF throughfall while compared to MSF throughfall it was lower. These differences, however, are not significant. Manganese concentration in throughfall in both sub-types of forest, MSF and LPF, was also lower than in rainfall but was not significantly different.

Iron and phosphate concentrations did not show seasonal differences between dry and wet seasons. Phosphate concentration in throughfall is higher than in rainfall but this was not significant while iron was significantly different. Nitrite concentrations in throughfall in both, MSF and LPF are significantly higher than in rainfall.

Again, since throughfall water is derived from rainfall similar reasons can be given to explain why nitrite concentrations did not show a seasonal pattern between wet and dry periods. For example, nitrite can be produced during dry and wet season from natural soil (Sanhueza, 1997; Skiba & Smith, 2000) and from soils used for agriculture (Freney, 1997); during dry season from biomass burning (Radojevic & Tan, 2000) and during wet season from lighting (Bond *et al.*, 2002). Iron and manganese concentrations were low during the study period, and did not show a seasonal pattern between wet and dry periods.

The highest nutrient concentration in throughfall (mg l^{-1}) did not result in the greatest amount of that nutrient in throughfall (kg ha^{-1}) reaching the ground in the same period of time. For example, the highest calcium concentration of MSF throughfall during 24 June-21 July 2001 (3.898±1.65 mg kg^{-1}) resulted in a calcium input to the forest floor of only 0.426±0.23 kg ha^{-1}. In contrast, the greatest calcium input of 2.80±0.70 kg ha^{-1}occurred during 22 July – 18 August 2001 when the calcium concentration of throughfall was 3.76±1.05 mg kg^{-1}. The reason for this apparent anomaly was that the amount of throughfall water (and rainfall) was higher during 22 July – 18 August 2001 than 24 June- 21 July 2001 while the nutrient concentration was nearly the same.

Table 4.2.2: Nutrient concentrations in bulk precipitation (R) and throughfall (T) in several tropical forests.

No	Location	Forest type	Rain (mm)	Ca $Mg\ l^{-1}$	Mg $mg\ l^{-1}$	K $mg\ l^{-1}$	Na $mg\ l^{-1}$	Fe $mg\ l^{-1}$	Mn $mg\ l^{-1}$	NO_2 .$mg\ l^{-1}$	PO_4-P $mg\ l^{-1}$	NH_4 $mg\ l^{-1}$	Reference
1	This study (R)	Peat swamp forest	2809	0.89	0.28	0.59	0.30	0.09	0.007	0.03	0.17	0.84	This study
	In MSF (T)		1969	1.51	0.72	1.84	0.50	0.15	0.01	0.20	0.21	1.15	
	In LPF (T)		2136	1.56	0.78	1.52	0.60	0.16	0.01	0.11	0.17	0.75	
2	Selangor (R)	Peat swamp forest	2665	0.78	0.22	0.98	1.26	-	-	-	-	0.73	Ahmad-Shah *et al.* 1992
	Malaysia (T)		1986	2.52	0.79	2.86	2.99	-	-	-	-	1.02	
3	Kuala Lumpur (R)	Dipterocarp forest	3286	0.54	0.30	0.84	1.05	0.3	0.045	-	-	1.64	Abas *et al.*, 1992
	Malaysia (T)		2585	1.47	0.40	0.50	1.31	0.35	0.073	-	-	1.72	
4	Puerto Rico (.R)	Montane tropical rain forest	3750	0.58	0.13	0.49	1.53	-	-	-	-	-	Veneklaas (1990)
	(T)		2775	1.25	0.33	5.59	3.00	-	-	-	-	-	
5	Colombia (.R)	Montane tropical rain forest	2115	0.48	0.15	0.38	1.14	-	-	-	0.04	0.86	Veneklaas (1990)
	(T)		1854	1.46	0.58	5.14	1.45	-	-	-	0.09	1.16	
6	Boundary Range	Tropical karst terrain forest	2089	1.02	0.09	0.13	0.26	-	-	-	-	-	Crowther (1987a)
	Malaysia (T)		-	2.76	0.97	3.85	0.66	-	-	-	-	-	
7	Selangor (R)	Tropical karst terrain forest	2441	1.48	0.14	0.15	0.21	-	-	-	-	-	Crowther (1987a)
	Malaysia (T)		-	7.04	1.99	5.71	0.50	-	-	-	-	-	
8	Monteverde, (R)	Tropical lower montane forest	2678	0.22	0.16	0.14	1.23	-	-	-	0.002	0.09	Clark *et al*, 1998
	Costa Rica (T)			1.24	0.43	3.48	2.05	-	-	-	0.029	0.07	

Table 4.2.3: Annual fluxes of nutrients in bulk precipitation (R) and throughfall (T) in several tropical forests.

No	Location	Forest type	Rain (mm)	Ca kg ha^{-1}	Mg kg ha^{-1}	K kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	NO_2 kg ha^{-1}	PO_4-P kg ha^{-1}	NH_4 kg ha^{-1}	Reference
1	This study (R)	Peat swamp forest	2809	15.72	5.79	9.61	5.52	3.25	0.22	0.54	4.62	16.51	This study
	In MSF (T)		1969	19.18	9.54	24.13	5.66	3.95	0.20	3.35	4.64	15.12	This study
	In LPF (T)		2136	22.34	11.6	21.33	7.75	4.31	0.19	2.20	5.04	13.24	This study
2	Selangor (R)	Peat swamp forest	2665	20.15	5.12	26.36	31.42	-	-	-	-	18.12	Ahmad-Shah *et al.* 1992
	Malaysia (T)		1986	46.74	13.41	50.87	48.50	-	-	-	-	17.19	
3	Kuala Lumpur, (R)	Dipterocarp forest	3286	18.2	9.7	27.0	33.7	9.7	1.3	-	-	52.0	Abas *et al.*, 1992
	Malaysia (T)		2585	35.31	10.50	38.84	32.86	9.05	1.92	-	-	44.2	
4	Puerto Rico (.R)	Montane tropical rain forest	3750	21.8	4.9	18.2	57.2	-	-	-	-	-	Veneklaas (1990)
	(T)		2775	34.8	9.2	155.0	83.2	-	-	-	-	-	
5	Colombia (.R)	Montane tropical rain forest	2115	10.1	3.2	7.9	24.1	-	-	-	0.72	18.28	Veneklaas (1990)
	(T)		1854	27.1	10.7	95.2	26.9	-	-	-	1.67	21.45	
6	Boundary Range (R)	Tropical karst terrain forest	2089	21.3	1.9	2.7	5.4	-	-	-	-	-	Crowther (1987a)
	Malaysia (T)			65.0	22.3	92.1	4.5	-	-	-	-	-	
7	Selangor (R)	Tropical karst terrain forest	2441	36.1	3.4	3.7	5.1	-	-	-	-	-	Crowther (1987a)
	Malaysia (T)			89.5	32.1	98.2	3.8	-	-	-	-	-	
8	Monteverde (R)	Tropical lower montane forest	2678	5.8	2.4	3.0	20.5	-	-	-	0.05	1.7	Clark *et al*, 1998
	Costa Rica (T)			23.7	7.8	63.6	41.3	-	-	-	0.48	1.3	
9	New Guinea (R)	Montane rain forest	3800	3.6	1.3	7.3	-	-	-	-	0.5	-	Edwards. (1982)
	(T)		2585	19.0	10.9	71.1	-	-	-	-	2.5	-	

4.2.3. Nutrient enrichment in throughfall

Table 4.2.4. shows nutrient inputs in rainfall, MSF throughfall, LPF throughfall, enrichment of nutrients in absolute values in MSF and LPF, and enrichment factors for MSF and LPF.

Table 4.2.4: Nutrient inputs in rainfall (RF) and throughfall in MSF (MTH) and LPF (TF) reaching the peat surface in the Sg. Sebangau catchment, Central Kalimantan.

Nutrient	RF kg ha^{-1}	MTH kg ha^{-1}	TF kg ha^{-1}	Enrichment MTH(kg ha^{-1})	Enrichment TF (kg ha^{-1})	Enrichment factor MSF	Enrichment factorLPF
Ca	15.72	19.18	22.34	3.46	6.62	1.22	1.42
Mg	5.79	9.54	11.61	3.75	5.82	1.65	2.01
K	9.61	24.13	21.33	14.52	11.72	2.51	2.22
Na	5.52	5.66	7.75	0.14	2.23	1.03	1.40
Fe	3.25	3.95	4.31	0.70	1.06	1.21	1.33
Mn	0.22	0.20	0.19	-0.02	-0.03	0.90	0.85
NO_2-N	0.54	3.35	2.20	2.81	1.66	6.21	4.07
PO_4-P	4.62	4.64	5.04	0.02	0.42	1.01	1.09
NH_4-N	16.51	15.12	13.24	-1.39	-3.27	0.92	0.80

Most chemical elements analysed were enriched during the study period. The largest enrichment of nutrients, based on absolute values in MSF and LPF throughfall, was K with +14.52 and +11.72 kg ha^{-1}, respectively. The PO_4 nutrient enrichment is the smallest in both types of forest with only 0.02 kg ha^{-1} in MSF and 0.42 kg ha^{-1} in LPF. Manganese exhibited decreases of 0.02 kg ha^{-1} in MSF and 0.03 kg ha^{-1} in LPF. Ammonium also decreased by 1.39 kg ha^{-1} in MSF and 3.27 kg ha^{-1} in LPF. Nutrient enrichment in MSF throughfall based on absolute values is in the order of K> Mg> Ca> NO_2-N> Fe> Na> PO_4-P. In comparison, nutrient enhancement in LPF throughfall was K> Ca> Mg> Na> NO_2-N> Fe> PO_4-P.

The greatest degree of enrichment, based on enrichment factors, was nitrite with 6.21 in MSF and 4.07 in LPF. This is followed by potassium with 2.51 in MSF and 2.22 in LPF. Phosphate was the lowest with 1.01 in MSF and 1.09 in LPF.

Compared to other tropical forests K, in both sub-type of forest, MSF (2.51) and LPF (2.22), was below the range (4.8 – 26.8, n=6) while sodium in MSF (1.03) and LPF (1.40) was in the range (0.9 – 1.5, n=5; Veneklaas, 1990). The enrichment factor for calcium in MSF (1.22) was lower than for tropical forest in Panama (Ca=1.26; Cavelier *et al.*, 1997) while the enrichment factor for calcium in LPF (1.42) was higher. Negative values for the differences in the annual flux of ammonium and manganese in throughfall and precipitation suggest that these two nutrients are being absorbed by the canopy. Foliar uptake has been reported for ammonium (Carlisle, 1966; Potter *et al.*, 1991; Cavelier *et al.*, 1997; Moreno *et al.*, 2001; Rodrigo *et al.*, 2003), phosphate (Carlisle, 1966), and hydrogen (Stottlemyer & Hanson, 1989; Potter *et al.*, 1991; Rodrigo *et al.*, 2003).

4.3. STEMFLOW

4.3.1. The Quantity of stemflow

Table 4.3.1. shows comparison of stemflow in this study with data from several other places. It can be seen that the percentage of stemflow to rainfall, in MSF throughfall is near to the bottom of the range while LPF stemflow is in the middle of the range provided. Rainfall is included as a comparison.

Comparison between MSF and LPF stemflow shows that the percentage of stemflow to rainfall was higher in LPF stemflow than MSF stemflow. T-test between the amount of water in MSF and LPF was significantly different (Appendix 3). Forest structure may be the key factor that distinguishes between MSF and LPF sub-forest types in terms of the amount of stemflow water. In LPF there are more small diameter trees (between 5 and 15 cm) than in MSF. Moreover, the total number of trees (> 5 cm diameter) in LPF was higher than MSF. In contrast, tree biomass was greater in MSF than LPF (Waldes & Page, 2002).

Quantity of stemflow varies greatly, even for trees within the same diameter class, during the same storm (Jordan, 1978; Loustau, 1992). Several reasons have been suggested to explain the different percentages of water stemflow to rainfall Firstly, there may be differences in the architecture of tree crowns within the canopy (Jordan, 1978). Intermediate sized trees have branches inserted at low angles to the stem which funnels water toward the stem. Emergent trees often have branches at greater angles to the stem, sometimes 90 degrees, resulting in water dripping from the branches before it reached the stem. Secondly, the size of the rain event is important (Crockford & Richardson, 2000; Schroth *et al.*, 2001). The percentage of rain that becomes stemflow depends greatly upon the amount of rain. Showers contribute less, proportionately, to stemflow than downpours and there is a minimum amount of rainfall that has to be exceeded before any appears as stemflow. For example, in the study of Clements & Colon (1975) cited in Jordan (1978) in montane rain forest, Puerto Rico it took 10 mm of rain on average before stemflow occurred, and the percentage of rain that became stemflow increased with the length and intensity of the storm (Jordan, 1978). Thirdly, outside of the tropics there may be differences between the growing (leafed) and dormant (leafless) seasons, i.e. the winter period. Neal *et al.* (1993) reported that stemflow was 1-2 % during the leafed and 6-16 % during the dormant winter period in a *Fagus sylvatica* plantation in Hampshire, southern England. Fourthly, leaf size, shape and texture may also be factors. Stemflow varied from 1 to 13 % of precipitation in coniferous stands and between 1 and 8 % of broad-leaved forest in Chile (Huber & Iroume, 2001). Much of the water, which becomes stemflow on small trees, starts out as throughfall from larger trees. Fifthly, bark type, i.e. thickness, texture, absorbance, will also influence the amount of stemflow since there is great variation within and between different tree species of similar size and between the same species at different ages. Smooth, easily wetted bark has the potential for high stemflow yield (Crockford & Richardson, 2000). For example, in this study pelawan (*Tristaniopsis* spp) bark is smoother than tumih (*Combretocarpus rotundatus*).

Table 4.3.1: The quantity of stemflow (S) in several places in the world. Rainfall (R) is included as a comparison.

No	Location	Forest type/ species	Stemflow (% of rainfall)	Reference
1	Palangka Raya, Indonesia (R)	Peat swamp forest	2761 mm	This study
	MSF stemflow (S)		2.97 %	
	LPF stemflow (S)		4.93 %	
2	Kuala Lumpur, Malaysia (R)	Lowland Dipterocarp forest	3286 mm	Abas *et al.*, 1992
	Stemflow (S)		1.2 %	
3	Hampshire, England (R)	Beech plantation	636 mm	Neal *et al.*, 1993
	Stemflow (S)		5 %	
4	Lancashire, England (R)	*Quercus petraea*	1710 mm	Carlisle *et al.*, 1967
	Stemflow (S)		2.1 %	
5	Venezuela (R)	Lowland tropical rain forest	-	Jordan, 1978
	Stemflow in Laterite site (S)		6.8 – 7.7 %	
	Stemflow in Podsol site (S)		1.8 – 2.7 %	
6	Chile (R)		1000-3500 mm	Huber & Iroume, 2001
	Stemflow (S)	Coniferous forest	1- 13 %	
	Stemflow (S)	Broadleaved forest	1 – 8 %	
7	Yunnan, China (R)	*Lithocarpus &Casnopsis*	2170 mm	Liu *et al*, 2002b
	Stemflow (S)		2.8 %	
8	Massachusetts (R)	*Populus grandidentata*	1190 mm	Herwitz & Levia Jr, 1997
	Stemflow (S)		5.4 – 9.9 %	

4.3.2. Chemistry of stemflow

Comparisons of pH and nutrient concentration in stemflow in this study with data from several other places are presented in Table 4.3.2. It can be seen that the values of pH in MSF and LPF stemflow are near to the bottom of the range provided. Calcium, magnesium, potassium, phosphorus and ammonium concentrations in both MSF and LPF stemflow are in the middle of the range. Sodium is near to the bottom of the range. Iron and manganese are lower than those of Abas *et al.* (1992), the only data available for comparison. There are no data on nitrite for comparison.

Comparison between MSF and LPF stemflow pH shows that MSF stemflow pH was higher than LPF stemflow pH. T-test between MSF stemflow pH and LPF stemflow pH was significant.

Comparison between nutrient concentrations in MSF and LPF stemflow (Table 4.3.2) shows that the concentrations of Ca, Mg, K, and NH_4 were higher in LPF than MSF. In contrast, concentrations of Na, Fe, Mn, NO_2, and phosphate were higher in MSF stemflow than LPF stemflow. T-tests between Mg and nitrite concentrations in MSF stemflow and LPF stemflow were significant while those for calcium, potassium, sodium, iron, manganese, phosphate, and ammonium concentration were not (Appendix 3). Forest structure may be the key factor that distinguishes between MSF and LPF sub-forest types in terms of amount of water, pH, and nutrient concentration of stemflow (similar reason with throughfall). In MSF, the forest is tall and stratified, with an upper canopy at a height of 35 m, below which there is a closed layer between 15 and 25 m and then a more open layer of smaller trees 7 – 12 m in height (Page *et al.*, 1999). In contrast, LPF has only two canopy layers with the upper reaching a maximum height of 20 m and the lower at a height of 12 – 15 m and more closed (Page *et al.*, 1999).

Table 4.3.3. shows comparison of annual nutrient inputs in stemflow in this study with other data from several other places. It can be seen that the amounts of Ca, Mg, K, Na, Fe, Mn, phosphorus and NH_4 were higher in LPF stemflow than MSF stemflow. In contrast, the amount of NO_2 was higher in MSF stemflow than LPF stemflow. T-tests comparing the amounts of elements in MSF and LPF stemflow were significant for Ca, Mg, K, Na, Fe and ammonium while manganese, nitrite, and

phosphorus were not. The main reason for this is the greater yearly volume of LPF stemflow than MSF stemflow that is reflected in the total annual amount of nutrients.

Comparison with data for several other locations suggests that the amount of MSF stemflow reaching the forest floor in Central Kalimantan throughout the study period (Table 4.3.2) is in the middle of the range for calcium, magnesium, potassium, sodium, phosphorus, and ammonium. Iron is higher and manganese is lower than the findings of Abas *et al.* (1992), the only data available for comparison of these two elements. In contrast, LPF stemflow is higher than the range for calcium and magnesium. Potassium is near to the top of the range. Sodium, phosphorus, and ammonium are in the middle of the range. Similarly to MSF stemflow, the amount of iron in LPF stemflow is higher and manganese is lower than the findings of Abas *et al.* (1992).

Several reasons have been suggested to explain different pH values, nutrient concentrations and the amounts of nutrients in the stemflow. Firstly, different locations of the study sites will have different element concentrations in the rainfall (Van Breemen *et al.*, 1982; Takagi *et al.*, 1997; Levia & Frost, 2003). Takagi *et al.* (1997) reported that pH and nutrient concentrations in stemflow collected from *Ilex rotunda* in an urban area were higher than in a suburban area. The higher pH in the urban stemflow may have resulted from neutralization by higher concentrations of K, Mg, and Ca originating from road dust, leaching of Ca from concrete pits and limestone contained in pits. Other reports, however, suggest that stemflow of some tree species is acidified by sulphur dioxide and nitric acid (from fossil fuel, e.g, automobile and power station) on the surface of leaves. After leaching by rainwater this will produce lower pH values (Van Breemen *et al.*, 1982). In this study, the pH stemflow value was more acid than rainfall pH. The acidification of stemflow was probably caused by leaching of organic acids (leaching old bark). In this study (during 1 year period), the main nutrient input was from agriculture activity although the other possibility was from pollen from the surrounding study area. Secondly, differences in species composition and canopy structure (Crockford & Richardson, 2000). In MSF, there are three canopy layers (35 m, 15-25 m, and 7-12 m) while in LPF there are only two canopy layers at 20 m and 7–12 m (Page *et al.*, 1999). Thirdly, the availability of nutrients from the atmosphere (Westman, 1978) may be derived from other forest surrounding study area.

Table 4.3.2: The quantity, pH and nutrient concentration of stemflow (S) in several places in the world. Rainfall (R) is included as a comparison.

No	Location	Forest type/ species	Stemflow % of rainfall	.pH	Ca mg l^{-1}	Mg Mg l^{-1}	K .mg l^{-1}	Na Mg l^{-1}	Fe mg l^{-1}	Mn mg l^{-1}	NO_2 mg l^{-1}	PO_4 mg l^{-1}	NH_4 mg l^{-1}	Reference
1	Palangka Raya, Indonesia (R)	Peat swamp forest	2761 mm	5.96	0.89	0.28	0.59	0.30	0.09	0.01	0.03	0.17	0.84	This study
	MSF stemflow (S)		2.97 %	4.03	1.91	0.58	4.31	0.50	0.18	0.01	0.20	0.21	1.29	
	LPF stemflow (S)		4.93 %	3.57	2.16	1.22	4.44	0.45	0.15	0.01	0.07	0.18	1.32	
2	Kuala Lumpur, Malaysia (R)	Lowland Dipterocarp forest	3286 mm	4.37	0.54	0.30	0.84	1.05	0.30	0.04	-	-	1.64	Abas *et al*., 1992
	Stemflow (S)		1.2 %	4.71	1.59	0.53	1.94	1.40	0.37	0.07	-	-	2.10	
3	Lancashire, England (R)	*Quercus petraea*	1710 mm		2.23	1.29	0.48	9.16	-	-	-	0.07	-	Carlisle *et al*., 1967
	Stemflow (S)		2.1 %		15.4	4.9	9.9	40.6	-	-	-	0.18	-	
4	Venezuela (R)	Lowland tropical rain forest	-	-	-	-	-	-	-	-	-	-	-	Jordan, 1978
	Stemflow in Laterite site (S)		6.8 – 7.7 %	-	0.2	0.1	1.4	-	-	-	-	0.6	1.0	
	Stemflow in Podsol site (S)		1.8 – 2.7 %	-	0.6	0.6	2.7	-	-	-	-	0.4	0.8	
5	Yunnan, China (R)	*Lithocarpus &Casnopsis*	2170 mm	6.42	0.35	0.13	0.15	0.08	-	-	-	0.05	0.11	Liu *et al*, 2002b
	Stemflow (S)		2.8 %	5.95	2.78	0.73	7.31	0.13	-	-	-	0.08	0.86	
6	Japan (R)		-	5.2	-	-	-	-	-	-	-	-	-	Takagi *et al*., 1997
	Stemflow (S) in Tenjin	*Ilex rotunda*	-	5.7	-	-	-	-	-	-	-	-	-	
	Stemflow (S) in Hakozaki	*Ilex rotunda*	-	5.0	-	-	-	-	-	-	-	-	-	
7	Netherlands (R)		-	4.54	-	-	-	-	-	-	-	-	-	Van Breemen *et al*, 1982
	Stemflow (S) location 1	*Quercus robur*	-	5.46	-	-	-	-	-	-	-	-	-	
	Stemflow (S) location 2	*Pinus sylvestris*	-	3.47	-	-	-	-	-	-	-	-	-	

Table 4.3.3: Annual fluxes of nutrients in stemflow (S) in several places in the world. Rainfall (R) is included as a comparison.

No	Location	Forest type/ species	Ca kg ha^{-1}	Mg kg ha^{-1}	K .kg ha^{-1}	Na Kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	NO_2 kg ha^{-1}	PO_4 kg ha^{-1}	NH_4 kg ha^{-1}	Reference
1	Palangka Raya, Indonesia (R)	Peat swamp forest	15.72	5.79	9.61	5.52	3.25	0.22	0.54	4.62	16.51	This study
	MSF stemflow (S)		1.01	0.28	2.08	0.21	0.16	0.01	0.11	0.15	0.70	
	LPF stemflow (S)		2.23	1.48	3.02	0.37	0.24	0.01	0.07	0.27	1.29	
2	Kuala Lumpur, Malaysia (R)	Lowland Dipterocarp forest	18.2	9.7	27.0	33.7	9.7	1.3	-	-	52.0	Abas *et al.*, 1992
	Stemflow (S)		0.55	0.18	0.66	0.47	0.12	0.02	-	-	0.71	
3	Lancashire, England (R)	*Quercus petraea*	-	-	-	-	-	-	-	-	-	Carlisle *et al.*, 1967
	Stemflow (S)		2.01	0.71	1.56	5.91	-	-	-	0.01	-	
4	Venezuela (R)	Lowland tropical rain forest	-	-	-	-	-	-	-	-	-	Jordan, 1978
	Stemflow in Laterite site (S)		0.4	0.2	2.8	-	-	-	-	1.2	2.2	
	Stemflow in Podsol site (S)		0.4	0.3	1.5	-	-	-	-	0.2	0.4	
5	Yunnan, China (R)	*Lithocarpus &Casnopsis*	7.95	3.23	2.97	1.72	-	-	-	-	2.69	Liu *et al*, 2002b
	Stemflow (S)		1.25	0.48	3.73	0.07	-	-	-	-	0.58	
6	Spain (R)	*Quercus ilex*	9.69	1.16	1.7	5.77	-	-	-	0.246	5.36	Rodrigo *et al.*, 2003
	Stemflow (S) location LC	*Quercus ilex*	0.032	0.067	0.548	0.141	-	-	-	0.014	0.083	
7	North Carolina, USA	Alluvial Swamp Forest	4.8	1.43	3.0	-	-	-	-	0.49	-	Brinson *et al.*, 1980
	Stemflow (S)		2.01	0.70	1.56	-	-	-	-	0.26	-	

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4.4. LITTERFALL

4.4.1. Rate of litter production

Table 4.4.1. shows the amount of litterfall in this study using Excel and Wilm's methods together with other data from several locations and types of forest in the tropics.

Table 4.4.1: The amount of litterfall in different locations and types of forest in the tropics.

No	Location	Forest type	Litterfall (ton ha^{-1})	Reference
1	Central Kalimantan, Indonesia (Mixed swamp forest) (Excel)	Peat Swamp Forest	8.4	This study
	MSF (Wilm's)	Peat Swamp Forest	8.2	This study
2	Central Kalimantan, Indonesia (Low pole forest) (Excel)	Peat Swamp Forest	6.5	This study
	LPF (Wilm's)	Peat Swamp Forest	6.4	This study
3	Malaysia	Mixed forest	6.4	Crowther (1987a)
4	Colombia	Lowland rain forest	8.5	Vitousek(1984)
5	Costa Rica	Lowland rainforest	8.1	Vitousek(1984)
6	Panama	Lowland forest	11.1	Vitousek(1984)
7	Papua New Guinea	Lowland rain forest	10.1	Rogers (2002)
8	Australia	*Araucaria* plantation	10.2	Brasell *et al.*,1980
9	Australia	Rain forest	9.0	Brasell *et al.*,1980
10	Malaysia	Alluvial forest	11.5	Proctor *et al.*, 1983
11	Malaysia	Dipterocarp forest	8.8	Proctor *et al.*, 1983
12	Malaysia	Heath forest	9.2	Proctor *et al.*, 1983
13	Malaysia	Limestone forest	12.0	Proctor *et al.*, 1983
14	New Guinea	Lower montane forest	7.6	Edwards (1982)
15	North Carolina	Alluvial Forest	6.4	Brinson *et al.*, 1980
16	Padang Sugihan, Indonesia	Peat swamp forest	11.9	Brady, 1997
17	Sugihan east, Indonesia	Peat swamp forest	7.3	Brady, 1997
18	Padand island a, Indonesia	Peat swamp forest	6.9	Brady, 1997
19	Padang Island b, Indonesia	Peat swamp forest	5.5	Brady, 1997
20	Padang Island c, Indonesia	Peat swamp forest	5.1	Brady 1997
21	Para, Brazil	Terra-firm forest	9.7	Smith *et al.*, 1998a

Many workers have studied litterfall in forests of different regions (Edwards, 1982; Proctor *et al.*, 1983; Vitousek, 1984). This study showed that annual litterfall

Table 4.4.2. Nutrient concentration of litterfall collected in various tropical forests.

No	Location	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Reference
	Leaf Litterfall									
1	CK, Indonesia	5528	121	3098	11378	2678	309	150	18	This Study MSF
2	CK Indonesia	3426	79	1789	9524	2506	298	123	9	This Study LPF
3	New Guinea (V)	11600	660	5700	15000	3400	-	-	-	Edwards (1982)
4	Malaysia, (AF)	9000	267	2620	24400	1960	59	-	-	Proctor *et al.*1983
5	Malaysia, (DF)	9500	105	4470	1510	1070	86	-	-	Proctor *et al.*1983
6	Malaysia (HF)	5670	142	2300	8820	1550	52	-	-	Proctor *et al.*1983
7	Malaysia (LF)	11700	376	1560	31800	3340	125	-	-	Proctor *et al.*1983
8	Malaysia (BPMH)	-	-	2500	34600	3700	560	-	-	Crowther (1987a)
9	Malaysia (SPMF)	-	-	2500	54800	4900	140	-	-	Crowther (1987a)
10	Sabah, Malaysia	13800	370	4780	5540	2440	-	80	96	Burghouts *et al.*1998
	Branches									
1	CK, Indonesia	5770	120	2114	14465	1899	327	139	11	This Study MSF
2	CK, Indonesia	4076	89	1376	9208	1611	295	123	6	This Study LPF
3	New Guinea (V)	7600	380	1910	12600	1350	-	-	-	Edwards (1982)
4	Malaysia, (AF)	7100	172	1300	28800	1220	42	-	-	Proctor *et al.*1983
5	Malaysia, (DF)	6170	38	1820	1320	660	42	-	-	Proctor *et al.*1983
6	Malaysia (HF)	4170	113	940	10000	680	39	-	-	Proctor *et al.*1983
7	Malaysia (LF)	7710	138	730	3540	1540	96	-	-	Proctor *et al.*1983
8	Malaysia (BPMH)	-	-	1000	18000	2400	130	-	-	Crowther (1987a)
9	Malaysia (SPMF)	-	-	1200	12600	1000	190	-	-	Crowther (1987a)
10	Sabah, Malaysia	8300	200	3180	5020	1320	-	40	57	Burghouts *et al.*1998
	Reproductive									
1	Reproductive	11055	392	4782	5476	2303	305	144	10	This Study MSF
2	Reproductive	7874	242	3629	5443	1919	247	90	4	This Study LPF
3	New Guinea (V)	-	-	-	-	-	-	-	-	Edwards (1982)
4	Malaysia, (AF)	11900	723	4000	13800	1600	74	-	-	Proctor *et al.*1983
5	Malaysia, (DF)	11600	506	4820	1330	1120	84	-	-	Proctor *et al.*1983
6	Malaysia (HF)	9760	574	3270	6730	1390	93	-	-	Proctor *et al.*1983
7	Malaysia (LF)	17100	935	3110	12300	1850	119	-	-	Proctor *et al.*1983
8	Malaysia (BPMH)	-	-	-	-	-	-	-	-	Crowther (1987a)
9	Malaysia (SPMF)	-	-	-	-	-	-	-	-	Crowther (1987a)
10	Sabah, Malaysia	-	-	-	-	-	-	-	-	Burghouts *et al.* 1998
	Other debris									
1	Other debris	9493	314	2643	9005	2026	364	406	13	This Study MSF
2	Other debris	7738	263	1658	8618	1787	323	307	8	This Study LPF
3	New Guinea (V)	17500	1030	3500	15500	3000	-	-	-	Edwards (1982)
4	Malaysia, (AF)	14200	747	2100	23800	1610	100	-	-	Proctor *et al.*1983
5	Malaysia, (DF)	13100	415	3430	2070	1270	167	-	-	Proctor *et al.*1983
6	Malaysia (HF)	9990	364	2160	8560	1180	135	-	-	Proctor *et al.*1983
7	Malaysia (LF)	19400	768	1940	23300	2220	162	-	-	Proctor *et al.*1983
8	Malaysia (BPMH)	-	-	3300	26800	2500	380	-	-	Crowther (1987a)
9	Malaysia (SPMF)	-	-	3100	43900	3300	210	-	-	Crowther (1987a)
10	Sabah, Malaysia	20100	800	3330	6360	2500	-	400	103	Burghouts *et al.*1998

- = no data

(Edwards & Grubb, 1977) and in Sarawak (Proctor *et al.*, 1983). This study adds to these latter findings that litterfall peaks in the wet season.

In this study, the seasonal pattern of litterfall in the Sebangau catchment, average of both mixed swamp forest and low pole forest, exhibited bimodal peaks, according with the findings of Spain (1984) and John (1973). The first peak occurs in the heavy rain period towards the end of the wet season (Feb-March) and, the second, at the end of the dry season (August-Sept). The first peak (1083 kg ha^{-1} 4 $weeks^{-1}$) was higher than the second peak (849 kg ha^{-1} 4 $weeks^{-1}$). The maximum litterfall was related, at least in part, to mechanical rather than periodic physiological effects, resulting from high winds during certain times (Spain, 1984). It may also be due to the washing down of litter retained in the canopy during the wet season (Edwards & Grubb, 1977).

Litterfall is the last of a complex series of physiological processes in trees. These processes are influenced by several environmental factors in different ways and the actual fall of litter may be caused by a combination of these factors including wind, rain (Spain, 1984), mechanical stress, and not least the physiological characteristics of species and their phenological cycle (the reproductive cycles of many species are long and often irregular (Brown & Lugo, 1982)). Thus, there is no reason to assume that any single environmental factor controls the timing of litterfall for large numbers of tropical forest plants (Proctor *et al.* 1983).

The correlation between rainfall and litterfall in each sub type of forest, MSF and LPF, and the average of them, was examined. The results of the present study seem to agree with Proctor *et al.* (1983) that there is no single environmental factor controlling the timing of litterfall. The results also indicate that none of the relationships proved significant, with the r value 0.01 for MSF, 0.59 for LPF, and average of them is 0.35.

4.4.2. Litter mineral nutrient concentration

Table 4.4.2. shows the nutrient concentration of each of the litterfall categories in this study together with other data from several locations in the tropics.

Table 4.4.2. Nutrient concentration of litterfall collected in various tropical forests.

No	Location	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Reference
	Leaf Litterfall									
1	CK, Indonesia	5528	121	3098	11378	2678	309	150	18	This Study MSF
2	CK Indonesia	3426	79	1789	9524	2506	298	123	9	This Study LPF
3	New Guinea (V)	11600	660	5700	15000	3400	-	-	-	Edwards (1982)
4	Malaysia, (AF)	9000	267	2620	24400	1960	59	-	-	Proctor *et al.* 1983
5	Malaysia, (DF)	9500	105	4470	1510	1070	86	-	-	Proctor *et al.* 1983
6	Malaysia (HF)	5670	142	2300	8820	1550	52	-	-	Proctor *et al.* 1983
7	Malaysia (LF)	11700	376	1560	31800	3340	125	-	-	Proctor *et al.* 1983
8	Malaysia (BPMH)	-	-	2500	34600	3700	560	-	-	Crowther (1987a)
9	Malaysia (SPMF)	-	-	2500	54800	4900	140	-	-	Crowther (1987a)
10	Sabah, Malaysia	13800	370	4780	5540	2440	-	80	96	Burghouts *et al.* 1998
	Branches									
1	CK, Indonesia	5770	120	2114	14465	1899	327	139	11	This Study MSF
2	CK, Indonesia	4076	89	1376	9208	1611	295	123	6	This Study LPF
3	New Guinea (V)	7600	380	1910	12600	1350	-	-	-	Edwards (1982)
4	Malaysia, (AF)	7100	172	1300	28800	1220	42	-	-	Proctor *et al.* 1983
5	Malaysia, (DF)	6170	38	1820	1320	660	42	-	-	Proctor *et al.* 1983
6	Malaysia (HF)	4170	113	940	10000	680	39	-	-	Proctor *et al.* 1983
7	Malaysia (LF)	7710	138	730	3540	1540	96	-	-	Proctor *et al.* 1983
8	Malaysia (BPMH)	-	-	1000	18000	2400	130	-	-	Crowther (1987a)
9	Malaysia (SPMF)	-	-	1200	12600	1000	190	-	-	Crowther (1987a)
10	Sabah, Malaysia	8300	200	3180	5020	1320	-	40	57	Burghouts *et al.* 1998
	Reproductive									
1	Reproductive	11055	392	4782	5476	2303	305	144	10	This Study MSF
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3	New Guinea (V)	-	-	-	-	-	-	-	-	Edwards (1982)
4	Malaysia, (AF)	11900	723	4000	13800	1600	74	-	-	Proctor *et al.* 1983
5	Malaysia, (DF)	11600	506	4820	1330	1120	84	-	-	Proctor *et al.* 1983
6	Malaysia (HF)	9760	574	3270	6730	1390	93	-	-	Proctor *et al.* 1983
7	Malaysia (LF)	17100	935	3110	12300	1850	119	-	-	Proctor *et al.* 1983
8	Malaysia (BPMH)	-	-	-	-	-	-	-	-	Crowther (1987a)
9	Malaysia (SPMF)	-	-	-	-	-	-	-	-	Crowther (1987a)
10	Sabah, Malaysia	-	-	-	-	-	-	-	-	Burghouts *et al.* 1998
	Other debris									
1	Other debris	9493	314	2643	9005	2026	364	406	13	This Study MSF
2	Other debris	7738	263	1658	8618	1787	323	307	8	This Study LPF
3	New Guinea (V)	17500	1030	3500	15500	3000	-	-	-	Edwards (1982)
4	Malaysia, (AF)	14200	747	2100	23800	1610	100	-	-	Proctor *et al.* 1983
5	Malaysia, (DF)	13100	415	3430	2070	1270	167	-	-	Proctor *et al.* 1983
6	Malaysia (HF)	9990	364	2160	8560	1180	135	-	-	Proctor *et al.* 1983
7	Malaysia (LF)	19400	768	1940	23300	2220	162	-	-	Proctor *et al.* 1983
8	Malaysia (BPMH)	-	-	3300	26800	2500	380	-	-	Crowther (1987a)
9	Malaysia (SPMF)	-	-	3100	43900	3300	210	-	-	Crowther (1987a)
10	Sabah, Malaysia	20100	800	3330	6360	2500	-	400	103	Burghouts *et al.* 1998

\- = no data

Comparison between MSF and LPF shows that the concentrations of all nutrients (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration were higher in MSF than LPF. T-tests between N, P, K, Ca, Mg, Na, and Mn concentrations in MSF and LPF were significant while that for iron concentration was not (Appendix 4). Decomposition processes may be the key factor that distinguishes between MSF and LPF sub-forest types in terms of nutrient concentration of litterfall.

Comparison with other data for tropical forests suggests that the concentration of leaf litterfall in Central Kalimantan throughout the study period (Table 4.4.2) is at the lower end of the range for nitrogen and phosphorus. Potassium, calcium and magnesium are near to the bottom of the range. Sodium is in the middle of the range.

Nitrogen and phosphorus concentrations in branch litterfall are near to the bottom of the range while potassium, calcium and magnesium are in the middle of the range. Sodium was higher than the range.

Similarly to leaf litterfall, phosphorus concentration in reproductive parts is lower than the range while potassium and calcium concentration are in the middle of the range. Magnesium was higher than the range. Nitrogen concentration in MSF litterfall branches is in the middle of the range while nitrogen concentration in LPF litterfall branch is lower than the range.

Nitrogen and phosphorus concentration in other debris are lower than the range while calcium and magnesium are in the middle of the range. Sodium concentration is near to the top of the range. Potassium concentration in MSF litterfall other debris is in the middle of the range while in LPF litterfall other debris is lower than the range.

Several reasons have been suggested to explain different nutrient concentrations in the same litter categories, for example, different species making up the leaf litterfall (Cuevas & Lugo, 1998), and soil fertility (Proctor *et al.*, 1983). Other litter categories are more variable because different workers use different criteria, for example, Crowther (1987) included reproductive parts in other debris (miscellaneous) while Proctor *et al.* (1983) separated reproductive parts from other debris.

In general, all litter components (leaves, branches, reproductive parts, and other debris) in both forest sub-types have low concentrations of iron and manganese. Similar results have been reported by Burghouts *et al.* (1998) from lowland Dipterocarp rain forest in Sabah, Malaysia.

Compared to leaf litter, reproductive parts have higher contents of nitrogen, phosphorus, and potassium. In contrast, leaf litter is higher in calcium, magnesium, sodium, iron and manganese than reproductive parts. Comparison between the two sub-types of forest show that concentrations of N, P, K, Ca, Mg, Na, Fe, and Mn in MSF are higher than in LPF in each litter component.

Similar results have been reported by Proctor *et al.* (1983) who found that nitrogen, phosphorus, and potassium concentrations were higher in reproductive parts than in leaf litterfall while calcium and magnesium were higher in leaf litterfall than reproductive parts (see Table 4.4.2). Similar results were reported by Crowther (1987) who found that potassium concentration in other debris was higher than in leaf littterfall probably as result of including reproductive parts into other debris.

This study found that N, P, K, Ca, Mg, Na, Fe, and Mn concentrations in litterfall for both sub types of forest did not shown seasonal variation between dry and wet seasons. Several reasons can be suggested to explain this. Litter (leaf, branch, reproductive, and other debris) from different tree species was in each litter trap during the various collection periods and these have different element concentrations. For example, calcium concentration in the leaves of *Calophyllum sclerophyllum* was 21.4 g kg^{-1} while in leaves of *Combretocarpus rotundatus* it was only 5.5. g kg^{-1}. Moreover, the same species may have different concentrations as a result of different soil characteristics, such that potassium concentration in leaves of *Gonystylus bancanus* (Plot 1) is 7.4 g kg^{-1} while in Plot 3 it is 17.6 g kg^{-1} (Tuah *et al.*, 2000). Edward (1982) stated that in dry months potassium and magnesium concentration were higher than in wet months probably because of a reduction of leaching during the dry period, but water is unlikely to be a limiting factor for tree growth in this peatland study area during study period.

4.4.3. Litter mineral nutrient content

Comparison between MSF and LPF shows that the amounts of N, P, K, Ca, Mg, Na, Fe, and Mn were higher in MSF than LPF (supported by 't' tests). The total content was 197.956 kg ha^{-1} $year^{-1}$ in MSF and 115.715 kg ha^{-1} $year^{-1}$ in LPF reflecting the higher amount of litterfall deposited in MSF than LPF. The annual total element nutrient transfer in MSF litterfall decreased in the order: Ca(48.2%)>N(25.4%)>K(13.2%)>Mg(10.5%)>Na(1.4%)>Fe(0.7%)>P(0.6%) >Mn(0.1%) while in LPF it was Ca(53.4%)>N(21.5%)>Mg(12.6%)>K(9.7%)>

Na(1.6%)>Fe(0.7%)>P(0.5%>Mn(0.1%). Total element content in different litter components was greatest in leaf litter (73.1%) followed by branches (14.6%), reproductive parts (6.4%) and other debris (5.9%) for MSF while in LPF it was greatest in leaf litter (74.0%) followed by branch (18.8%), other debris (4.5%), and reproductive parts (2.8%).

Table 4.4.3: Annual quantities of certain nutrients in litterfall collected in various tropical forests.

No	Location	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Reference
1	Palangka Raya, Indonesia	50.88	1.21	25.92	97.55	21.40	2.77	1.45	0.14	This Study MSF
2	Palangka Raya, Indonesia	25.73	0.53	10.69	59.47	13.80	1.73	0.75	0.05	This Study LPF
3	Papua New Guinea	90.8	5.1	27.8	94.7	19.2	-	-	-	Edwards(1982)
4	Malaysia, (AF)	111	4.1	26.1	286	20.1	0.73	-	-	Proctor *et al.* (1983)
5	Malaysia, (DF)	81	1.2	33	13	8.9	0.75	-	-	Proctor *et al.* (1983)
6	Malaysia (HF)	55	1.6	18	83	12	0.55	-	-	Proctor *et al.* (1983)
7	Malaysia (LF)	140	4.5	16	370	33	1.5	-	-	Proctor *et al.* (1983)
8	Sabah, Malaysia	153.0	4.7	47.5	62.6	24.9	-	0.9	9.5	Burghouts *et al.*(1998)
9	Malaysia (BPMH)	-	-	14.5	181	18.9	2.4	-	-	Crowther (1987a)
10	Malaysia (SPMF)	-	-	19.2	386	34.1	1.2	-	-	Crowther (1987a)
11	Australia, (Ara)	91	11.5	66.8	172	23.5	3.38	-	-	Brasell (1980)
12	Australia (For)	136	13.1	77.8	229	28.4	2.23	-	-	Brasell (1980)
15	Padang Sugihan, Indonesia	240	16	-	-	-	-	-	-	Brady (1997)
16	Sugihan east, Indonesia	130	9	-	-	-	-	-	-	Brady (1997)
17	Padand island a, Indonesia	100	4	-	-	-	-	-	-	Brady (1997)
18	Padang Island b, Indonesia	60	4	-	-	-	-	-	-	Brady (1997)
19	Padang Island c, Indonesia	50	3	-	-	-	-	-	-	Brady (1997)
20	Brazil (prim)	115.1	-	-	-	-	-	-	-	Smith *et al.*, (1998a)

Comparison with other data on the quantities of total nutrient elements in various tropical areas suggests that annual litter production in Mixed Swamp Forest and Low Pole Forest in the Sg. Sebangau catchment was lower than the range for nitrogen and phosphorus while sodium is near to the top of the range. Potassium in MSF litterfall was near to the bottom of the range while in LPF it was below the range. Magnesium in MSF litterfall was in the middle of the range while in LPF it was near to the bottom of the range (Table 4.4.3).

Several reasons have been suggested to explain variations in the annual nutrient content in litterfall in tropical forests, for example, soil fertility (Crowther, 1987a; Madeira *et al.*, 1995), soil texture, slope, and altitude (Proctor *et al.*, 1983; Crowther, 1987a). Moreover, different methods have been employed (Proctor *et al.*, 1983; Vitousek, 1984), and different forest communities or types investigated (Proctor *et al.*, 1983; Vitousek, 1984; Reiners & Lang, 1987), different methods have been used for nutrient analysis and elucidation of the decomposition processes in different ecosystems.

4.5. DECOMPOSITION

4.5.1. Weight loss and rate of decomposition

In this study litter mass loss was very rapid and significant in both mixed swamp forest and low pole forest during the first six months but in subsequent periods of 12 and 18 months the rate of loss decreased and differences between time periods were not significant (Appendix 5). Very rapid weight losses have been observed almost universally in the first few weeks of leaf litter decomposition experiments carried out by several workers (such as, Smith *et al.*, 1998a; Heneghan *et al.*, 1998; Palma *et al.*, 1998; Torreta & Takeda, 1999; De Costa & Atapattu, 2001; Hartemink & O'Sullivan, 2001; Chuyong *et al.*, 2002).

Several reasons have been suggested to explain this loss in the first few weeks of decomposition. Physical and biological processes are involved in this stage (Berg & Wessen, 1984 cit Taylor, 1998) and most of the loss may be from the water-soluble fraction rather than the lignocellulose fraction (Andren & Paustian, 1987). Soluble material in leaf litter consists mostly of simple organic compounds, including reducing sugars, phenolic and amino acids (Suberkropp *et al.*, 1976) while the lignocellulose fraction consists mainly of lignin, cellulose and xylan (Andren & Paustian, 1987).

In general, litter decay was higher in mixed swamp forest than in low pole forest although T-test comparisons of weight losses after 6 months, 12 months, and 18 months showed that these were not significant. Trends of weight loss indicate that this is greater in MSF than LPF probably because of differences in surface flooding and surface peat water logging patterns throughout the year. In MSF the water table was above the peat surface during rainy season while in LPF it was mostly closer to or above the peat surface throughout the year (Page *et al.*, 1999). This means that in LPF the peat was water-saturated throughout most of the year and would have been in an aerobic condition for much longer than that in MSF. Similar results were reported by Brady (1997) and Latter (1998) who suggested that the rate of decay was reduced during flooding periods (due to anaerobic conditions) and Haraguchi (2002) who stated that water table depth is the most important environmental parameter in the decomposition rate in peat mires. Furthermore, the decomposition rate is mainly determined by the activity of microorganisms in a soil as determined by microbial biomass, activity types of microorganisms and environmental conditions (e.g. aerobic or anaerobic condition). Microorganism activity is indicated by the CO_2 emission rate (Jauhiainen *et al.*, 2002) with maximum CO_2 evolution and microbial activity observed under 50% water holding capacity (Tarafdar *et al.*, 2001).

Guo & Sim (2001) showed that light intensity increased significantly the rate of decomposition of *Eucalyptus* leaves in New Zealand. Greater dry mass loss was found from litter exposed to light than from the shade litter. This light effect was not confirmed by the results of the present study in which decomposition rate in MSF (taller more closed canopy) was greater than in LPF (lower more open canopy). Decomposition rate in MSF was faster than in LPF. Other workers have suggested that the rate of decomposition is faster at higher temperatures and higher moisture contents (Bloomfield *et at.*, 1993 cit Guo & Sim, 2001; Cortez, 1998). The effects of temperature and moisture are not constant, however, since these two factors interact in a complicated way (Guo & Sim, 2001). Moreover, Gunadi *et al.* (1998) reported that variation in water content appeared to affect decomposition of pine litter in Salatiga, Indonesia more than temperature although the latter was relatively stable in their study.

In this study temperature was also relatively stable (diurnal and annual variations in temperature are low) suggesting that water table level variation throughout a year is the most important factor influencing the activity of decomposer microorganisms in the surface peat. In addition, the apparent differences in soil faunal activities on the forest floor may influence litter decomposition rate (Prescott, 1996) and fungi may play some special role in the initial loss of litter dry mass as they play an important role in the initial stages of organic matter decomposition (Troeh & Thompson, 1993 cit Guo & Sims, 2001). It is known, for example, that several types of fungi (e.g. Basidiomycota and Xylariaceous ascomycota) are able to decompose lignocellulose in leaf litter, which constitutes 70-80 % of fresh organic material (Rayner & Boddy, 1988 cit Osono & Takeda, 2001). Moreover, organic matter decomposition in the sense of mineralization is mostly a microbial activity (Hattenschwiler & Bretscher, 1991). Soil fauna and other microbial activities were not monitored in this study but it is likely that the effects of effluent depth water table would increase these activities through aerobic condition. Further work is required to confirm whether or not this is indeed the case.

In litter decomposition studies, the annual instantaneous decay constant (*k* per year) is widely used to compare litter decomposition rates between species or to determine the effects of environmental factors. In general, the higher the *k* value is, the faster the rate of decomposition. In this study *k* in mixed swamp forest (MSF) was 0.396 and 0.285 in low pole forest (LPF) (Table 4.5.1) and is relatively low compared to other decomposition studies of tropical forests except for similar results from another peatland area in Central Kalimantan (Rahajoe *et al.*, 2000) which was nearly the same.

There are several reasons that could explain the low *k* values obtained in this study. Firstly, anaerobic conditions prevail for most of the year in this study area, more so in LPF than MSF. It is well known that the rate of decomposition is reduced during anaerobic conditions (flooding and permanently high water table) (Brady, 1997; Latter, 1998). Secondly, evidence suggests that plant species from nutrient-poor environments produce litter that is more difficult to decompose than litter of species from nutrient-rich environments (Murayama & Zahari, 1992; Couteaux *et al.*, 1999; Vitousek *et al.*, 1994; Van Breemen, 1995; Aerts and Caluwe, 1997). Thirdly, substrate acidity affects the activity of decomposer microorganisms, including fungi, (Murayama & Zahari, 1992) and the peat soil pH values obtained in this study were low (2.82 – 3.80).

Table 4.5.1: Instantaneous decay constants (*k*) for leaf litter decomposition in various tropical areas.

No	Location	Species	*k* per year	Reference
1	Sebangau, Central Kalimantan, Indonesia (MSF)	Mixed litter	0.396	This study
2	Sebangau, Central Kalimantan, Indonesia (LPF)	Mixed litter	0.285	This study
3	New Guinea	*Dysoxylum*	2.22	Rogers, 2002
	New Guinea	*Celtis*	2.12	Rogers, 2002
	New Guinea	Pometia	1.17	Rogers, 2002
4	Lahei, Central Kalimantan, Indonesia	*Vatica Oblongivolia*	0.292	Rahajoe *et al.*, 2000
		Buchanania sessilifolia	0.730	Rahajoe *et al.*, 2000
		Gluta cf laurifolia	0.328	Rahajoe *et al.*, 2000
		Mix litter	0.438	Rahajoe *et al.*, 2000
	Heath forest	*Calophyllum pulcherrimum*	0.438	Rahajoe *et al.*, 2000
		Tristaniopsis sp	1.423	Rahajoe *et al.*, 2000
		Palaquium sp	0.547	Rahajoe *et al.*, 2000
		Mix litter	0.912	Rahajoe *et al.*, 2000
5	Sri Lanka	*Calliandra*	2.65	De Costa & Atapattu, 2001
		Senna	8.58	De Costa & Atapattu, 2001
		Euphatorium	5.52	De Costa & Atapattu, 2001
		Flemingia	1.74	De Costa & Atapattu, 2001
		Gliricidia	8.41	De Costa & Atapattu, 2001
		Tithonia	7.38	De Costa & Atapattu, 2001
6	Thailand	*Schima wallichii*	0.61	Torreta & Takeda, 1999
		Castanopsis accuminatissima	1.05	Torreta & Takeda, 1999
7	Brazil	Mix litter	0.605	Smith *et al.*, 1998b
		Pinus caribaea	0.398	Smith *et al.*, 1998b
		Carapa guianensis	0.477	Smith *et al.*, 1998b
		Euxylophora paraensis	0.550	Smith *et al.*, 1998b

There is a wide range of *k* value between different workers. Several reasons have been suggested to explain different *k* values. Firstly, different resource quality, for both the quantity and type of the structural and nutritional constituents of the litter may be important (Melillo *et al.*, 1982; Gunadi *et al.*, 1998; Xuluc-Tolosa *et al.*, 2003). Rate of decomposition will differ between tree species (Rogers, 2002), and will be influenced by nutrient availability and mobility (Dezzeo *et al.*, 1998). Secondly, abiotic factors such as moisture content (Gunadi *et al.*, 1998), soil chemical and physical characteristics (Proctor *et al.*, 1983; Cuevas & Medina, 1988), temperature (Cortez, 1998; Guo & Sims, 2001), light (Guo & Sims, 2001), the characteristics of litterbags, and degree of waterlogging will all exert their own specific influences. Thirdly, biotic factors, such as earthworm (Cortez, 1998; Cortez & Bouche, 1998), fungal (Osono & Takeda, 2001) and others microorganism activities will be important variables.

4.5.2. Nutrient concentration and release from leaf litter

The initial nutrient contents of litter leaves from mixed tree species from both MSF and LPF placed in litterbags are compared with similar litter decomposition studies of tropical forests in other areas (Table 4.5.2.).

Table 4.5.2. The mean initial nutrient concentrations in leaf litter samples used in decomposition studies in several tropical forests

Location	Species	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Reference
Central Kalimantan, Indonesia (MSF)	Mix litter	15352	105	554	6072	1002	234	170	8	This study
LPF	Mix litter	8036	69	331	2455	454	184	131	5	This study
New Guinea	Dysoxylum	18000	1400	4900	13700	3400	-	-	-	Rogers , 2002
New Guinea	Celtis	15000	700	9300	53300	3300	-	-	-	Rogers , 2002
New Guinea	Pometia	27300	1600	10500	17100	3900	-	-	-	Rogers , 2002
Sri Lanka	*Calliandra*	38690	585	41330	-	-	-	-	-	De Costa & Atapattu, 2001
	Senna	35870	514	32000	-	-	-	-	-	De Costa & Atapattu, 2001
	Euphatorium	26810	700	44000	-	-	-	-	-	De Costa & Atapattu, 2001
	Flemingia	22630	566	35500	-	-	-	-	-	De Costa & Atapattu, 2001
	Gliricidia	35780	675	56000	-	-	-	-	-	De Costa & Atapattu, 2001
	Tithonia	41890	1105	72000	-	-	-	-	-	De Costa & Atapattu, 2001
Central Africa	*Berlinia bracteosa*	17900	970	11880	14800	4180	-	-	-	Chuyong *et al.*, 2002
	Didelotia africana	16800	680	5070	13100	2590	-	-	-	Chuyong *et al.*, 2002
	Microberlinia bisulcata	13900	550	4950	14200	3460	-	-	-	Chuyong *et al.*, 2002
	Tetraberlinia bifoliolata	15300	950	6430	5500	1810	-	-	-	Chuyong *et al.*, 2002
	Cola verticillata	10700	550	5590	13400	2870	-	-	-	Chuyong *et al.*, 2002
	Oubanguia alata	12900	490	6370	8200	2660	-	-	-	Chuyong *et al.*, 2002
Brazil	Mix litter forest	14000	-	-	-	-	-	-	-	Smith *et al.*, 1998b
	Pinus caribaea	4400	-	-	-	-	-	-	-	Smith *et al.*, 1998b
	Carapa guianensis	13000	-	-	-	-	-	-	-	Smith *et al.*, 1998b
	Euxylophora paraensis	7000	-	-	-	-	-	-	-	Smith *et al.*, 1998b

In this study, the mean initial nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentrations in leaf litter used for decomposition studies in mixed swamp forest were higher than litter from low pole forest. Comparison between N, P, K, Mg, Na, Fe, and Mn concentrations in MSF and LPF were not significantly different, however, while Ca concentration was significantly different.

The amounts of nutrients lost during decomposition were calculated as the ratio of the nutrient concentration at the time of sampling corrected for dry weight loss over the original nutrient concentration and expressed as a percentage. The pattern of element loss in MSF and LPF was relatively similar to that reported in the literature.

Potassium is the element most rapidly lost. After the first six months only 39.3 % of K remained in leaves in MSF and 8.9 % in LPF confirming the findings of several other workers (Adam & Angradi, 1996; Rogers, 2002; Chuyong *et al.*, 2002). Potassium is a highly mobile element in plants and soil and is readily leached out. It usually occurs in plants in amounts excess to decomposer demand (Gosz *et al.*, 1973; Dezzeo *et al.*, 1998). The low proportion of K remaining in litter early in the incubation period is consistent with the high mobility of K and its lack of incorporation into organic plant structures (Marshner, 1985 cit Ribeiro *et al.*, 2002). The rapid rate of K loss shows the importance of leaching from leaves during leaf senescence and decomposition (Swift *et al.*, 1981; Adam & Angradi, 1996).

Similarly to potassium, magnesium was also lost rapidly in the first 6 months (36.1 % in MSF and 54.3% in LPF) as a result of leaching, confirming the work of others (Gosz *et al.*, 1973; Dezzeo *et al.*, 1998; Staaf & Berg, 1982 cit Adam & Angradi, 1996). Mg was reduced. It has been suggested that K and Mg releases do not depend on biotic activity; but are the result of physical leaching (Adam & Angradi, 1996). Magnesium retained in LPF increased from 45.7 % (6 months) to

46.1 % (12 months). Several reasons have been suggested to explain increases in the magnesium remaining at later stages of decomposition, such as immobilization of Mg while organic matter is still being decomposed. Similar results were reported for Scots pine litter in the latter stages of decay and also in litter with low initial Mg concentrations (Staaf & Berg, 1982 cit Adam & Angradi, 1996). Moreover, magnesium could be imported into the litter layer from other sources, such as rainfall, throughfall, stemflow, animal frass or translocation in fungal hyphae from surface soil and lower strata of the litter layer (O'Connel & Grove, 1966 cit Guo & Sim 1999), while differences could also relate to different plant species in the litter that was sampled at different time periods during the decomposition study period.

In this study calcium was also lost rapidly during the first six months (40.8 % in MSF and 44.6% in LPF) similar to results of a study of several species in leaf litter in Central Africa (Chuyong *et al.*, 2002). In contrast, calcium loss from litter during the first six months of a study carried out in a forest in the Caura River, Venezuela was relatively slow (Dezzeo *et al.*, 1998). Various factors may influence the rate of calcium release from litter.For example, a faster release of calcium (and magnesium) from litter in Amazonia terra firme forest occurred when it was in contact with fine roots, suggesting there must be a nutrient release mechanism that is mediated by these roots and/or their associated microorganisms (Cuevas & Medina, 1988). Calcium plays many roles within plants but its major one is as a constituent of structural components (e.g. cell walls) to which it can be bound strongly (Ribeiro *et al.*, 2002). As a result, calcium is not susceptible to leaching (Attiwill, 1967 cit Dezzeo *et al.*, 1998). In addition, the similar patterns of calcium and dry weight losses indicate that decomposition is mostly responsible for calcium release from litter (Dezzeo *et al.*, 1998).

The losses of nitrogen (32.5% in MSF and 17.8 % in LPF) were much lower than potassium, magnesium and calcium in both sub-types of forest (MSF and LPF). Nitrogen and phosphorus releases in this study are generally comparable to other studies (e.g. Roger, 2002; Dezzeo *et al.*, 1998). One reason given to explain the slow nitrogen release from organic substrates is that it is difficult to obtain a C/N ratio value lower than the critical one of (20-35:1) (Ribeiro *et al.*, 2002).

Similarly to magnesium in LPF, nitrogen remaining in MSF after six months decomposition (67.5%) increased greatly after 12 months (95.2%) in common with the results of other studies. Several studies have also reported increase in N content of litter during the initial stage of decomposition in both terrestrial and aquatic ecosystems (e.g. Bocock &Gilbert, 1957; Gosz *et al.*, 1973; Day, 1982; Garden & David, 1988 cit Dezzeo *et al.*, 1998). Explanations of this apparently anomalous N-increase include addition of N by biological fixation, fungal translocation of N and immobilization (Melillo *et al.*, 1982). N immobilization is usually attributed to accumulation of microbial protein (Suberkropp *et al.*, 1976) although variations in the tree species comprising the leaf litter sampled at different times during the decomposition studies could also be a factor.

Rapid loss of phosphorus was observed during the first six months of decomposition (27.3 % in MSF and 25.7% in LPF) and was significantly different (Appendix 5). Similar results have been reported for several leaf litter studies (Cortez, 1996 cit Ribeiro *et al.*, 2002) while Polglase *et al.* (1992) reported initial P release by both direct leaching and through microbial biomass activity.

Sodium loss in the litter is relatively slow (4.7% in MSF and –0.9% in LPF) during the first six months and perhaps sodium is not a leachable element but may be dependent on biotic activity for its release. Iron and manganese losses were also incurred during the study period but the absolute values involved were very small (micronutrient). Similarly to calcium, manganese was also more dependent on biotic activity than leaching, probably because this element is also bound to plant cell walls (Rogalla & Romheld, 2002). It is not possible to compare sodium, iron and manganese losses in this decomposition study with those of other workers owing to a lack of data.

4.6. BIOMASS

4.6.1. Nutrient concentration of above ground biomass

4.6.1.1. Nutrient concentration in leaves

Table 4.6.1. shows the nutrient concentration in leaves in this study together with other data from several locations and types of forest in the tropics.

Table 4.6.1. The mean concentration of nutrient in leaf samples from biomass studies in several places in the tropics

Location	Species	N mg kg^{-1}	P Mg kg^{-1}	K mg kg^{-1}	Ca Mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Reference
Leaves										
Palangka Raya, Indonesia MSF	Mix species	11447	217	6235	12570	3687	344	185	25	This study
Palangka Raya, Indonesia, LPF	Mix species	7423	147	6295	11523	2869	301	192	9	This study
New Guinea	Average	12300	770	6000	10900	2300	160	-	-	Grubb & Edwards, 1982
Brazil	Mean 38 species	18800	1200	10300	4700	2400	-	-	-	Thompson *et al.*, 1992
East Kalimantan, Indonesia	*Milletia sericea*	20910	-	8260	11820	1900	-	-	-	Ruhiyat, 1993
	Dacryodes sp	19910	-	6200	31360	1560	-	-	-	Ruhiyat, 1993
	Cryptocarya sp	29800	-	6000	12710	3050	-	-	-	Ruhiyat, 1993
	Shorea laevis	16320	-	4150	4620	1290	-	-	-	Ruhiyat, 1993
Costa Rica	*Albizia guachapele*	40900	2300	13400	3900	2900	-	-	-	Montagnini, 2000
	Virola koschnyi	15700	1200	6300	8600	2300	-	-	-	Montagnini, 2000
	Terminalia amazonia	16500	1600	7200	7400	2700	-	-	-	Montagnini, 2000
	Dipteryx panamensis	24800	2000	10900	4600	1400	-	-	-	Montagnini, 2000
Xishuangbanna, Cina	*Pomentia tomentosa*	10500	1000	10600	5100	5400	-	-	-	Shanmughavel *et al.*, 2001
	Barringtonia macrostachya	9700	1000	9500	4400	5200	-	-	-	Shanmughavel *et al.*, 2001
	Terminalia myriocarpa	9300	900	9000	3800	4900	-	-	-	Shanmughavel *et al.*, 2001
	Gironniera subaeqnalis	9000	900	8700	3300	4300	-	-	-	Shanmughavel *et al.*, 2001

In general, concentrations of most of the leaf nutrients in mixed swamp forest were higher than in low pole forest, except for potassium and iron. Comparison using t-test between MSF and LPF was significant for nitrogen, phosphorus and manganese while potassium, calcium, magnesium, sodium, and iron concentration were not significant. Decomposition processes and nutrient contents in peat soil may be the key factors that distinguish between MSF and LPF sub-forest types in terms of nutrient concentrations of fresh leaves. In general, the high nutrient concentration in the trees comes from higher nutrient concentrations in peat soils while low nutrient concentrations in the tree come from lower concentration in peat soils.

Comparison with the data of other workers who carried out research in the tropics indicates that the element concentration of fresh leaves in Central Kalimantan (Table 4.6.1) is at the lower end of the range for phosphorus. Potassium, calcium, and magnesium are in the middle of the range. Nitrogen in MSF is near to the bottom of the range while nitrogen in LPF is below the range. Sodium is above the range, but with only one data set for comparison and data for iron and manganese are not available for comparison.

Several reasons have been suggested to explain different nutrient concentrations in the leaves, for example, different tree species (Grubb & Edwards, 1982; Montagnini, 2000; Shanmughavel *et al.*, 2001), different leaf age when samples were taken for nutrient analysis (Grubb & Edwards, 1982) and differences in soil fertility (Proctor *et al.*, 1983; Regina & Tarazona, 2001).

4.6.1.2. Nutrient concentration in branches

Table 4.6.2. shows the nutrient concentration in branches in this study together with other data from several locations and types of forest in the tropics.

Table 4.6.2. The mean concentration of nutrients in branch samples for biomass studies in several places in the tropics

Location	Species	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca Mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Reference
Palangka Raya, Indonesia MSF	Mix species	7830	220	5037	17393	2093	257	191	6	This study
Palangka Raya, Indonesia, LPF	Mix species	4855	123	4941	17732	2522	248	194	6	This study
New Guinea	Average 28 species	2400	110	2400	6900	600	70	-	-	Grubb & Edwards, 1982
Costa Rica	*Albizia guachapele*	12100	1800	11100	4100	1400	-	-	-	Montagnini, 2000
	Virola koschnyi	7100	900	10500	4900	1800	-	-	-	Montagnini, 2000
	Terminalia amazonia	3100	1000	4400	2300	600	-	-	-	Montagnini, 2000
	Dipteryx panamensis	6700	1200	7300	3800	500	-	-	-	Montagnini, 2000
Xishuangbanna, Cina	*Pomentia tomentosa*	8900	800	10000	4300	4800	-	-	-	Shanmughavel *et al.*, 2001
	Barringtonia macrostachya	8200	800	8900	3800	4600	-	-	-	Shanmughavel *et al.*, 2001
	Terminalia myriocarpa	7900	800	8400	3100	4000	-	-	-	Shanmughavel *et al.*, 2001
	Gironniera subaeqnalis	7000	800	7800	2900	3800	-	-	-	Shanmughavel *et al.*, 2001

Similarly to leaves, concentrations of most of the nutrients in branches were higher in mixed swamp forest than in low pole forest, except for calcium, magnesium and iron. Comparison using t-test between MSF and LPF was significant for nitrogen only while phosphorus, potassium, calcium, magnesium, sodium, iron and manganese were not significant.

Comparison with other data for tropical forests suggests that the concentration of elements in fresh branches in Central Kalimantan (Table 4.6.2) is in the middle of the range for nitrogen, potassium, and magnesium. Phosphorus is near to the bottom of the range. Calcium is above the range. Sodium is higher than reported by Grubb & Edwards (1982) (only one item of data available for comparison). Iron and manganese cannot be compared because data are not available.

Similarly to leaf concentrations, similar reasons can be suggested to explain different concentrations in branches, for example, different species (Grubb & Edwards, 1982; Montagnini, 2000; Shanmughavel *et al.*, 2001), different branch ages and soil fertility (Proctor *et al.*, 1983).

Compared to leaves, branches have lower contents of nitrogen, phosphorus, potassium, magnesium, sodium, and manganese. In contrast, branches are higher in calcium and iron than leaves.

Similar results have been reported by Shamughavel *et al.* (2001) who found that nitrogen, phosphorus, potassium, and magnesium concentrations were higher in fresh leaf material than in branches. They also found that calcium was also lower in branches than leaves (Shamughavel *et al.*, 2001) while in this study calcium was higher in branches than leaves (Table 4.6.1 and 4.6.2). Similar results were reported by Montagnini (2000) who found that nitrogen, phosphorus, potassium, and magnesium were higher in leaves than branches for tree species studied while calcium concentration in some species was higher in leaves than branches and vice versa in others. For example, calcium concentration in *Terminalia amazonia* leaves was 7400 mg kg^{-1} and 2300 mg kg^{-1} for branches. In contrast, calcium concentration in *Albizia guachapele* leaves was 3900 mg kg^{-1} but 4100 mg kg^{-1} for branches.

4.6.2. Total above ground biomass and nutrient content

The total above ground biomass and nutrients in this study together with other data from several locations and types of forest in the tropics are shown in Table 4.6.3.

Table 4.6.3. The total above ground biomass (TAGB) and nutrients in different locations and types of forest in several places in the tropics

Location	Forest type	Weight Ton ha^{-1}	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Reference
Palangka Raya, Indonesia MSF	Peat swamp forest	313.9	2643	65	1660	4577	804	82	52	5	This study
Palangka Raya, Indonesia, LPF	Peat swamp forest	252.5	1563	36	1450	3730	684	70	49	2	This study
New Guinea	*Lower montane forest*	310	683	37	668	1270	187	-	-	-	Edwards & Grubb, 1982
East Kalimantan, Indonesia	*Dry land forest*	491.9	1177	-	796	1395	232	-	-	-	Ruhiyat, 1993
East Kalimantan, Indonesia	*Mixed Dipterocarp*	509	-	-	-	-	-	-	-	-	Yamakura *et al.*, 1986
Central Kalimantan, Indonesia	*Heath forest*	200-250	-	-	-	-	-	-	-	-	Miyamoto *et al.*, 2000
Ghana	*Lowland rain forest*	233	1690	112	753	2370	320	-	-	-	Greenland & Kowal, 1960
Brazil	Lowland rain forest	356	-	-	-	-	-	-	-	-	Laurance *et al.*, 1999
Hawai	*Eucalyptus* plantation	323	134	28	170	295	31	-	-	-	Binkley & Ryan, 1998
Hawai	*Albizia* Plantation	215	323	16	169	244	29	-	-	-	Binkley & Ryan, 1998
Xishuangbanna, Cina	Tropical rain forest		2010	196	2124	832	1005	-	-	-	Shanmughavel *et al.*, 2001
Amazon, Brazil	Tropical evergreen forest	288-346	-	-	-	-	-	-	-	-	Cummings *et al.* 2002
Costa Rica	Tropical wet forest	161-186	-	-	-	-	-	-	-	-	Clark & Clark, 2000
Brazil	Tropical moist forest	285	-	-	-	-	-	-	-	-	Brown *et al.*, 1995

Aboveground litter plays a major function in nutrient turnover and transfer of energy between plants and soil, as the source of the nutrients accumulated in the upper layer of the soil (Regina & Tarazona, 2001). Moreover, it is currently understood that much of the world's tropical rain forests exist on very poor soils and are only able to do so by retaining a high proportion of the available nutrients within their biomass (Regina & Tarazona, 2001). Furthermore, the vegetation largely depends on recycling the nutrients contained in plant detritus (Regina, 2000). The proportion that is lost is replenished through nutrients imported to the site largely in rainfall (Shamughavel, 2001).

The total biomass and amount of nutrients in mixed swamp forest was higher than in low pole forest. This difference could be explained by differences in decomposition processes, water table depth and peat-pore water chemistry (Moore *et al.*, 2002). Decomposition and peat soils could affect tree biomass in at least two ways. Firstly, decomposition and peat soil fertility may influence species composition that constitute the forest biomass. Faster decomposition processes and more nutrients in peat soil could support a higher forest biomass. More fertile soil could be associated with higher forest biomass (Laurance *et al.*, 1999). Secondly, trees could simply grow bigger on more fertile substrates regardless of species composition (Newbery & Proctor, 1984). Decomposition processes and peat soil factors appear to have a marked influence on floristic composition in this study, suggesting that the first of these mechanisms could be very important.

Comparison with other workers who carried out research in the tropics indicates that the total above ground biomass in Central Kalimantan (Table 4.6.3) is in the middle of the range. The above ground biomass in low pole forest was 252.5 ton ha^{-1}, which is similar to lowland rain forest with above ground biomass of 233 ton ha^{-1} (Greenland & Kowal, 1960) and 200 and 250 ton ha^{-1} in heath forest in Central

Kalimantan, Indonesia (Miyamoto *et al.*, 2000). The total above ground biomass in mixed swamp forest in this study averaged 313.9 ton ha^{-1}, which compares to estimates of 310 ton ha^{-1} in lower montane forest (Edwards & Grubb, 1982), 323 ton ha^{-1} in *Eucalyptus* plantation (Binkley & Ryan, 1998) and 288-346 ton ha^{-1} in tropical evergreen forest, Amazon, Brazil (Cummings *et al.*, 2002).

Several reasons have been suggested to explain differences in the total above ground biomass including the following.

(a) Differences in sample design and analysis (Araujo *et al.*, 1999; Houghton *et al.*, 2001; Nascimento & Laurance, 2002). Moreover, Brown *et al.* (1989) cited in Brown *et al.* (1995) suggested that field studies in small plots resulted in higher total above ground biomass (TAGB) estimates because of a bias by researchers and/or foresters in site selection.

(b) Differences in tree species and forest types also resulted in different TAGB (Brown *et al.*, 1995). For example, Binkley & Ryan (1998) found that TAGB in a *Eucalyptus* plantation was 323 ton ha^{-1} while in an *Albizia* plantation it was only 215 ton ha^{-1}.

(c) Soil fertility could also result in different TAGB (Newbery & Proctor, 1984; Vitousek & Sanford, 1986; Laurance *et al.*, 1999; Regina & Tarazona, 2001). Moreover, Laurance *et al.* (1999) state that higher soil fertility mostly resulted in higher TAGB than low soil fertility.

(d) Differences in the relative weights of biomass components included in the total biomass value (Brown *et al.*, 1995). For example, some estimates only consider standing live above ground biomass for trees greater than certain diameters. Others include litter, standing and fallen dead trunks, stemless palms, (Nascimento & Laurance, 2002). The latter reported 397.7 ton ha^{-1} in central Amazonian rainforest, Brazil. The components of the biomass included depends on the objective of the study.

Compared to other studies carried out in several places in the tropics (Table 4.6.3) the amount of nitrogen in MSF is above the range while in LPF it is near to the top of the range while phosphorus is in the middle of the range. Potassium and magnesium are near to the top of the range and calcium is above the range. There are no data available on sodium, iron and manganese for comparison.

Similarly to the total above ground biomass, similar reasons can be given to explain differences in the amount of nutrients in above ground biomass, because to obtain the total amount of a nutrient its concentration is multiplied by the weight of that part. Moreover, different tree species taken as representing the biomass for determination of nutrient content could result in different results for the amount of nutrients.

4.6.3. Nutrient concentration of below ground biomass (roots)

The mean concentration of nutrients in roots sampled in this study together with other data from several locations and types of forest in the tropics are shown in Table 4.6.4.

Table 4.6.4. The mean concentration of nutrients in below ground biomass studies in several places in the tropical zone

Location	Forest type/ root species	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na Mg kg^{-1}	Fe mg kg^{-1}	Mn Mg kg^{-1}	Reference
Palangka Raya, Indonesia MSF	Peat Swamp forest	10688	160	5718	6702	2817	200	204	3	This study
Palangka Raya, Indonesia, LPF	Peat swamp forest	8959	97	3096	5308	1784	172	202	1	This study
New Guinea	Lower montane forest	5300	290	7700	14300	1000	320	-	-	Edwards & Grubb, 1982
Padang sugihan, Sumatra, Indonesia	Peat swamp forest	13100	800	-	-	-	-	-	-	Brady, 1997
Sugihan east, Sumatra, Indonesia	Peat swamp forest	13000	610	-	-	-	-	-	-	Brady, 1997
Padang Island a Riau, Indonesia	Peat swamp forest	12500	600	-	-	-	-	-	-	Brady, 1997
Padang Island b Riau, Indonesia	Peat swamp forest	11600	610	-	-	-	-	-	-	Brady, 1997
Padang Island c Riau, Indonesia	Peat swamp forest	10100	320	-	-	-	-	-	-	Brady, 1997
Xishuangbanna, Cina	*Pomentia tomentosa*	7700	700	8400	3900	4300	-	-	-	Shanmughavel *et al.*, 2001
	Barringtonia macrostachya	7300	700	3600	3600	3900	-	-	-	Shanmughavel *et al.*, 2001
	Terminalia myriocarpa	6900	600	7300	3400	3500	-	-	-	Shanmughavel *et al.*, 2001
	Gironniera subaeqnalis	6300	600	6900	2900	3100	-	-	-	Shanmughavel *et al.*, 2001

Nutrient concentration in mixed swamp forest root biomass was higher than in low pole forest for all elements except calcium, magnesium and iron. Comparison using t-test between MSF and LPF was significant for nitrogen, phosphorus, potassium, magnesium, and manganese while calcium, sodium, and iron were not significant.

Comparison with other data for tropical forests shows that nutrient concentrations in roots are highly variable (Edwards & Grubb, 1982) and suggests that the nutrient concentration of roots in Central Kalimantan (Table 4.6.4) is in the middle of the range for nitrogen, calcium, and magnesium. Phosphorus is below the range. Potassium in MSF is near to the bottom of the range while potassium in LPF is below the range. Sodium concentration is lower than that of Grubb & Edwards (1982) (only one value available for comparison). There are no iron or manganese data from other workers for comparison. In general, iron and manganese concentrations were low in both MSF and LPF.

The major reason suggested to explain different concentrations in roots are different species (Edwards & Grubb, 1982; Shanmughavel *et al.*, 2001).

4.6.4. Total below ground (roots) biomass and nutrient contents

Table 4.6.5 shows the total live below ground biomass (roots) and the amount of nutrients in this study together with other data from several locations and types of forest in the tropics.

Table 4.6.5: The total live below ground biomass (TBGB) and nutrient in different locations and types of forest in several places in tropical area

Location	Forest type	Weight Ton ha^{-1}	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Reference
TBGB											
Palangka Raya, Indonesia MSF	Peat swamp forest	26.5	287	4	145	185	75	6	6	0.09	This study
Palangka Raya, Indonesia, LPF		14.4	129	2	47	77	27	2	3	0.02	This study
New Guinea	*Lower montane forest*	40	137	6	186	333	61	6.9	-	-	Edwards & Grubb, 1982
Ghana	Lowland rain forest	54	326	24	143	268	65	-	-	-	Greenland & Kowal, 1960
Brazil	Lowland rain forest	67	553	7	62	83	55	-	-	-	Klinge, 1975 cit Edwards & Grubb, 1982
Padang sugihan, Sumatra, Indonesia	Peat swamp forest	5.4	70	4	-	-	-	-	-	-	Brady, 1997
Sugihan east, Sumatra, Indonesia	Peat swamp forest	22.0	290	13	-	-	-	-	-	-	Brady, 1997
Padang Island a Riau, Indonesia	Peat swamp forest	28.1	350	17	-	-	-	-	-	-	Brady, 1997
Padang Island b Riau, Indonesia	Peat swamp forest	40.5	470	25	-	-	-	-	-	-	Brady, 1997
Padang Island c Riau, Indonesia	Peat swamp forest	129.9	1310	41	-	-	-	-	-	-	Brady, 1997
Hawai	*Eucalyptus* plantation	11.8	-	-	-	-	-	-	-	-	Binkley & Ryan, 1998
Hawai	*Albizia* Plantation	15.4	-	-	-	-	-	-	-	-	Binkley & Ryan, 1998

Similarly to the above ground biomass, the mass and the amount of nutrients in MSF roots were greater than LPF. Comparison using t-test between the total below ground biomass in MSF and LPF was significant. Similarly to the total below ground biomass, comparison of the total amount of all nutrients studied using t-test was also significant between MSF and LPF.

In this study, comparison with other data for tropical forests suggests that the amount of biomass of roots in Central Kalimantan (Table 4.6.5) is near to the bottom of the range. Several reasons have been suggested to explain different result in the amount of roots biomass. For example, different species and type of forest (Schulze *et al.*, 1996; Binkley & Ryan, 1998); density of trees (Regina & Tarazona, 2001); different depths of roots have been taken for biomass determination (Schulze *et al.*, 1996); different root diameters have been taken to categorise samples (Hart *et al.*, 2003).

Comparison with other data for tropical forests suggests that the amount of nitrogen in roots in Central Kalimantan (Table 4.6.5) is near to the bottom of the range. Phosphorus is below the range. Potassium and calcium are in the middle of the range. Magnesium in MSF is above the range while magnesium in LPF is below the range. Sodium is lower than Grubb & Edwards (1982) report (only one data set available for comparison). In general, iron and manganese are low in both MSF and LPF although there are no data from other workers for comparison.

Similarly to nutrient concentrations, the major reasons that have been suggested to explain the differences in amounts of nutrients in roots are different species (Edwards & Grubb, 1982; Shanmughavel *et al.*, 2001). Moreover, any values extrapolated value small sample areas to the whole forest may also be used as a reason to explain differences in the amount of nutrients in the roots.

Root/shoot ratios (root weight/shoot weight) in this study are 0.08 for MSF and 0.06 for LPF. Similar results have been reported by Ogawa *et al.* (1965) cited in Deans *et al.* (1996) who found root shoot ratios of between 0.12 and 0.07 but this was recalculated to a range from 0.03 to 0.81 by Deans *et al.* (1996) from appendix 1 of Brown & Lugo (1982) for woody species in moist tropical forests. Moreover, on average, tropical forests on Spodosol (USDA classification), tropical deciduous, montane and lowland rain forest have root/shoot ratios of 0.60, 0.33, 0.18 and 0.12, respectively. There is no information on peat swamp forest. The low value of root / shoot ratio indicates that peat swamp forest trees are supported by a very small amount of root biomass (Deans *et al.*, 1996).

Very few studies have been carried out of nutrients both in above- and below-ground biomass of mature trees from which nutrient root/shoot ratios can then be derived (Hart *et al.*, 2003). In the only other study, in New Zealand, (Dyck & Beets , 1987 cit Hart *et al.*, 2003) root/shoot ratios of 0.14 and 0.17 were obtained for N in 42 and 29 year old *Pinus radiata* forest. The range of root/shoot ratios over seven Northern hemisphere species (Nihlgard, 1972; Morisson, 1990 cit Hart *et al.*, 2003) was N: 0.10-0.24; P, 0.07-0.43; K, 0.09-0.28; Ca, 0.07-0.025; Mg, 0.11-0.31. The hard beech root / shoot ratio for N, P, K, Ca and Mg was 0.24, 0.40, 0.34, 0.18 and 0.47, respectively (Hart *et al.*, 2003).

In this study, mixed swamp forest root/ shoot ratio for N was 0.11; 0.06 (P); 0.09 (K); 0.04 (Ca); 0.09 (Mg); 0.07 (Na); 0.12 (Fe); and 0.02 (Mn). Nitrogen and potassium were within the published ranges while phosphorus, calcium and magnesium ratio were lower than these ranges. There is no sodium, iron, and manganese ratio data available for comparison.

In low pole forest, root/shoot ratio for N was 0.08; 0.06 (P); 0.03 (K); 0.02 (Ca); 0.04 (Mg); 0.03 (Na); 0.06 (Fe); and 0.01 (Mn). Nitrogen, phosphorus, potassium, calcium, and magnesium were lower than the range. With such wide ranges it is difficult to generalise between species and sites until additional studies are available. If a consistent nutrient R/S ratio could be established it would allow easy assessment of harvesting impacts on the proportion of various nutrients removed from the ecosystem (Hart *et al.*, 2003).

4.7. PEAT SOIL

4.7.1. Nutrient concentration of peat soil

Table 4.7.1. shows the nutrient concentration of peat soil at 50 cm depth in this study together with other peat data from several locations in the tropics.

Table 4.7.1. The mean concentration of peat sample 50 cm depth together with other data from several places in tropical area

Location	.pH	N mg kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	Ca mg kg^{-1}	Mg mg kg^{-1}	Na mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Reference
Palangka Raya, Indonesia MSF	3.30	28637	183	288	941	709	311	469	4	This study
Palangka Raya, Indonesia, LPF	3.49	21901	139	220	889	669	140	271	4	This study
Sg. Enok, Riau	4.16	16300	500	800	2800	1600	-	-	-	Suhardjo& Widjaja-Adhi (1976)
Sg. Siak, Riau	3.55	19800	500	600	1700	800	-	-	-	Suhardjo &Widjaja-Adhi (1976)
Sg.Rokan, Riau	3.80	21300	900	800	-	1200	-	-	-	Suhardjo &Widjaja-Adhi (1976)
Sg. Sebangau (MSF) Central Kalimantan	2.9	1800	278	135*	22*	21*	-	-	-	Page *et al.*, 1999 * (extractable)
Sg. Sebangau (MSF) Central Kalimantan	3.2	1000	272	125*	35*	25*	-	-	-	Page *et al.*, 1999 * (extractable)
Sg. Sebangau (LPF) Central Kalimantan	3.2	1400	340	130*	48*	40*	-	-	-	Page *et al.*, 1999 * (extractable)
Dalat, Sarawak, Malasia	3.40	18000	-	-	-	-	-	-	-	Yamaguchi *et al.*, 1997
Padang sugihan, Sumatra, Indonesia	3.95	18700	283	-	-	-	-	-	-	Brady, 1997
Sugihan east, Sumatra, Indonesia	4.47	18300	214	-	-	-	-	-	-	Brady, 1997
Padang Island a Riau, Indonesia	4.19	18500	200	-	-	-	-	-	-	Brady, 1997
Padang Island b Riau, Indonesia	3.96	17900	118	-	-	-	-	-	-	Brady, 1997
Padang Island c Riau, Indonesia	3.79	14200	79	-	-	-	-	-	-	Brady, 1997
Palangka Raya, Indonesia	3.5	15400	-	-	-	-	-	-	-	Kurnain *et al.*, 2002
Sugihan Kiri, Sumatra, Indonesia	4.3	-	-	-	-	-	-	-	-	Hartatik & Nugroho, 2002

Nutrient concentrations of all nutrients studied in peat soil in mixed swamp forest were higher than in low pole forest while pH was higher in LPF than MSF.

Comparison using t-test between MSF and LPF was significant for pH, nitrogen, phosphorus, sodium and manganese while potassium, calcium, magnesium and manganese were not significant.

Comparison with other tropical data suggest that the pH of peat in this study (Table 4.7.1) is nearly the same as that found by Page *et al.* (1999) and Kurnain *et al.* (2002) who carried out their research in the same vicinity as this study area. In contrast, pH values in this study were lower than those obtained by Suhardjo & Widjaja-Adhi (1976) and Brady (1997) from studies in Sumatra. Nitrogen was higher than the range. Phosphorus is near to the bottom of the range. Potassium, calcium, and magnesium were lower than Suhardjo & Widjaja-Adhi (1976). There are no data on sodium, iron and manganese available for comparison.

Several reasons have been suggested to explain different pH and nutrient concentrations in this study area compared to Riau and South Sumatra. Firstly, the thickness of peat (Radjagukguk, 1992), the nutrient content and pH of thin peat is higher than that of thick peat (Suharjo & Widjaja-Adhi, 1976). Secondly, degree of organic matter decomposition, thick peats are less decomposed and poorer in nutrients than thin peats (Notohadiprawiro, 1996). Thirdly, the nature of the underlying mineral soil, for example, peat developed over quartz sand is poorer in nutrients compared to that developed on top of loam or clay (Widjaja-Adhi, 1988). Fourthly, different methods used for chemical analysis, could also result in different findings. For example, in this study nitrogen concentration was determined by persulphate digestion (Purcell & King, 1996) while Kurnain *et al.* (2002) used Kjeldahl digestion. Moreover, the chemistry of peat is affected by many factors, including the original plant material, environmental conditions, the supply of inorganic solutes, the activities of plants and animals including microorganisms, and the history of peat development (Brady, 1997).

4.7.2. Mass of peat soil and amount of nutrients

Mass of peat soil and the amount of nutrients contained in 50 cm depth of peat in this study together with other data from several locations in the tropics are shown in Table 4.7.2.

Table 4.7.2. Mass and the amount of nutrients in peat at 50 cm depth in this study together with other data for several locations in the tropics.

Location	Forest type	Weight ton ha^{-1}	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	Ca kg ha^{-1}	Mg kg ha^{-1}	Na kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Reference
Palangka Raya, Indonesia MSF	Peat swamp forest	750	21478	137	216	706	532	233	351	2.7	This study * BD 0.15
Palangka Raya, Indonesia, LPF	Peat swamp forest	750	16426	105	165	667	502	105	203	2.7	This study * BD 0.15
Padang sugihan, Sumatra, Indonesia	Peat swamp forest	660.7	12400	433	-	-	-	-	-	-	Brady, 1997 * 40 cm deep BD 0.17
Sugihan east, Sumatra, Indonesia	Peat swamp forest	596.4	10900	414	-	-	-	-	-	-	Brady, 1997 * 40 cm deep BD 0.15
Padang Island a Riau, Indonesia	Peat swamp forest	560.1	10800	370	-	-	-	-	-	-	Brady, 1997 * 40 cm deep BD 0.14
Padang Island b Riau, Indonesia	Peat swamp forest	470.6	8300	208	-	-	-	-	-	-	Brady, 1997 * 40 cm deep BD 0.12
Padang Island c Riau, Indonesia	Peat swamp forest	397.3	5600	129	-	-	-	-	-	-	Brady, 1997 * 40 cm deep BD 0.10
New Guinea	Lower montane forest	Mineral soil	19200	16	403	3750	682	-	-	-	Edwards & Grubb, 1982 *30 cm
Ghana	Lowland rain forest	Mineral soil	4950	13	649	2580	295	-	-	-	Greenland & Kowal, 1960 *30 cm

Very few studies have been carried out of mass and amount of nutrients in peat. The few studies available have been of mineral soil and for extractable nutrients. The mass of peat in this study (750 ton ha^{-1}) was higher than Brady's result (397.3 to 660.7 ton ha^{-1}). Several reasons have been suggested to explain different results of peat mass, for example, firstly, different in bulk density. A high bulk density results in a high mass of peat while low bulk density results in a low mass of peat (calculation for peat mass see Appendix 1). Secondly, the rate and extent of organic decomposition influences the bulk density. A high decomposition degree (e.g. Sapric) has a higher bulk density (0.1 – 0.30 g cm^{-3}) than a low decomposition degree (e.g. Fibric) (0.06 – 0.15 g cm^{-3}) (Widjaja-Adhi, 1988).

Similarly to the mass of peat, the amount of nitrogen in this study was higher than Brady's report while phosphorus was lower. There are no potassium, calcium, magnesium, sodium, iron, and manganese data available for comparison.

Similar reasons can be given to explain differences in the nutrient concentrations and total amount of nutrients in peat soil (Table 4.7.2) because the amount of nutrients is derived from nutrient concentration multiplied by peat mass. Firstly, the thickness of peat (Radjagukguk, 1992), the nutrient content in thin peat is higher than in thick peat (Suharjo & Widjaja-Adhi, 1976). Secondly, degree of organic matter decomposition is important (Notohadiprawiro, 1996). Thirdly, the nature of the underlying mineral soil, peat developed over quartz sand is poor in nutrients compared to that developed on top of loam or clay (Widjaya-Adhi, 1988).

4.8. RUNOFF

Table 4.8.1. shows the amount of nutrients lost through runoff in this study together with other data from several locations and types of forest in the tropics.

Table 4.8.1. The amount of nutrients lost (kg ha^{-1} yr^{-1}) through runoff in this study together with other data from several locations and types of forest in the tropics.

Type of land use	Ca kg ha^{-1} yr^{-1}	Mg kg ha^{-1} yr^{-1}	K kg ha^{-1} yr^{-1}	Na kg ha^{-1} yr^{-1}	Fe kg ha^{-1} yr^{-1}	Mn kg ha^{-1} yr^{-1}	Nitrite kg ha^{-1} yr^{-1}	P tot kg ha^{-1} yr^{-1}	Reference
Peat swamp Forest (MSF)	8.15	2.51	2.21	4.85	0.72	0.01	0.26	0.26	This study
Peat swamp forest (LPF)	7.15	2.24	1.29	4.69	0.71	0.02	0.23	0.07	This study
Lowland forest (Caura river, Venezuela)	15.5	6.0	14.6	-	-	-	-	0.24	Lewis, 1986
Lowland rain forest; Gua anak Takun, Malaysia	764	45	20	-	-	-	-	-	Crowther, 1987a, 1987b
Lowland rain forest; Kinta valley, Malaysia	795	89.9	75.7	-	-	-	-	-	Crowther, 1987a, 1987b
Agathis Plantation; Watu belah, Indonesia	29.0	30.5	22	-	-	-	-	0.7	Bruijnzeel, 1991

The amount of nutrient loss through runoff in MSF was higher than in LPF. Comparison using t-test between MSF and LPF indicates that calcium, magnesium, nitrite and phosphate are significant while potassium, sodium, iron and manganese are not significant (Appendix 8). Differences in the amount of nutrient loss are probably a result of different nutrient concentrations of runoff water in both sub-types of forest. Nutrient concentration of water in MSF is higher than LPF. Again, differences in decomposition processes, stemflow and throughfall could have resulted in different nutrient concentration of runoff water.

Comparison with other data for the tropics indicates that the amount of nutrients (Ca, Mg, K, and phosphate) lost through runoff in this study was lower than the range. There are no data on the amount of sodium, iron, manganese, and nitrite for comparison.

Several reasons have been suggested to explain different results of nutrient losses in runoff from various ecosystems. Firstly, different soil types and soil fertility will influence the chemistry of runoff (Dambrine & Range, 2000). For example, in this study the substrate was peat while in Crowther's (1987a and 1987b) investigations it was mineral soil developed from limestone. Nutrient loss in this study (MSF) was only 8.15 kg ha^{-1} yr^{-1} (Ca) while in Kinta valley, Malaysia it was 795 kg ha^{-1} yr^{-1}(Ca) (Crowther, 1987a; 1987b). Secondly, differences between ecosystems will lead to different results (Lewis, 1986). For example, Bruiijzeel (1991) studied an *Agathis* plantation whilst this study focussed on a natural ecosystem. Nutrient loss of calcium in Bruiijzeel's (1991) study was 29.0 kg ha^{-1} yr^{-1} while in this study (MSF) it was only 8.15 kg ha^{-1} yr^{-1}(Ca). Thirdly, differences in slope (Crowther, 1987a). Tropical forests on steep slopes lose more nutrients than those in topographically flat areas, such as, the vast peatland landscape investigated in this study. Fourthly, the methodologies used vary greatly (Bruijnzeel, 1991). In this study (runoff), for example, nutrient losses were based on differences between rainfall and evapotranspiration while Crisp (1966) made direct measurements in the field using a Munro water level recorder.

4.9. COMPARISON OF WILM' S METHOD AND EXCEL

Wilm's method as described by Rieley *et al.* (1969) and used by Ahmad-Shah & Rieley (1989) for collection and determination of throughfall and litterfall involves the use of "fixed" and randomly "roving" gauges. Wilm (1946) suggested that this technique could be used for the collection and statistical analysis of variable data in time and space and provide corrected mean values (a co-variance method) for each collection period (e.g. day, week, 2 weeks, 4 weeks) and total values for aggregate periods (e.g. 3, 6 or 12 months). The advantage of Wilm's method over other 'static' sampling methods is that relatively few sampling devices need to be used (Rieley *et al*, 1969). In order to test the applicability of Wilm's Method to tropical forest conditions it was used in the present study for the collection and measurement of throughfall and litterfall. Comparison was made with a conventional statistics approach using Microsoft Excel spreadsheets. It is hoped that comparison of the two methods of data analysis can give better understanding of the problems of collecting and analysing replicate samples under a tropical forest canopy and enable an evaluation to be made of the advantages and disadvantages of both methods.

For throughfall, volume of water, pH, nutrient concentration and the amount of nutrients (Ca, Mg, K, Na, Fe, Mn, NO_2, PO_4, NH_4) both Wilm's Method and Excel were used. Similarly, the amounts of each litter component (leaves, branches, reproductive parts and other debris) and the total amount of litterfall were obtained using both methods. Nutrient concentration and the amounts of each nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) in each litter fraction and in the total litter were determined using Excel only because litter components (leaves, branches, reproductive parts and other debris) from the "fixed" and "roving" litter traps in the same collection time were bulked prior to chemical analysis.

The results of this present study accord with the findings of Rieley (1969), Ahmad-Shah (1984) and Ahmad-Shah & Rieley (1989) that Wilm's Method leads to reductions in the standard errors of the mean values for each collection period and the total values for the year. For example, the throughfall pH value during 4 February- 7 March 2001 in this study in MSF was 5.14±0.41 (SD Excel) or 5.14±0.14 (SE Excel) and 5.07±0.13 (Wilm SE) (see chapter 3.2 and figure 3.2.2 a and 3.2.2.b). Wilm's method reduced variation to around 7.1% compared to Excel, which is nearly the same as the results of Rieley (1969). Twenty randomly placed fixed gauges produced an error up to 11 % of the mean for each time period (Rutter, 1963). If collecting gauges are moved to new random positions after each time period this error can be reduced to 3 -5 % of the mean (Rieley, 1969).

In this study Wilm's Method reduced the variability in the means of 4 weekly period sampling during the 1-year period. For example, the highest litterfall in MSF was 1213.4±406.3 kg ha^{-1} (4 February-March 2001) and the lowest was 269.3 ±37.6 kg ha^{-1} (24 June-21 July 2001) using Excel while using Wilm the highest was 820.3±103.4 kg ha^{-1} (4 February–7 March 2001) and the lowest was 478.9±85.0 kg ha^{-1} (27 May-23 June 2001) (see Chapter 3.3. Figures 3.3.1a and 3.3.1b). The difference between the highest and the lowest values using Excel was 944.1 kg ha^{-1} while using Wilm it was only 341.4 kg ha^{-1}.

Wilm's Method has disadvantages. If there is big variation in sample values between successive time periods high standard errors result and mean differences are smoothed out. For example, the lowest amount of iron in throughfall MSF occurred during 24 June – 21 July 2001 (0.013±0.004 kg ha^{-1}) (SD Excel) or 0.013± 0.0013 kg ha^{-1} (SE Excel). When using Wilm the mean value for iron during 24 June-21 July 2001 was 0.002±0.032 kg ha^{-1} (SE Wilm) showing that the standard error using Wilm is very high.

The other disadvantage of Wilm's method is the long time it takes to input data and carry out the analyses. These operations have to be carried out on every component separately. For example, input of data and analysis of leaf litter cannot be carried out together with branch litter. It also takes a long time if many nutrients have been analysed in leaf litter. In contrast, using Excel, the data can be analysed using SPSS immediately after data input.

4.10. NUTRIENT INPUTS AND OUTPUTS

Nutrient inputs in rainfall and nutrient losses in runoff in this study together with other data from several locations in the tropics are shown in Table 4.10.1.

Table 4.10.1. Nutrient additions in precipitation (I), losses in drainage water (L) and the nutrient budget (differences) (I-L) (kg ha yr^{-1}) in this study together with other data in the tropics.

Location		Caura River (Venezuela)1	Gua anak takun (Malaysia)2	Kinta Valley (Malaysia)2	Watubelah (Indonesia)3	MSF (Indonesia)4	LPF (Indonesia)4
Annual rainfall (mm)		3850	2440	2845	4670	2761	2761
Annual runoff (mm)		2425	1255	1605	3590	1523	1523
Calcium	I	1.3	36.1	11.4	9.9	15.7	15.7
	L	15.5	764	795	29.0	8.2	7.1
	I-L	-14.2	-728	-784	-19.1	+7.5	+8.6
Magnesium	I	0.3	3.4	1.4	4.0	5.8	5.8
	L	6.0	45	89.9	30.5	2.5	2.2
	I-L	-5.7	- 42	-88.5	-26.5	+3.3	+3.6
Potassium	I	1.0	3.7	3.4	9.6	9.6	9.6
	L	14.6	20	75.7	22.00	2.2	1.3
	I-L	- 13.6	-16	-72.3	-12.4	+7.4	+8.3
Phosphorus	I	0.14	-	-	1.2	4.6	4.6
	L	0.24	-	-	0.7	0.26	0.07
	I-L	- 0.1	-	-	+0.5	+4.34	+4.53
Nitrogen	I	2.3	-	-	15.4	16.5	16.5
	L	6.3	-	-	10.6	-	-
	I-L	-4.0	-	-	+4.8	-	-
Sodium	I	-	-	-	-	5.5	5.5
	L	-	-	-	-	4.8	4.7
	I-L	-	-	-	-	+0.7	+0.8
Iron	I	-	-	-	-	3.2	3.2
	L	-	-	-	-	0.7	0.7
	I-L	-	-	-	-	+2.5	+2.5
Manganese	I	-	-	-	-	0.22	0.22
	L	-	-	-	-	0.01	0.02
	I-L	-	-	-	-	+0.21	+0.20

Sources: 1, Lewis (1986) and Lewis *et al.*(1987); 2. Crowther (1987a;1987b); 3. Bruijnzeel (1991) 4. This study

From table 4.10.1., it can be seen that, in this study (natural peat swamp ecosystem), there was an annual gain for all nutrients studied and the overall nutrient budgets for LPF and MSF are nearly identical in spite of major structural differences in these two forest sub-types.

Compared to data for other tropical forests (Table 4.10.1) this study shows increases in the natural peat swamp forest ecosystem of calcium, magnesium, potassium, phosphorus, sodium, iron and manganese. In contrast, other studies show mostly annual nutrient losses, especially of calcium, magnesium, and potassium from the ecosystem. Phosphorus increase was also reported for an *Agathis* plantation in Watu Belah, Indonesia (Bruijnzeel, 1991), while only a small annual loss of 0.1 kg ha yr^{-1} was reported from the Caura River ecosystem in Venezuela (Lewis, 1986; Lewis, 1987). The small gains or losses of phosphorus has been attributed to the low mobility of this element (Bruijnzeel, 1991) although this does not explain the much larger degree of phosphorus retention in peat swamp forest in the Sebangau catchment, Indonesia. There are no data on sodium, iron, and manganese available in the literature for comparison with this study.

Similar reasons can be given to explain differences in nutrient budgets and different nutrient losses from the ecosystem (Table 4.10.1) because nutrient budgets are derived from nutrient inputs minus nutrient losses. These variations relate to differences in soil type and soil fertility (Vitousek & Stanford, 1986; Crowther, 1987a and 1987b; Dambrine & Ranger, 2000), differences in the type of forest ecosystem studied (Lewis, 1986; Bruiijzeel, 1991), differences in slope (Crowther, 1987a) and differences in the methods used for field sampling and chemical analysis (Bruijnzeel, 1991). Standardisation of methodology is essential if comparability of results is to be improved.

Table 4.10.1 shows that all of nutrient budgets in this study are positive while in other studies they are mostly negative except in Bruijnzeel's (1991) study in Watubelah, Indonesia for phosphorus and nitrogen. The main reason in this study is that the site is a natural ecosystem in which elements are being retained in the peat swamp forest ecosystem and are probably being stored in accumulating peat. The other sites in the tropics for which nutrient budget information is available are all on mineral soils, often on sloping ground from which nutrients are constantly being removed over and near the surface in runoff water and below ground by sub-surface leaching.

4.11. IMPLICATIONS OF NUTRIENT DYNAMIC STUDY FOR TROPICAL PEAT SWAMP FOREST MANAGEMENT

Figures 4.11.1. and 4.11.2 show the results of this nutrient dynamics study in mixed swamp forest and low pole forest in Central Kalimantan, Indonesia.

Owing to increasing demands for forest products and an increasing concern for the well being of forest ecosystems, nutrient dynamic studies have become very important (Ranger & Turpault, 1999; Shanmughavel, 2001; Pare *et al.*, 2002). For example, (the important of nutrient dynamics studies in plantation, Montagnini, 2000) state that nutrient cycling characteristics of individual tree species can also help in choosing management strategies to conserve site nutrients (Montagnini, 2000). He gives an example, *Terminalia amazonian, and Virola koschnyi* had the highest Ca content in foliage, and they also had a high rate of annual litterfall. *Terminalia amazonian* had the fastest litter decomposition of the species studied, while *Virola koschnyi* decomposed slowest. *Terminalia amazonian* had a beneficial effect on soil nutrients, while *Virola koschnyi* contributed to better soil protection. Mixed litter had an average decomposition rate and performed as well as mulch (Kershnar & Montagnini, 1998 cit Montagnini, 2000).

Nutrient dynamics studies, including the distribution of nutrients in biomass production systems, are not only important in plantations but are also essential in the management of natural ecosystems (Shanmughavel, 2001). In natural ecosystems nutrient inputs may be relatively small while the amount of nutrients stored (biomass) can be considerable (Ranger & Turpault, 1999). Disruption of the natural ecosystem (e.g. by land use change and development) may provide a nutrient deficient landscape that will be a problem for agricultural productivity and require considerable inputs of soil ameliorants and chemicals (e.g. lime and fertilisers) that will impose financial constraints upon the likelihood of success. Therefore, understanding of nutrient distribution in different biomass components of tree species in the tropical forest in terms of cycling through geochemical, biochemical and biogeochemical processes need to be investigated in order to provide information on nutrient budgeting within the ecosystem (Whitmore, 1984; Forrest & Ovington, 1970; Shamughavel, 2001; Pare *et al.*, 2002). These processes can be studied by examining soil litter systems, uptake of nutrients, distribution of nutrients in natural and plantation forest ecosystems. Furthermore, the calculation of whole-stand nutrient budgets can assist in the selection of tree species and plantation management strategies (in plantation areas) to encourage more efficient nutrient recycling mechanisms and effective site nutrient conservation (Montagnini, 2000). Moreover, sustainable forest management systems require that a balance must be reached between ecosystem nutrient losses and gains in the course of a rotation (Ranger & Turpault, 1999; Pare *et al.*, 2002).

Most tropical moist forests could be managed as truly renewable resources, if human involvement operated within the inherent limits of the natural cycle of growth and decay (Whitmore, 1990), ensuring that nutrient losses by harvesting timber can be replaced without any compensatory fertilisation (Ranger & Turpault, 1999). Moreover, forest recovery following logging depends on several factors, including maintenance of soil fertility, the stock of seedlings and saplings that survive logging and presence of natural pollinating and dispersal agents. Furthermore, sustainable forest management should maintain environmental and ecological parameters in a near natural condition (Whitmore, 1990).

Based on the results of this study (nutrient input, transfer, output and storage), it is concluded that nutrient concentrations in peat soils are low and the substrates are acidic. These factors are likely to be strongly limiting to agricultural development, including plantations of estate crops and trees. Because of that, management and conservation of the peat swamp forest in a natural condition is the best choice. If there is timber production in that area, conservation of nutrients should be a primary consideration. Well-managed selective and sustainable felling of primary forest is probably one alternative to produce economic value of the forest without disturbing the natural ecosystem and conserving nutrients and biodiversity. The other alternative is that provision of natural ecosystem services (e.g. carbon storage, watershed, biodiversity maintenance, timber production in certain time period) is likely to be a far wiser land use from a long-term perspective.

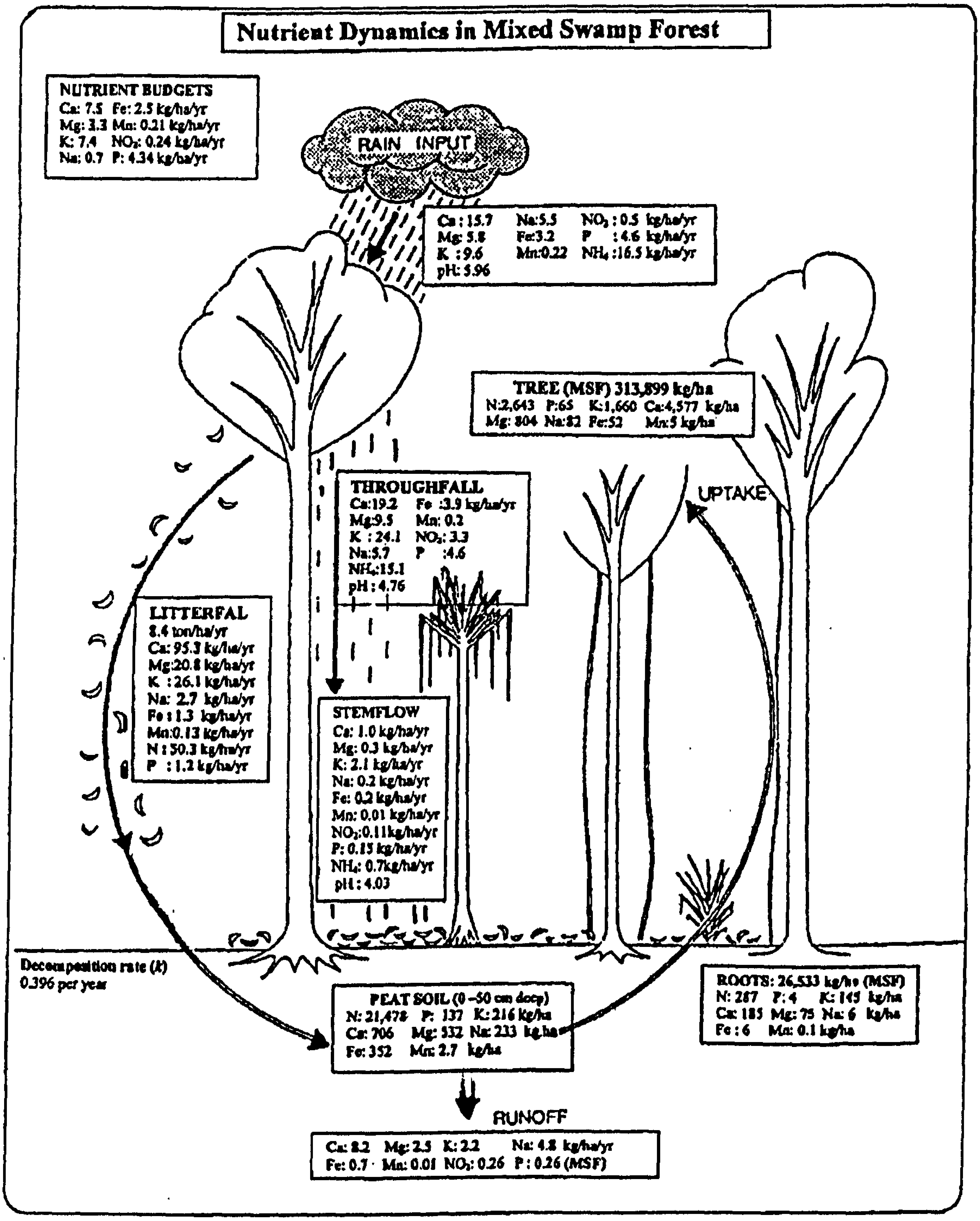

Figure 4.11.1. Nutrient dynamics in mixed swamp forest in upper catchment of Sebangau River, Central Kalimantan, Indonesia (figure template is based on Edwards, 1982).

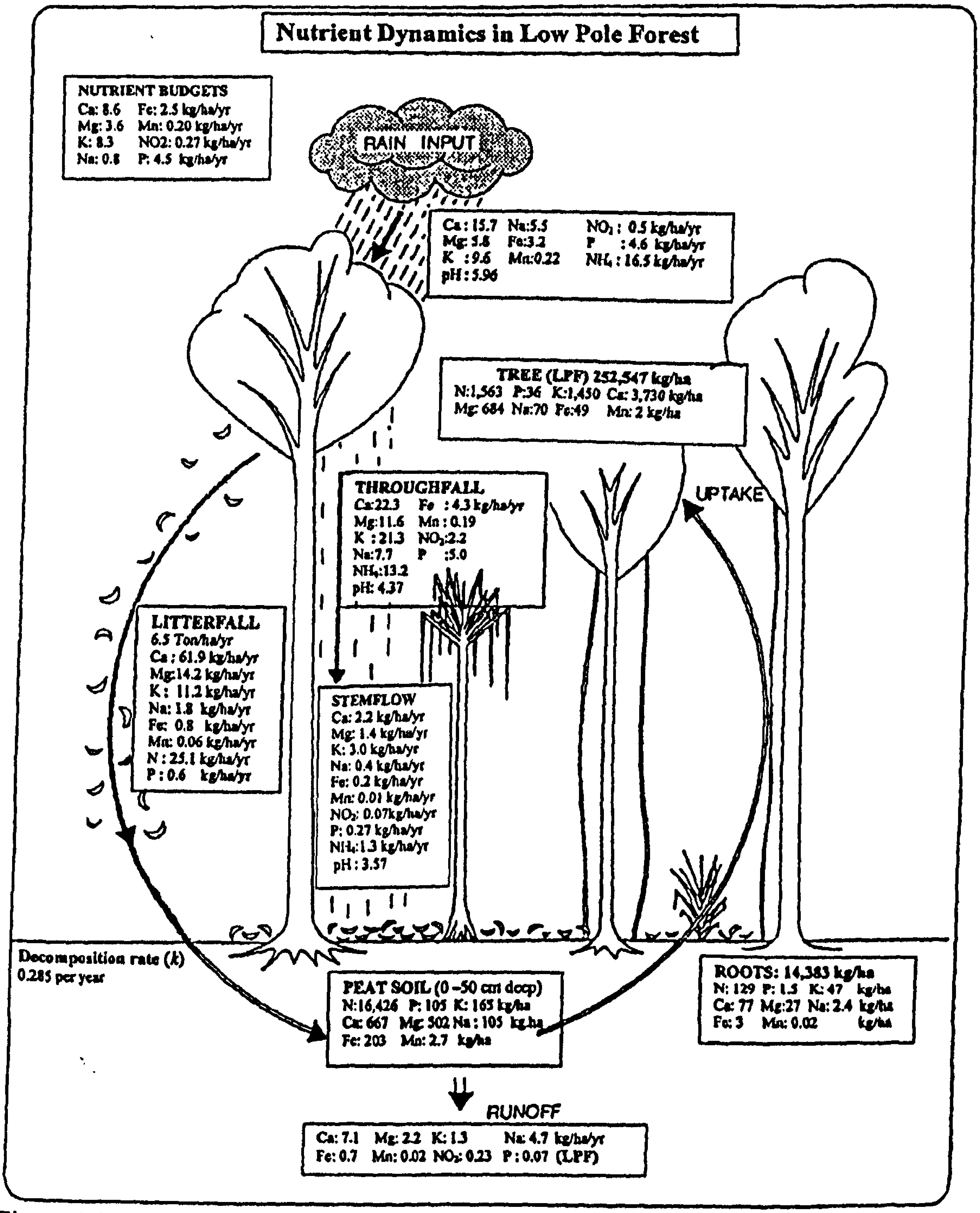

Figure 4.11.2. Nutrient dynamics in low pole forest in upper catchment of Sebangau River, Central Kalimantan, Indonesia (figure template is based on Edwards, 1982).

4.12. SUGGESTION FOR FUTURE RESEARCH

4.12.1. Large scale study (catchment-based)

This study was in the upper catchment of Sg. Sebangau, Central Kalimantan, Indonesia where five sub-types of forest have been distinguished, based upon differences in forest structure and tree species (Rieley & Ahmad-Shah, 1996; Shepherd *et al.*, 1997; Page *et al.*, 1999). These are riverine forest, mixed swamp forest, low pole forest, tall interior forest, and very low canopy forest. In this study it was possible to investigate the nutrient dynamics of only two of these, mixed swamp forest and low pole forest. There is a major need to carry out similar studies of the other sub-types, namely, riverine forest, tall interior forest, and very low canopy forest in order to build a more accurate picture of the nutrient functioning in the forest throughout the Sebangau catchment as a whole. The first priority is to investigate the tall interior forest that straddles the watershed and has emergent trees over 40 metres tall. This sub-type resembles lowland terrestrial Dipterocarp forest in its structure and species diversity more than any of the other sub-types. At the other extreme of canopy height, the very low canopy forest should also be studied. The area occupied by each of the forest sub-types also needs to be determined in order to produce a catchment-based nutrient budget.

Related to the management and conservation of peat swamp forest, other studies on the economic value of medicine trees, non timber products (e.g. fish, latex etc) and carbon storage on the study area as a whole should also give attention. This result then can be compared to other different land use in the same peat land, such as, economic value of agriculture and plantation.

4.12.2. Small scale study (specific experiment)

Nitrogen input from nitrogen-fixing organisms (symbiotic and non-symbiotic nitrogen fixation) has not been studied in this time. This input from nitrogen fixation in the canopy or peat soil environment may be a significant source of N to this system. What is the importance, distribution, and spatial and temporal variability in N-fixation in this forest? Temporal variability may be high between wet and dry seasons and between hollows and hummocks.

The decomposition study in this thesis used mixed litter, but should need to be carried out using leaves from known species in order to know which tree leaves are the fastest to decompose and which the slowest, although in natural ecosystems decomposition processes operate on mixed litter. Decomposition of branches and trees trunks should also be studied in the near future. Studies of microbiological activities related to decomposition processes need to be carried out to determine, for example, which microorganisms have the most important role in decomposition processes. Which species dominate in the peat swamp forest ecosystem?

In this study, the amount of nutrients in live above ground biomass was carried out by bulking samples from several dominant trees in the study area. The contribution of individual trees should be determined, especially the leaves, branches and stems of commercial species, such as, ramin (*Gonystylus bancanus).*

The impact of individual tree species on the volume and chemistry of rainfall also needs to be studied in order to determine which tree species have the ability to absorb and/or release nutrients (especially NH_4^+) from precipitation. For example, Wilson (1992) in a study of Norway spruce (*Picea abies* L) and Scots pine (*Pinus sylvestris* L) found that shoots of the former absorbed NH_4^+ from external solution while the latter released NH_4^+ to external solution.

4.13. LIMITATIONS OF THE STUDY

4.13.1. Short duration

The major weakness of the results presented in the current study is that they cover only one year, which may not be representative of the rainfall, litterfall, throughfall, stemflow and run off pattern over time. In addition, the one-year data set, while providing a measure of the variation between the sampling periods employed, does not indicate variation between years. In spite of these shortcomings, which can only be redressed by intensive long-term, continuing study, the information collected is the most detailed and comprehensive database of the nutrient dynamics of peat swamp forest anywhere in the world and will be a benchmark against which to compare all future investigations.

Some other studies of tropical forests, however, show that annual variation in litterfall over several years is small. For example, there was no significant variation in year to year litter production in a five year study of valley and hill sites in a Mexican tropical deciduous forest although there were significant differences between the sites (Martinez-Yrizar & Sarukhan, 1990). The low variation in annual litterfall was attributed to the low variation in annual leaf litterfall, the major component.

4.13.2 Comparison with other studies of forested peatlands

There are no data available for comparison with this study especially for tropical peat swamp forest. Several studies have been made of the nutrient dynamics of tropical forest growing on mineral soils, for example, Edwards (1982) in Papua New Guinea and Proctor (1983) in Malaysia. Unfortunately, neither of these are ideal comparisons.

4.13.3 Under or over estimation of results

The accuracy of litterfall studies is limited by the sample collection techniques employed and these invariably lead to an underestimate of total litterfall. For instance, this could result from the exclusion of large stems and branches in the procedure used. These canopy components are falling throughout the year but will take several, or many years to decompose and release their nutrient capital back into the ecosystem. Their contribution to the overall nutrient dynamics is thought to be small but a future study should attempt to quantify the amount involved.

In addition, some decomposition may take place in the litter traps between collection periods, especially during the wet season. Litter decomposition studies using bags placed in the peat substrate indicate a relatively slow rate of decomposition even under optimum conditions and, in drier conditions, above ground is likely to be less. The fortnightly collection interval used, however, for litter sampling in this should have minimised such losses.

The nutrient content of biomass could be under or over estimated since element concentrations were determined only for leaf and branch samples and trunk samples were not analysed. In the time available, it was not possible to collect and analyse the nutrient contents of the very large number of different trees present within the study plots, even though their trunks make up the largest component of the forest biomass.

4.13.4. Sampling of surface runoff water

The sampling of runoff water near to the end of the rainy season only may influence the reliability of these results. The chemical contents in water could be different at the beginning and middle of the rainy season when the run off rates would be different. The sampling and analysis of runoff is a problem that should be dealt with in a future study.

4.13.5. Other peat swamp forest sub-types and continua

There are five sub-type of forest in this study area. These are riverine forest, mixed swamp forest, low pole forest, tall interior forest, and very low canopy forest. In this study it was possible to investigate the nutrient dynamics of only two of these, mixed swamp forest and low pole forest. The reason of that these two sub-types of forest have quite a large distribution in the upper Sg. Sebangau catchment and are within a few hours walk on foot from the research project base camp. . Owing to access difficulties, the tall interior forest and very low canopy forest sub types were not able to be investigated but these should be included in future research plans. Furthermore, at the moment the tall interior forest is subject to illegal logging activities that presents problems for research logistics and security. Riverine forest in the upper Sg. Sebangau area has mostly been felled and the area burned so that it has largely disappeared. and replaced by sedge swamp.

CHAPTER 5

CONCLUSION

This study provides information on nutrient dynamics in two different sub-types of peat swamp forest, mixed swamp forest and low pole forest, in the upper catchment of Sungai Sebangau (river), Central Kalimantan, Indonesia. This information should provide scientific knowledge for improvement of productivity and stability of the tropical peatland ecosystem. It is hoped that the data obtained from the present study will be used as a baseline for further detailed investigation of the tropical peat swamp ecosystem in general, and for providing information of value to the understanding and management of the greater Sebangau catchment area in particular.

This study documents marked seasonality of rainfall, throughfall, and litterfall in the Sebangau, Central Kalimantan peat swamp forest. The results reflect environmental conditions, particularly the climate, which is the major determinant of the temporal pattern of rainfall and biomass production. It is confirmed that there are variations in throughfall and litterfall in different peat forest communities in relation to varying environmental conditions that affect the amount of biomass produced and litter deposited and the distribution of certain trees, such as, *Gonystylus bancanus* within the study area. Based on these results, it can be concluded that no one vegetation community can be taken as representative of the forest as a whole and studies are required of all sub-types present within it.

This study also provides information on the relative amounts of various chemical elements of importance in plant mineral nutrition in total live above ground biomass, below ground biomass, peat, rainfall, throughfall, water run off, and tree litter in two sub-types of forest, mixed swamp forest and low pole forest. The rates of litter decomposition in these forest sub-types were also studied. T-tests of data from both MSF and LPF demonstrate the validity of the initial hypothesis that different peat swamp forest communities have different total live above ground biomass, below ground biomass and litter production and in the chemical element capital within each of these. In addition the chemical contents of peat and water run off also differed between these forest types. The results suggest that different communities or perhaps different tree species have specific preferences for mineral nutrient cycling.

It seems that differences in biomass (above and below ground), nutrient contents of litter and peat, and decomposition rates in both sub types of forest are controlled by various factors, the most important of which are probably hydrological condition and nutrient availability in an ombrotrophic environment. There are differences in the water table in both sub types of forest and the way in which these change throughout the year. The degree of water saturation, especially in the surface peat, will control decomposition rate through the soil microbial population and the factors that control their activities. This, in turn, will have an effect on the amount and rate of nutrients released and recycled back to the forest above. Soil microbial populations and their activities were higher in aerobic areas than in anaerobic ones. Moreover, rates of decomposition are most rapid under aerobic but moist conditions, and become slower in sites that are continually dry but are slowest in permanently anaerobic areas. The most important factor limiting decay rates in natural peatlands are moisture availability and waterlogging, although other factors such as low nutrient concentration and low pH may also be important.

This study also provides information on the nutrients stored in different components of this ecosystem and transfers between them during the 1-year study period whereby all of the nutrients studied were positive (nutrient input was greater than nutrient output). Moreover, the results also highlight that nutrient concentrations in peat soils are low and the substrates are acidic. These factors are likely to be strongly limiting to agricultural development, including plantations of estate crops and trees. Under such conditions the maintenance of intact forest for natural ecosystem services (e.g. carbon storage, watershed or natural hydrology maintenance, biodiversity maintenance, timber production in certain time period) is likely to be a far wiser land use from a long-term perspective.

The principal aim of this investigation and the various objectives has been accomplished. In terms of the former, two comprehensive and detailed nutrient budgets have been constructed for mixed swamp forest and low pole forest in the upper Sg. Sebangau catchment of Central Kalimantan, Indonesia. These are only for a one-year period but are sufficiently detailed to indicate that the overall inputs of nutrients to and outputs from these two forest sub-types are very similar while each has markedly different biomass, especially above ground. These data confirm the close dynamic relationship between the peat swamp forest and its peat substrate that is maintained by precipitation inputs and cycling of nutrients between these two components. The negative balance of nutrients (inputs exceed outputs) suggests that peat is still accumulating in this peat swamp forest, which would still therefore be an active carbon sink.

The various operational objectives that were fulfilled support this aim and there has now been accumulated a large database of information on the physical, chemical and biological attributes of tropical peat swamp forest, the sources of various plant nutrient elements and their losses from the ecosystem, the relative amounts of these elements in peat, peat water and vegetation. It has also been possible to prepare nutrient budgets to represent the biomass of the major components in two major forest sub-types in this ecosystem and their nutrient capital with transfers between them during an entire year.

Consequently, the initial null hypothesis has been proved in that these peat swamp forest sub-types receive all of their nutrient inputs from precipitation and via the cycling of elements released from decomposition of biomass and surface peat, while excess is removed in the mass flow of surface runoff water in the wet season. In addition, it was also confirmed that the pathways of nutrient transfer in these two forest sub-types are similar and that inputs, outputs and retentions are almost equal even though their respective biomasses differ markedly.

Future work could be carried out to elucidate similar information on other major forest sub-types, especially the tall interior forest where trees reach a canopy height of up to 50 metres, very low pole forest where they never exceed 16 metres and transitional forest between two types. This present study suggests, however, that although these will differ from the two sub-types investigated here they are likely to behave in the same overall manner by retaining some of the nutrients entering the system in accumulating peat whilst supporting different amounts of biomass.

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APPENDIX 1. (calculations used in this thesis)

1.1. RAINFALL

Funnel diameter $= 25$ cm
Square of funnel $= \pi r^2$
$= 3.14 \times (12.5)^2$ cm^2
$= 490.625$ cm^2
1 litre volume of water $= 1{,}000$ cm^3

Height of 1 litre water in 25 cm diameter was 20.4 mm
Volume = square x height
Height = volume x square^{-1}
$= 1{,}000$ cm^3 / 490.625 cm^2
$= 2.038$ cm
$= 20.4$ mm

For example:
Rain gauge no.1 in riverine forest during 4 weeks collected 5.250 litres equivalent to = 107.100 mm (20.4 x 5.250)

Calcium calculation in the rain:

For example Calcium = 0.13 mg l^{-1} (Recorded from AAS)
During 4 weeks rainfall recorded = 107.100 mm (see above)
Calcium in that rain = 0.13 mg l^{-1}x 107.100 (rainfall) x 10,000 l *
= 139230 mg ha^{-1}.
= 0.14 kg ha^{-1}

Note
* from 1 mm water in 1 ha = 10,000 l
Volume = 10,000 cm x 10,000 cm x 0.1 cm
= 10,000,000 cm^3 (1 litre = 1,000 cm^3)
= 10,000 l ha^{-1}.

1.2. THROUGHFALL

Calculations for throughfall are the same as for rainfall, because the funnel diameter is the same (25 cm)

1.3. STEMFLOW

Calculations for the stemflow water were expressed as millimetres of rain and nutrients as kg ha^{-1} by using the product of the mean stemflow per tree and the number of trees per hectare (Carlisle *et al.*, 1967; Jordan, 1978).

1.3. LITTERFALL

Calculation from AAS to mg kg^{-1} in litter (Ca, Mg, K, Na, Fe, and Mn)

$$result(i.e.Ca) = \frac{25ml(digestionsolution)}{0.25g(sample)} x result AAS x 5(dilution) x \frac{100xWc}{100}$$
$$= A \text{ mg kg}^{-1}$$

$$N(result) = \frac{50ml(digestionsolution)}{0.025g(sample)} x result Spectrophotometer x \frac{100xWc}{100}$$
$$= A \text{ mg kg}^{-1}$$

$$P(result) = \frac{25ml(solution)}{0.25g(sample)} x result Spectrophotometer x \frac{100xWc}{100}$$
$$= \text{A mg kg}^{-1}.$$

Note:
Wc = Water content

Amount of nutrient (N, P, Ca, Mg, K, Na, Fe and Mn) deposited in litter in 1 hectare (from mg kg^{-1} to g ha^{-1})

$$result(i.e.Ca) = \frac{ODWg(litter)}{0.3845m^2} x 10,000m^2(ha^{-1}) x A result \frac{g}{1000,000g}(mgkg^{-1})$$

$$= B \text{ g ha}^{-1}$$

Note :
ODW = oven dry weight of litter
0.3845 m^2 = collecting area of litter trap (70 cm diameter)

Conversion from gm^{-2} to kg ha^{-1}

$$1gm^{-2} = \frac{0.001kg}{0.0001ha} = 10kgha^{-1}$$

<u>example</u>

$$3.5gm^{-2} = \frac{0.0035kg}{0.00035ha} = 35kgha^{-1}$$

1.3. DECOMPOSITION

Calculation for nutrient concentration in litterbag leaves is the same as litterfall (See also Chapter 2)

1.4. BIOMASS

Above ground (trees)

Calculation of nutrient concentration in trees is the same as litterfall (See also Chapter 2)

Below ground (roots)

Calculation of nutrient concentration in tree roots is the same as litterfall (See also Chapter 2)

1.5. PEAT SOIL

Calculation of nutrient concentration (N, P, K, Ca, Mg, Na, Fe, and Mn) is the same as litterfall

Amounts of nutrients (N, P, K, Ca, Mg, Na, Fe, and Mn) in peat soil are based on 1 hectare area 50 cm deep (rooting layer).

Peat weight 1 ha 50 cm depth = Volume x bulk density
= (50 cm x 10,000 cm x 10,000 cm) x 0.15 g cm^{-3}*
= 750,000,000 g
= 750,000 kg

* Average bulk density on study area (Kurnain, *et al.*, 2002).

Amount of nutrient (i.e K) in 1 ha = 254.14 mg kg^{-1} x 750,000 kg
= 190,605,000 mg
= 190.605 kg

1.6. RUNOFF

Runoff (1 year) = input (rainfall) - evapotranspiration
= 2760.7 mm – (364 x 3.4 mm(daily evapotranpiration*))
= 1523.1 mm

* 3.4 mm (Takahashi, 2002)

This becomes litre ha^{-1} yr^{-1} = 1523.1 X 10,000 l (1 mm in 1 ha = 10,000 l)
= 15,231,000 l ha^{-1} yr^{-1}

1 mm in 1 ha = 10,000 l
Volume = 10,000 cm x 10,000 cm x 0.1 cm
= 10,000,000 cm^3 (1 litre = 1,000 cm^3)
= 10,000 l ha^{-1}.

Example

K concentration of surface water was 0.593 mg l^{-1}
Amount of K nutrient in run off was = 0.593 mg l^{-1} x 15,231,000 l ha^{-1} yr^{-1}
= 9031983 mg ha^{-1} yr^{-1}
= 9.03 kg ha^{-1} yr^{-1}

APPENDIX 2
(Statistical analysis for rainfall, throughfall in MSF and throughfall in LPF).

2.a. Anova for nutrient (Ca, Mg, K, Na, Fe, Mn, NO2, PO4, and NH4) concentration in rainfall, MSF throughfall and LPF throughfall.

		Sum of Squares	df	Mean Square	F	Sig *
Ca concentration	Between Groups	17.719	2	8.859	4.010	.019
	Within Groups	625.177	283	2.209		
	Total	642.896	285			
Mg concentration	Between Groups	9.409	2	4.704	10.359	.000
	Within Groups	128.523	283	.454		
	Total	137.931	285			
K concentration	Between Groups	56.945	2	28.473	11.256	.000
	Within Groups	715.894	283	2.530		
	Total	772.840	285			
Na concentration	Between Groups	3.189	2	1.594	4.062	.018
	Within Groups	111.081	283	.393		
	Total	114.270	285			
Fe concentration	Between Groups	.184	2	.092	2.934	.055
	Within Groups	8.853	283	.031		
	Total	9.037	285			
Mn concentration	Between Groups	.000	2	.000	.293	.746
	Within Groups	.096	283	.000		
	Total	.096	285			
NO2 concentration	Between Groups	1.087	2	.544	11.718	.000
	Within Groups	12.992	280	.046		
	Total	14.079	282			
PO4 concentration	Between Groups	.056	2	.028	.363	.696
	Within Groups	21.662	279	.078		
	Total	21.718	281			
NH4 concentration	Between Groups	3.910	2	1.955	.842	.432
	Within Groups	622.251	268	2.322		
	Total	626.161	270			

* = If the value less than 0.5 indicated statistically different ($p<0.05$)

2.a.1. Duncan test for Ca concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	.8934	
MSF throughfall 2	117		1.5087
LPF throughfall 3	117		1.5625
Sig.		1.000	.816

2.a.2. Duncan test for Mg concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	.28249	
MSF throughfall 2	117		.71664
LPF throughfall 3	117		.77784
Sig.		1.000	.560

2.a.3. Duncan test for K concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	.58797	
LPF throughfall 3	117		1.52175
MSF throughfall 2	117		1.84242
Sig.		1.000	.196

2.a.4. Duncan test for Na concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	.30065	
MSF throughfall 2	117		.49837
LPF throughfall 3	117		.59806
Sig.		1.000	.307

2.a.5. Duncan test for Fe concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	.09148	
MSF throughfall 2	117		.15250
LPF throughfall 3	117		.16049
Sig.		1.000	.772

2.a.6. Duncan test for Mn concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05
RFMTHTF		1
Rainfall 1	52	.00667
LPF throughfall 3	117	.00758
MSF throughfall 2	117	.00886
Sig.		.475

2.a.7. Duncan test for NO_2 concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05		
RFMTHTF		1	2	3
Rainfall 1	51	.03079		
LPF throughfall 3	115		.11301	
MSF throughfall 2	117			.19895
Sig.		1.000	1.000	1.000

2.a.8. Duncan test for PO_4 concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05
RFMTHTF		1
Rainfall 1	51	.17478
LPF throughfall 3	114	.17814
MSF throughfall 2	117	.20569
Sig.		.510

2.a.9. Duncan test for NH_4 concentration in rainfall, MSF throughfall and LPF throughfall

	N	Subset for alpha = .05
RFMTHTF		1
LPF throughfall 3	108	.81310
Rainfall 1	51	.85202
MSF throughfall 2	112	1.06788
Sig.		.325

2.b. Anova for amount nutrient (Ca, Mg, K, Na, Fe, Mn, NO2, PO4, and NH4) in rainfall, MSF throughfall and LPF throughfall.

		Sum of Squares	df	Mean Square	F	Sig. *
Volume (mm)	Between Groups	138851.002	2	69425.501	6.800	.001
	Within Groups	2889395.088	283	10209.877		
	Total	3028246.090	285			
.pH	Between Groups	92.978	2	46.489	104.996	.000
	Within Groups	125.303	283	.443		
	Total	218.280	285			
Amount of Ca	Between Groups	9.649	2	4.824	2.189	.114
	Within Groups	623.696	283	2.204		
	Total	633.345	285			
Amount of Mg	Between Groups	7.077	2	3.538	4.280	.015
	Within Groups	233.941	283	.827		
	Total	241.018	285			
Amount of K	Between Groups	44.003	2	22.002	8.587	.000
	Within Groups	725.148	283	2.562		
	Total	769.152	285			
Amount of Na	Between Groups	1.791	2	.895	2.513	.083
	Within Groups	100.834	283	.356		
	Total	102.624	285			
Amount of Fe	Between Groups	.229	2	.115	.418	.659
	Within Groups	77.718	283	.275		
	Total	77.947	285			
Amount of Mn	Between Groups	.000	2	.000	.067	.935
	Within Groups	.532	283	.002		
	Total	.532	285			
Amount of NO_2	Between Groups	1.723	2	.861	5.073	.007
	Within Groups	48.061	283	.170		
	Total	49.784	285			
Amount of PO_4	Between Groups	.048	2	.024	.037	.964
	Within Groups	185.458	283	.655		
	Total	185.506	285			
Amount of NH_4	Between Groups	3.267	2	1.634	.797	.452
	Within Groups	580.156	283	2.050		
	Total	583.423	285			

* = If the value less than 0.5 indicated statistically different ($p<0.05$)

2.b.1. Duncan test for volume in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
MSF throughfall 2	117	150.3557	
LPF throughfall 3	117	166.9452	
Rainfall 1	52		212.3643
Sig.		.292	1.000

2.b.2. Duncan test for pH in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05		
RFMTHTF		1	2	3
LPF throughfall 3	117	4.3915		
MSF throughfall 2	117		4.7616	
Rainfall 1	52			5.9897
Sig.		1.000	1.000	1.000

2.b.3. Duncan test for amount of Ca in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	1.20920	
MSF throughfall 2	117	1.46773	1.46773
LPF throughfall 3	117		1.71184
Sig.		.264	.292

2.b.4. Duncan test for amount of Mg in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	.44518	
MSF throughfall 2	117		.73055
LPF throughfall 3	117		.88760
Sig.		1.000	.268

2.b.5. Duncan test for amount of K in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	.73927	
LPF throughfall 3	117		1.61942
MSF throughfall 2	117		1.83140
Sig.		1.000	.395

2.b.6. Duncan test for amount of Na in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05
RFMTHTF		1
Rainfall 1	52	.42461
MSF throughfall 2	117	.43524
LPF throughfall 3	117	.59273
Sig.		.088

2.b.7. Duncan test for amount of Fe in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05
RFMTHTF		1
Rainfall 1	52	.25170
MSF throughfall 2	117	.30192
LPF throughfall 3	117	.33124
Sig.		.362

2.b.8. Duncan test for amount of Mn in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05
RFMTHTF		1
Rainfall 1	117	.01459
LPF throughfall 3	117	.01532
MSF throughfall 2	52	.01723
Sig.		.715

2.b.9. Duncan test for amount of NO_2 in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05	
RFMTHTF		1	2
Rainfall 1	52	.04094	
LPF throughfall 3	117	.16713	.16713
MSF throughfall 2	117		.25726
Sig.		.050	.161

2.b.10. Duncan test for amount of PO_4 in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05
RFMTHTF		1
Rainfall 1	52	.35467
MSF throughfall 2	117	.35714
LPF throughfall 3	117	.38273
Sig.		.836

2.b.11. Duncan test for amount of NH_4 in rainfall, MSF throughfall, and LPF throughfall

	N	Subset for alpha = .05
RFMTHTF		1
LPF throughfall 3	117	.99037
MSF throughfall 2	117	1.15948
Rainfall 1	52	1.26849
Sig.		.242

APPENDIX 3 (statistical analysis for stemflow in MSF and LPF)

3.a. T test between pH, nutrient (Ca, Mg, K, Na, Fe, Mn, nitrite, phosphorus, and ammonium) concentration in MSF and LPF stemflow.

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		T	df	Sig.(2-tailed)*
					Lower	Upper			
Pair 1	.pH	0.460	0.330	0.053	0.354	0.567	8.721	38	0.000
Pair 2	Ca concentration	-0.250	1.106	0.177	-0.609	0.108	-1.414	38	0.166
Pair 3	Mg concentration	-0.640	0.378	0.061	-0.762	-0.517	-10.556	38	0.000
Pair 4	K concentration	-0.125	2.826	0.453	-1.042	0.791	-0.277	38	0.783
Pair 5	Na concentration	0.053	0.265	0.042	-0.033	0.139	1.245	38	0.221
Pair 6	Fe concentration	0.026	0.124	0.020	-0.014	0.066	1.309	38	0.199
Pair 7	Mn concentration	0.005	0.028	0.004	-0.004	0.014	1.024	38	0.312
Pair 8	NO_2 concentration	0.132	0.292	0.047	0.037	0.227	2.813	38	0.008
Pair 9	PO_4 concentration	0.034	0.330	0.053	-0.073	0.141	0.65	38	0.52
Pair 10	NH_4 concentration	0.018	1.451	0.239	-0.466	0.502	0.076	36	0.94

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

3.b. T test between amount of water and nutrient (Ca, Mg, K, Na, Fe, Mn, nitrite, phosphorus, and ammonium) in MSF and LPF stemflow.

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		T	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Amount of water	-4.161	3.500	0.560	-5.295	-3.026	-7.424	38	0.000
Pair 2	Amount of Ca	-0.094	0.097	0.015	-0.126	-0.063	-6.086	38	0.000
Pair 3	Amount of Mg	-0.092	0.070	0.011	-0.115	-0.070	-8.283	38	0.000
Pair 4	Amount of K	-0.072	0.166	0.027	-0.126	-0.018	-2.702	38	0.010
Pair 5	Amount of Na	-0.013	0.018	0.003	-0.018	-0.007	-4.441	38	0.000
Pair 6	Amount of Fe	-0.006	0.016	0.002	-0.011	-0.001	-2.515	38	0.016
Pair 7	Amount of Mn	0.000	0.002	0.000	-0.001	0.000	-0.372	38	0.712
Pair 8	Amount of NO_2	0.003	0.012	0.002	-0.001	0.007	1.723	38	0.093
Pair 9	Amount of PO_4	-0.010	0.032	0.005	-0.020	0.001	-1.867	38	0.070
Pair 10	Amount of NH_4	-0.045	0.132	0.021	-0.088	-0.003	-2.143	38	0.039

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

APPENDIX 4 (Statistical analysis for leaves, branches, reproductive part, and other debris litter)

4.a. T-test between nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) in MSF and LPF

4.a.1. T-test between nutrient concentration in leave litter in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	N concentration in leaves in MSF and LPF	2101.53	2879.13	461.03	1168.22	3034.83	4.56	38	0.000
Pair 2	P concentration in leaves in MSF and LPF	42.34	64.12	10.27	21.55	63.12	4.12	38	0.000
Pair 3	K concentration in leaves in MSF and LPF	1308.69	1244.12	199.22	905.40	1711.99	6.57	38	0.000
Pair 4	Ca concentration in leaves in MSF and LPF	1854.61	3489.78	558.81	723.35	2985.87	3.32	38	0.002
Pair 5	Mg concentration in leaves MSF and LPF	172.13	826.05	132.27	-95.64	439.91	1.30	38	0.201
Pair 6	Na concentration in leaves MSF and LPF	11.51	179.05	28.67	-46.53	69.55	0.40	38	0.690
Pair 7	Fe concentration in leaves MSF and LPF	27.70	187.16	29.97	-32.97	88.38	0.92	38	0.361
Pair 8	Mn concentration in leaves MSF and LPF	8.69	7.79	1.25	6.17	11.22	6.97	38	0.000

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

4.a.2. T-test between nutrient concentration in branches in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	N concentration in branch in MSF and LPF	1703.05	2368.58	379.28	935.24	2470.85	4.49	38	0.000
Pair 2	P concentration in branch in MSF and LPF	30.77	100.91	16.16	-1.94	63.48	1.90	38	0.064
Pair 3	K concentration in branch in MSF and LPF	738.58	1884.24	301.72	127.78	1349.38	2.45	38	0.019
Pair 4	Ca concentration in branch in MSF and LPF	5192.91	8923.09	1428.84	2300.38	8085.45	3.63	38	0.001
Pair 5	Mg concentration in branch in MSF and LPF	297.02	1008.39	161.47	-29.86	623.90	1.84	38	0.074
Pair 6	Na concentration in branch in MSF and LPF	33.06	280.35	44.89	-57.82	123.94	0.74	38	0.466
Pair 7	Fe concentration in branch in MSF and LPF	16.47	124.03	19.86	-23.73	56.68	0.83	38	0.412
Pair 8	Mn concentration in branch in MSF and LPF	5.66	8.74	1.40	2.83	8.50	4.05	38	0.000

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

4.a.3. T-test between nutrient concentration in reproductive part litter in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	N concentration in reproductive MSF and LPF	3057.21	4547.63	728.20	1583.04	4531.39	4.20	38	0.000
Pair 2	P concentration in reproductive MSF and LPF	149.65	210.08	33.64	81.55	217.75	4.45	38	0.000
Pair 3	K concentration in reproductive MSF and LPF	1283.68	2843.83	455.38	361.81	2205.54	2.82	38	0.008
Pair 4	Ca concentration in reproductive MSF and LPF	18.05	3396.34	543.85	-1082.92	1119.02	0.03	38	0.974
Pair 5	Mg concentration in reproductive MSF and LPF	389.22	942.45	150.91	83.72	694.73	2.58	38	0.014
Pair 6	Na concentration in reproductive MSF and LPF	61.18	147.08	23.55	13.50	108.85	2.60	38	0.013
Pair 7	Fe concentration in reproductive MSF and LPF	52.95	107.45	17.21	18.11	87.78	3.08	38	0.004
Pair 8	Mn concentration in reproductive MSF and LPF	6.66	6.98	1.12	4.40	8.92	5.96	38	0.000

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

4.a.4. T-test between nutrient concentration in other debris litter in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	N concentration in other debris in MSF and LPF	1755.58	3424.94	548.43	645.35	2865.82	3.20	38	0.003
Pair 2	P concentration in other debris in MSF and LPF	51.26	142.32	22.79	5.12	97.39	2.25	38	0.030
Pair 3	K concentration in other debris in MSF and LPF	985.00	962.59	154.14	672.96	1297.03	6.39	38	0.000
Pair 4	Ca concentration in other debris in MSF and LPF	387.25	3357.87	537.69	-701.24	1475.75	0.72	38	0.476
Pair 5	Mg concentration in other debris in MSF and LPF	238.25	583.07	93.37	49.24	427.26	2.55	38	0.015
Pair 6	Na concentration in other debris in MSF and LPF	41.38	134.76	21.58	-2.31	85.06	1.92	38	0.063
Pair 7	Fe concentration in other debris in MSF and LPF	99.34	1107.34	177.32	-259.62	458.29	0.56	38	0.579
Pair 8	Mn concentration in other debris in MSF and LPF	5.42	7.22	1.16	3.08	7.76	4.69	38	0.000

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

4.b. T test between Amount of litter and amount of nutrient (N, P, K, Ca, Mg, Na, Fe, ang Mn) in MSF and LPF

4.b.1. T test between amount of total litter weight and amount of total nutrient (N, P, K, Ca, Mg, Na, Fe, ang Mn) in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Amount of total litter weight in MSF and LPF	36.08	198.91	9.19	18.02	54.15	3.92	467	0.000
Pair 2	Amount of N in total litter in MSF and LPF	0.48	1.47	0.07	0.35	0.62	7.11	467	0.000
Pair 3	Amount of P in total litter in MSF and LPF	0.01	0.04	0.00	0.01	0.02	6.07	467	0.000
Pair 4	Amount of K in total litter in MSF and LPF	0.29	0.88	0.04	0.21	0.37	7.09	467	0.000
Pair 5	Amount of Ca in total litter in MSF and LPF	0.64	2.64	0.12	0.40	0.88	5.26	467	0.000
Pair 6	Amount of Mg in total litter in MSF and LPF	0.13	0.48	0.02	0.08	0.17	5.76	467	0.000
Pair 7	Amount of Na in total litter in MSF and LPF	0.02	0.08	0.00	0.01	0.02	4.64	467	0.000
Pair 8	Amount of Fe in total litter in MSF and LPF	0.01	0.06	0.00	0.01	0.02	4.03	467	0.000
Pair 9	Amount of Mn in total litter in MSF and LPF	0.00	0.00	0.00	0.00	0.00	7.58	467	0.000

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

4.b.2. T test between amount of leaves litter weight and amount of nutrient ((N, P, K, Ca, Mg, Na, Fe, ang Mn) in leave in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Amount of leave litter weight in MSF and LPF	103.99	287.41	26.57	51.36	156.61	3.91	116	0.000
Pair 2	Amount of N in leave litter in MSF and LPF	1.33	2.10	0.19	0.94	1.71	6.83	116	0.000
Pair 3	Amount of P in leave litter in MSF and LPF	0.02	0.04	0.00	0.02	0.03	6.56	116	0.000
Pair 4	Amount of K in leave litter in MSF and LPF	0.82	1.19	0.11	0.60	1.04	7.44	116	0.000
Pair 5	Amount of Ca in leave litter in MSF and LPF	1.93	3.85	0.36	1.23	2.64	5.43	116	0.000
Pair 6	Amount of Mg in leave litter in MSF and LPF	0.36	0.80	0.07	0.21	0.51	4.82	116	0.000
Pair 7	Amount of Na in leave litter in MSF and LPF	0.05	0.14	0.01	0.02	0.07	3.55	116	0.001
Pair 8	Amount of Fe in leave litter in MSF and LPF	0.02	0.08	0.01	0.01	0.04	2.91	116	0.004
Pair 9	Amount of Mn in leave litter in MSF and LPF	0.00	0.01	0.00	0.00	0.01	7.39	116	0.000

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

4.b.3. T test between amount of branch litter weight and amount of nutrient (N, P, K, Ca, Mg, Na, Fe, ang Mn) in branch in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Amount of branch litter weight in MSF and LPF	-0.37	237.29	21.94	-43.82	43.08	-0.02	116	0.987
Pair 2	Amount of N in branch litter in MSF and LPF	0.08	1.04	0.10	-0.11	0.27	0.79	116	0.432
Pair 3	Amount of P in branch litter in MSF and LPF	0.00	0.02	0.00	0.00	0.01	1.79	116	0.076
Pair 4	Amount of K in branch litter in MSF and LPF	0.09	0.32	0.03	0.03	0.15	3.03	116	0.003
Pair 5	Amount of Ca in branch litter in MSF and LPF	0.32	3.22	0.30	-0.27	0.91	1.09	116	0.279
Pair 6	Amount of Mg in branch litter in MSF and LPF	0.05	0.27	0.03	0.00	0.10	1.84	116	0.068
Pair 7	Amount of Na in branch litter in MSF and LPF	0.01	0.07	0.01	0.00	0.02	1.35	116	0.180
Pair 8	Amount of Fe in branch litter in MSF and LPF	0.00	0.03	0.00	0.00	0.01	1.39	116	0.168
Pair 9	Amount of Mn in branch litter in MSF and LPF	0.00	0.00	0.00	0.00	0.00	2.62	116	0.010

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

4.b.4. T-test between amount of reproductive litter weight and amount of nutrient (N, P, K, Ca, Mg, Na, Fe, ang Mn) in reproductive part in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Amount of reproductive litter weight in MSF and LPF	22.3756	113.6892	10.5106	1.5581	43.1931	2.13	116	0.035
Pair 2	Amount of N in reproductive litter in MSF and LPF	0.3315	1.4767	0.1365	0.0611	0.6019	2.43	116	0.017
Pair 3	Amount of P in reproductive litter in MSF and LPF	0.0125	0.0690	0.0064	-0.0001	0.0252	1.96	116	0.052
Pair 4	Amount of K in reproductive litter in MSF and LPF	0.1711	1.0786	0.0997	-0.0264	0.3686	1.72	116	0.089
Pair 5	Amount of Ca in reproductive litter in MSF and LPF	0.1409	0.7819	0.0723	-0.0023	0.2840	1.95	116	0.054
Pair 6	Amount of Mg in reproductive litter in MSF and LPF	0.0619	0.3412	0.0315	-0.0006	0.1243	1.96	116	0.052
Pair 7	Amount of Na in reproductive litter in MSF and LPF	0.0078	0.0350	0.0032	0.0014	0.0142	2.40	116	0.018
Pair 8	Amount of Fe in reproductive litter in MSF and LPF	0.0031	0.0138	0.0013	0.0006	0.0056	2.43	116	0.017
Pair 9	Amount of Mn in reproductive litter in MSF and LPF	0.0004	0.0024	0.0002	0.0000	0.0008	1.78	116	0.078

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

4.b.5. T-test between amount of other debris litter weight and amount of nutrient (N, P, K, Ca, Mg, Na, Fe, ang Mn) in other debris in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Amount of other debris litter weight in MSF and LPF	18.3416	30.9735	2.8635	12.6701	24.0131	6.41	116	0.000
Pair 2	Amount of N in other debris litter in MSF and LPF	0.2009	0.2519	0.0233	0.1547	0.2470	8.63	116	0.000
Pair 3	Amount of P in other debris litter in MSF and LPF	0.0069	0.0089	0.0008	0.0053	0.0086	8.45	116	0.000
Pair 4	Amount of K in other debris litter in MSF and LPF	0.0671	0.0950	0.0088	0.0497	0.0845	7.64	116	0.000
Pair 5	Amount of Ca in other debris litter in MSF and LPF	0.1719	0.2925	0.0270	0.1184	0.2255	6.36	116	0.000
Pair 6	Amount of Mg in other debris litter in MSF and LPF	0.0403	0.0601	0.0056	0.0293	0.0513	7.26	116	0.000
Pair 7	Amount of Na in other debris litter in MSF and LPF	0.0076	0.0116	0.0011	0.0054	0.0097	7.07	116	0.000
Pair 8	Amount of Fe in other debris litter in MSF and LPF	0.0127	0.0667	0.0062	0.0005	0.0250	2.07	116	0.041
Pair 9	Amount of Mn in other debris litter in MSF and LPF	0.0004	0.0004	0.0000	0.0003	0.0004	8.83	116	0.000

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

APPENDIX 5
(Statistical analysis for decomposition in MSF and LPF).

5.1. Weight and nutrient concentration

5.1.a. Anova for weight remaining, nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration in decomposition study 0, 6, 12, and 18 months in MSF.

		Sum of Squares	df	Mean Square	F	Sig.*
Weight	Between Groups	3136.6	3	1045.5	9.72	0.002
	Within Groups	1290.3	12	107.5		
	Total	4427.0	15			
N concentration	Between Groups	218460347.7	3	72820115.9	6.53	0.007
	Within Groups	133770653.8	12	11147554.5		
	Total	352231001.4	15			
P concentration	Between Groups	85.1	3	28.4	0.03	0.992
	Within Groups	10343.3	12	861.9		
	Total	10428.5	15			
K concentration	Between Groups	255353.0	3	85117.7	1.42	0.284
	Within Groups	717924.6	12	59827.0		
	Total	973277.6	15			
Ca concentration	Between Groups	48120688.9	3	16040229.6	0.67	0.588
	Within Groups	288549825.1	12	24045818.8		
	Total	336670514.0	15			
Mg concentration	Between Groups	741447.3	3	247149.1	0.87	0.485
	Within Groups	3422468.6	12	285205.7		
	Total	4163915.9	15			
Na concentration	Between Groups	64942.3	3	21647.4	11.62	0.001
	Within Groups	22348.7	12	1862.4		
	Total	87291.0	15			
Fe concentration	Between Groups	18917.5	3	6305.8	7.34	0.005
	Within Groups	10311.2	12	859.3		
	Total	29228.7	15			
Mn concentration	Between Groups	5.6	3	1.9	0.12	0.946
	Within Groups	184.4	12	15.4		
	Total	190.0	15			

* = If the value less than 0.5 indicated statistically different ($p<0.05$)

5.1.a.1. Duncan test for weight remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05	
MONTHS		1	2
18 Months	4	66.10	
12 months	4	67.48	
6 months	4	73.43	
0 months	4		100.71
Sig.		.361	1.000

5.1.a. 2. Duncan test for N concentration during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05	
MONTHS		1	2
18 Months	4	11738.85	
6 months	4	14339.79	
0 months	4	15352.10	
12 months	4		21782.42
Sig.		.171	1.000

5.1. a.3. Duncan test for P concentration during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05
MONTHS		1
0 months	4	104.79
6 months	4	104.97
18 months	4	108.93
12 months	4	109.94
Sig.		.822

5.1. a.4. Duncan test for K concentration during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05
MONTHS		1
18 Months	4	199.29
12 months	4	367.21
6 months	4	410.47
0 months	4	553.54
Sig.		.081

5.1.a.5. Duncan test for Ca concentration during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05
MONTHS		1
18 Months	4	2652.36
0 months	4	6071.96
12 months	4	6633.81
6 months	4	7031.81
Sig.		.264

5.1. a.6. Duncan test for Mg concentration during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05
MONTHS		1
18 Months	4	518.94
12 months	4	955.20
0 months	4	1002.39
6 months	4	1065.70
Sig.		.204

5.1. a.7. Duncan test for Na concentration during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05		
MONTHS		1	2	3
12 months	4	135.14		
0 months	4		234.28	
18 Months	4		256.91	256.91
6 months	4			311.06
Sig.		1.000	.472	.101

5.1. a.8. Duncan test for Fe concentration during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05	
MONTHS		1	2
6 months	4	122.56	
0 months	4		170.24
18 Months	4		191.05
12 months	4		216.23
Sig.		1.000	.056

5.1. a.9. Duncan test for Mn concentration during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05
MONTHS		1
18 Months	4	7.32
6 months	4	7.56
0 months	4	7.88
12 months	4	8.87
Sig.		.614

5.1.b. Anova for weight remaining and nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration in decomposition study during 0, 6, 12, and 18 months in LPF.

		Sum of Squares	df	Mean Square	F	Sig.*
Weight	Between Groups	2002.8	3	667.6	97.52	0.000
	Within Groups	82.2	12	6.8		
	Total	2085.0	15			
N concentration	Between Groups	3402376.4	3	1134125.5	0.13	0.939
	Within Groups	103499069.1	12	8624922.4		
	Total	106901445.6	15			
P concentration	Between Groups	130.1	3	43.4	0.23	0.873
	Within Groups	2257.8	12	188.2		
	Total	2387.9	15			
K concentration	Between Groups	196494.7	3	65498.2	19.29	0.000
	Within Groups	40745.6	12	3395.5		
	Total	237240.3	15			
Ca concentration	Between Groups	2588482.4	3	862827.5	2.31	0.128
	Within Groups	4483605.4	12	373633.8		
	Total	7072087.8	15			
Mg concentration	Between Groups	87806.5	3	29268.8	16.58	0.000
	Within Groups	21190.6	12	1765.9		
	Total	108997.2	15			
Na concentration	Between Groups	36261.6	3	12087.2	11.85	0.001
	Within Groups	12238.1	12	1019.8		
	Total	48499.7	15			
Fe concentration	Between Groups	19128.1	3	6376.0	7.64	0.004
	Within Groups	10010.7	12	834.2		
	Total	29138.8	15			
Mn concentration	Between Groups	9.1	3	3.0	4.11	0.032
	Within Groups	8.8	12	0.7		
	Total					

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

5.1. b.1. Duncan test for weight remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05		
MONTHS		1	2	3
18 Months	4	73.01		
12 months	4	75.17	75.17	
6 months	4		77.66	
0 months	4			100.84
Sig.		.266	.203	1.000

5.1. b.2. Duncan test for N concentration during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05
MONTHS		1
18 Months	4	7787.00
12 months	4	7909.44
6 months	4	8036.31
0 months	4	8956.23
Sig.		.611

5.1. b.3. Duncan test for P concentration during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05
MONTHS		1
6 Months	4	66.84
12 months	4	67.40
0 months	4	69.31
18 months	4	74.09
Sig.		.502

5.1. b.4. Duncan test for K concentration during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05		
MONTHS		1	2	3
6 Months	4	38.73		
18 months	4	114.61		
12 months	4		226.18	
0 months	4			330.93
Sig.		.090	1.000	1.000

5.1. b.5. Duncan test for Ca concentration during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05	
MONTHS		1	2
18 Months	4	1377.54	
12 months	4	1601.05	1601.05
6 months	4	1774.06	1774.06
0 months	4		2454.52
Sig.		.400	.084

5.1. b.6. Duncan test for Mg concentration during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05	
MONTHS		1	2
6 Months	4	268.88	
12 months	4	284.19	
18 months	4	299.97	
0 months	4		453.53
Sig.		.339	1.000

5.1. b.7. Duncan test for Na concentration during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05		
MONTHS		1	2	3
12 Months	4	109.37		
0 months	4		184.06	
18 months	4		195.53	195.53
6 months	4			242.05
Sig.		1.000	.621	.062

5.1. b.8. Duncan test for Fe concentration during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05	
MONTHS		1	2
6 Months	4	77.35	
0 months	4		130.54
12 months	4		155.22
18 months	4		167.44
Sig.		1.000	.111

5.1.b.9. Duncan test for Mn concentration during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05	
MONTHS		1	2
6 Months	4	3.09	
18 months	4	3.73	3.73
0 months	4		4.61
12 months	4		5.02
Sig.		.310	.065

5.2. Amount of nutrient remaining

5.2.a. Anova for amount of nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) remaining in decomposition study 0, 6, 12, and 18 months in MSF.

		Sum of Squares	df	Mean Square	F	Sig.*
N remaining	Between Groups	1608051.1	3	536017.0	18.049	0
	Within Groups	356372.5	12	29697.7		
	Total	1964423.5	15			
P remaining	Between Groups	34.4	3	11.5	4.06	0.033
	Within Groups	33.9	12	2.8		
	Total	68.3	15			
K remaining	Between Groups	4086.0	3	1362.0	4.731	0.021
	Within Groups	3454.8	12	287.9		
	Total	7540.8	15			
Ca remaining	Between Groups	431544.5	3	143848.2	1.258	0.332
	Within Groups	1371968.6	12	114330.7		
	Total	1803513.1	15			
Mg remaining	Between Groups	9143.7	3	3047.9	2.574	0.103
	Within Groups	14211.9	12	1184.3		
	Total	23355.6	15			
Na remaining	Between Groups	535.3	3	178.4	10.589	0.001
	Within Groups	202.2	12	16.8		
	Total	737.4	15			
Fe remaining	Between Groups	131.5	3	43.8	3.637	0.045
	Within Groups	144.7	12	12.1		
	Total	276.2	15			
Mn remaining	Between Groups	0.3	3	0.1	1.645	0.231
	Within Groups	0.7	12	0.1		
	Total	0.9	15			

* = If the value less than 0.5 indicated statistically different ($p<0.05$)

5.2.a.1. Duncan test for N remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05		
MONTHS		1	2	3
18 Months	4	757.278		
6 months	4		1024.979	
12 months	4			1436.204
0 months	4			1546.261
Sig.		1.000	1.000	0.384

5.2.a.2. Duncan test for P remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05	
MONTHS		1	2
18 months	4	6.95097	
12 months	4	7.16746	
6 months	4	7.46701	
0 months	4		10.55536
Sig.		.687	1.000

5.2. a.3. Duncan test for K remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05	
MONTHS		1	
18 Months	4	12.48910	
12 months	4	23.60024	
6 months	4	26.71440	
0 months	4		55.76105
Sig.		.281	1.000

5.2.a.4. Duncan test for Ca remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05
MONTHS		1
18 Months	4	155.10278
12 months	4	415.27240
6 months	4	456.68771
0 months	4	611.75811
Sig.		.101

5.2.a.5. Duncan test for Mg remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05	
MONTHS		1	2
18 Months	4	34.15585	
12 months	4	61.09231	61.09231
6 months	4	71.22521	71.22521
0 months	4		100.9782 2
Sig.		.172	.144

5.2.a.6. Duncan test for Na remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05		
MONTHS		1	2	3
12 months	4	9.12859		
18 months	4		16.91379	
6 Months	4		22.76165	22.76165
0 months	4			23.59457
Sig.		1.000	.067	.779

5.2.a.7. Duncan test for Fe remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05	
MONTHS		1	2
6 months	4	9.24556	
18 months	4	12.90050	12.90050
12 Months	4	14.57578	14.57578
0 months	4		17.14278
Sig.		.060	.125

5.2.a.8. Duncan test for Mn remaining during 0, 6, 12, and 18 months in MSF

	N	Subset for alpha = .05
MONTHS		1
18 Months	4	.43966
6 months	4	.52185
12 months	4	.58361
0 months	4	.79399
Sig.		.072

5.2.b. Anova for nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) remaining in decomposition study during 0, 6, 12, and 18 months in LPF.

		Sum of Squares	df	Mean Square	F	Sig.*
N remaining	Between Groups	142405.83	3	47468.61	0.809	0.513
	Within Groups	704167.14	12	58680.60		
	Total	846572.97	15			
P remaining	Between Groups	9.62	3	3.21	2.629	0.098
	Within Groups	14.64	12	1.22		
	Total	24.27	15			
K remaining	Between Groups	2118.11	3	706.04	33.625	0
	Within Groups	251.97	12	21.00		
	Total	2370.07	15			
Ca remaining	Between Groups	53041.73	3	17680.58	10.125	0.001
	Within Groups	20955.60	12	1746.30		
	Total	73997.33	15			
Mg remaining	Between Groups	1793.66	3	597.89	73.844	0
	Within Groups	97.16	12	8.10		
	Total	1890.82	15			
Na remaining	Between Groups	292.74	3	97.58	14.758	0
	Within Groups	79.34	12	6.61		
	Total	372.08	15			
Fe remaining	Between Groups	126.24	3	42.08	8.264	0.003
	Within Groups	61.11	12	5.09		
	Total	187.35	15			
Mn remaining	Between Groups	0.13	3	0.04	8.555	0.003
	Within Groups	0.06	12	0.01		
	Total	0.19	15			

* = If the value less than 0.5 indicated statistically different ($p<0.05$)

5.2.b.1. Duncan test for N remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05
MONTHS		1
18 Months	4	569.59040
12 months	4	598.95825
6 months	4	696.24572
0 months	4	810.67246
Sig.		.216

5.2.b.2. Duncan test for P remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05	
MONTHS		1	2
12 Months	4	5.05327	
6 months	4	5.18741	
18 months	4	5.44626	5.44626
0 months	4		6.99007
Sig.		.641	.072

5.2.b.3. Duncan test for K remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05		
MONTHS		1	2	3
6 Months	4	3.00577		
18 months	4	8.27612		
12 months	4		16.92959	
0 months	4			33.36719
Sig.		.130	1.000	1.000

5.2.b.4. Duncan test for Ca remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05	
MONTHS		1	2
18 Months	4	99.71812	
12 months	4	117.21054	
6 months	4	137.51614	
0 months	4		247.4787
Sig.		.247	1.000

5.2.b.5. Duncan test for Mg remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05	
MONTHS		1	2
6 Months	4	20.85964	
12 months	4	21.17978	
18 months	4	21.84000	
0 months	4		45.73124
Sig.		.652	1.000

5.2.b.6. Duncan test for Na remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05		
MONTHS		1	2	3
12 Months	4	8.24980		
18 months	4		14.29280	
0 months	4			18.55911
6 months	4			18.80178
Sig.		1.000	1.000	.896

5.2.b.7. Duncan test for Fe remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05	
MONTHS		1	2
6 Months	4	5.99070	
12 months	4		11.72123
18 months	4		12.21482
0 months	4		13.16304
Sig.		1.000	.407

5.2.b.8. Duncan test for Mn remaining during 0, 6, 12, and 18 months in LPF

	N	Subset for alpha = .05		
MONTHS		1	2	
6 Months	4	.23949		
18 months	4	.27165	.27165	
12 months	4		.37899	.37899
0 months	4			.46474
Sig.		.531	.052	.111

APPENDIX 6 (Statistical analysis for decomposition study in MSF and LPF)

6.a. T test between MSF and LPF nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration during 0, 6, 12, 18 months

6.a.1. T test between MSF and LPF nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration during 0 and 6 months

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	N concentration 0 month	7315.80	4730.32	2365.16	-211.20	14842.80	3.09	3	0.054
Pair 2	P concentration 0 month	35.48	27.25	13.62	-7.88	78.83	2.60	3	0.08
Pair 3	K concentration 0 month	222.61	198.92	99.46	-93.91	539.13	2.24	3	0.111
Pair 4	Ca concentration 0 month	3617.43	3689.50	1844.75	-2253.39	9488.26	1.96	3	0.145
Pair 5	Mg concentration 0 month	548.86	363.41	181.71	-29.41	1127.13	3.02	3	0.057
Pair 6	Na concentration 0 month	50.22	28.72	14.36	4.53	95.91	3.50	3	0.04
Pair 7	Fe concentration 0 months	39.69	26.38	13.19	-2.28	81.67	3.01	3	0.057
Pair 8	Mn concentration 0 months	3.27	3.14	1.57	-1.72	8.27	2.09	3	0.128
Pair 9	N concentration 6 months	5383.56	7632.91	3816.45	-6762.10	17529.22	1.41	3	0.253
Pair 10	P concentration 6 months	38.13	27.49	13.74	-5.61	81.86	2.77	3	0.069
Pair 11	K concentration 6 months	371.74	412.45	206.23	-284.57	1028.05	1.80	3	0.169
Pair 12	Ca concentration 6 months	5257.75	6751.99	3375.99	-5486.16	16001.67	1.56	3	0.217
Pair 13	Mg concentration 6 months	796.82	830.83	415.41	-525.21	2118.85	1.92	3	0.151
Pair 14	Na concentration 6 months	69.01	127.03	63.52	-133.12	271.15	1.09	3	0.357
Pair 15	Fe concentration 6 months	45.21	59.24	29.62	-49.05	139.47	1.53	3	0.224
Pair 16	Mn concentration 6 months	4.48	4.09	2.05	-2.04	10.99	2.19	3	0.117

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

6.a.2. T test between MSF and LPF nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration during 12 and 18 months

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	N concentration 12 month	13872.98	6382.08	3191.04	3717.66	24028.30	4.35	3	0.022
Pair 2	P concentration 12 month	42.55	24.93	12.46	2.88	82.21	3.41	3	0.042
Pair 3	K concentration 12 month	141.02	87.61	43.81	1.61	280.43	3.22	3	0.049
Pair 4	Ca concentration 12 month	5032.76	3902.46	1951.23	-1176.93	11242.45	2.58	3	0.082
Pair 5	Mg concentration 12 month	671.00	434.92	217.46	-21.05	1363.05	3.09	3	0.054
Pair 6	Na concentration 12 month	25.77	15.42	7.71	1.23	50.31	3.34	3	0.044
Pair 7	Fe concentration 12 months	61.00	34.29	17.15	6.43	115.57	3.56	3	0.038
Pair 8	Mn concentration 12 months	3.84	4.06	2.03	-2.62	10.31	1.89	3	0.155
Pair 9	N concentration 18 months	3951.85	2378.15	1189.07	167.69	7736.01	3.32	3	0.045
Pair 10	P concentration 18 months	34.84	40.25	20.13	-29.21	98.89	1.73	3	0.182
Pair 11	K concentration 18 months	84.68	49.71	24.85	5.59	163.78	3.41	3	0.042
Pair 12	Ca concentration 18 months	1274.82	2359.12	1179.56	-2479.07	5028.71	1.08	3	0.359
Pair 13	Mg concentration 18 months	218.97	165.74	82.87	-44.76	482.70	2.64	3	0.078
Pair 14	Na concentration 18 months	61.39	28.17	14.08	16.57	106.21	4.36	3	0.022
Pair 15	Fe concentration 18 months	23.60	53.66	26.83	-61.78	108.99	0.88	3	0.444
Pair 16	Mn concentration 18 months	3.59	4.41	2.20	-3.42	10.60	1.63	3	0.202

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

6.b. T test between MSF and LPF amount of nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) remaining during 0, 6, 12, 18 months

6.b.1. T test between MSF and LPF amount of nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) remaining during 0 and 6 months

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Weight 0 month	-0.13	0.31	0.16	-0.62	0.36	-0.84	3	0.464
Pair 2	N remaining 0 month	735.59	479.48	239.74	-27.37	1498.54	3.07	3	0.055
Pair 3	P remaining0 month	3.57	2.77	1.38	-0.84	7.97	2.58	3	0.082
Pair 4	K remaining 0 month	22.39	20.13	10.07	-9.64	54.43	2.22	3	0.113
Pair 5	Ca remaining 0 month	364.28	372.34	186.17	-228.19	956.75	1.96	3	0.145
Pair 6	Mg remaining 0 month	55.25	36.79	18.39	-3.29	113.78	3.00	3	0.057
Pair 7	Na remaining 0 month	5.04	2.88	1.44	0.46	9.61	3.50	3	0.039
Pair 8	Fe remaining 0 month	3.98	2.62	1.31	-0.19	8.15	3.04	3	0.056
Pair 9	Mn remaining 0 month	0.33	0.32	0.16	-0.18	0.83	2.08	3	0.129
Pair 10	Weight leave remaining 6 months	-4.23	10.20	5.10	-20.47	12.00	-0.83	3	0.468
Pair 11	N remaining 6 months	328.73	459.90	229.95	-403.06	1060.53	1.43	3	0.248
Pair 12	P remaining 6 months	2.28	0.93	0.46	0.81	3.75	4.93	3	0.016
Pair 13	K remaining 6 months	23.71	25.52	12.76	-16.90	64.31	1.86	3	0.16
Pair 14	Ca remaining 6 months	319.17	417.20	208.60	-344.68	983.03	1.53	3	0.223
Pair 15	Mg remaining 6 months	50.37	48.46	24.23	-26.74	127.47	2.08	3	0.129
Pair 16	Na remaining 6 months	3.96	10.84	5.42	-13.29	21.21	0.73	3	0.518
Pair 17	Fe remaining 6 months	3.25487	5.74451	2.872255	-5.88593	12.39567	1.133	3	0.34
Pair 18	Mn remaining 6 months	0.28236	0.210632	0.105316	-0.0528	0.61752	2.681	3	0.075

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

6.b.2. T test between MSF and LPF amount of nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) remaining during 12 and 18 months

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Weight leave remaining 12 months	-7.69	8.63	4.32	-21.42	6.05	-1.78	3	0.173
Pair 2	N remaining 12 months	837.25	232.55	116.28	467.20	1207.29	7.20	3	0.006
Pair 3	P remaining 12 months	2.11	0.98	0.49	0.55	3.68	4.31	3	0.023
Pair 4	K remaining 12 months	6.67	5.03	2.51	-1.33	14.67	2.65	3	0.077
Pair 5	Ca remaining 12 months	298.06	231.66	115.83	-70.55	666.68	2.57	3	0.082
Pair 6	Mg remaining 12 months	39.91	22.45	11.23	4.19	75.64	3.56	3	0.038
Pair 7	Na remaining 12 months	0.88	2.05	1.02	-2.38	4.14	0.86	3	0.454
Pair 8	Fe remaining 12 months	2.85	2.47	1.24	-1.08	6.79	2.31	3	0.104
Pair 9	Mn remaining 12 months	0.20	0.24	0.12	-0.17	0.58	1.72	3	0.184
Pair 10	Weight leave remaining 18 months	-6.91	11.21	5.60	-24.75	10.93	-1.23	3	0.305
Pair 11	N remaining 18 months	187.69	96.03	48.02	34.87	340.50	3.91	3	0.03
Pair 12	P remaining 18 months	1.50	1.66	0.83	-1.13	4.14	1.82	3	0.167
Pair 13	K remaining 18 months	4.21	2.48	1.24	0.27	8.16	3.40	3	0.043
Pair 14	Ca remaining 18 months	55.38	133.95	66.98	-157.77	268.54	0.83	3	0.469
Pair 15	Mg remaining 18 months	12.32	11.46	5.73	-5.92	30.55	2.15	3	0.121
Pair 16	Na remaining 18 months	2.62	3.62	1.81	-3.14	8.38	1.45	3	0.243
Pair 17	Fe remaining 18 months	0.6857	5.93297	2.96648	-8.755	10.1264	0.231	3	0.832
Pair 18	Mn remaining 18 months	0.168	0.20743	0.10372	-0.1621	0.4981	1.62	3	0.204

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

APPENDIX 7 (Statistical analysis for Biomass (above and below ground))

7.a. Above ground biomass

7.a.1. T-test between nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration in leaves in MSF and LPF

		F	Sig.	t	df	Sig. (2-tailed)*	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
N concentration	Equal variances assumed	3.732	.074	4.796	14	.000	4024.21	839.00	2224.73	5823.70
	Equal variances not assumed			4.423	8.324	.002	4024.21	909.76	1940.45	6107.98
P concentration	Equal variances assumed	.089	.770	6.141	14	.000	70.05	11.41	45.59	94.52
	Equal variances not assumed			6.018	11.922	.000	70.05	11.64	44.67	95.43
K concentration	Equal variances assumed	2.294	.152	-.053	14	.958	-59.90	1124.89	-2472.55	2352.76
	Equal variances not assumed			-.048	7.478	.963	-59.90	1241.19	-2957.24	2837.44
Ca concentration	Equal variances assumed	3.653	.077	.447	14	.662	1046.43	2341.45	-3975.49	6068.35
	Equal variances not assumed			.401	7.025	.700	1046.43	2610.44	-5121.82	7214.68
Mg concentration	Equal variances assumed	5.810	.030	1.123	14	.280	817.82	728.17	-743.95	2379.59
	Equal variances not assumed			1.034	8.256	.330	817.82	790.63	-995.59	2631.23
Na concentration	Equal variances assumed	6.925	.020	.940	14	.363	43.23	46.00	-55.44	141.90
	Equal variances not assumed			1.016	12.415	.329	43.23	42.55	-49.13	135.59
Fe concentration	Equal variances assumed	1.311	.271	-.583	14	.569	-6.85	11.73	-32.01	18.32
	Equal variances not assumed			-.623	13.178	.544	-6.85	10.99	-30.55	16.86
Mn concentration	Equal variances assumed	9.226	.009	2.622	14	.020	16.04	6.12	2.92	29.17
	Equal variances not assumed			2.349	6.980	.051	16.04	6.83	-0.12	32.20

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

7.a.2. T-test between nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration in branches in MSF and LPF

		F	Sig.	t	df	Sig. (2-tailed)*	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
N concentration	Equal variances assumed	2.502	.136	2.190	14	.046	2974.88	1358.41	61.38	5888.38
	Equal variances not assumed			1.987	7.525	.084	2974.88	1497.32	-516.24	6466.00
P concentration	Equal variances assumed	4.102	.062	1.447	14	.170	97.62	67.48	-47.10	242.35
	Equal variances not assumed			1.280	6.472	.245	97.62	76.29	-85.79	281.04
K concentration	Equal variances assumed	1.803	.201	.115	14	.910	95.46	828.82	-1682.18	1873.11
	Equal variances not assumed			.105	7.907	.919	95.46	906.22	-1998.57	2189.50
Ca concentration	Equal variances assumed	11.081	.005	-.083	14	.935	-338.79	4101.75	-9136.17	8458.60
	Equal variances not assumed			-.074	6.768	.943	-338.79	4601.72	-11296.05	10618.48
Mg concentration	Equal variances assumed	.172	.685	-1.044	14	.314	-428.92	410.83	-1310.05	452.22
	Equal variances not assumed			-1.019	11.678	.329	-428.92	420.88	-1348.74	490.91
Na concentration	Equal variances assumed	.002	.962	.246	14	.809	9.44	38.39	-72.90	91.77
	Equal variances not assumed			.245	12.922	.810	9.44	38.48	-73.75	92.62
Fe concentration	Equal variances assumed	4.043	.064	-.137	14	.893	-2.93	21.40	-48.84	42.98
	Equal variances not assumed			-.149	12.011	.884	-2.93	19.68	-45.81	39.95
Mn concentration	Equal variances assumed	.703	.416	.281	14	.783	0.47	1.68	-3.12	4.07
	Equal variances not assumed			.274	11.651	.789	0.47	1.72	-3.28	4.23

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

7.b. Below ground biomass (roots)

7.b.1. T-test between nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration in roots in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	N concentration	1729.53	2366.55	611.04	418.98	3040.08	2.830	14	.013
Pair 2	P concentration	63.00	54.07	13.96	33.06	92.95	4.513	14	.000
Pair 3	K concentration	2621.37	1853.57	478.59	1594.89	3647.84	5.477	14	.000
Pair 4	Ca concentration	1393.65	3093.11	798.64	-319.26	3106.56	1.745	14	.103
Pair 5	Mg concentration	1032.81	1029.72	265.87	462.58	1603.05	3.885	14	.002
Pair 6	Na concentration	28.55	148.95	38.46	-53.94	111.03	.742	14	.470
Pair 7	Fe concentration	1.73	131.19	33.87	-70.92	74.38	.051	14	.960
Pair 8	Mn concentration	2.17	2.30	0.59	0.90	3.45	3.652	14	.003

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

7.b.2. T-test between roots weight, amount of nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) in roots in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Roots weight	12150.67	9731.43	2512.65	6761.58	17539.75	4.836	14	.000
Pair 2	Amount of nitrogen	158.68	114.30	29.51	95.38	221.97	5.377	14	.000
Pair 3	Amount of phosphorus	2.69	2.28	0.59	1.42	3.95	4.557	14	.000
Pair 4	Amount of potassium	97.05	69.68	17.99	58.46	135.64	5.394	14	.000
Pair 5	Amount of calcium	107.86	119.11	30.76	41.90	173.83	3.507	14	.003
Pair 6	Amount of magnesium	47.30	37.25	9.62	26.67	67.92	4.918	14	.000
Pair 7	Amount of sodium	3.31	5.14	1.33	0.46	6.15	2.494	14	.026
Pair 8	Amount of iron	3.25	5.03	1.30	0.46	6.03	2.497	14	.026
Pair 9	Amount of manganese	0.07	0.08	0.02	0.03	0.12	3.575	14	.003

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

APPENDIX 8 (statistical analysis for peat soil 50 cm deep in MSF and LPF)

8.a. T test between pH, nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) concentration in MSF and LPF 50 cm deep.

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		T	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	. pH	-0.19	0.27	0.05	-0.30	-0.09	-3.790	26	.001
Pair 2	N concentration	6736.41	8095.40	1557.96	3533.98	9938.84	4.324	26	.000
Pair 3	P concentration	43.28	59.77	11.50	19.63	66.92	3.762	26	.001
Pair 4	K concentration	67.45	275.99	53.12	-41.73	176.63	1.270	26	.215
Pair 5	Ca concentration	52.16	536.32	103.22	-160.00	264.32	.505	26	.618
Pair 6	Mg concentration	40.16	264.06	50.82	-64.30	144.62	.790	26	.437
Pair 7	Na concentration	171.29	145.02	27.91	113.92	228.66	6.137	26	.000
Pair 8	Fe concentration	197.81	302.55	58.23	78.12	317.50	3.397	26	.002
Pair 9	Mn concentration	0.00	1.52	0.29	-0.60	0.60	-.003	26	.997

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

8.b. T test between amount of nutrient (N, P, K, Ca, Mg, Na, Fe, and Mn) in MSF and LPF 50 cm deep.

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Amount of nitrogen	5052.31	6071.55	1168.47	2650.48	7454.13	4.324	26	.000
Pair 2	Amount of phosphorus	32.46	44.83	8.63	14.72	50.19	3.762	26	.001
Pair 3	Amount of potassium	50.59	207.00	39.84	-31.30	132.47	1.270	26	.215
Pair 4	Amount of calcium	39.12	402.24	77.41	-120.00	198.24	.505	26	.618
Pair 5	Amount of magnesium	30.12	198.04	38.11	-48.22	108.46	.790	26	.437
Pair 6	Amount of sodium	128.47	108.77	20.93	85.44	171.49	6.137	26	.000
Pair 7	Amount of iron	148.36	226.92	43.67	58.59	238.12	3.397	26	.002
Pair 8	Amount of manganese	0.00	1.14	0.22	-0.45	0.45	-.003	26	.997

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

APPENDIX 9 (Statistical analysis for water run off)

9.a. T test between pH, nutrient (Ca, Mg, K, Na, Fe, Mn, NO_2 and PO_4) concentration in water run off MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	.pH	0.0569	0.0484	0.0090	0.0385	0.0753	6.329	28	.000
Pair 2	Calcium concentration	0.0655	0.1215	0.0226	0.0193	0.1117	2.905	28	.007
Pair 3	Mg concentration	0.0177	0.0389	0.0072	0.0029	0.0325	2.451	28	.021
Pair 4	K concentration	0.0609	0.3055	0.0567	-0.0553	0.1771	1.073	28	.293
Pair 5	Na concentration	0.0103	0.0676	0.0126	-0.0154	0.0361	.824	28	.417
Pair 6	Fe concentration	0.0007	0.0321	0.0060	-0.0115	0.0129	.122	28	.904
Pair 7	Mn concentration	-0.0004	0.0012	0.0002	-0.0009	0.0001	-1.797	28	.083
Pair 8	NO_2 concentration	0.0016	0.0027	0.0005	0.0006	0.0027	3.196	28	.003
Pair 9	PO_4 concentration	0.0124	0.0290	0.0054	0.0013	0.0234	2.297	28	.029

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)

9.a. T test between amount of nutrient (Ca, Mg, K, Na, Fe, Mn, NO_2 and PO_4) loss in MSF and LPF

		Paired Differences Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)*
					Lower	Upper			
Pair 1	Amount of calcium	0.998	1.850	0.344	0.294	1.702	2.905	28	.007
Pair 2	Amount of magnesium	0.270	0.593	0.110	0.044	0.496	2.451	28	.021
Pair 3	Amount of potassium	0.927	4.653	0.864	-0.843	2.697	1.073	28	.293
Pair 4	Amount of sodium	0.158	1.030	0.191	-0.234	0.549	0.824	28	.417
Pair 5	Amount of iron	0.011	0.489	0.091	-0.175	0.197	0.122	28	.904
Pair 6	Amount of manganese	-0.006	0.019	0.004	-0.014	0.001	-1.797	28	.083
Pair 7	Amount of nitrite	0.025	0.042	0.008	0.009	0.041	3.196	28	.003
Pair 8	Amount of phosphate	0.189	0.442	0.082	0.020	0.357	2.297	28	.029

* = If the value less than 0.5 indicated statistically different (T-test, $p<0.05$)