

Biogeochemical Investigations in Old Growth and Disturbed Forest Sites at Mount Kilimanjaro

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SUMMARY

Areas covered by mountain rainforests in East Africa have important functions as habitats for endemic species and as catchment areas for the streams in the savannah. Still, little is known about the biogeochemical processes in these often threatened ecosystems. The current study aims to present basic information on soils and different parameters of the water and nutrient cycle in intact as well as disturbed tropical mountain rainforest sites at Mt. Kilimanjaro in order to assess the long term effects of forest dissection on biogeochemical parameters.

For this purpose, the chemical and physical soil properties, soil water tension, rainfall, throughfall, litter percolate and soil solution were determined on twelve main study sites in mature forest, secondary forest and elder clearings between 2100 and 2300 m a.s.l. on the southwestern slopes of the mountain. The soil water tension was monitored from May 2000 to August 2002. The simultaneously collected water samples were combined to form fortnight samples and subsequently analysed for their content of K, Mg, Ca, Na, NO₃-N, NH₄-N, TOC, TON, TOS and TOP.

The soils, which comprised of several buried horizons, were classified as Andisols with high C and N stocks, some hydromorphic properties and comparatively low pH values. The latter led to very small ECEC values and low base saturation. Consequently, the retention of cationic nutrients in the soil was considered to be poor.

Rainfall amounts were slightly less at the higher sampling sites where the mature forest was located and differed between the two study years (2600 mm and 2480 mm at 2100 m, 2210 mm and 1960 mm at 2250 m). Rainfall interception was close to zero in the clearings, but reached up to 30% of incident rainfall in both studied forest types. The analyses of the soil water tension revealed the driest conditions to be under secondary forests. The reason for this was probably a combination of the topographic position of the secondary forest sites and the forest fragmentation. Since the secondary forest sites and the clearings had higher sand contents, the water holding capacity of these sites was lower than in the mature forest. In the clearings, the greatest throughfall amounts reached the ground surface so that soil water tensions were lower than in the adjacent secondary forest.

With the exception of NO₃-N in the forests, all nutrients in rainfall were increased upon passage through the forest canopy, but nutrient fluxes in rainfall as well as

throughfall were still low compared to other mountain rainforests, especially for Mg, Ca and K. Considering the lower biomass of the clearings compared to the forest, the amount of nutrients leached from the vegetation of the clearings was relatively high. Since $\text{NO}_3\text{-N}$ was not assimilated by the vegetation of the clearings, $\text{NO}_3\text{-N}$ throughfall fluxes were higher in the clearings as were the K fluxes, which was probably attributable to different leaf properties of the vegetation at the different sites. In the mature forest, the highest concentrations of nutrients were found in the litter percolate, followed by a pronounced decline in the soil solution. This was especially the case for K. $\text{NO}_3\text{-N}$ was an exception since it exhibited the highest concentrations only in the topsoil solution. Nutrient concentrations in litter percolate and the topsoil solution were usually higher in the clearings than in both forest types. This probably resulted in higher belowground nutrient fluxes since greater water amounts reached the ground surface in the clearings. The high belowground nutrient concentrations were likely the result of the higher mineralisation rates in the clearings induced by higher temperatures and the greater nutrient contents of the litter. With increasing soil depths, nutrient concentrations in seepage water below the clearings declined so that the differences among sites were not significant at deeper soil layers.

The contribution of organically bound nutrients to the total concentrations of respective nutrients was highest in throughfall water and lowest in the soil solution, in which OM concentrations were overall lower than in other mountain forests. This was most likely attributable to the adsorption of organically bound nutrients to the mineral phase of the Andisols studied. Again, the highest concentrations in seepage water were measured in the clearings.

The results show that mature forests at Mt. Kilimanjaro exhibit a more closed nutrient cycle, especially for basic cations, while the nutrient cycle in the clearings is more open. This probably reflects the different nutrient usage and conservation strategies of the pioneer and the late successional vegetation. Therefore, the forest disturbance on Mt. Kilimanjaro leads to long term changes in biogeochemical cycles. The opening of the forest at lower elevations, which resulted in the formation of large clearings with impeded regeneration and highly fragmented secondary forest patches, led to a higher spatial and seasonal variability of soil moisture and nutrient contents in seepage water. The large scale effects of these forest conversions on water yields and nutrient outputs need to be tested in the future.

ZUSAMMENFASSUNG

Bergregenwälder haben in Ostafrika große Bedeutung als Lebensraum für eine Vielzahl endemischer Tier- und Pflanzenarten. Bewaldete Bergregionen stellen oft wichtige Wassereinzugsgebiete für die ökonomisch bedeutenden Flüsse tieferer und trockenerer Lagen dar. Dennoch ist wenig über die biogeochemischen Prozesse in diesen durch Landnutzungsänderungen, Holzeinschlag und Feuer gefährdeten Bergwaldökosystemen bekannt. Das Ziel dieser Arbeit bestand darin, am Beispiel des Kilimanjaro Parameter des Wasser- und Nährstoffkreislaufs im naturnahen Waldbestand zu erfassen und potentielle langfristige Änderungen von Störungen aufzuzeigen.

Die Untersuchung umfasste naturnahe Waldflächen (vier 400 m²-Flächen), Sekundärwald (drei Flächen) und ältere Lichtungen (drei, später sechs Flächen) am Südwesthang des Kilimanjaro zwischen 2100 und 2300 m ü. NN. Dabei wurden die chemischen und physikalischen Bodeneigenschaften, die Bodenwasserspannung, der Freiland- und Bestandesniederschlag, das Streuperkolat und die Bodenlösung untersucht. Die Flächen wurden von Mai 2000 bis August 2002 mindestens einmal wöchentlich beprobt. Zweiwochenmischproben der gewonnenen Lösungen wurden auf ihren Gehalt an K, Mg, Ca, Na, NO₃-N, NH₄-N, TOC, TON, TOS und TOP untersucht.

Bei den Böden im Untersuchungsgebiet handelt es sich um Andisols, die zum Teil Stauwassereinfluss zeigen und mehrere fossile Horizonte enthalten. Sie sind durch einen hohen C- und N-Vorrat, stark saure pH-Werte, eine niedrige KAK und eine geringe Basensättigung gekennzeichnet. Entsprechend wird die Rückhaltekapazität der Böden für kationische Nährstoffe gering eingeschätzt.

Die Niederschlagsmengen zeigten eine hohe Differenz zwischen den beiden untersuchten Jahren und waren im höher gelegenen Teil des Untersuchungsgebiets etwas niedriger als im unteren (2100 m: 2600 mm and 2480 mm, 2250 m: 2210 mm and 1960 mm). Die Interzeption war auf den Lichtungen gering, in den Wäldern erreichte sie dagegen Werte von bis zu 30% des Freilandniederschlags. Im Boden wurden die trockensten Bedingungen in den Sekundärwäldern festgestellt. Die höhere Bodenfeuchte auf den Lichtungen lässt sich am besten über höhere Niederschlagseinträge und vermutlich geringere Transpirationsraten erklären. Für die Unterschiede zwischen den beiden Waldtypen kann die topographische Lage einiger Plots und das Auftreten von Stauhorizonten im Bereich der naturnahen

Waldflächen verantwortlich sein. Denkbar ist auch eine Beteiligung von Randeffekten am Übergang der Lichtungen zu den Wäldern, die durch die starke Fragmentierung der verbliebenen Sekundärwaldflächen in den unteren Höhenlagen eine größere Rolle spielen. Höhere Sandgehalte, wie sie durch Austrocknung in Andisols entstehen können, führen auf den Sekundärwaldflächen und den Lichtungen zu einer geringeren Wasserspeicherkapazität im Vergleich zu den naturnahen Waldstandorten.

In den Wäldern wurden mit Ausnahme des $\text{NO}_3\text{-N}$ alle untersuchten Nährstoffe im Niederschlag beim Durchgang durch das Kronendach angereichert. Im Vergleich zu anderen Bergregenwäldern waren die Nährstoffflüsse mit dem Freiland- und Bestandesniederschlag, insbesondere für Mg, Ca und K, unerwartet gering. Trotz der geringeren Biomasse auf den Lichtungen waren die Nährstoffflüsse im Bestandesniederschlag nicht geringer als in den Wäldern und lagen für $\text{NO}_3\text{-N}$ und K sogar darüber. Während sich dies für $\text{NO}_3\text{-N}$ durch die Absorption im Kronendach der Wälder erklären lässt, sind im Falle von K vermutlich Unterschiede in den Blatteigenschaften der Vegetation der Lichtungen und der Wälder verantwortlich, die eine verschiedene Auswaschbarkeit von K bedingen. In den naturnahen Wäldern wurden die höchsten Lösungskonzentrationen im Streuperkolat gefunden, während die Bodenlösungsproben deutlich geringere Nährstoffkonzentrationen aufwiesen. Dies traf besonders auf K zu. $\text{NO}_3\text{-N}$ bildete eine Ausnahme, da es erst im Oberboden die maximalen Konzentrationen aufwies. Mit Ausnahme von N wurden im Sickerwasser des naturnahen Waldes die niedrigsten Nährstoffkonzentrationen und die geringsten Jahresamplituden gemessen. Auf den Lichtungen wurden im Streuperkolat und im Sickerwasser des Oberbodens meist höhere Nährstoffkonzentrationen gemessen als in den Wäldern. Da die auf den Oberboden der Lichtungen auftreffende Wassermenge größer war als in den angrenzenden Wäldern, kann angenommen werden, dass vermutlich auch die Nährstoffflüsse insgesamt höher waren. Dafür können höhere Mineralisationsraten auf den Lichtungen verantwortlich sein, die durch höhere Temperaturen und eine nährstoffreichere Streu bedingt sind. In größerer Bodentiefe nahmen auch die Nährstoffkonzentrationen im Sickerwasser auf den Lichtungen ab, so dass keine signifikanten Unterschiede zwischen den Standorten gefunden wurden.

Der Anteil organisch gebundener Nährstoffe an Stoffverlagerungen im Boden war unerwartet gering. Für gelösten organischen N lag der Anteil im Sickerwasser unter 40% und im Bodenwasser zum Teil sogar unter 10% des gesamten N. Insgesamt lagen die Konzentrationen im Bodenwasser unter den in anderen Bergwäldern

gemessenen Werten, was vermutlich mit der hohen Sorptionskapazität der untersuchten Andisols zusammenhängt. Auch bei den organisch gebundenen Nährstoffen wurden die höchsten Konzentrationen auf den Lichtungen gemessen.

Die Ergebnisse zeigen, dass die naturnahen Wälder insbesondere für K einen geschlossenen Nährstoffkreislauf aufweisen, während dieser auf den Lichtungen eher offen ist. Die Sekundärwälder nehmen meist eine Zwischenstellung ein, ähneln aber eher den naturnahen Wäldern. Diese Unterschiede sind vermutlich auf verschiedene Strategien der Ressourcenausnutzung und der Ressourcenschonung der Pioniervegetation der Lichtungen auf der einen Seite und der Klimaxvegetation des naturnahen Waldes auf der anderen Seite zurückzuführen. Auf diese Weise wirkt sich eine Störung des Waldes nicht nur unmittelbar nach dem Eingriff aus, sondern hat auch längerfristige Folgen für biogeochemische Prozesse. Im Fall des Kilimanjaro führt die Auflichtung der Wälder in den unteren Höhenlagen zu einer höheren räumlichen und zeitlichen Variabilität des Bodenwassergehalts und der Nährstoffkonzentrationen im Sickerwasser. Großräumige Auswirkungen dieser Umwandlungen auf die Abflussmengen und die Höhe der aus dem Gebiet ausgetragenen Nährstoffmengen bedürfen einer weitergehenden Prüfung.

1 General Introduction

MOUNTAIN RAINFORESTS IN TANZANIA

During the past decade, tropical mountain rainforests have attracted increasing scientific attention due to their high degree of faunal and floristic endemism (e.g. Leo 1995), their often high biodiversity (Myers et al. 2000) and their importance as catchment areas (Bruijnzeel & Proctor 1995). In Tanzania, broad-leaved forests cover only 2% of the surface area. The majority of these forests are mountain rainforests in the Eastern Arc mountains or on isolated volcanoes like Mt. Kilimanjaro, Mt. Meru or the Ngorongoro-Crater (Bjørndalen 1992). These mountain rainforests harbour most of the 1120 endemic vascular plant species of Tanzania (Mwasaga 1991). As the forests of the Eastern Arc mountains have been comparatively stable for the last two million years, they have developed a high degree of endemism and biodiversity compared to young volcanoes like Mt. Kilimanjaro (Bjørndalen 1992, Axmacher et al. 2004).



Fig. 1.1 Tropical mountain rainforest at 2250 m, Mt. Kilimanjaro.

Besides their importance for the preservation of species, mountain rainforests are the primary water source in Tanzania, since most lowland areas are subhumid to semiarid. At Mt. Kilimanjaro, for instance, the highest rainfall amounts occur in the forest belt (Hemp 2001, Sarmett & Faraji 1991). A high density of bryophytes in these habitats increases water yields and helps to regulate the water flow as it intercepts and stores a huge amount of water, which is then slowly released (Pócs 1991, Pócs

1980). The sources of Mt. Kilimanjaro are of local and regional importance. They enable highly productive agriculture direct on the mountain slopes and also feed the Pangani River Basin, one of the economically most important river basins of Tanzania. The water from this basin is used for irrigation agriculture and generation of hydroelectricity (Bjørndalen 1991). Despite their importance as headwater areas, the forests at Mt. Kilimanjaro have been strongly altered by humans in the past.

HISTORY OF HUMAN INFLUENCES ON THE FORESTS OF MT. KILIMANJARO

The lower slopes of Mt. Kilimanjaro up to an elevation of 1700 m were constantly settled by agricultural people during the past 2000 years (Schmidt 1989). The population density remained constant for a long time and the forest at higher elevations remained more or less untouched. In 1904, parts of the forests of Mt. Kilimanjaro were appointed as forest reserve by the German colonial government. Before 1941, forestry at Mt. Kilimanjaro was only weakly developed and consequently only small numbers of trees were cut for timber production. During the Second World War, the demand for timber, mainly for sleepers for main tracks, increased dramatically, resulting in a more than hundredfold increase in harvested wood between 1941 and 1942 and the establishment of a number of sawmills within the forest (Wood 1964b). Following this large-scale felling, efforts were undertaken to improve the degraded forests. This was mainly accomplished by improving the regeneration of camphor trees by slashing weeds or poisoning old trees harmful to camphor regrowth (Wood 1964b).

Following a rapid population increase which started almost 100 years ago, the population pressure on the natural resources of the mountain had dramatically increased. This led to the establishment of a half-mile forest strip in 1941 as a managed buffer zone between the agricultural land and the forest reserve, which was meant to provide the local people with firewood and timber. Between demarcation and 1962, a total of 450 ha of trees had been planted in part of the forest reserve mainly by communal labour (Kivumbi & Newmark 1991). Following independence in 1962, the forest management was turned over to the central government, resulting in a shift from social to commercial forest. While the half-mile forest strip had been formerly used by the people at minimum cost, prices were now raised and the former privilege of collecting many forest products for free was denied. This resulted

in resentment among local people and increased the rate of illegal cutting of trees in the whole forest reserve (Kivumbi & Newmark 1991).

Between 1958 and 1987, 6.3% of the indigenous forest had been cleared by the Tanzania Forestry Department for softwood plantations of *Pinus* and *Cupressus* at the northeastern and western slopes (Lamprey et al. 1991). As a consequence, the natural forest was divided into a northern and southern section with only a small corridor left between. At present, the forest is mainly threatened by illegal logging of indigenous tree species, manmade fires, charcoal production and, to a lesser extent, by forest villages, livestock grazing, small cultivated fields in the forest belt and landslides (Lambrechts et al. 2002). A recent aerial survey revealed that the entire forest of the southern slopes below 2500 m is affected by logging activities (Lambrechts et al. 2002). The forest at the lower slopes bordering the half-mile forest strip has already been depleted of valuable timber wood, mainly *Ocotea usambarensis*, and ongoing logging has extended to higher elevations. The impact of forest fires was also evident at many sites.

Taken together, these activities led to a fragmentation of the forest, especially at its lower and hence easier accessible slopes, where a mosaic of different stages of forest regeneration is found today. There are reports of large grassy openings in the forests at the western slopes of the mountain, where no forest regeneration occurs (Wood 1964a). Personal communication with regional foresters also revealed that forest regeneration in some clearings at the southern slopes was suppressed following the invasion of bracken fern and lianas (Fig. 1.2). Similarly, pole cutting was said to inhibit forest regeneration at the Usambara Mountains, southeast of Mt. Kilimanjaro (Hamilton & Mwashia 1989). Mwasaga (1991) observed an overall decrease in tree diameters, a dominance of early successional tree species and a depletion of tree species with economic value at the southern slopes. He assumes that even if human activities stop, the species composition of the forest will probably not return to a pre-disturbance composition.

The effect of increasing isolation and forest conversion on the populations of large mammals was described by Newmark et al. (1991). Studies on the water yield from the mountain revealed a decrease in the dry season discharge of some non-spring fed rivers from the mid 1960's to the late 1970's (Sarmett & Faraji 1991). Losses in the vegetation cover following forest clearing led to increasing flood peaks in the rainy season and decreasing dry season runoff in the Usambara Mountains as well (Bruen 1989). Although changes at Mt. Kilimanjaro were mainly attributed to an increasing

diversion of water from rivers, effects induced by land use changes and forest degradation seem very likely to have contributed. Newmark (1991) summarised that past and ongoing human activities proved to have adverse effects on water, forest and wildlife resources at Mt. Kilimanjaro. The need for an interdisciplinary inventory of the forest belt and the analysis of effects caused by human disturbances in order to preserve the various functions of the forest was stressed by Bjørndalen (1991). Therefore, a research project of the Department of Biogeography and the Department of Soil Science and Soil Geography of the University of Bayreuth together with the Botany Department of the University of Dar es Salaam was initiated in 1999 in order to fill at least part of the knowledge gap associated with forest regeneration at Mt. Kilimanjaro.



Fig. 1.2 Around its lower border, the forest is highly fragmented and at some clearings regeneration seems to be impeded as can be seen on this picture.

THE KNOWLEDGE GAPS

The vegetation of Mt. Kilimanjaro has been comparatively well studied (e.g. Axmacher 2003, Greenway 1974, Hemp 2001, 2002, Hemp & Beck 2001, Hemp et al. 1999, Mwasaga 1991, Pócs 1991, Richter 1980). According to Axmacher 2003, much is known about birds, reptiles and larger mammals in East Africa, but information on diverse insect groups is scarce. As knowledge about the latter species rich groups is important to assess overall biodiversity of this region, much more work is necessary. In order to increase the knowledge about the diversity of moths, Axmacher et al. (2004) analysed the moth community of a forest succession at Mt. Kilimanjaro.

While the soils of Mt. Kenya are well documented (Desaules 1987, Frei 1978, Speck 1983, 1986), data on soil properties of Mt. Kilimanjaro are very scarce. The runoff regime of a region is dependant on the infiltration capacity and the water storage capacity of soils. Therefore, deterioration of physical soil parameters following forest clearance can have negative effects on the water yields (Bruijnzeel 1996). Furthermore, a degradation of chemical soil properties induced by rapid mineralisation of soil humus accompanied by high leaching losses might also occur following logging activities and forest fires. This has adverse effects on the nutrient availability of the sites and thus might affect the regeneration of natural vegetation. Consequently, detailed knowledge on soil properties and their susceptibility to deterioration following deforestation is important. From other studies on soils which developed on volcanic ash material, it has been shown that such soils exhibit specific features including a high accumulation of organic material, low bulk densities, high contents of amorphous clay constituents, high P fixation and a high water retention capacity (Wada 1985). At Mt. Kilimanjaro, Mizota et al. (1988) and Iseki et al. (1981) studied the clay mineralogy of cultivated soils. The effect of the conversion of natural forest in *Cupressus* plantations on soil properties was studied by Maro et al. (1991). They found an acidification and a decrease in C and N contents in topsoils under *Cupressus* plantations as compared to natural forest. But up to now, no information on the soils within the natural forest belt of the southern, wetter slopes is available.

Similarly, there is an overall lack in long-term climatic observations within the forest. General information considering the effects of seasonality, orientation and altitude on rainfall were given in Coutts (1969). Below the forest belt, rainfall amounts and mean temperatures were regularly measured at several stations around the mountain (Sarmett & Faraji 1991). The altitude receiving the greatest amounts of rainfall on the southern slopes is still a matter of controversy. In one of the latest studies presented in Hemp (2001) for the southern slopes of the mountain, the author measured greatest rainfall amounts of about 3000 mm at 2100 m. Richter (1980) conducted some analysis on the daily variation in microclimate at different altitudes along the Marangu tourist route.

The effects of forest clearance on water fluxes in downstream areas are contradictory as some studies reported constant or increased water yields in streams following disturbance (Edwards 1979, Sahin & Hall 1996), while others observed a decrease in dry season runoff (Bruen 1989). This was mainly attributed to differences in the clearing method and soil properties. Usually the removal of the vegetation leads to an increase in rainfall amounts reaching the ground because interception by the

vegetation is reduced. Tropical mountain rain forests which are frequently covered in clouds form a special case, since interception of cloud water by the vegetation can contribute significantly to total throughfall amounts (Cavelier et al. 1996). Thus, with the removal of the forest vegetation, throughfall additions by cloud combing are lost, resulting in reduced rainfall amounts reaching the ground at places where the contribution of horizontal precipitation has formerly been high (Bruijnzeel 1989). Most studies have concentrated on the effects of large scale forest clearings on water yields, but the results of Kapos (1989) indicate that the fragmentation of a forest will also affect the soil water regime, especially at the forest edges. Less is known about the effects of afforestation on water budgets. Bruijnzeel (1996) supposed that the high water demand of a vigorously growing secondary vegetation could lead to drier soil conditions compared to the undisturbed forest. These results suggest that changes in the hydrological cycle are likely to occur following the conversion of a closed natural cloud forest into a mosaic of different regeneration states. But so far, this has not been confirmed at Mt. Kilimanjaro.

The nutrient cycle is closely linked to the hydrological cycle (Bruijnzeel 1989). In order to be able to detect and predict changes in water and nutrient cycling following disturbance, general knowledge about processes occurring within intact forests is essential. Studies on internal nutrient cycling and nutrient fluxes have been mainly restricted to tropical mountain rainforests in the Neotropics (e.g. Hafkenscheid 2000, McDowell 1998, Veneklaas 1990, Wilcke et al. 2001) and Asia (e.g. Bruijnzeel et al. 1993, Liu et al. 2002). In West Africa, some studies have been performed on lowland rainforests (Croizat 1979, Roose & Lelong 1981), but information on mountain rainforests in the Palaeotropic is scarce. At the Usambara-Mountains in Tanzania, Lundgren (1978) studied soils, biomass and litterfall of natural forests as well as plantation forests and later on, aboveground water fluxes (Lundgren & Lundgren 1979). Mountain rainforests on isolated volcanoes in East Africa are usually surrounded by subhumid or semiarid savannah plains with a high wind erosion potential during dry seasons (Prospero 1999). Thus, nutrient inputs via wet and dry deposition and overall nutrient fluxes might differ from mountain rain forest of more humid regions in the tropics.

The direct effects of forest clearing and burning on the composition of soil solution and on soil properties have often been investigated in tropical lowland rainforests (Alegre et al. 1988, Eden et al. 1991, Garcia-Oliva et al. 1999, Giardina et al. 2000, Klinge 1997, Uhl & Jordan 1984). Studies including analyses of soil solution usually reported a return to predisturbance levels within a few months to a few years.

Nevertheless, changes in the nutrient stocks during forest regeneration indicate that the nutrient cycle at the regenerating sites probably still differs from the mature forest (Chandrashekara & Ramakrishnan 1994, Robertson 1984). McDonald & Healey (2000) concluded that a 20 year old secondary forest in Jamaica had already re-established soil nutrient stocks comparable to undisturbed forest and a tight nutrient cycle. The time needed for this development is likely to be dependant on the type and degree of disturbance, edaphic and climatic factors as well as the type of regenerating vegetation. Due to the worldwide destruction of tropical rainforests, the area covered in secondary vegetation continues to increase. This development calls for analyses of differences in nutrient retention strategies between primary and secondary vegetation.

The importance of dissolved organic C and N, and, to a lesser extent, also S and P for the nutrient cycle of temperate forests has received increasing attention during recent years (Kalbitz et al. 2000, Michalzik et al. 2001, Neff et al. 2003, Perakis & Hedin 2002). Little is known about their relevance in tropical forests since dissolved organic nutrients were not included in most studies. One of the few exceptions is the work of Möller (2001), who analysed changes in the concentrations of DOC and DON in water during its passage through tropical mountain rainforest vegetation in Thailand and in seepage water in the soil. Similarly, Wilcke et al. (2001) studied TOC concentrations in a mountain rainforest in Ecuador and Klinge (1997) analysed DON concentrations in an Amazonian lowland rainforests. Their results indicate that the proportion of DON to total N concentration in the soil solution and in streams is lower in the tropical sites compared to temperate forests. To date, no information is available on DOS and DOP cycling in tropical mountain forests.

GENERAL OBJECTIVES

The overall aim of this study is the characterisation of water and nutrient dynamics at different successional stages of the forest covering the southwestern slopes of Mt. Kilimanjaro, in order to assess the long term effects of forest dissection on biogeochemical parameters. The following objectives are addressed:

1. Soil types, genesis and fertility of soils in the study area. Eight soil profiles along an altitudinal transect from 1800 to 3150 m were described and chemically characterised. Additionally eleven soil profiles were analysed under clearings, secondary forest and mature forest between 2100 and 2300 m.

2. Differences in aboveground water fluxes, soil water tension and water storage capacities between clearings, secondary forest and mature forest.

Four plots of mature forest, three secondary forest plots and three clearings between 2100 and 2300 m were included in this analysis. Rainfall and throughfall amounts were determined using collectors inside the stand and in the open. Soil water suction was reported at four soil depths using tensiometers. Soil water characteristics were analysed in the laboratory using undisturbed volume samples from soil profiles next to each plot. Precipitation and soil water tension were monitored for over two years.

3. Internal nutrient dynamics of the mature forest at Mt. Kilimanjaro in relation to other tropical mountain rainforests.

Besides rainfall and throughfall, litter percolate was also collected at the mature forest sites around 2250 m using zero-tension lysimeters. Soil solution was extracted from three soil depths by applying ceramic suction cups. Samples were taken over a period of two years and analysed for their contents of K, Mg, Ca, Na, NO₃-N and NH₄-N.

4. Comparison of the nutrient cycle at sites at different regeneration stages.

Rainfall, throughfall, litter percolate and soil solution were regularly collected at clearings, secondary forest and mature forest sites over a period of two years. In the water samples, K, Mg, Ca, Na, NO₃-N and NH₄-N contents were determined.

5. Relevance of DOM in the nutrient cycle of the mountain forest and effects of disturbance and subsequent changes in the vegetation cover on DOM dynamics.

Besides inorganic nutrients, organically bound C, N, S and P were analysed in the water samples from all sites. To measure the direct effects of disturbance on OM release in the soil solution, three out of six clearings were cut and burnt during the study period.

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2 Genesis and Nutrient Status of Forest Soils on the SW-Slopes of Mt. Kilimanjaro

INTRODUCTION

The formation of the East African Rift Valley was accompanied by volcanic activity, creating large volcanoes such as Mt. Kilimanjaro and Mt. Meru in Tanzania and Mt. Kenya and Mt. Elgon in Kenya. The soils of these mountains, developed from volcanic ashes, exhibit special characteristics compared with other soils formed under similar climatic conditions. These characteristics include high contents of organic matter, low bulk densities, high contents of amorphous clay constituents with variable charge, high P fixation and a high water retention capacity (Wada 1985).

A chronosequence of soils derived from volcanic ash was studied in Mexico by Miehlich (1991). He observed increases in organic matter, total porosity, clay content, dithionite-soluble Al and Fe, oxalate-soluble Al and Si and cation exchange capacity with soil age, which were usually most pronounced under humid conditions. In order to study the effect of climate on soil properties, altitudinal gradients have often been used. Grieve et al. (1990) found lower clay contents, a decline in the ratio of free to total Fe in the soil, and higher C contents with increasing altitude in Costa Rican volcanic soils. Similar results were obtained in Rwanda by Nizeyimana (1997), who observed increases in C content, cation exchange capacity, P fixation, water holding capacity and a decrease in bulk density with increasing elevation and rainfall quantities. These trends were generally ascribed to a decrease in organic matter and amorphous constituents as a consequence of higher decomposition rates and advanced stages of weathering at lower elevations. Another study in East Africa (Mizota et al. 1988) analysed the effect of the rainfall regime on the chemistry and mineralogy of volcanic soils on three Tanzanian volcanoes. The authors found an increase in C and N, but a decrease in pH and exchangeable basic cations with increasing annual rainfall. A perudic moisture regime led to the formation of allophane, gibbsite and Al-humus complexes, while under udic to ustic moisture regimes kaolinite and halloysite dominated. Similar results on clay mineralogy were also obtained in Rwanda by Nizeyimana et al. (1997).

In comparison with other East African mountains, the soils along the slopes of Mt. Kenya have been intensively studied and mapped (Desaules 1987, Frei 1978, Speck

1983, 1986). Most pedological investigations of other East African mountains focussed mainly on the nutrient status of cultivated soils and on the effects of land use changes (Glaser et al. 2001, Lundgren 1980, Muchena & Gachene 1990, Muchena & Kiome 1995, Solomon 2001, Temple 1972, Vlek 1995). For example Muchena & Gachene (1990) and Liniger (1988) summarised the properties of soils in the mountain regions of Kenya, but concentrated on agricultural soils. Soils under the natural forests usually received little attention. This also holds true for Mt. Kilimanjaro, where studies were restricted to the lower cultivated slopes. For instance Mizota et al. (1988) and Iseki et al. (1981) studied the clay mineralogy of cultivated soils on Mt. Kilimanjaro. Maro et al. (1991), working on lower-elevation soils, found acidification and a decrease in C and N contents in topsoils under *Cypressus* plantations as compared with natural forest remnants at the western slopes. No information exists to date on the forest soils at higher elevations.

The aim of the present study is the characterisation of soils in the actual forest belt on the south-western slopes of Mt. Kilimanjaro, with respect to their genesis and nutrient parameters. Particular attention is given to changes induced by climatic variations in the altitudinal range and consequent changes in vegetation composition.

MATERIALS AND METHODS

STUDY AREA

The isolated volcanic complex of Mt. Kilimanjaro is situated in Tanzania, 300 km south of the equator (between 2° 45' and 3° 25' S and 37° 00' and 37° 43' E), and rises from about 700 m on the dry savannah plains to 5892 m. The study transect is located on the south-western slopes of Mt. Kilimanjaro between the deeply incised rivers Kikafu and Weru-Weru, following the Machame Tourist Trail along a ridge from the lower boundary of the forest reserve at 1800 m to the ericaceous woodland above 3100 m.

The Kilimanjaro region has a bimodal rainfall distribution with intensive precipitation from March to June and in November and December. Overall, the southwestern slopes of the mountain receive the highest amounts of rainfall (Coutts 1969). The annual amounts reach a maximum within the forest belt, but the altitude of this maximum is still open to discussion due to a lack of reliable long-term data and regional differences (Axmacher 2003, Hemp 2001). Recent measurements by

Hemp (2001) on the central southern slopes showed a rainfall maximum of about 3000 mm at 2100 m, which decreased to 90, 70 and 50 % at 2400, 2700 and 3000 m, respectively. Similarly, Sarmett & Faraji (1991) expected maximum rainfalls at about 2000 m.

From the viewpoint of plant sociology, the forest belt on the southern slopes can be divided into the following: an *Agauria-Ocotea* forest (1800-2000 m), an *Ocotea-Podocarpus* forest (2100-2300 m), a *Podocarpus-Ocotea* forest (2400-2700 m) and an *Erica excelsa* or *Hagenia-Rapanea* forest which gradually changes to shrublands at elevations above 3000 m (Hemp 2002). On the lower slopes of the study area, *Agauria salicifolia*, *Myrica salicifolia* and especially *Macaranga kilimanjarica* dominate the canopy layer. These are replaced by *Ocotea usambarensis* from around 2100 m up to altitudes above 2700 m, with an increasing share of *Podocarpus latifolius*. The latter becomes dominant at higher altitudes, where it is accompanied by *Hagenia abyssinica*, *Rapanea melanophloeos*, *Erica excelsa* and *Prunus africana*. At mid elevations the tree fern *Cyathea manniana* occurs frequently, indicating high humidity, as do the Hymenophyllaceae, which are mainly distributed at altitudes between 1900 and 2400 m (Hemp 2001). At around 2700 m, *Erica excelsa* becomes very numerous creating forests rich in mosses and lichens up to an elevation of 3100 m (Hemp et al. 1999). A complete species list of vascular plants on the studied transect was provided by Axmacher (2003).

Geologically, the bedrock along the transect is mainly formed by phonolites and trachytes of the Lent group, which change to the small-rhomb porphyry group at higher elevations (Downie & Wilkinson 1972).

SOIL TRANSECT

For the transect study, eight sites at 1850, 2090, 2265, 2530, 2700, 2900, 3100 and 3150 m were selected, under forest vegetation. In the following, these sites will be referred to as P 1850, P 2090, P 2265, P 2530, P 2700, P 2900, P 3100 and P 3150. The exact location of the plots is presented in Figure 2.1; for the coordinates see Appendix B. The inclination at the study sites varied from 0 to 20°. At each plot of 400 m², the composition of the vegetation was determined (Axmacher 2003). Then a soil pit was dug by hand in the central part of each plot until bedrock or little-weathered ash layers were reached, or to a maximum depth of 2.3 m. Horizon designation and soil classification were made in accordance with US Soil Taxonomy (Soil Survey Staff 2003), and Munsell colours were given for moist soil. Samples for

laboratory analysis were taken by horizon from three sides of the pit walls. Bulk density was determined on three undisturbed soil cores with a volume of 100 cm³, which were taken from each soil horizon. The litter layer was collected separately for Oi, Oe and Oa horizons. Mixed samples from 3 randomly chosen points at each plot were prepared. Data on pyrophosphate extractable Al from twelve additional soil profiles was also included. These profiles, which were located between 2000 and 2330 m, were in the main study area of the forest regeneration study. These should assist in forming theories about the significance of metal-humus complexes in the soils at Mt. Kilimanjaro.

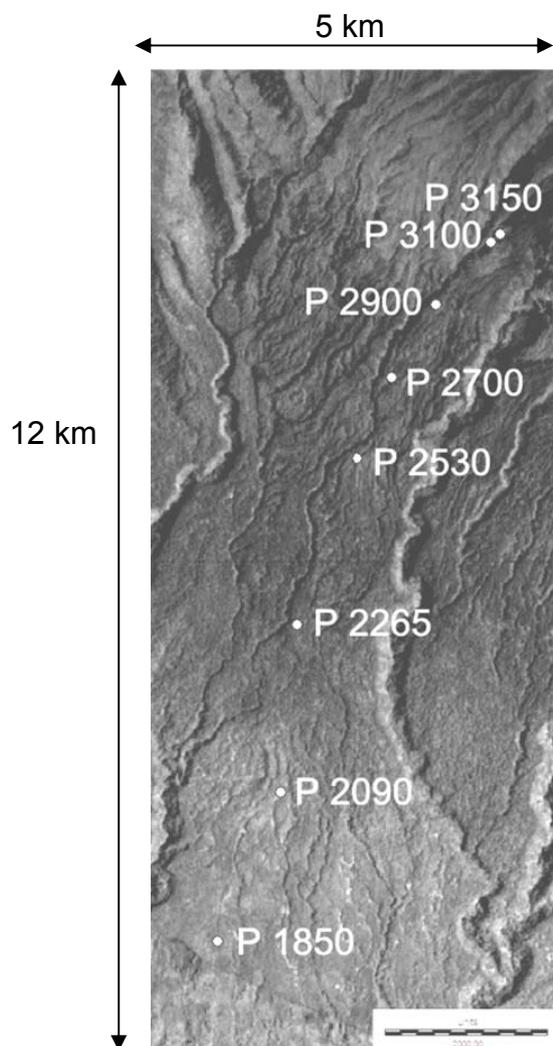


Fig. 2.1 Location of the plots along the transect. Section 303500-308500 and 9648000-9660000, Landsat 7TM+, Channel 8 (multispectral), 21.2.2000, 15 m x 15 m resolution.

CHEMICAL ANALYSES

Analyses of the mineral soil material were carried out on air dried samples (30°C) of the fraction < 2 mm. Soil pH was determined using H₂O and 1 M KCl at a soil : solution ratio of 1 (m) : 2.5 (v) and a standard combined electrode with integrated temperature probe (WTW SenTix 41 pH 330). Total carbon (C_t) and nitrogen (N_t) contents were analysed on ball-milled samples using a total element analyser (Elementar Vario EL). Exchangeable cations (K, Ca, Mg, Na, Al) were extracted by an unbuffered 0.5 M NH₄Cl solution (Trüby & Aldinger 1989) and measured by atomic absorption (Varian SpectrAA 400). The ECEC was calculated as the sum of exchangeable base cations and exchangeable Al. At ten profiles in the main study area between 2100 and 2330 m, Fe and Al in metal-humus complexes (Fe_p, Al_p) were extracted by shaking 2 g of soil in 0.1 M sodium pyrophosphate (pH 10) for 16 h, followed by centrifugation, after addition of CaCl₂. Fe, Al and Si in ferrihydrite, allophane, imogolite and metal humus complexes (Fe_o, Al_o, Si_o) were determined in all soils using a 0.2 M oxalate solution (pH 3) (Schwertmann 1964). The cold dithionite-citrate buffer (DCB) method (Holmgren 1967) was used to analyse the amounts of Fe and Al (Fe_d, Al_d) in crystalline oxides and fractions from metal-humus complexes and amorphous constituents. P retention was determined for all horizons in the soil profiles at 2090 and 2265 m following Burt (1996). In order to determine total element contents in the litter layer, dried samples were ground and digested with concentrated HNO₃ under pressure (Heinrichs et al. 1986).

Element stocks were calculated by multiplying concentration with values for bulk density per horizon and refer to kg per ha and 1 m soil depth or to a shallower lithic or paralithic contact.

STATISTICAL ANALYSES

Correlation analyses were performed as Pearson Product-Moment Correlations using the statistical work package STATISTICA 5.0 (Statsoft, Inc., Tulsa, UK). Mantel Tests were used to compare vegetation composition and nutrient concentrations in the litter layer. Present-absent data of vascular plant composition at the plots as given in Axmacher (2003) were used to create distance matrices, applying the Sørensen-index as a distance measure. Distance matrices for nutrient parameters were based on the Euclidean distance. For calculation of the p-level, randomisation Monte-Carlo-Tests with 3000 repetitions were used. These analyses were conducted using the program PC-ORD 4.0 (MjM Software, Oregon).

RESULTS AND DISCUSSION

MORPHOLOGICAL CHARACTERISTICS

Figure 2.2 gives information about soil types and selected soil properties along the catena (Complete descriptions of individual soil profiles are presented in Appendix B). All soils can be classified as Andisols showing andic soil properties within 0.6 m of the soil surface (Soil Survey Staff 2003). A typical feature was the occurrence of buried horizons. The lowest profile at 1850 m exhibited the least pronounced profile differentiation between the topsoil and 2 m soil depth, below which a fossil A horizon was observed. Fossil A horizons were best developed between 2265 and 2530 m, where they were composed of thick, black, humus-rich layers. Their colour resembled the dark colour of the actual humus layer of the highest profile at 3150 m under the recently (1997) burned *Erica* vegetation. A maximum of four buried A horizons were found in the profile at 2265 m and three were identified at 2530 m. The profile at 2700 m still contained two buried soils, while the profiles at 2900 m and above only showed one less expressed fossil soil. The $\delta^{14}\text{C}$ analysis of charcoal and humic acids gave an age spectrum between 6254 ± 61 and 9387 ± 96 a BP for the upper and lower boundaries of the 2A horizon in profile 2900 m, around 10386 ± 96 a BP for the 2A horizon at 2700 m, 16298 ± 111 a BP for the upper boundary of the 2A horizon at 2265 m and from 9533 ± 89 to 15756 ± 132 a BP for the upper and lower boundaries of the 2A horizon at 2090 m. These results indicate that the actual surface soils of the catena have an approximate age of less than 16000 a, and at higher elevations probably even less than 10000 a BP. The topsoil of the profile at 1850 m was divided in two sections by a thin B horizon. The resulting buried A horizon close to the soil surface appeared to be much younger than in the other profiles and might have been a local phenomenon caused by human activities, as the profile was close to the main path of the Machame Tourist Route.

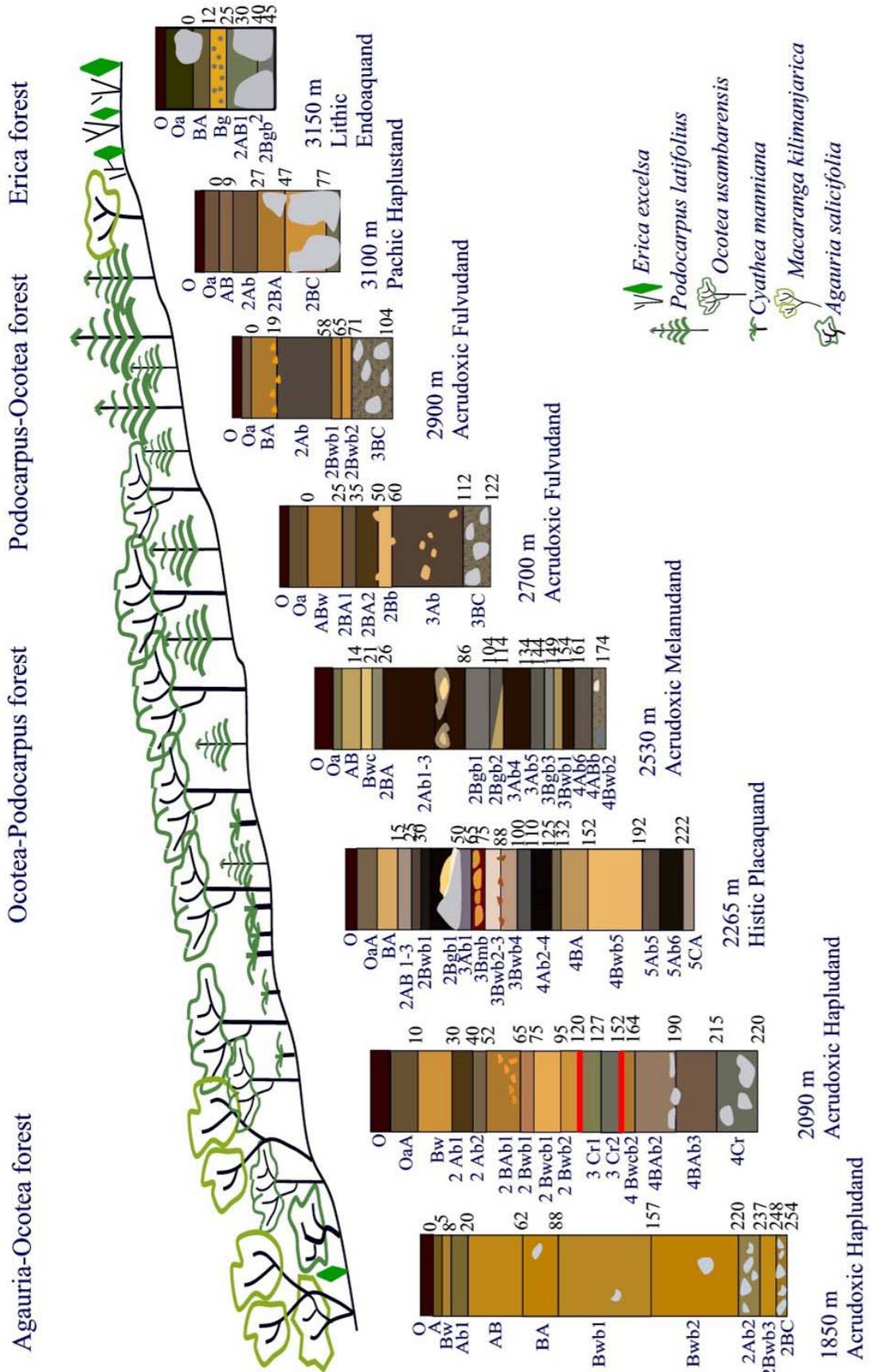


Fig. 2.2 Schematic view on the soil profiles along the transect.

Hydromorphic features became most obvious in soils around 2300 m, where placic horizons were frequently found and where the water table in the rainy season rose to a soil depth of less than 1 m. In the soils between approximately 2100 m and 2530 m, the water table also rose, but was not observed closer than one meter below the soil surface in these profiles. A typical feature of the soils around 2300 m, apart from the placic horizons, was indurated horizons, with thicknesses ranging from a few up to 200 mm. They occurred between 0.8 and 1.4 m below the mineral soil surface, acting as an effective barrier for roots and retaining percolating water, which was observed to leak from the crust in the soil profiles during rainy periods. Bleached soil colours above these hardened horizons indicated the removal of Fe and Mn with seepage water as a consequence of frequent reducing conditions. Therefore, the soil at 2265 m was classified as Placaquand. In the soil profile at 2090 m, redox phenomena and placic horizons were encountered below 0.5 m and thus did not comply with the requirements of an Aquand. Hydromorphic features (pale colors or concretions) were less evident at higher elevations. This might be due to reduced precipitation or to better drainage. The possibility that the dark colour of fossil A horizons covered redoximorphic features at P 2530 and P 2700 cannot be excluded. At the highest soil profile at 3150 m, drainage was impeded by bedrock resulting in the formation of a peaty gley soil, the development of which was further supported by low litter decomposition under grass and *Erica* vegetation.

The accumulation of soil organic material at the soil surface reached the requirements of histic epipedons only at P 2265 and P 3150. As these profiles also showed most evidence for aquic soil conditions, this might be a partial explanation for the low activity of decomposers at these altitudes.

SOIL CHEMICAL CHARACTERISTICS AND SOIL GENESIS

The ratio between pyrophosphate extractable Al (Al_p) and acid oxalate extractable Al (Al_o) is normally used in order to distinguish between allophanic and nonallophanic Andisols, (Shoji et al. 1993). But interpretation of the pyrophosphate extract is problematic: firstly, Al in pyrophosphate extracts might not only be attributable to Al in humus complexes and secondly, pyrophosphate acts as a dispersing agent for clays and oxides (Kaiser & Zech 1996). Thus, it is possible that Al_p values are overestimated due to additionally suspended soil particles in the extract. Because of these uncertainties, pyrophosphate extractable Al was only measured in the main study site of the regeneration study between 2075 and 2330 m. As the values decreased with increasing soil depth and showed a good correlation with total C

contents of the respective horizons (Fig. 2.3), the results were considered to be appropriate. With the exception of some humus rich surface layers, most horizons showed Al_p/Al_o ratios of less than 0.4 (Fig. 2.3), indicating that, according to Shoji et al. (1993), the soils were mainly allophanic (including the fossil horizons). Due to high organic carbon contents of all horizons, the soils were further classified as humus-rich allophanic Andisols. For soils above 2300 m, the Si_o content was used in order to differentiate between sil-andic and alu-andic soils (Shoji et al. 1996). All soils along the transect had at least some horizons at higher soil depths which had Si_o contents above 6 g kg^{-1} (Table 2.1, Appendix C). Thus, they belonged to the sil-andic group, which contains at least some quantities of allophane.

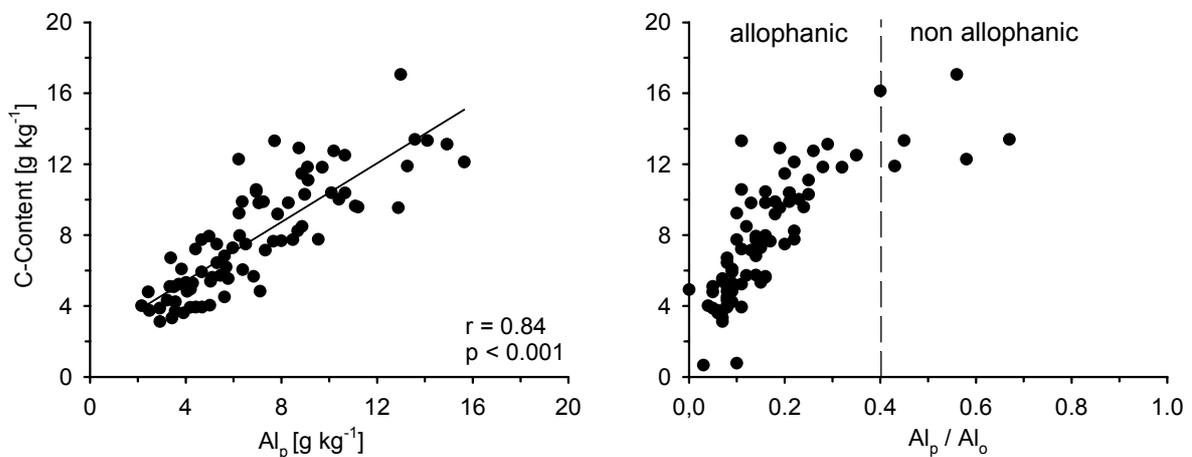


Fig. 2.3 Relation between C content and a) pyrophosphate extractable Al (Al_p) and b) the ratio between Al_p and Al_o (acid oxalate extractable Al).

Several approaches based on the Si_o content and the Al_o/Si_o ratio have been proposed in order to evaluate the amount of allophane in soils (Parfitt 1990, Parfitt & Henmi 1982, Shoji et al. 1993). In areas with high rainfall, leaching leads to low Si concentrations in the soil solution. Under these conditions, Al-rich allophanes with a high Al/Si ratio are preferentially formed as compared with halloysite (Parfitt & Wilson 1985). The latter might be synthesised when the soil drainage is poor. For soils in New Zealand, Parfitt (1990) reported Al/Si ratios of 0.4 to 4.0. As some Si and Al might be incorporated in ferrihydrite minerals, calculation of the allophane content from Si_o values is problematic in ferrihydrite-rich soils (Parfitt & Childs 1988). Profile 2265 showed Al/Si ratios between 2 and 3, indicating the presence of Al-rich allophane (Table. 2.1, Appendix C). Based on the equation proposed by Parfitt et al. (1988), the allophane content ranged from 15 to 26%. The high Al/Si ratio of the 2AB horizon indicates that the allophane content of 44% was most probably overestimated and should be excluded from interpretation. The highest

allophane contents were observed in fossil A horizons in the subsoils despite their high C contents. This can be explained by the burial status of these horizons. In humus rich topsoil allophane is not usually present in high amounts because Al released by weathering binds preferentially to the organic material and is not available for allophane formation. Once the horizon is buried no new organic material is added by the vegetation, and if the existing binding sites for Al in the humus are occupied the surplus Al can react with the dissolved Si to form allophane (Shoji et al. 1993).

Low Fe_o and Fe_d contents above the 3 Bm horizon in P 2265 indicate frequent reducing conditions due to water saturation in the soil matrix above this indurated horizon, leading to depletion of iron. The mobilised iron was partly oxidised and fixed in iron bands which could be observed in the 3 Bm layer, and partly leached downslope. It appeared in the field that as well as Fe another cementing agent, probably Si, led to the formation of the thick crusts (20 - > 200 mm) observed in subsoil horizons throughout this altitude. Jongmans et al. (2000) suggested that allophane and imogolite might be responsible for the formation of cemented horizons under similar climatic conditions and a similar ground water table in volcanic ash soils in Costa Rica. However this could not be proven with the soil data available for Mt. Killimanjaro.

Pyrophosphate extractable Al was only determined for the main study area of the regeneration study between 2100 and 2300 m. The soils in the transect also contained considerable amounts of ferrihydrite, which falsifies the results. Consequently Al/Si ratio and allophane content were not estimated for these soils. Because highest overall Si_o contents occurred in P 2350 m, it is probable that the highest amounts of allophane also occurred at this altitude, although individual horizons with high Si_o contents also occurred at higher elevations. No consistent trend with increasing elevation could be observed for concentrations of Si_o , Fe_o , Al_o , Fe_d or Al_d (Table 2.1).

Table 2.1 C contents, pH and Al_o, Al_d, Fe_o, Fe_d and Si_o contents of representative pedons. Allophane was calculated following the equation in Mizota & Reeuwijk (1989) and ferrihydrite after Parfitt et al. (1988).

	Depth	C	pH	Al _o	Al _d	Fe _o	Fe _d	Si _o	Al _o -Al _p /Si _o	Alloph	Ferrih.	P _{ret}
	[cm]	[g kg ⁻¹]	(H ₂ O)	[g kg ⁻¹]						[%]	[%]	[%]
1850 m												
A	- 5	128	5.1	32	46	25	78	5			4.2	
Bw	- 8	80	5.2	27	27	14	83	7			2.4	
Ab1	- 20	102	5.3	35	48	45	96	5			7.7	
AB	- 62	101	5.4	45	51	22	68	12			3.7	
BA	- 88	72	5.2	51	39	22	65	15			3.7	
Bwb1	- 157	49	5.2	66	40	28	71	15			4.7	
Bwb2	- 220	46	5.0	35	53	31	96	9			5.3	
2Ab2	- 237	65	4.9	54	56	27	97	15			4.7	
2Bwb3	- 248	39	5.1	61	48	19	92	18			3.2	
2BC	- 254+	45	5.1	71	38	19	91	20			3.2	
2265 m												
BA	- 15	98	4.4	33	38	46	86	3	n.d.	n.d.	7.8	95.9
2BA	- 25	97	4.3	48	35	26	51	10	4.1	44	4.5	99.3
2AB1	- 30	113	4.3	61	20	11	19	18	2.9	21	2.0	99.3
2AB2	- 45	116	4.4	71	21	4	10	22	2.9	25	0.8	99.3
2AB3	- 50	73	4.5	74	10	4	7	29	2.4	26	0.6	99.3
2Bwb1	- 50	57	4.8	65	5	4	6	25	2.4	22	0.6	99.3
2Bgb1	- 55	38	4.7	57	7	1	2	22	2.3	19	0.2	99.3
3AB4	- 65	71	4.5	68	14	4	8	26	2.4	23	0.7	99.5
3Ab1	- 65	62	4.5	62	13	4	9	21	2.5	20	0.7	99.5
3Bmb	- 75	62	4.6	54	32	33	127	20	2.6	19	5.6	99.6
3Bwb2	- 78	62	4.4	55	21	18	38	21	2.4	19	3.0	99.4
3Bwb3	- 88	38	4.4	43	21	18	41	13	2.9	15	3.0	99.5
3Bwb4	- 100	60	4.4	59	32	30	74	20	2.8	21	5.1	99.5
4Ab1	- 110	98	4.5	62	23	14	32	20	2.7	21	2.4	99.6
4Ab3	- 125	130	4.5	54	18	6	9	15	2.7	15	1.0	99.6
4Ab4	- 132	70	4.7	56	20	4	5	18	2.3	15	0.7	99.6
4BA	- 152	64	4.7	52	8	5	9	20	n.d.	n.d.	0.9	99.3
4Bwb5	- 192	26	4.7	51	1	6	6	21	n.d.	n.d.	1.0	98.9
5Ab5	- 222+	61	4.8	63	8	2	4	23	n.d.	n.d.	0.4	99.5
2700 m												
ABw	- 25	130	4.7	34	51	49	87	3			8.3	
2BA1	- 35	160	4.6	37	46	35	67	2			6.0	
2BA2	- 50	154	4.5	41	54	32	64	3			5.5	
2Bb	- 60	76	4.9	48	47	17	50	10			2.9	
3Ab	- 112	123	4.9	54	33	26	44	11			4.4	
3BC	- 125+	40	5.1	60	17	10	22	11			1.7	
3100 m												
AB	- 9	108	5.1	40	34	18	39	11			3.1	
2Ab	- 27	149	4.9	20	21	23	45	2			3.8	
2BA	- 47	123	5.1	34	27	22	43	6			3.8	
2BC	- 77+	65	5.2	62	21	11	24	20			1.9	

n.d. : no determined

According to Shoji et al. (1993) allophanic Andisols usually exhibit pH-values above 5.0 (H₂O). Nevertheless, in this study they were often slightly lower. This might be due to high rainfall amounts and subsequent high leaching of basic cations resulting in a low base saturation and high contents of exchangeable Al (see Table 2.2). Similarly, the observed high content of organic material might have been responsible for low pH values. Interestingly, C was strongly negatively correlated with pH (KCl) values of the topsoil as well as with individual soil horizons of the soil profiles (Fig. 2.4). No correlation between pH values and base saturation was obtained. However, the correlation between pH (H₂O) and exchangeable Al was closer ($r = -0.84$, $p < 0.01$) and that between exchangeable Al and pH (KCl) was very strong ($r = -0.97$, $p < 0.001$), indicating that the hydration of Al which was replaced by K at the exchange sites contributed to the lower pH values.

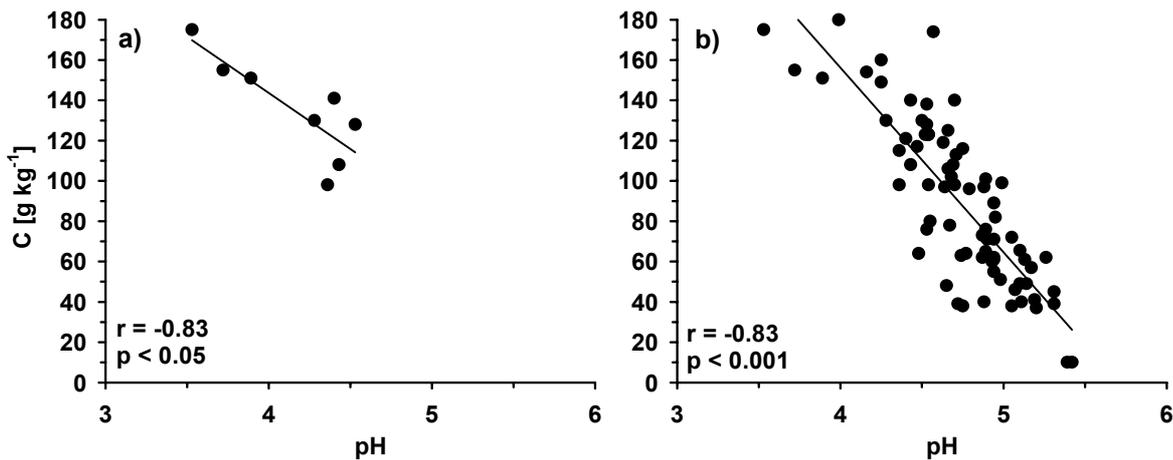


Fig. 2.4 Correlation between C content and pH (KCl) in a) topsoil horizons, and b) all horizons.

The difference between pH (KCl) and pH (H₂O) (Δ pH) indicates the presence of variable positive charge in the soils (Uehara & Gillman 1981). Along the Kilimanjaro transect the majority of positive Δ pH values were measured at low elevations between 1850 and 2265 m (Fig. 2.5). While Δ pH values increased with increasing soil depth at P 1850 and P 2090, highest values were already obtained within 1 m soil depth in P 2265. To a certain degree these trends with increasing soil depths are reflected by the Si₀ contents, which rose with increasing soil depth at P 1850 and were generally highest in P 2265 (Table 2.1). Nevertheless, no significant correlation was obtained between Δ pH and Si₀ contents. At higher elevations, Δ pH values were lower. The soil at 2530 m showed comparatively low Δ pH values due to very high C

contents in the fossil horizons. The rapid decrease in ΔpH values at deeper soil layers of P 2900 was possibly caused by less weathered ash material in the C horizon. These results suggest a maximum of positive charges in the soils at elevations between 2000 and 2300 m. Oxides and hydroxides as well as amorphous silicates are probably responsible for this result.

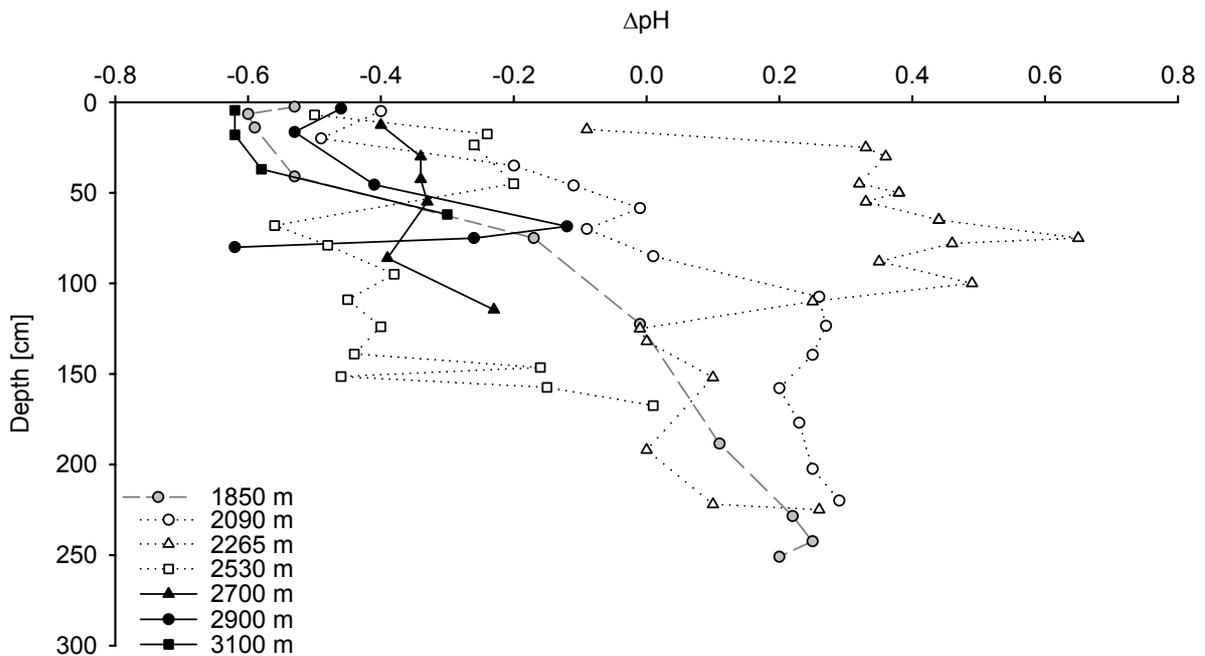


Fig. 2.5 ΔpH values (pH (KCl) - pH (H₂O)) at different altitudes.

Mizota et al. (1988) analysed a soil profile in Machame located directly below the studied transect at 1570 m. They classified the soil as Humic Nitisol, indicating a more advanced stage of weathering. With values between 89 and 39 g kg⁻¹, C contents were slightly lower and pH values higher (5.0 - 6.3, H₂O) than in the forest belt. The oxalate extractable Si_o content (61 - 67 g kg⁻¹ SiO₂) was also higher, presumably due to reduced leaching of Si and Al as a result of lower precipitation and pH values which were more favourable for the formation of allophane and allophane-like soil constituents. Vermiculite-chlorite intergrades, gibbsite and quartz were identified in the clay fraction in addition to amorphous constituents.

NUTRIENT STOCKS

Soil organic matter serves as an absorbent for nutrients, stabilises the soil structure and enhances the water holding capacity. It therefore is an important parameter for soil fertility. Andisols usually contain high amounts of organic carbon (OC) in the mineral soil (Wada 1985). Several reasons for the stabilisation of humus in volcanic soils have already been discussed. These include the formation of Al- and Fe-humus complexes, the sorption to allophane, imogolite and ferrihydrite, reduced microbial activity due to P deficiencies, and the sorption of enzymes to allophane and imogolite (Shoji et al. 1996, Wada 1989). The SOC (soil organic carbon) contents along the study transect were very high with values between 98 and 170 g kg⁻¹ in the A horizons. In the subsoil, OC contents were usually above 40 g kg⁻¹. In P 3100 and P 3140, the OC contents did not decrease below 60 g kg⁻¹ throughout the profiles. For Andisols developed on 9500 year old ashes under a udic moisture regime in Mexico, Miehlich (1991) reported mean OC contents of 60 g kg⁻¹. In A horizons of Humic Andosols on Mt. Kenya, an OC accumulation of 38 to 61 g kg⁻¹ was reported, which decreased to 9 - 28 g kg⁻¹ in B horizons (Speck 1986). At Volcan Barva in Costa Rica and on a volcano in Rwanda, an increase in the C content of the soils was reported with increasing elevation (Grieve et al. 1990, Nizeyimana 1997). This trend was attributed to decreasing rates of decomposition with increasing elevation. Additionally, higher biomass production due to higher amounts of rainfall at 2700 m was responsible for high C accumulations in Rwanda. At Mt. Kilimanjaro, no altitudinal trend in carbon contents was observed in the topsoil (Fig. 2.7). Overall values exhibited a high fluctuation probably due to small-scale differences in the incorporation of organic material in the mineral soil by bioturbation. High activity levels of wild pigs were observed between 1800 and 2400 m. These animals mixed the soil in areas of several square meters and to a depth of around 0.3 m. The contribution of ants to bioturbation of the surface soil was apparently mainly limited to the area around their mounds and probably changed with altitude. The spatial heterogeneity in C contents of the topsoil caused by differences in bioturbation indicates that it might be more informative to assess SOC stocks rather than C concentration in individual soil horizons for comparison of C accumulation at different sites.

Figure 2.6 shows total carbon stocks (up to 1 m soil depth), the proportion of the organic layers, and the organic layers combined with the upper 0.2 m of the soil, which usually represented the mineral soil material above the first buried A horizon. Maximum C stocks in organic layers were observed at mid elevations of 2265 and

2530 m and declined above that altitude. A second maximum occurred at P 3150 in a peaty soil developed on impermeable bedrock. A similar pattern with maximum humus contents at mid elevations was observed by Hetsch (1976) in the Venezuelan Andes. He suggested that this was caused by different temperature dependencies of biomass production and decomposition rates. While the microbial activity is already reduced at mid elevations, biomass production is not, thus leading to a high accumulation of organic materials. At higher elevations biomass production is also impeded, resulting in lower C accumulations. In the study transect, all soils - with the exception of the highest profile - were under natural forest vegetation. Maximum tree heights of 38 m were observed at 2530 m, declining with increasing elevation especially above 2700 m (Axmacher 2003). Above this altitude, the coverage of the tree layer was also reduced, indicating that a decline in biomass production might be responsible for lower nutrient stocks. In Costa Rica, Heaney & Proctor (1989) found a decrease in the annual amount of litter fall with increasing elevation together with a continuous increase in the litter layer from 100 to 2700 m. In this case, the effect of the reduced activity of decomposers at higher altitudes - probably caused by lower temperatures, higher humidity or changes in the litter quality - was apparently still stronger than the decline in annual litter fall.

With 88-188 t ha⁻¹, C-stocks in the O layers of Mt. Kilimanjaro accounted for 15% (1800 m) to 53% (3150 m) of the total C stocks calculated to a soil depth of 0.1 m. If only the upper 0.2 m of the mineral soil above the first fossil horizons were considered, the proportion rose to 29-84%. Yet with the exception of the highest profile, 48 to 71% of the total stocks were found in the huge, C-rich buried horizons, leading to total stocks of 286 t ha⁻¹ (3150 m) to 945 t ha⁻¹ (2530 m). Although a high accumulation of organic matter is characteristic of montane rainforests as well as of volcanic ash soils (Hetsch 1976, Shoji et al. 1993, Tanner et al. 1998), the total C stocks in the soils of Mt. Kilimanjaro were still remarkably high. For montane rainforests in Venezuela, Grimm & Fassbender (1981) found on average 38 t ha⁻¹ OC in organic horizons and 621 t ha⁻¹ for the whole soil up to 1.2 m. In Jamaica, C stocks of 30-250 t ha⁻¹ were reported (Tanner 1977) and young soils developed on volcanic ash in Hawaii (4000 a) accumulated 66 t ha⁻¹ in organic layers, but only 117 t ha⁻¹ in the whole soil (Vitousek et al. 1983). Unfortunately most studies on soils developed on volcanic ash deal with C contents of the soil horizons, but stocks have not been calculated.

The N_t and S_t stocks along the catena at Mt. Kilimanjaro displayed a similar pattern with increasing altitude to that found for OC. The proportion of N_t bound in organic surface horizons (14-65%) was slightly higher than that of OC. The percentage of S_t in the litter layer was considerably lower (7-47%), whereas a greater percentage was found in the buried mineral horizons (55-85%, with 19% at 3150 m).

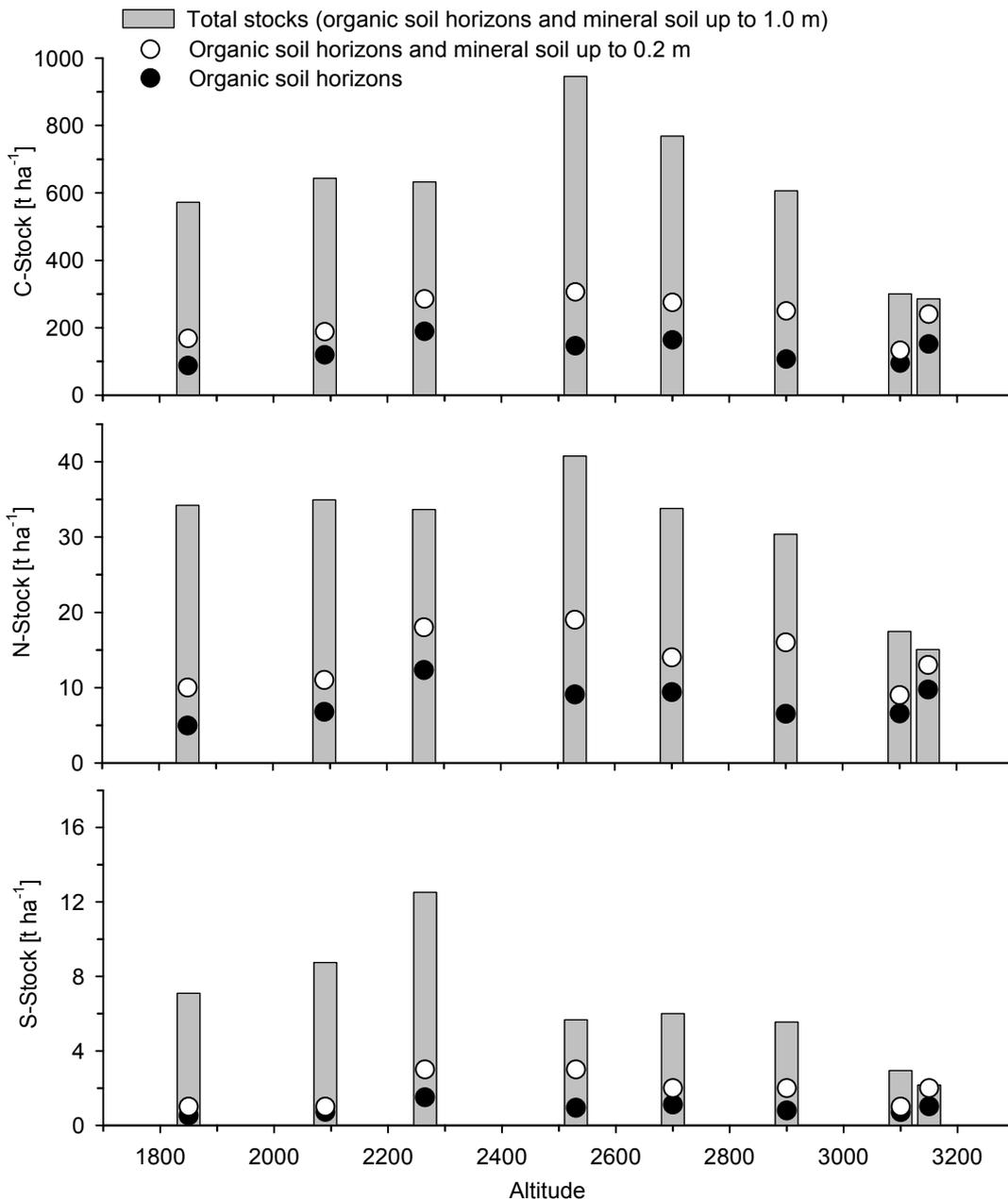


Fig. 2.6 Organic carbon, total nitrogen and total sulfur stocks in the soil profiles along the catena at the southwestern slopes of Mt. Kilimanjaro between 1850 and 3100 m a.s.l.

According to Wada (1985), high C/N ratios are also characteristic of Andisols. With values between 28 and 39, the C/N ratios of the litter layer were very wide in Mt. Kilimanjaro forest soils, indicating a low decomposability of the biomass (Yamakura & Sahunalu 1990). In the mineral soil, the C/N ratio was often highest in the topsoil where values ranged between 15 and 25. The highest C/N ratios above 30 in the subsoil were observed at 2530 m and might be attributable to a high content of black carbon in the very dark humic buried horizons. The profiles at 1850 showed the lowest C/N ratio.

CEC AND BASE SATURATION

The CEC of Andisols is mainly controlled by allophanic clays and humus and is thus pH dependent. It is often measured in 1M CH₃COO-NH₄ at pH 7, but, particularly in acidic Andisols, these values considerably overestimate the exchange capacity and provide little information about the actual capacity of the soils to retain ions. That is why in this study the CEC was measured at soil pH (1M KCl). Because the soils were acidic, the ECEC, defined as the sum of exchangeable base cations and Al, was very low (Table 2.2). Highest values were obtained for Oa and humus rich epipedons, and the ECEC usually decreased with increasing soil depth. Subsoil horizons overall exhibited low ECEC values, but exchange capacities were usually slightly higher in the humusrich buried A horizons than in the horizons above and below, indicating dependency of the CEC on soil organic matter.

The sum of exchangeable base cations plus Al has to be lower than 2 cmol_c kg⁻¹ fine earth to fulfil the requirements for acrodoxic properties in the Keys to Soil Taxonomy (Soil Survey Staff 2003). These are characteristic for highly leached and weathered Andisols. This condition was encountered at almost all the buried horizons at lower elevations and also in at least some horizons at higher elevations. With the exception of the deepest, probably less intensively weathered horizons in the profiles, the base saturation was below 50%, which further proves that the soils were highly leached. Most exchangeable nutrients were concentrated in the Oa layer and mineral topsoil horizons, while the subsoil exhibited only a low nutrient retention capacity. The higher number of exchange sites in fossil A horizons were mainly occupied by Al as indicated by the low base saturation of these horizons. In many soils, exchangeable Mg was present almost exclusively in the Oa and in the mineral surface horizons. The same was true for Ca, while some traces of K also occurred in the subsoil.

Table 2.2 Exchangeable cations and ECEC of selected soil profiles (BS is expressed as the percentage of exchangeable basic cations of ECEC). For other profiles, see Appendix C.

	Depth	K	Ca	Mg	Na	Al	ECEC	BS
	[cm]	[cmol _c kg ⁻¹ fine earth]						[%]
1850 m								
A	- 5	0.30	0.03	0.09	0.16	2.05	2.47	21
Bw	- 8	0.18	0.03	0.04	0.06	1.34	1.58	18
Ab1	- 20	0.21	0.02	0.08	0.09	1.17	1.48	24
AB	- 62	0.10	0.01	0.02	0.08	0.59	0.72	25
BA	- 88	0.06	0.00	0.01	0.06	0.24	0.31	32
Bwb1	- 157	0.02	0.01	0.02	0.06	0.13	0.19	43
Bwb2	- 220	0.04	0.02	0.03	0.05	0.21	0.30	37
2Ab2	- 237	0.14	0.02	0.04	0.05	0.11	0.31	67
2Bwb3	- 248	0.07	0.02	0.04	0.07	0.09	0.21	66
2BC	- 254	0.11	0.12	0.25	0.04	0.00	0.49	99
2265 m								
Oa2	+ 15	0.32	0.12	0.60	0.68	5.82	7.53	17
BA	- 15	0.14	0.11	0.03	0.09	1.98	2.34	14
2BA	- 25	0.14	0.09	0.01	0.09	0.83	1.16	28
2AB1	- 30	0.10	0.07	0.01	0.09	0.63	0.90	30
2AB2	- 45	0.07	0.06	0.01	0.05	0.71	0.90	22
2AB3	- 50	0.10	0.07	0.02	0.06	0.45	0.70	36
2Bwb1	- 50	0.10	0.06	0.01	0.05	0.27	0.50	44
2Bgb1	- 55	0.14	0.08	0.01	0.06	0.51	0.80	36
3AB4	- 65	0.16	0.05	0.02	0.05	0.42	0.70	40
3Ab1	- 65	0.24	0.06	0.02	0.06	0.52	0.89	41
3Bmb	- 75	0.09	0.02	0.00	0.04	0.15	0.30	50
3Bwb2	- 78	0.10	0.08	0.01	0.03	0.58	0.80	27
3Bwb3	- 88	0.17	0.04	0.01	0.04	0.83	1.08	23
3Bwb4	- 100	0.12	0.04	0.01	0.08	0.35	0.59	42
4Ab1	- 110	0.09	0.04	0.01	0.04	1.03	1.22	13
4Ab3	- 125	0.10	0.03	0.01	0.07	2.43	2.64	7
4Ab4	- 132	0.10	0.03	0.02	0.07	0.93	1.16	19
4BA	- 152	0.11	0.03	0.03	0.07	0.74	0.99	25
4Bwb5	- 192						0.00	
5Ab5	- 222+	0.10	0.03	0.02	0.06	0.49	0.69	29
2700								
Oa2	+ 15	0.53	0.12	0.69	1.73	10.18	13.26	17
ABw	- 25	0.08	0.07	0.02	0.09	3.24	3.51	7
2BA1	- 35	0.11	0.05	0.02	0.07	3.06	3.30	7
2BA2	- 50	0.08	0.04	0.02	0.08	4.35	4.57	5
2Bb	- 60	0.12	0.06	0.04	0.63	1.28	2.13	36
3Ab	- 112	0.06	0.06	0.01	0.06	0.54	0.73	21
3BC	- 125 +	0.03	0.04	0.01	0.03	0.05	0.17	56
3100								
Oa	+ 13	0.63	0.16	0.27	1.08	7.06	9.20	21
AB	- 9	0.22	0.14	0.14	0.22	1.98	2.70	25
2Ab	- 27	0.20	0.12	0.19	0.28	3.42	4.21	18
2BA	- 47	0.17	0.12	0.11	0.22	1.38	1.99	29
2BC	- 77	0.08	0.09	0.04	0.10	0.16	0.47	65

In most other studies on volcanic ash soils, the CEC was measured in 1 M $\text{CH}_3\text{COO-NH}_4$ at pH 7, and consequently only the sum of exchangeable basic cations could be compared with the values determined at Mt. Kilimanjaro. In some Humic Andosols developed on volcanic ash material at Mt. Kenya (Speck 1983), the sum of exchangeable bases was higher than at Mt. Kilimanjaro. The same was true for soils along an altitudinal transect in Costa Rica (Grieve et al. 1990). Soils developed on volcanic ash in Rwanda also showed higher amounts of exchangeable Al measured in 1 M KCl (Nizeyimana 1997). Some volcanic soils in the Philippines were found to have similarly low ECEC values in the subsoil, but these soils contained considerably less organic matter (Poudel & West 1999).

Neither ECEC nor base saturation in the topsoil showed a consistent trend with increasing elevation. However, ECEC was positively correlated with the C content in the topsoil. When entire profiles were considered, the relationship between ECEC and C contents resembled a saturation curve (Fig. 2.8). A good relationship between CEC (pH 7) and organic carbon content has often been reported for Andisols (Poudel & West 1999, Shoji et al. 1993).

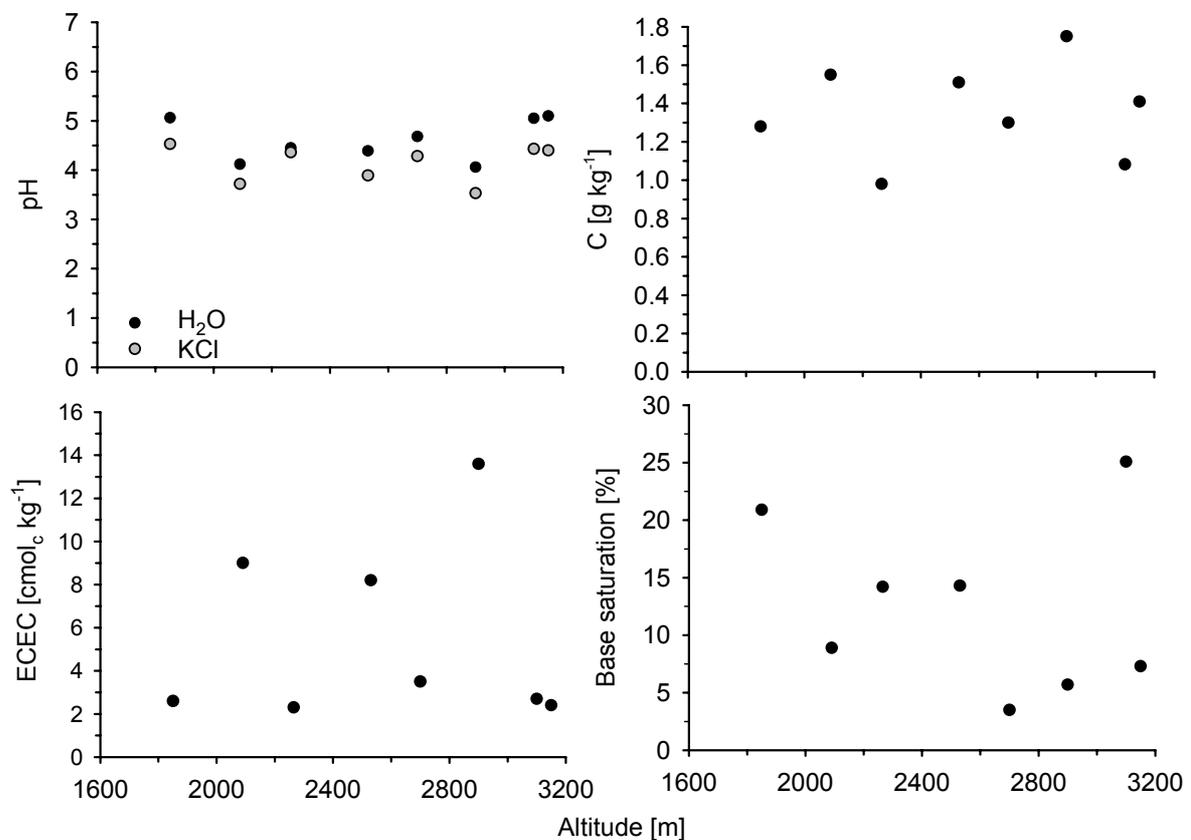


Fig. 2.7 Changes in topsoil pH, C, ECEC and base saturation with increasing elevation.

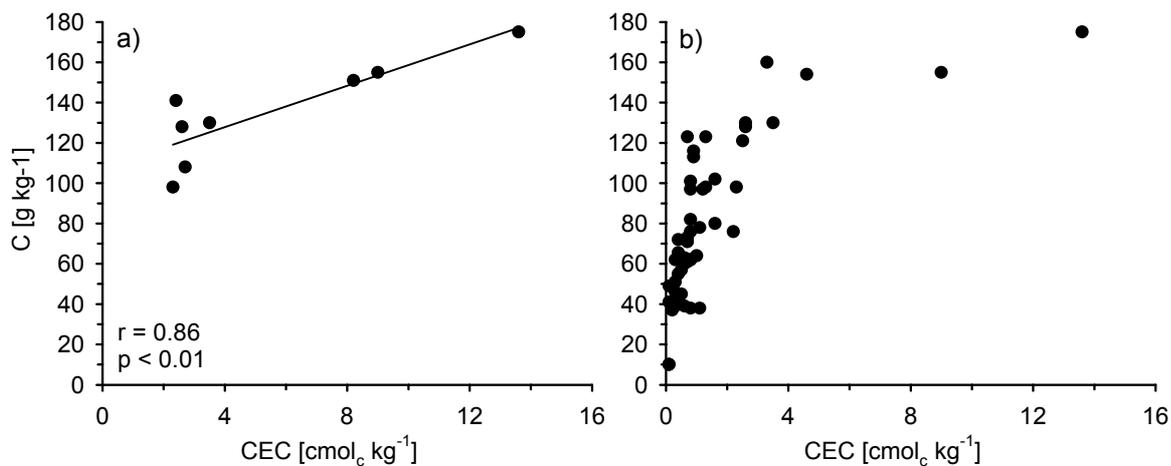


Fig. 2.8 Relationship between C contents and CEC in a) surface horizons, b) all horizons of P 1850, P 2090, P 2165, P 2700 and P 2900.

ELEMENTAL COMPOSITION OF THE LITTER LAYER

The nutrient content of the litter layer depends partly on the composition of the vegetation producing the litter. As well as species-specific variations in the litter composition, the nutritional status of the plants is also said to control the quantity of nutrients in litterfall, as plants may regulate nutrient losses with litterfall by internal reallocation. Although the litter layer on the forest floor differs from freshly fallen leaves in that some nutrients are already leached in the course of decomposition, the composition of the litter layer will still reflect some vegetational characteristics. Along the transect, a decrease in nitrogen contents (Fig. 2.9) and an associated increase in the C/N ratio ($r = 0.86$, $p < 0.01$) with elevation was observed. P 3100 was excluded from this analysis as the sample became contaminated following an invasion of rats in the Tanzanian drying cupboard and could not be included in this study. The N contents in the litter layer were correlated with the S contents, but the latter did not show a significant correlation with increasing elevation. With values between 12-17 g kg⁻¹, N contents of the litter layer were in the same range as at Volcan Barva in Costa Rica (7-15 g kg⁻¹, Heaney & Proctor 1989), where a decrease in the N content of litterfall with increasing elevation was also observed. A similar trend was observed in Malaysia (Proctor et al. 1983). The decreasing N concentrations in leaf litter were attributed to a decrease in N availability with increasing elevation, caused by a decline in nitrogen mineralisation (Marrs et al. 1988). Bruijnzeel et al. (1993) argued that low N contents in litterfall might also be

associated with scleromorphous leaves. However, no correlation between the percentage of scleromorphous leaves in the canopy layer, as shown by Axmacher (2003), and the N content in the litter layer was found along the transect at Mt. Kilimanjaro.

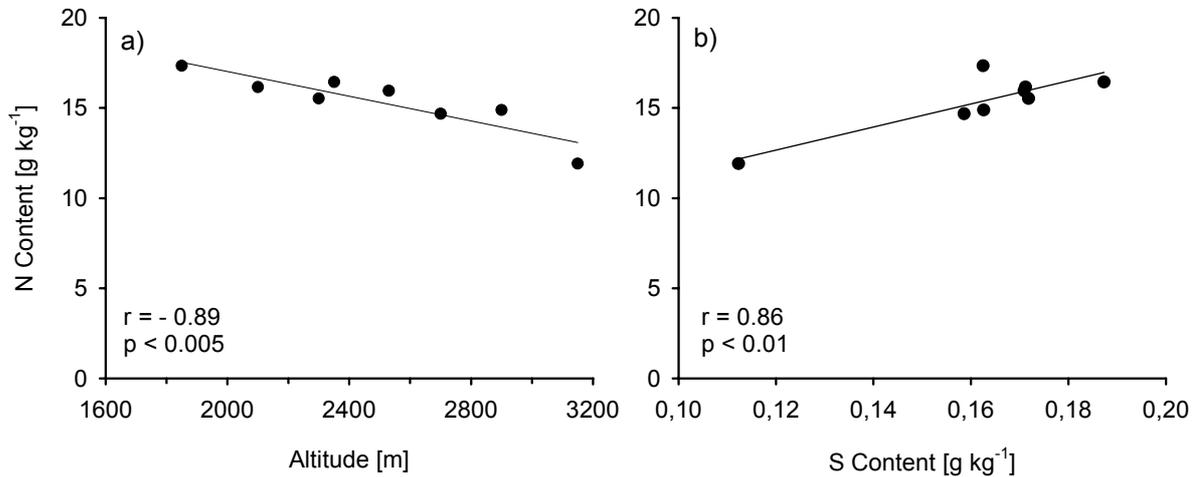


Fig. 2.9 Correlation between the N contents in the ground litter layer and a) altitude, and b) the S contents.

For P, no consistent trend with altitude was observed in the literature summarised by Bruijnzeel & Proctor (1995). The same was true for the transect at Mt. Kilimanjaro (Fig. 2.10). Compared with the P contents of litterfall at various mountain rain forest sites worldwide, P contents in the litter layer at Mt. Kilimanjaro were at the upper end. Values between 0.09-0.31 g kg⁻¹ in the litter layer at Volcan Barva, Costa Rica (Heaney & Proctor 1989) were less than half as high as at Mt. Kilimanjaro (0.81-1.29 g kg⁻¹).

No trend with increasing altitude was observed for litter K, Mg and Ca. The Ca contents were highest between 2265 and 2900 m, where they remained more or less constant. Comparison with nutrient contents in the litter layer at Costa Rica (Heaney & Proctor 1989) reveals that K, Ca, Mg and Na contents were on average higher at Mt. Kilimanjaro. Lundgren (1978) studied the litter layer under a forest dominated by *Ocotea usambrensis* on an acidic soil at 1800 m in the Usambara Mountains, Tanzania. There he found lower P and K, but higher N, Ca and Mg contents (K 1.2, Ca 16.5, Mg 2.5, P 0.7, N 22.6 g kg⁻¹) than in the corresponding components of the forests under study at Mt. Kilimanjaro.

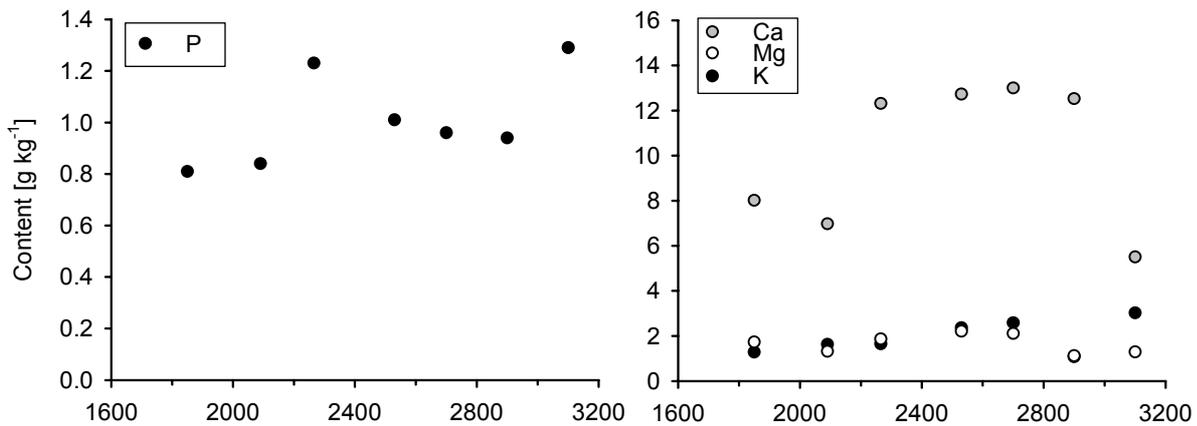


Fig. 2.10 Changes in the nutrient content of litter layer (Oi) with elevation.

CORRELATION BETWEEN NUTRIENT CONCENTRATIONS IN THE LITTER LAYER AND THE COMPOSITION OF THE VEGETATION

Mantel tests provide a useful tool for comparison between plant species composition and environmental factors. They test whether two distance matrixes based on different variables recorded at the same plots, e.g. vegetation composition in the first and nutrient characteristics in the second matrix, are correlated. A positive correlation indicates a similar shift in vegetation and environmental characteristics, although this does not imply a causal dependency as both factors might have been similarly affected by a third parameter. Tests between plant species composition and soil nutrient parameters such as pH, CEC, base saturation or exchangeable Al in the topsoil did not result in significant correlations. Plants in mountain rainforests often develop thick root mats in the humus layer of the soil, indicating that, in some cases at least, plants rely on nutrients directly released from decomposing organic material. The composition and biodegradability of organic material depends on the amount and composition of litterfall and root litter. These in turn might depend on both species composition and the nutritional status of the forest, as plants are said to reallocate higher amounts of nutrients if these are in short supply, resulting in reduced nutrient concentrations of the litterfall.

Table 2.3 Comparisons between nutrient concentrations in the Oi layer of the forest floor and the vegetation composition in different layers using Mantel-Tests between 1850 and 3150 m.

	Total Vegetation Composition	Canopy Layer	Epiphytes	Shrub Layer	Herb Layer
Altitude	0.65 ***	0.58 ***	0.47 *	0.61 ***	0.65 ***
Organic Bound Nutrients					
N	0.79 # **	0.57 # *	0.65 *	0.64 # **	0.66 # **
C/N	0.80 # ***	0.60 # *	0.73 # *	0.73 # ***	0.69 # ***
S	0.72 (*)	0.51 (*)	0.75 *	0.61 (*)	0.53 *
P	0.80 ⁺ **	n.s.	0.46 # *	n.s.	0.34 (*)
All	0.77 **	0.59 *	0.73 *	0.73 ***	0.69 ***
Main Nutrient Cations					
K	0.36 (*)	n.s.	0.39 *	0.43 *	0.39 (*)
Mg	n.s.	n.s.	n.s.	n.s.	n.s.
Ca	0.56 # **	n.s.	0.44 *	0.39 *	0.57 # **
All	0.56 ***	n.s.	0.57 **	0.39 (*)	0.57 **

**** < 0.001, *** < 0.005, ** < 0.01, * < 0.05, (*) < 0.1, n.s.: not significant

significant after sequential Bonferroni correction

⁺ without P 2290

The correlation between vegetation composition and the content of nutrients in the litter layer was significant for N, Ca and the C/N ratio (Table 2.3). S, P and K also exhibited slight correlations, but these were not significant after sequential Bonferroni correction. As individual vegetation layers in the forest might have a different impact on the nutrient composition of the litter, for example depending on differing contributions to total litterfall masses, correlations of nutrient contents in the litter were afterwards tested separately for each vegetation layer. The results consistently showed the best correlation between vegetation composition and C/N ratios as well as with N contents. For the canopy layer, the correlation was weaker as compared with the total vegetation composition. Closer and more significant

correlations were obtained for the herb and the shrub layer than in the canopy layer. Ca was also significantly correlated with the herb layer even after sequential Bonferroni correction. The composition of the epiphyte community showed relations to N, S and P, but correlations were only significant for the C/N ratio and P. Mg contents never correlated significantly with the vegetation. Correlations with K were consistently stronger, but not significant after Bonferroni correction. The same was true for S.

Vegetation composition was consistently most strongly correlated with N contents as well as with the C/N ratios in the litter layer. N contents and C/N ratios were also strongly correlated with altitude. The same was true for the vegetation composition, but correlation of the total vegetation composition with altitude was weaker than with N and C/N ratios in the litter layer. The rate of mineralisation of N depends on soil moisture and temperature, but it is more affected by the temperature regime (Sierra 1997). This indicates a decrease in N mineralisation rates with increasing elevation, which was also observed by Marrs et al. (1988) in Costa Rica. Because both, decomposition rates and N stocks decline at higher altitudes, a decrease in plant N availability with increasing elevation is expected. van der Krift & Berendse (2001) tested the effects of different plant species on soil nitrogen mineralisation and found that the plant species adapted to nutrient- poor environments reduce soil nitrogen mineralisation, while those adapted to nutrient- rich environments lead to higher N mineralisation rates in the soil. The authors ascribed this effect to differences in the litter quality and in the amounts of litter production. High litter C/N ratios were reported as a result of low fertility soils and further induce low decomposition rates (Yamakura & Sahunalu 1990). For the Mt. Kilimanjaro transect, the results indicate that the decrease in the N content of the litter with increasing elevation might be the result of an overall decrease in the N availability due to reduced decomposition rates induced in turn by lower temperatures. This leads to a vegetation composition more adapted to reduced N supplies and hence produces litter of lower decomposability with higher C/N ratios. This would explain the strong correlation between vegetation composition and decreasing N contents in the litter layer. Silver (1994) did not find a relationship between total N in the soil and the inverse of litterfall N concentrations, referred to as nutrient use efficiency, for a variety of tropical forest soils. His results indicate that a correlation between N availability and N content in the litter cannot always be expected.

The most significant results were generally obtained from the correlation between nutrient contents in the litter layer and the shrub or the herb layer, whereas the correlation with the tree canopy layer was weaker. This is surprising because the canopy layer is supposed to contribute most to the total amounts of litterfall, and should thus most strongly determine the litter composition. But with only 18 species in the canopy layer along the whole transect altitudinal changes were expressed more in terms of changes in the abundance of individual species than in a shift of species composition. Because presence-absence data was used for Mantel tests, changes in the abundance of individual tree species were not considered. But for the composition of the litter layer, abundance is also important, assuming that litter of individual species differs in chemical composition. So a stable species composition with changing dominant species along the study transect would only result in a weak correlation between species composition in the canopy layer. Altitude is probably responsible for the weak correlations between species composition of the canopy layer and the nutrient content of the litter.

On the other hand, the composition of the herb layer might not only have been affected by altitude and associated changes in climate, but also by the abundance of the different tree species. These influence competition for light and nutrients and might create a different substratum for the germination and growth of herbal plants. Hence the strong correlation with the herb layer is not necessarily a direct effect of the nutrient content in the herb litter. The shift in the composition of the species-rich herb layer and shrub layer could also simply have reflected changes in the forest better than did the presence-absence data of the species-poor canopy layer. Correlations with the species composition of the epiphyte layer are also unlikely to be a direct effect of epiphytic litter fall on the nutrient composition of the litter layer. But changes in the composition of the epiphytic community are first of all influenced by changes in microclimate such as temperature and especially humidity along the altitudinal gradient. Apart from the microclimate, the stature of the inhabited tree species influences colonisation with respect to light regime and suitable places for fixation. The good correlation between the C/N ratio and changes in the epiphyte species composition is more likely to be the result of changes in humidity than a temperature effect, which would have resulted in a stronger correlation of epiphytic species with altitude as the temperature declines linearly with elevation.

CONCLUSIONS

The soils of the forest belt on the south western slopes of Mt. Kilimanjaro all exhibit typical characteristics of Andisols, with high amounts of amorphous constituents such as allophane and ferrihydrite and a high accumulation of SOM. As the soils are already in an advanced stage of weathering and leaching, the availability of nutrient cations is low as induced by a low ECEC and a low base saturation. Stabilisation of organic matter by amorphous materials as well as unfavourable conditions for decomposition such as low temperatures, high humidity and high C/N ratios of the litter indicate low mineralisation rates of the organic material. This results in an overall low nutrient availability and possibly in a close nutrient cycle in the forest.

Comparison of vegetation and nutrient parameters revealed that N contents in particular and also the C/N ratio in the litter layer changed in a similar manner with increasing elevation as did plant species composition. The decreasing N contents in the litter layer together with lower N stocks and possible decreasing N-mineralisation rates with increasing elevation indicate that the shift in plant species composition with elevation probably makes for a plant community that is better adapted to nitrogen limitations.

Selective logging has led to disturbance of the forest on the lower slopes in particular and recently also at higher altitudes. This has given rise to large clearings in the forest. At higher elevations, in the zone of transition to the ericaceous belt, the forest is also strongly threatened and reduced by fires. The low cation retention capacity of the soils indicates that any disturbance to the forest will soon lead to leaching losses of released nutrients. This in turn is likely to have an adverse effect on the regeneration of the forest.

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3 Above and Below Ground Water Dynamics in Mature forest, Secondary Forest and Clearings in the Forest Belt of Mt. Kilimanjaro

INTRODUCTION

Although they cover an area of less than 2% of Tanzania, rainforests form important catchment areas that help to ensure a stable water supply to streams (Bjørndalen 1992). One major northern Tanzanian and southern Kenyan catchment area is formed by the forest belt of Mt. Kilimanjaro. The streams that originate on its slopes result in highly productive agriculture around the mountain, and also feed the Pangani River Basin, one of the most important streams in Tanzania. Because the hydroelectric power stations along the Pangani River rely on a constant water flow, the conservation of the water resources at Mt. Kilimanjaro is not only of local, but also of regional interest. Sarmett & Faraji (1991) studied the dry season discharge of rivers at the lower slopes of Mt. Kilimanjaro between the 1950s and 1970s. They observed a decrease in the runoff water of streams that were not spring-fed and ascribed it to increased water diversion and changes in the land use accompanied by losses of vegetation cover. Since the beginning of the last century, the forest of Mt. Kilimanjaro has experienced some major changes due to logging and the establishment of forest plantations on the western and eastern slopes, which has resulted in a segmentation of the natural forest (Lamprey, et al. 1991). During the past decades, the forest has been mainly affected by selective logging which has led to an opening of the forest, creating a mosaic of different regeneration stages on the lower southern slopes. A shift in plant species composition accompanied these changes (Mwasaga 1991). Recently, illegal logging has also been expanded to higher altitudes after the lower slopes had been strongly depleted of valuable timber wood species such as *Ocotea usambarensis* (Lambrechts, et al. 2002).

Harvesting of the forest has a great impact on the hydrology of logged sites, but the effects of forest conversion on water yields remain a contradictory issue. In most cases, forest removal led to an increase in soil moisture and water yields of the streams as interception and evapotranspiration were reduced (Sahin & Hall 1996). An early catchment study in Tanzania obtained similar results (Edwards, K.A. 1979). On the other hand, other studies have reported a reduction of dry season runoff following deforestation in tropical regions (Bruen 1989, Bruijnzeel 1996). The latter author interpreted the decreasing dry season streamflow as an effect of reduced soil

infiltration rates. These are considered to be the consequence of inadequate wood extraction methods and poor soil conservation practices, and might be avoided using adequate wood harvesting techniques. Infiltration rates and hydraulic conductivity depend on physical soil properties. Thus, the soil types also determine the extent of ecosystem responses to forest conversion. Among tropical forests, cloud forests are a special case where additional horizontal precipitation reaches the ground due to the extraction of fog and cloud water by the forest vegetation (Stadtmüller 1986). This additional precipitation is lost after the forest has been converted, resulting in reduced streamflow and groundwater recharge (Bruijnzeel 1989). In the course of forest regeneration, an increasing evapotranspiration of the fast growing secondary vegetation leads to decreasing soil moisture and streamflow values (Parker 1985). The time period until the stream discharge returns to predisturbance levels depends on the growth rate of the secondary vegetation. Bruijnzeel (1996) pointed out that high water demands of a vigorously growing vegetation type might even result in drier soil conditions compared to undisturbed mature forest.

So far, despite the high catchment value of the forest belt of Mt. Kilimanjaro, no study on the hydrological cycle in the forest belt and on possible impacts of forest conversion appears to be available. Pócs (1991) emphasised the importance of the high density and diversity of bryophytes in the forest above 2200 m for the water storage capacity of the forest and the continuous supply of water to watercourses. The aim of this study was to characterise some soil hydraulic properties and to analyse the impact of forest conversion and regrowth on rainfall diversion and below ground water suction and water contents. Since the study was restricted to a small area, results are preliminary and intended being a basis for further investigations.

MATERIAL AND METHODS

LOCATION AND GENERAL CHARACTERISTICS OF THE STUDY SITE

The study was conducted on the southwestern slopes of Mt. Kilimanjaro, between the river gorges of Kikafu and Weru-Weru in the forest belt above Machame village at an altitude between 2100 and 2300 m. For the exact location of individual plots see Figure 3.1 and Appendix B. The annual rainfall distribution in northern Tanzania is bimodal with the greatest amount falling typically from November to December and from March to May. Annual amounts of rainfall vary greatly depending on position and elevation. While it is generally agreed that the greatest amount of rainfall occurs on the southern slopes within the rain forest belt, the absolute amount and elevation

of the precipitation maximum is still a matter of controversy because there is a lack of continuous measurements within the forest (the respective papers are summarised in Axmacher 2003). One of the most recent studies was presented by Hemp (2001) who reported maximum rainfalls of about 3000 mm at 2100 m on the southern slopes, which is in accordance with results of Sarmett & Faraji (1991), who expected the maximum at around 2000 m. According to the floristic classification by Hemp (2002), the study area is located within the Ocotea-Podocarpus forest (2100-2300 m) in transition to the Agauria-Ocotea forest (1800-2000 m) at the lower boundary. Soils in the study area have developed on layered volcanic ashes that overlay phonolites and trachytes of the Lent group (Downie & Wilkinson 1972) and have been classified as Fulvudands, Epiaquands and Placaquands (Soil Survey Staff 2003).

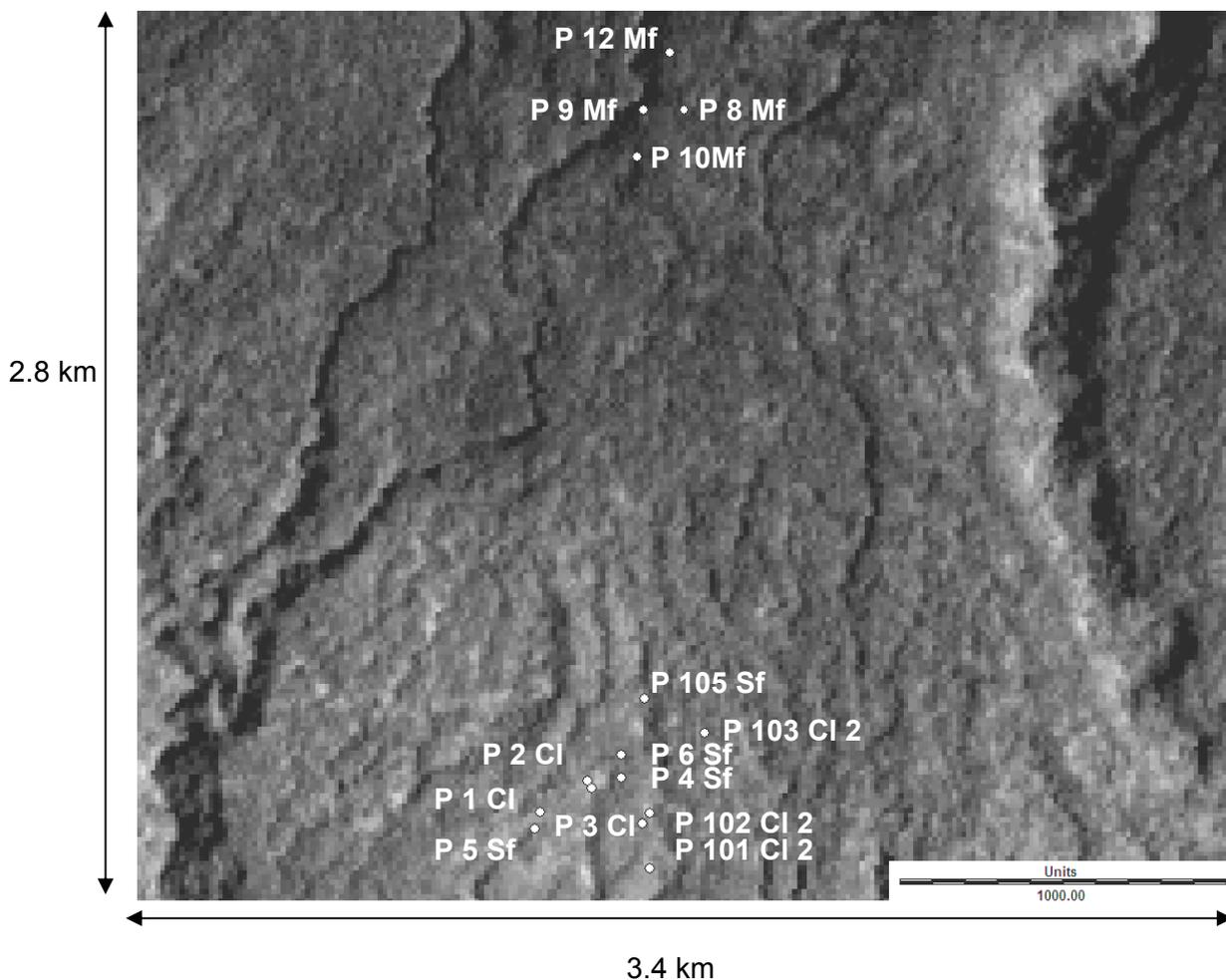


Fig. 3.1 Location of the study sites. Landsat 7TM+, channel 8 (multispectral), 21.2.2000, 15 m x 15 m resolution. Section: 303600-307000, 9650750-9653500, 3.4 x 2.75 m.

VEGETATION OF THE STUDY AREA

Three typical vegetation formations are found at the lower forest boundary of the southwestern slope of Mt. Kilimanjaro: mature forest, secondary forest and clearings. Trees in the mature forest reach heights of more than 40 m and a DBH of 1.8 m. The dominant tree species is *Ocotea usambarensis*. The lower tree layer and the shrub layer are dominated by tree ferns (*Cyathea manniana*) as well as by *Podocarpus latifolius*, *Ilex mitis*, *Dracaena afromontana* and several members of the family Rubiaceae. One characteristic of the mature forest is a high density and diversity of epiphytes, among them many pteridophytes and bryophytes. Hymenophyllaceae and thick moss layers indicate a constant high humidity within the forest.

The secondary forest has an age of approximately 60 years since the main logging phase in the region occurred during the Second World War. Above Machame village, a sawmill was operating at that time inside the forest (Dos 1968, Wood 1964). The canopy layer of the secondary forest consisted mainly of the pioneer tree species *Macaranga kilimanjarica* and some young *Ocotea usambarensis* trees. With a maximum of 0.5 to 1.0 m, stem diameters are smaller compared to mature forest, and also stand height is a bit lower (maximum 35 m). The abundance and diversity of epiphytes is reduced and the moss layer at the tree trunks is markedly thinner compared to mature forest plots (Axmacher 2003).

Clearings (> 500 m²) are dominated by bracken (*Pteridium aquilinum*), *Rubus steudneri* and *Begonia meyeri-johannis*. The two latter species are most abundant in old clearings. These clearings were created by selective logging and are today in an arrested stage of forest regeneration. According to regional foresters, some of them have remained in the present status for over a decade without invasion of tree species. A tree layer and subsequently also epiphytes are missing in all clearings, with the exception of some remaining dead, overgrown stems.

STUDY DESIGN

For each vegetation type, plots of 400 m² were selected with an inclination of less than 10° in order to avoid substantial effects of soil erosion. Because the area below 2200 m was depleted of mature forest stands, these plots had to be selected at slightly higher elevations, leading to a vertical distance of the mature forest sites and the disturbed sites of between 140 and 245 m. At the beginning of the study, four mature forest plots, three secondary forest sites and three clearings (clearings 1) were identified. These were supplemented by three more clearings (clearings 2) in the

second year. During the second year three clearings were burned, to simulate the fires which are probably one of the factors inhibiting forest regeneration at these sites. During the fire, tensiometers remained at the sites and were protected against the heat with a pottery cover.

Close to each plot, a soil pit was dug until either bedrock or hardly weathered ash layers were reached, or to a maximum depth of 2.3 m. Horizon designation and soil classification were made in accordance with the US Soil Taxonomy (Soil Survey Staff 2003). Samples were taken as composite samples of three profile walls from each soil horizon including the litter layer for a general characterisation of the soil. Undisturbed volume samples were taken at the four soil depths where tensiometers had been installed to analyse soil water characteristics and soil bulk densities. Homogeneity of the soils on the plots was tested using a soil auger.

Rainfall was collected in funnel-type gauges with a diameter of 115 mm. Funnel and collection bottle (2 l) were made of polyethylene. A net (0.5 mm mesh width) was fitted between the collector and funnel junction to minimise contamination. A table tennis ball was put into the funnel bottom to reduce evaporation losses. For the collection of rainfall, rain-catchers were placed on poles 1.5 m above the ground. The rim of the throughfall collectors was 0.3 m above the ground. As mature forests and regenerating sites had to be studied at some distance to each other, rainfall was measured in two clearings at 2100 m and another one at 2250 m close to the mature forest sites, with five collectors at each site. Every plot was equipped with ten randomly distributed throughfall collectors. Stemflow was collected at eight mature trees in the secondary and mature forest using gutter-like collectors made of cellular rubber coiled around the tree-trunk after removal of epiphytes and sealed up against the trunk using silicon. A tube connected the gutter to a 100 l container. Soil water suction was determined using a pressure transducer tensiometer (Stitch Tensiometer T1, UMS, Munich) at four soil depths (0.10-0.15, 0.20-0.25, 0.60-0.65 and 1.10-1.15 m) with two tensiometers per soil depth per plot. Since the narrowest tensiometer at 0.1 m soil depth was very short and in a very porous soil layer with a low bulk density, values were not always reliable at high water suctions during the dry seasons.

Tensiometer readings and rainfall measurements were taken twice a week on all plots during the first year. Sampling continued on a weekly basis in the second year until November 2001, when three of the clearings were burned. Measurements in the mature forest could be performed two days after the other plots during that period. From December 2001, readings of rainfall and tensiometer values at the lower plots

(clearings, secondary forests and natural forest remnants) were done twice a week, while readings at the mature plots were taken on a weekly basis.

SOIL PHYSICAL CHARACTERISATION

Particle size distribution was determined on fieldmoist samples taken at four soil depths (0.05-0.15, 0.20-0.30, 0.55-0.65 and 1.00-1.10 m) as composite samples from three walls of one soil profile per plot. For dispersion, 5 g of fieldmoist soil were shaken overnight in 500 ml de-ionised water after adding 20 ml 0.1 M $\text{Na}_4\text{P}_2\text{O}_7$ solution. Sand-size particles were removed by sieving, while silt and clay contents were determined using the pipett method (Gee & Bauder 1986).

In order to assess the soil-moisture characteristic curve, a total of 240 undisturbed soil cores were taken using 100 ml steel rings. Samples were taken at four distinct soil depths (0.05-0.15, 0.20-0.30, 0.55-0.65 and 1.00-1.10 m) from a profile at each plot studied. The five sample cores per soil layer were sealed and cooly stored (4°C) in a fieldmoist condition. The soil-moisture characteristic curve was determined using ceramic plates in the laboratory, starting with water saturated samples and subsequent dehydration to defined water suctions. Gravimetric soil water content was determined at five water potentials (ψ_M : -0.316, -1.0, -3.16, -10.0 and -31.6 kPa) after a respective equilibration period. Finally, samples were dried at 110°C to determine their bulk densities.

SOIL CHEMICAL CHARACTERISATION

Chemical analyses of mineral soil material were carried out on air dried samples (40°C) of the fraction < 2 mm. Soil pH was determined using H_2O and 1 M KCl at a soil : solution ratio of 1 (m) : 2.5 (v) and a standard combined electrode with integrated temperature probe (WTW SenTix 41 pH 330). Total carbon (C_t) and nitrogen (N_t) contents were analysed on ball-milled samples using a total element analyser (Elementar Vario EL). Exchangeable cations (K, Ca, Mg, Na, Al) were extracted by an unbuffered 0.5 M NH_4Cl solution (Trüby & Aldinger 1989) and measured by atomic absorption (Varian SpectrAA 400). The ECEC was calculated as the sum of exchangeable base cations and exchangeable Al. The amounts of Fe, Al and Si in ferrihydrite, allophane, imogolite and metal humus complexes (Fe_o , Al_o , Si_o) were determined in all soils using a 0,2 M oxalate solution (pH 3) (Schwertmann 1964). The cold dithionite-citrate buffer (DCB) method (Holmgren 1967) was used to

analyse Fe and Al in crystalline oxides and fractions from metal-humus complexes and amorphous constituents (Fe_d, Al_d).

DATA INTERPRETATION

To fit the measured relations between water tension and water content to a soil-moisture-characteristic curve, the Soil Hydraulic Properties Fitting (SHYPFIT) program (Durner 1994) was used, based on a retention model of Van Genuchten (1980). For curve-fitting, the means of the results obtained for individual horizons of each treatment (clearings 1, secondary forest, mature forest, clearings 2) were used. The obtained relationship between the water content and water tension for each vegetation type was then used to estimate mean soil water contents from the measured soil water tensions. The mean water storage of individual horizons was calculated separately for rainy and dry seasons according to the following equation:

$$WS_{sl} = \rho_{sl} * l_{sl} * \theta_{sl}$$

where WS_{sl} represents the water storage at an individual soil layer (sl), ρ_{sl} the bulk density, l_{sl} the thickness of the soil layer and θ_{sl} the estimated water content (Lilienfein, et al. 1999). Since the deepest soil horizon studied was only at 1.15 m, estimation of soil water storage of the whole pedon was limited by definition to a depth of 1.25 m and calculated after the equation used by Hodnett, et al. (1996):

$$S = \sum \theta_i \Delta_i z_i$$

where S represents the profile storage, θ_i the water content and z_i the thickness of the respective soil layer i . For estimation of the profile storage, the total profile was divided into four zones: 0-0.15, 0.15-0.45, 0.45-0.75 and 0.75-1.25 m and it was assumed that bulk densities and soil water characteristics measured within these zones were valid for their whole thickness. As no horizons with significantly different properties were supposed to be present between the measured horizons according to field observations, this seems probable. However, absolute water storage values can only present approximations.

In order to be able to compare soil chemical characteristics among vegetation types, data obtained on the basis of soil horizons were used to calculate the depth weighted mean concentrations for distinct soil sections (0-0.15, 0.15-0.3, 0.3-0.6, 0.6-1.0 and 1.0-1.5 m).

Statistical analyses were conducted using the statistical work package STATISTICA 5.0 (Statsoft, Tulsa, UK). If the analysis of variance (ANOVA) resulted in significant ($p < 0.05$) differences between the treatments, Scheffé-Tests were used to analyse individual differences among treatments. Analyses of variance were conducted on log-transformed data if necessary to avoid correlations between means and respective standard deviations. Correlation analyses were performed using Pearson Product-Moment Correlations.

RESULTS AND DISCUSSION

COMPARABILITY OF SOILS

Detailed knowledge of major soil properties is important for the interpretation of soil water characteristics. All the soil profiles developed on layered volcanic ashes, and in all profiles buried soils were identified. These conditions led to a high heterogeneity of soil properties with depths as well as with spatial distribution compared to the more homogenous, deeply weathered Oxisols and Vertisols on the old Precambrian shield in the surrounding savannah plains. According to US Soil Taxonomy (Soil Survey Staff 2003), all soils in the study area fulfilled the requirements of Andisols and were subsequently characterised by a high content of amorphous Fe and Al constituents, showed low bulk densities and even at deep soil layers, high amounts of soil organic material had accumulated (Table 3.1, 3.2). No significant differences between the soils under different vegetation types were obtained. Furthermore, soils were acidic and exhibited a low effective CEC especially at deep soil layers. Most exchange sites contained Al. Although no significant differences among sites were obtained, secondary forest sites had generally lower C contents in the topsoil, whereas mature forest sites were slightly more acidic and showed lower contents of dithionite-extractable Al_d and Fe_d at deep soil layers.

Table 3.1 Mean soil chemical characteristics of the different vegetation types (\pm standard error, $n = 3$).

	pH		C	N	S	KAK	Al _o +1/2 Fe _o	Al _d	Fe _d
	H ₂ O	CaCl ₂							
			g kg ⁻¹			cmol _c kg ⁻¹	g kg ⁻¹		
<i>Mature Forest</i>									
0-0.15	4.2	3.7	178.6	10.4	1.6	9.3	39.7	18.4	62.6
	± 0.1	± 0.0	± 6.0	± 0.3	± 0.1	± 1.4	± 5.2	± 2.0	± 3.8
0.15-0.3	4.7	4.3	125.3	6.3	1.4	2.7	65.1	43.4	67.0
	0.0	± 0.1	± 13.6	± 0.4	± 0.1	± 0.4	± 5.9	± 6.2	± 9.1
0.30-0.60	4.7	4.5	105.3	4.7	1.3	1.0	61.6	29.1	42.8
	± 0.0	± 0.0	± 12.9	± 0.5	± 0.2	± 0.3	± 7.4	± 4.4	± 15.4
0.60-1.00	4.6	4.8	69.9	3.0	1.4	0.6	57.5	27.2	42.2
	± 0.0	± 0.1	± 8.0	± 0.4	± 0.2	± 0.1	± 9.5	± 6.1	± 12.2
1.00-1.50	4.6	4.9	66.1	2.5	1.3	0.6	69.2	26.7	32.8
	± 0.1	± 0.1	± 19.1	± 0.8	± 0.2	± 0.4	± 7.0	± 8.7	± 12.9
<i>Secondary Forest</i>									
0-0.15	4.2	3.9	146.8	9.9	1.2	8.0	34.5	29.1	80.6
	± 0.1	± 0.1	± 9.0	± 0.6	± 0.1	± 0.9	± 9.5	± 2.8	± 4.6
0.15-0.3	4.7	4.4	106.0	6.3	1.2	1.9	63.8	52.3	68.0
	± 0.1	± 0.0	± 8.0	± 0.1	± 0.1	± 0.1	± 16.0		
0.30-0.60	4.9	4.8	93.1	5.7	1.2	1.0	51.6	33.9	59.7
	± 0.0	± 0.1	± 6.4	± 0.4	± 0.0	± 0.2	± 21.5	± 7.6	± 14.3
0.60-1.00	5.0	4.9	66.9	3.5	2.3	0.5	58.1	36.9	78.2
	± 0.1	± 0.0	± 7.0	± 0.1	± 0.2	± 0.1	± 3.4	± 3.0	± 2.0
1.00-1.50	5.1	5.1	45.9	2.2	2.7	0.5	60.8	23.0	54.2
	± 0.1	± 1	± 3.5	± 0.2	± 0.6	± 0.1	± 5.6	± 10.6	± 17.5
<i>Clearings</i>									
0-0.15	4.2	3.8	168.7	11.9	1.5	9.1	40.4	23.0	67.5
	± 0.2	± 0.0	± 9.2	± 0.7	± 0.1	± 0.8	± 6.0	± 0.4	± 3.3
0.15-0.3	4.6	4.4	114.6	7.6	1.4	3.0	63.2	38.6	66.0
	± 0.1	± 0.1	± 5.8	± 0.4	± 0.1	± 0.4	± 2.2	± 2.0	± 1.0
0.30-0.60	4.8	4.7	84.8	5.4	1.7	1.0	68.5	41.0	71.1
	± 0.1	± 0.0	± 3.7	± 0.3	± 0.1	± 0.3	± 7.6	± 0.4	± 2.6
0.60-1.00	5.3	5.3	69.3	4.2	2.3	0.5	69.2	45.2	80.0
	± 0.6	± 0.5	± 6.5	± 0.6	± 0.3	± 0.1	± 10.6	± 5.1	± 3.7
1.00-1.50	4.9	5.0	57.4	3.3	2.8	0.3	70.1	35.0	64.3
	± 0.2	± 0.1	± 9.7	± 0.8	± 0.3	± 0.1	± 7.6	± 0.9	± 0.7

One major problem which arose with regard to hydrological investigations was an irregular occurrence of cemented horizons in the profiles of the mature forest sites. Depth and expression of these horizons varied considerably among sites. While they were completely absent in some profiles, in others they reached a thickness of about 0.2 m. The shallowest depth where they were observed was 0.85 m, the deepest 1.35 m from the ground surface. While accumulations of Fe oxides were measured within the crusts, the main cementing agent was supposed to be silica. Where they occurred, the crusts served as an effective barrier for percolating water. During the rainy season, the ground water table was generally very high. According to our observations in the field, water was penetrating into the profiles from the walls above the crusts as well as from the profile base after water had been removed from the soil pit. During the installation of the equipment up to a depth of 1.15 m there were no difficulties with hardened horizons. Thus, it was assumed that crusts on the study plots - if present at all - occurred below that depth. Nevertheless where these crusts occurred, they surely would have had an influence on the soil water flow at deeper soil layers.

Table 3.2 Mean soil bulk densities at four soil depths (\pm standard error, $n = 3$).

Soil Depth [m]	Bulk Density		
	Mature Forest	Secondary Forest [t m ⁻³]	Clearings 1
0.05-0.15	0.32 \pm 0.06	0.37 \pm 0.03	0.30 \pm 0.02
0.20-0.30	0.40 \pm 0.04	0.38 \pm 0.03	0.35 \pm 0.06
0.60-0.70	0.61 \pm 0.10	0.61 \pm 0.05	0.63 \pm 0.07
1.05-1.15	0.56 \pm 0.05	0.61 \pm 0.02	0.53 \pm 0.01

RAINFALL VARIABILITY AND INTERCEPTION

A bimodal rainfall distribution was reflected in the distribution of rainfall amounts measured during the first year (Fig. 3.2). Records were started at the end of the rainy season in May 2000. The following dry conditions were most pronounced in September and October, but heavy rainstorms at the beginning of October interrupted the dry period. The following small rainy season extended until January

2001, when a drier period led over to the long rainy season starting in April 2001 and lasted until July 2001. During the second year until October 2002, rainfall was not collected simultaneously (see study design) at both altitudes. Thus, two week means were used to minimise differences caused by the sampling procedure (Fig 3.3). With 2210 mm at 2100 m and 1960 mm at 2250 m, rainfall amounts in the second year were well below those of the first one (2600 and 2480 mm respectively). A high variability of the annual and monthly rainfall amounts has often been reported for Tanzania (Lundgren & Lundgren 1979, Nieuwolt 1974, Sarmett & Faraji 1991). Long-term studies of the East African Meteorological Department between 1945-1958 at an altitude of 2100 m at Mt. Kilimanjaro registered mean annual rainfall amounts of 1840 mm with values varying between 1200 and 3815 mm (Hedberg 1964). Hence a rainfall reduction of 15% and 20% (secondary forest and mature forest respectively) in the second year is well within the natural rainfall variability observed in this region.

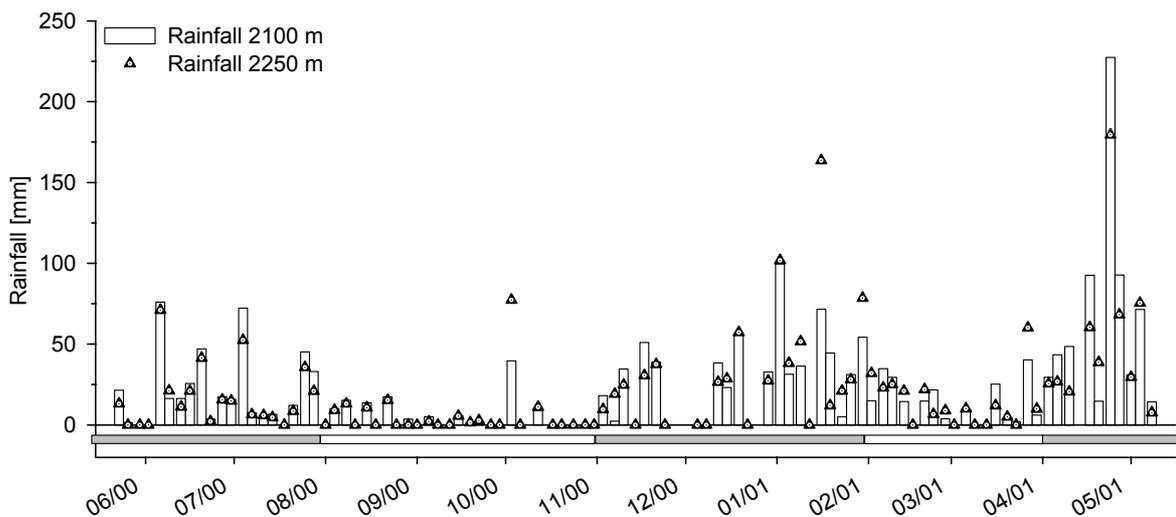


Fig. 3.2 Variability of rainfall during the first year at 2100 and 2250 m. Each data point represents the cumulative rainfall of half a week (3 and 4 days alternating). Greyish areas below the graph mark rainy periods, white ones dry periods.

Although collected the same day, rainfall amounts at 2100 and 2250 m differed remarkably during some periods, but the overall distribution observed was similar and in the long run, the means were also close (Table 3.3, 3.4). Some of the differences might have been caused by sampling time, as the reading of all plots took a whole day. The rain usually started after midday, and sampling in the afternoon often already included the rainfall of the day, while morning sampling did not. The missing amount would then be included in the next sampling. At some time periods, it was also obvious that differences were caused by different rainfall distributions.

Even within the lower plots, where rainfall was collected in two clearings which were located in adjacent small valleys with a vertical distance of only 200 m, rainfall amounts on a few occasions differed noticeably. Rainstorms of limited temporal and spatial distribution might be one reason for that observation. According to Nieuwolt (1974), Mt. Kilimanjaro is among the regions with the highest frequency of rainstorms in Tanzania. As a consequence, differences in rainfall amounts between the higher and lower sites might have been caused by the lack of individual rainstorm events affecting some sites and not others.

During a period of three months within the main rainy season of 2002, rainfall amounts at 2250 m were consistently below those at 2100 m. This period is marked with two dotted lines in Figure 3.3. It led to remarkably lower overall rainfall amounts at the higher sites for that particular rainy season (Table 3.3, 3.4). A closer look at individual rainfall amounts revealed that especially high rainfall events occurring at the lower sites were missing at higher elevations. With an average of 140 mm per month during the whole rainy season, the period was within the range observed during the two minor dry seasons (130 and 190 mm), with no marked effects on soil water suction of the mature forest sites (Fig. 3.7). However, the possibility of mistakes during sampling or documentation cannot be completely ruled out.

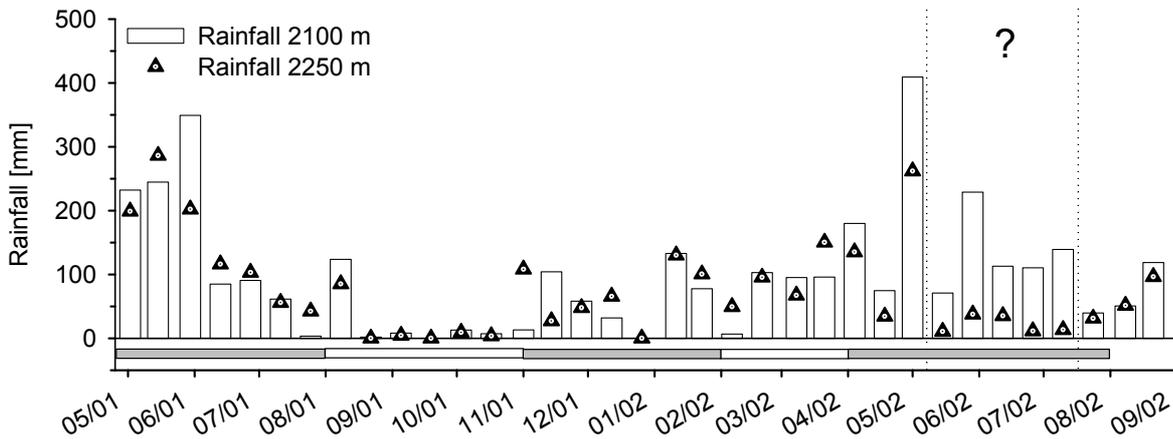


Fig. 3.3 Biweekly amounts of rainfall from May 2001 till September 2002 at 2100 and 2250 m. Dotted lines mark a time period when rainfall at 2250 m was considerably lower than at 2100 m. Greyish areas below the graph mark rainy periods, white ones dry periods.

The term “net throughfall” was introduced as the sum of direct throughfall, canopy drip and stemflow (Helvey & Patric 1965). In stunted elfin cloud forests, stemflow can contribute a large portion of net throughfall reaching up to 5-10 % of overall

rainfall amounts, which is mainly attributed to the high tree density (Bruijnzeel & Proctor 1995). The contribution of stemflow to lower mountain rain forests and lowland rain forests, on the other hand, is usually considered as being small (1-2% of incident rainfall, Bruijnzeel 1989, Bruijnzeel & Proctor 1995). With tree heights of up to 40 m, the forest at Mt. Kilimanjaro structurally resembles lower mountain forest types. Accordingly, the significance of stemflow to total throughfall amounts was low and in the sum accounted for less than 1% of incident rainfall per year. There was a tendency towards higher stemflow contributions at the secondary forest sites, where stems had a low epiphyte coverage. The high density of epiphytic mosses and ferns at the tree stems of the mature forest, and to a lesser extent also at the secondary forest caused some problems concerning the determination of stemflow. While the mosses and ferns were removed in the region of the gutters, they still formed thick layers of up to > 0.1 m above the collectors. During heavy rainstorms (minor rainfall events did not result in detectable stemflow amounts), water percolated down the trunk itself, but also within the moss layers. As the gutters only had a depth of 40 mm, the moss layer was wider and it appeared in the field that some water was dropping down the edges of the moss layers, hence bypassing the collector. Thus it must be assumed that the total amount of stemflow was slightly underestimated. Still, the total amount was probably small and will not be further discussed in detail.

Table 3.3 Amounts of rainfall, throughfall and intercepted water during the two years for the different vegetation types.

	Rainfall		Throughfall			Interception		
	2100 m	2250 m	Clearings	Secondary forest	Mature forest	Clearings	Secondary forest	Mature forest
	[mm]			[mm]		[mm]		
Year 1	2600	2480	2490 ± 80	1890 ± 100	2040 ± 27	110 ± 80 (3%)	712 ± 100 (27%)	438 ± 33 (18%)
Year 2	2210	1960	2010 ± 40	1500 ± 20	1370 ± 20	210 ± 40 (9%)	710 ± 20 (32%)	590 ± 20 (30%)

As biomass and the total percentage of vegetation cover was lowest in the clearings, interception at these sites was also very low, resulting in throughfall values close to rainfall amounts (Figure 3.4). With regard to the forests, interception was highest at

secondary forest sites. This led to greater throughfall amounts in the mature forest sites, although rainfall amounts were slightly less. With up to 32% of the actual rainfall in the second year, interception in the secondary forest was among the highest records observed for mountain rain forests (Bruijnzeel & Proctor 1995). Similar high values were observed in a New Guinean rainforest (32%, Edwards, P.J. 1982) and in Panamá (37%, Cavelier, et al. 1997). In the West Usambara Mts. in Tanzania, Lundgren & Lundgren & Lundgren (1979) measured interceptions of 23% in a submontane rain forest.

The higher interception of secondary forest as compared to mature forest was not expected since coverage and thickness of epiphytic bryophytes, which are known to intercept large quantities of water (Pócs 1980), was greater at the mature forest sites. Studies on the vegetation structure conducted by Axmacher (2003) revealed a higher percentage of coverage for the tree layer of the secondary forest as compared to the mature forest (83 and 69 % on average respectively). This might partly explain the observed difference.

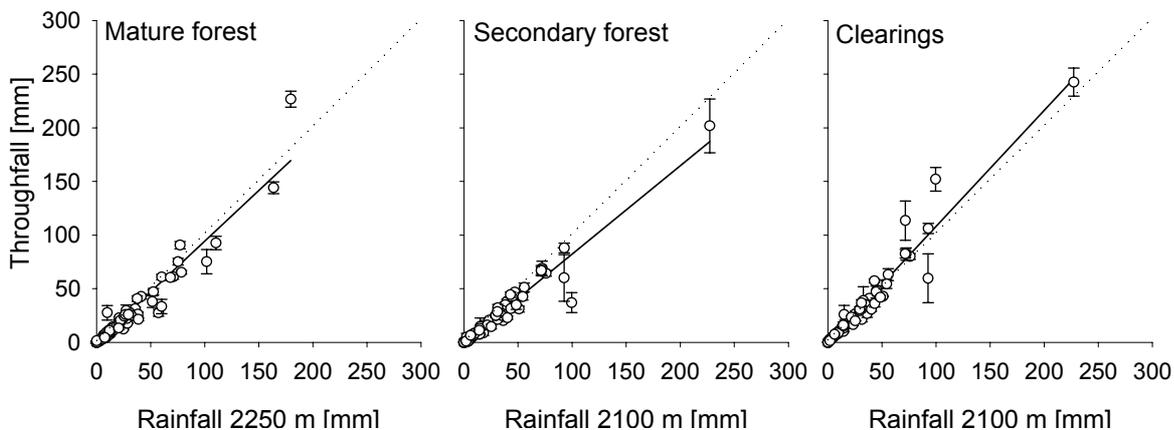


Fig. 3.4 Relation between rainfall and throughfall (\pm standard error) at the three vegetation type sites from June 2000 to May 2001 (first year). Dotted lines give the 1:1 relation and full lines show linear regressions.

During field work, a higher frequency of cloud and fog occurrence was observed within the mature forest as compared to the other sites. In this respect, it is very unfortunate that no measurements of fog or cloud (“occult” or “horizontal”) precipitation were possible within the scope of this project. Stadtmüller (1986) defined cloud forests as forests “in the humid tropics that are frequently covered in cloud or mist”. The term “frequently” is not further specified but forests should receive enough additional water through horizontal precipitation so that it has an

influence on the hydrologic regime and ecological parameters. Sporadic measurements of daily minimum and maximum humidity were taken on 50 individual days from May to October 2001 using thermo-hygrometers installed 1.5 m above the soil surface in the mature forest. Humidity within the forest was more or less constant between May and July 2001 with minimum and maximum values ranging between 85 and 99%. In the following exceptionally dry period from August to October, daily minimum and maximum values dropped continuously so that daily maxima ranged between 80 and 90%, and minima reached values as low as 40 % in October. For areas where no climatic data are available, Richter (2003) suggested the use of plant functional types and found that in southern Ecuador mosses, lichens and vascular epiphytes are suitable indicators for humidity. At the mature forest of Mt. Kilimanjaro, a constant high humidity was confirmed by the high abundance of *Cyathea manniana* and the abundance and diversity of mosses and other ferns, among them a number of Hymenophyllaceae (Axmacher 2003, Hemp 2001) which rely on atmospheric water. In eight out of 100 halfweek periods in the first year, throughfall values of the mature forest exceeded rainfall, but in only two periods did this also occur in the secondary forest. A negative difference between rainfall and throughfall is usually attributed to horizontal precipitation (Bruijnzeel & Proctor 1995). According to studies summarised in Bruijnzeel & Proctor (1995), the contribution of cloud stripping in cloud forests usually ranges between 5-20 % of ordinary rainfall. Nevertheless, additional humidity by fog or cloud passage does not necessarily result in a negative interception (rainfall - throughfall amounts). If the forest canopy is already wet due to cloud stripping prior to rainfall events, the interception is reduced as the water amount necessary for canopy saturation is markedly lowered. This process might have accounted for the observed effect of the low interception of mature forests compared to secondary forest sites. As the additional rainfall by cloud stripping of the forest was not analysed in this study, the reduction in rainfall amounts accompanying forest clearing cannot be quantified.

Because rainfall at 2250 m was collected in a gap of only about 500 m², it is also possible that rainfall was underestimated when accompanied by strong wind when the collectors might have been in the wind-shadow of the adjacent forest (closest distance to the forest canopy was approximately 10 m). According to studies summarised in Thimonier (1998) and Bruijnzeel (1989), ten raincatchers were used to determine throughfall volumes were at the lower end for quantitative estimations. If means per treatment are compared, a total of 40 raincatchers in the mature forest and of 30 raincatchers in secondary forests and clearings were included in the calculation, which is closer to numbers suggested by Bruijnzeel (1989). But as raincatchers from

the same plot cannot be considered as independent, the pooling of all catchers for statistical analysis did not appear to be appropriate. One way to reduce the error usually accompanied with a low number of raincatchers is the randomised rearrangement of the collectors after specific time periods (Lloyd & Marques Filho 1988). But in a study with an interdisciplinary approach, it is not possible to rearrange raincatchers after every sample collection as this results in trampling damage on the plot, destroys the ground vegetation, and litter as well as the topsoil will become compressed within a few weeks. Thus, in the present study, primarily randomly located collectors were connected with trails, along which raincatchers were relocated from time to time. Standard deviations for collected water amounts in individual raincatchers within one site were usually in the range of 10 and 20% of the mean. This error has to be kept in mind when interpreting the data since an unfavourable arrangement of collectors could also have accounted for some differences among sites and led to deviated total throughfall amounts.

ANNUAL COURSE OF SOIL WATER TENSION

The tensiometers used in this study can only reflect soil water conditions of a limited soil volume. Thus with only two parallels at four different soil depths per site it is certainly not possible to record the total heterogeneity of soil moisture conditions of single sites. However, the results are useful to generate general ideas about differences in soil moisture conditions under the different vegetation types.

The matrix potentials in the soil did not generally reflect the observed differences in throughfall amounts. As can be seen from Figure 3.5, secondary forest sites usually exhibited lowest soil water potentials during the first year as compared to mature forest and clearings, which is in accordance with the least amount of measured throughfall occurring at the secondary forest sites. Although the greatest amount of throughfall was measured in the clearings, the soil water tension was usually lowest under mature forest. Differences were most pronounced during dry seasons. As can be seen from minor dry periods, the matrix potential of the secondary forest soils reacted most sensitively to changes in the rainfall regime, while in the mature forest it only exhibited pronounced changes during the main dry season, otherwise remaining more or less constant. During the second year, which was generally drier than the first one, tensiometer measurements at the mature forest sites were not conducted on the same day as at secondary forest sites. Hence, only secondary forest sites and clearings could be directly compared (Fig. 3.6).

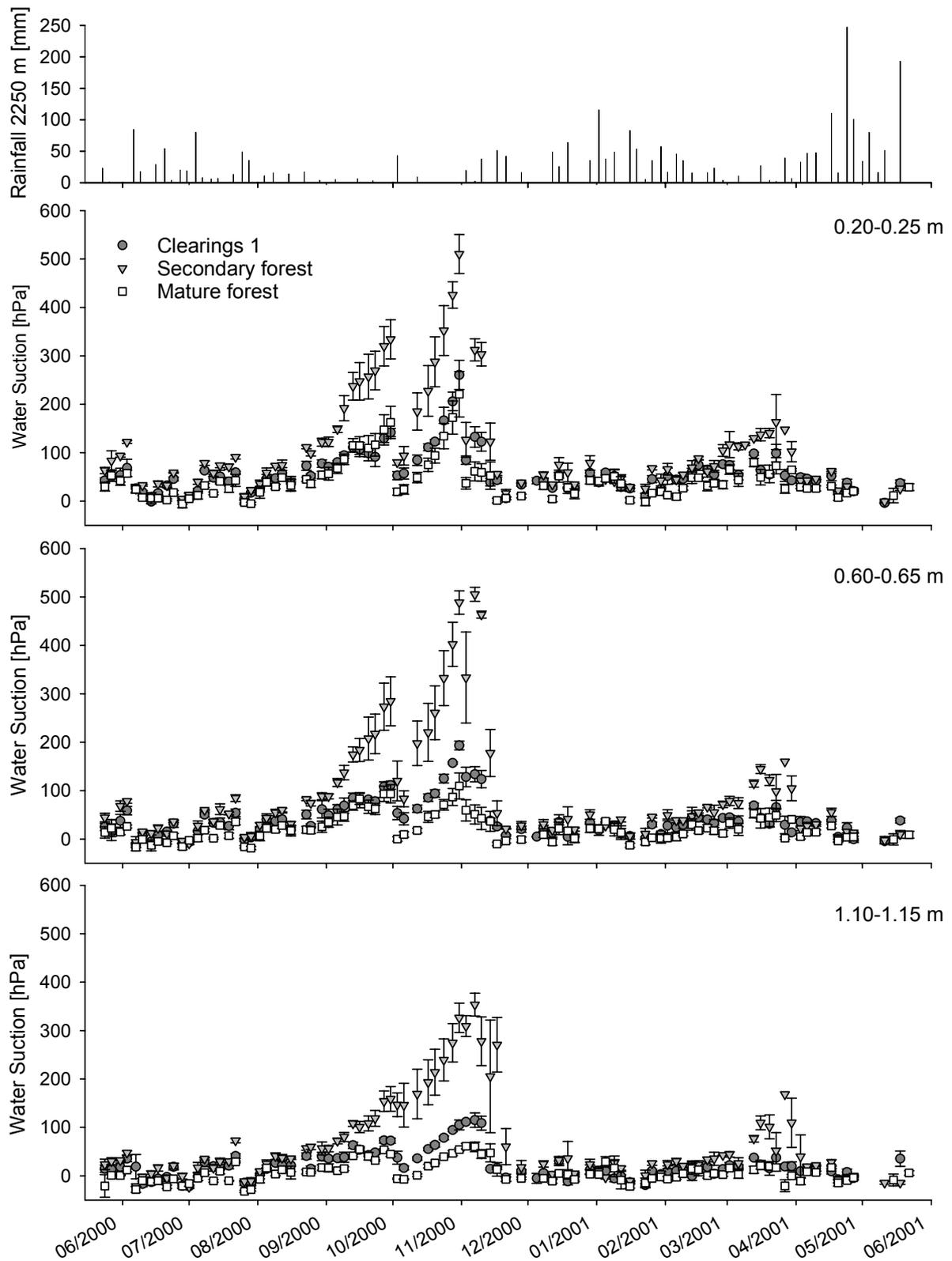


Fig. 3.5 Course of the mean soil water suction (\pm standard error) at three soil depths (0.20-0.25, 0.60-0.65, 1.10-1.15 m) under mature forest, secondary forest and clearings during the first year. The graph at the top shows cumulative halfweek rainfall amounts collected prior to tensiometer readings for comparison.

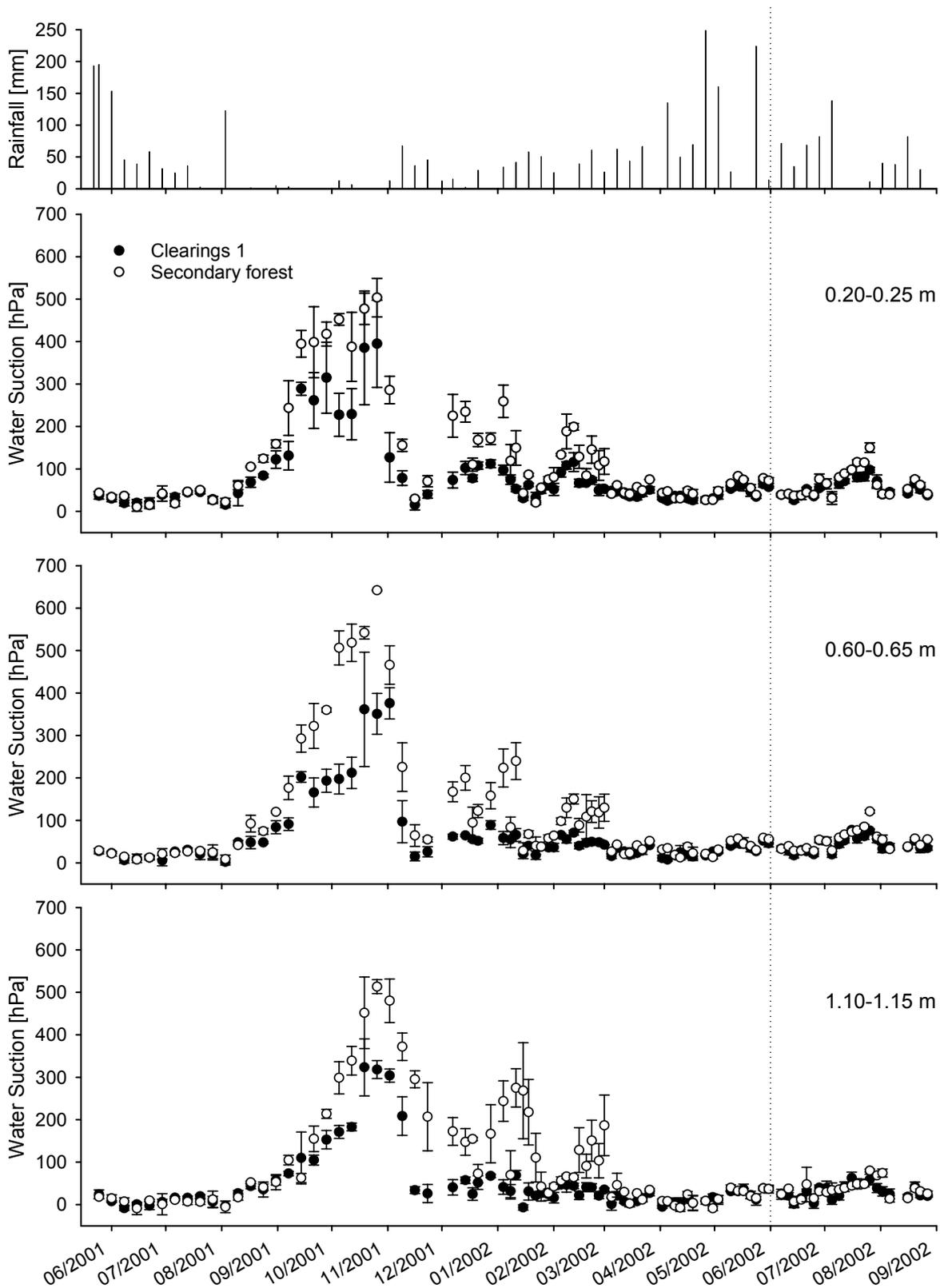


Fig. 3.6 Course of the mean soil water suction (\pm standard error) at three soil depths (0.20-0.25, 0.60-0.65, 1.10-1.15 m) under secondary forest and clearings from the beginning of the second year until the end of measuring in August 2002. Readings were first done weekly (June to November) and later twice a week. The graph at the top shows cumulative weekly rainfall amounts for comparison. The dotted line indicates the end of the second year.

The results revealed that clearings were on average wetter than secondary forest sites, especially during drier periods. In Figure 3.7, the annual course of the matrix potential at the secondary forest and mature forest sites is compared. While the mature forest was wettest during the long dry season in 2001, water tensions in 2002 were as high as at the secondary forest sites. But in the following minor wet and rainy periods, soil water tensions in the mature forest remained on a low level, while fluctuations at the secondary forest sites were much greater.

After a monitoring period of half a year, the vegetation on three of the six clearings studied in the second year was cut and subsequently burned. Prior to burning, a ditch of 0.3 m depth was dug around the plot. All roots were cut which might have originated from the vegetation of the adjacent forest. As can be observed from Figure 3.8, the disturbance of the clearings did not result in significant differences in water tensions. One reason for the absence of change in water content in response to the removed vegetation cover might have been the timing of the disturbance. As the fires were set at the beginning of the rainy season, and the infiltration rates of Andosols are generally high, the soil moisture was not significantly affected. Afterwards, vegetation cover recovered within only a few weeks so that similar conditions to the preburn level were obtained before the beginning of the next dry season. If the disturbance had been at the beginning of the dry season, the picture might have been different since regeneration probably would not have been as fast as under dry conditions with high temperatures at the exposed soil surface.

Differences in the soil water tension between secondary forests and clearings were most likely caused by lower interception and lower evapotranspiration rates at the clearings, resulting in higher soil humidity. Similar results were also obtained in other natural forest gaps and in clearings created by forest cutting and burning (Klinge 1997, Parker 1985). Daws, et al. (2002) emphasised the importance of the relief position on the soil water content of a semideciduous tropical forest in Panamá. They observed significantly higher soil matrix potentials on slopes compared to plateau sites throughout the measuring period. Similar results were obtained by Becker, et al. (1988). At Mt. Kilimanjaro, logging activities often concentrated on valleys rather than ridges, where logs were cut in poles in situ and transported downwards along the valleys. For this reason, one of the clearings studied in the first year was in a valley or down-slope position, while two of the secondary forest sites were situated in a ridge position. The clearings included in the study at the beginning of the second measuring year were on gentle slopes rather than in valleys. As they exhibited very similar soil water tensions as compared to the other clearings,

the differences in slope locations between the clearings did not seem to have a strong effect. Nevertheless, although the two secondary forest sites on ridges had at least one up-slope contributing area which permitted water additions by lateral flow, the mean upslope area was smaller compared to the clearings. Thus, additional effects of relief position on the observed differences in soil water tensions between clearings and secondary forest sites cannot be completely ruled out.

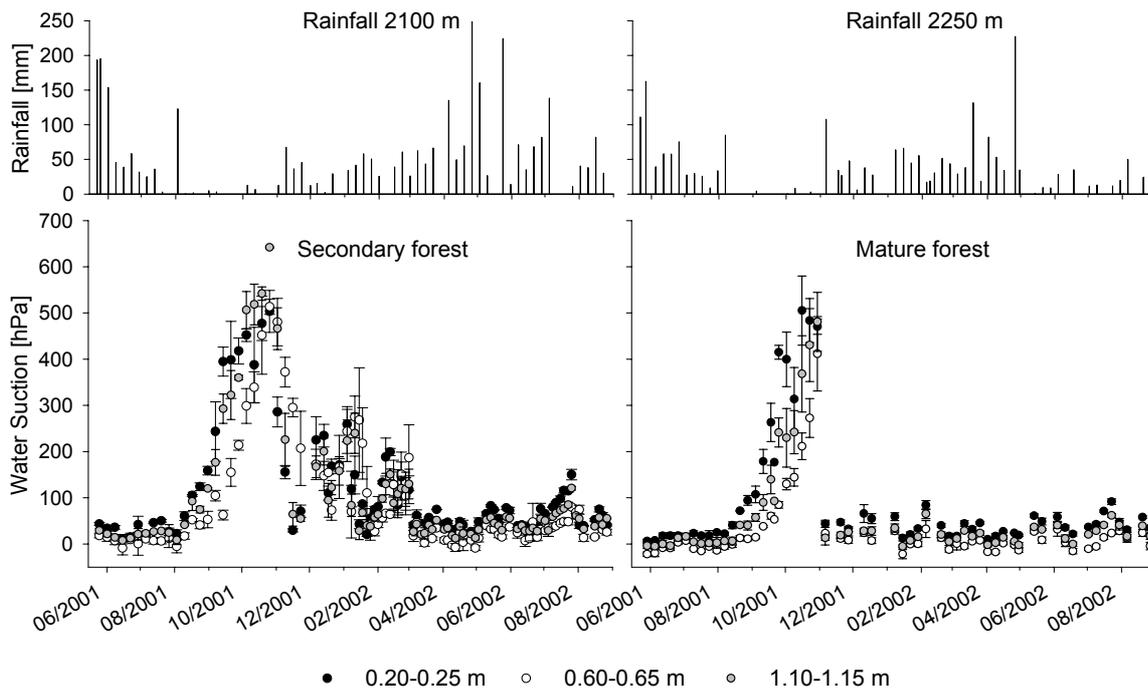


Fig. 3.7 Comparison of the tensiometer readings at the secondary forest and the mature forest from the beginning of the second year until the end of the measuring period in August 2002 (means \pm standard error, $n = 3$ for secondary and $n = 4$ for mature forests). Lines in the upper graph show cumulative weekly rainfall amounts.

Of all mature forest sites, two plots did not have a relevant upslope contributing area. As a consequence, differences in relief position might not have been responsible for the observed higher matrix potentials. But the cemented horizons observed at this altitudinal level probably had an influence where they occurred, as they act as a barrier for percolating water, thus producing a perched water table on top of the crusts. This might help to explain the low reaction of the soil water potential at periods of low rainfall (minor dry and rainy seasons). If major parts of the infiltrated water after a rainfall event are retained on top of the crusts, the arrested water is mainly reduced by evapotranspiration as downward movement is prevented and lateral movement might not be high due to the low inclination of the sites. But the

observed crusts were not continuous and the depth of their occurrence was fluctuating, leading to different effects on the soil water. In one soil profile, no cemented horizons were observed to a depth of over 2 m, and still, during the rainy season, water was standing close to the profile rim. This indicates a generally high water table independent of the occurrence of the crusts. Thus, the crust might not be solely responsible for the high water content of the mature forest sites.

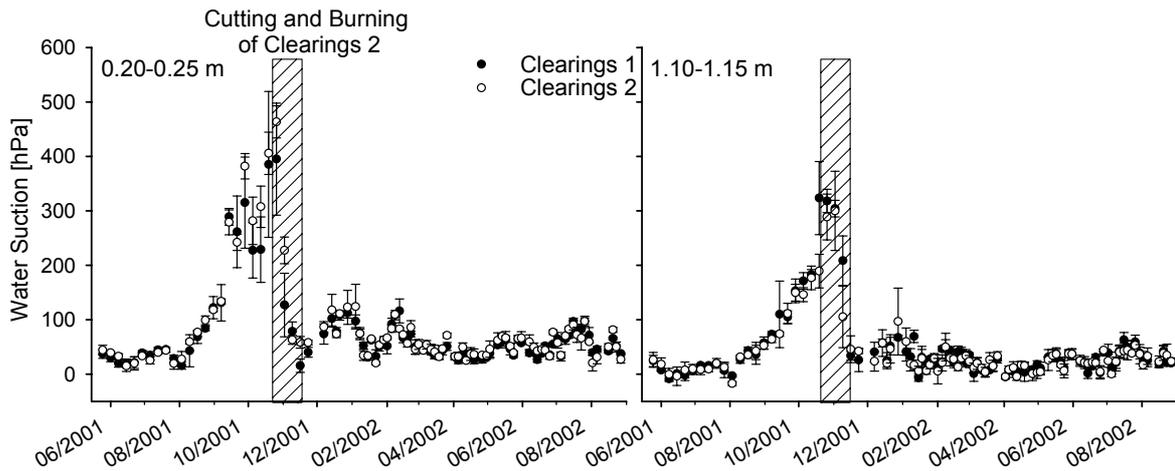


Fig. 3.10 Comparison of the soil water suctions at two different soil depths between six clearings before and after three sites were cut and burned between November 2001 and December 2001 (means \pm standard error, $n = 3$).

As the transpiration rate of the mature forest is supposed to be higher than that of the clearings and throughfall values were much lower at the mature forest sites, overall lower matrix potentials were expected. Still, mature forest sites usually exhibited lower soil water tensions than clearings. Besides differences in the relief position and the occurrence of dense soil horizons, further possible effects caused by the fragmentation and the accompanying change in species composition of the forest at the lower slopes should be considered. Water demand and vertical patterns of water uptake depend on plant species and life forms. Moreira, et al. (2000) studied the water uptake of abandoned pasture with shrub vegetation and a primary forest in eastern Amazonia. Despite the dogma of the generally shallow rooting of the Amazonian rain forest trees, they observed that trees were able to extract water from soil layers below 1 m, whereas lianas and the shrub vegetation at the abandoned pasture could not. The frequent observations of fog and clouds within the mature forest, high humidity within the stand and a high density of epiphytic bryophytes and pteridophytes all are characteristics of a cloud forest. According to Bruijnzeel &

Proctor (1995), the evapotranspiration rate of this forest type is low. This is independent on whether it is exposed to direct sun or not (Bruijnzeel 1996), leading to a reduced drying of the soil compared to other forests. As the secondary forests were dominated by early successional species which usually grow fast, their water demand might also be higher.

Furthermore, the fragmentation of the forest itself will probably influence the water relations as edge effects become more important. Kapos (1989) found at forest edges that due to higher temperatures and vapor pressure deficits, the water demand of plants increased up to 40 m inside the forest. Also wind disturbance is higher at forest edges and light is permitted to enter the forest. Both factors further increase the water demand. As the forest at lower elevations of Mt. Kilimanjaro today is strongly fragmented, the increase in forest edges might have led to an overall increase in evapotranspiration rates of the secondary forest vegetation, leading to drier soil conditions. The closed canopy of the mature forest is less aerodynamically rough than the fragmented areas. Hence, a more humid within-stand climate is maintained below the canopy, which is the prerequisite for many epiphytic species.

Another reason for the relative dryness of the clearings as compared to the mature forest especially, during dry seasons, might be the invasion of tree roots into clearings from the adjacent forest. Sternberg, et al. (2002) analysed the water uptake of small Amazonian trees (dbh < 120 mm) and observed the highest water uptake in the proximity of the stems. There was also evidence for water uptake from sources as far as 10 m away from the tree stems. According to Meinzer, et al. (1999), the root system of bigger trees showed a higher lateral extension than that of smaller trees in a seasonally dry tropical forest. These results make it highly probable that the area of the clearings at Mt. Kilimanjaro was also partially exploited by tree roots from adjacent secondary forest sites, increasing the transpiration rates and thus the water tension of the clearings. Before the fire experiment, all roots around the plot were cut to a depth of 0.3 m. Thus, the fire experiment indicates that the effect of very shallow tree roots is not expected to be of great significance.

SOIL WATER CHARACTERISTICS AND ESTIMATED WATER STORAGE OF THE SOILS

The soil water-retention parameters of mean temperate and tropical soils according to van Genuchten are different with tropical soils usually having a higher water-retention capacity due to lower bulk densities (Hodnett & Tomasella 2002). Andisols represent a special case. They are known to contain a great amount of plant available water as well as hygroscopic water because of their unique structure (Shoji, et al. 1993). Thus, the soil water contents of the Andisols at Mt. Kilimanjaro were determined at five adjusted matrix pressures. Figure 3.9 shows the fitted soil water characteristic curves at four soil depths under the different vegetation types. With more than 700 g kg⁻¹, all sites showed high water contents at saturation. For the secondary forest sites and the clearings, the shape of the soil-water characteristic curve changed with increasing soil depths from a more coarsely textured type in the topsoil towards smaller pore sizes at deeper soil horizons. Differences within the profile were much less pronounced at the mature forest sites. Among the sites, no significant differences (Scheffé-Test, $p < 0.05$) in the measured soil water contents were obtained in the subsoil (0.6 and 1.1 m) at any adjusted water tension. But in the topsoil (0.05-0.15 m), the water content of the mature forest sites was significantly higher compared to the secondary forest sites and the clearings at high water pressure (≥ 10 kPa or pF 2.0). At a soil depth of 0.20-0.25 m, the water content of the mature forest was significantly higher than that of the secondary forest for a water tension of 3.16 kPa and significantly higher than the secondary forest and clearings at a water tension of 10 kPa. Due to the higher heterogeneity, differences at 31.6 kPa were only significant at $p < 0.1$. Overall lowest water contents at 31.6 kPa (pF 2.5) were obtained for soils from secondary forest sites. The shapes of the soil-water-characteristic curves in the mature forest sites very much resembled those presented in Moldrup, et al. (2003) for 18 Japanese Andosols. Hodnett & Tomasella (2002) investigated the high water content of Andosols compared to other tropical and temperate soils at the range between pF 0 and pF 4.2. The shape of the water-characteristic curves they presented were more like the ones obtained at the topsoil of the secondary forests and clearings of Mt. Kilimanjaro.

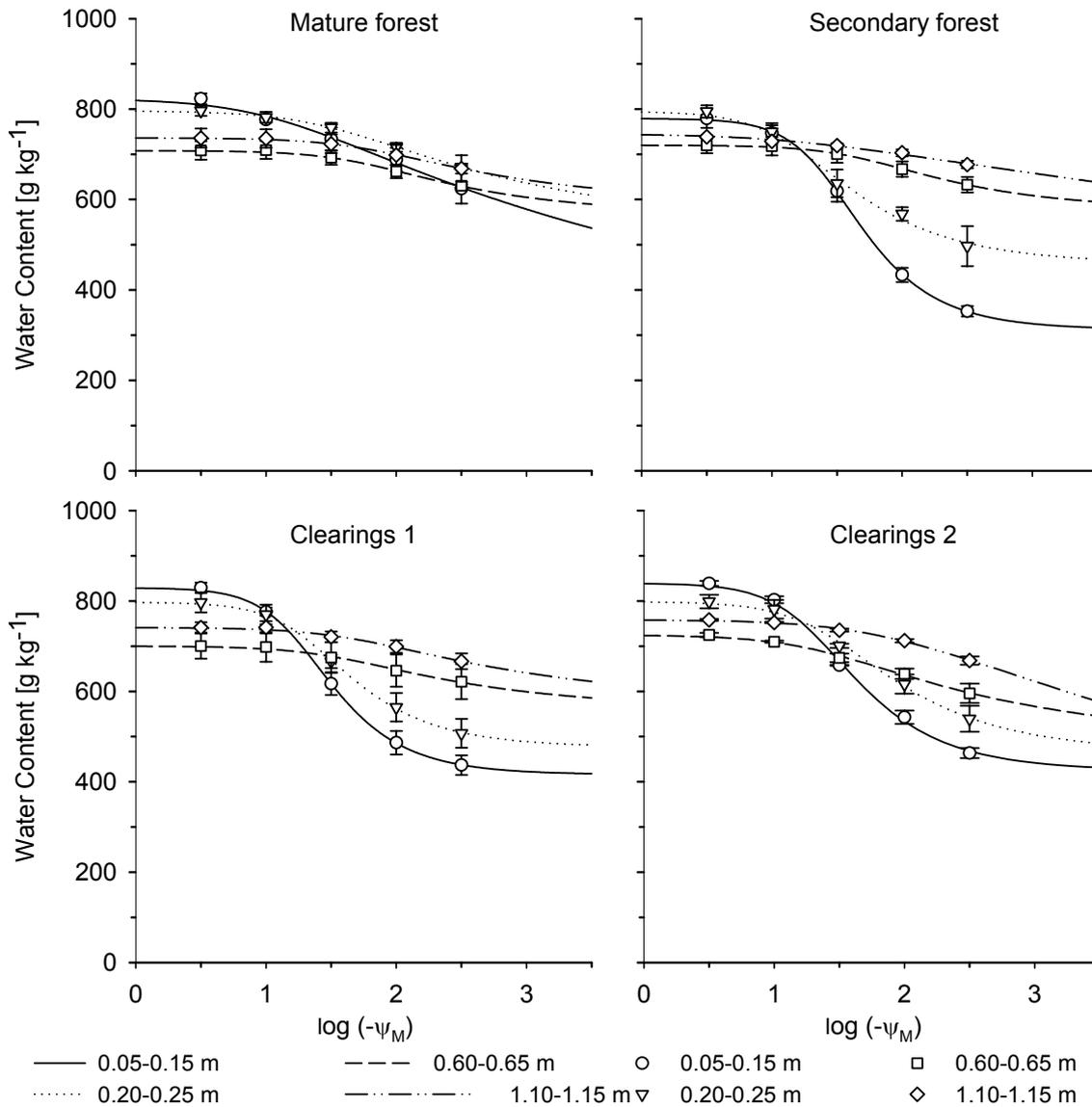


Fig. 3.9 Measured data points (\pm standard error, $n = 3$) and fitted (lines) soil-water characteristic curves at four soil depth under mature forest, secondary forest and clearings.

The differences in the topsoil water characteristics among sites indicate differences in the pore size distribution and thus aggregation or particle size distribution among sites. As bulk densities did not exhibit significant differences among sites, compaction is not supposed to be the reason. As can be seen from Figure 3.10, the sand content ($> 50 \mu\text{m}$) of the topsoil under secondary forest vegetation was significantly higher than under the mature forest. The sand content of the two groups of clearings was very similar and exhibited values between the two forest types. In consequence, the clay content was highest at the mature forest sites, indicating a higher percentage of micropores. The particle size analyses of Andisols has some

limitations as the high content of noncrystalline constituents inhibits proper particle dispersion (Shoji, et al. 1993), producing a potential source of error. Thus, prior to particle size analyses, some work on the optimisation of the dispersing agent was done to minimise these problems.

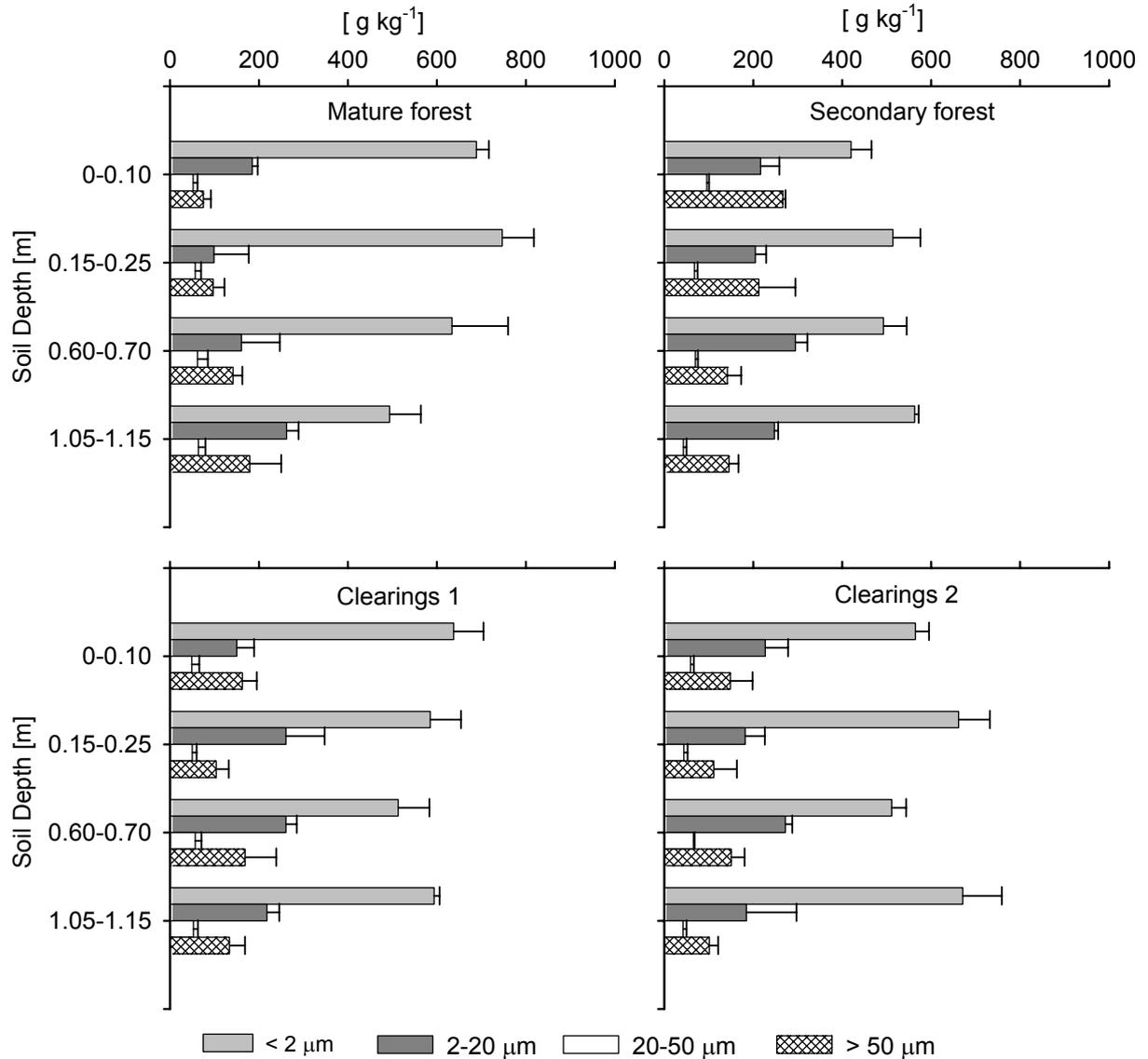


Fig. 3.10 Particle size distribution at four soil depths under mature forest, secondary forest and clearings (standard error, n = 3).

Andisols are known to irreversibly form stable aggregates after drying below a critical value between pF 3 and 4 (Wada 1989). This aggregation leads to changes in the particle size distribution, further affecting soil water retention, clay dispersibility, liquid limit and plastic limit (Shoji, et al. 1993). Usually, the clay content of volcanic ash soils increases with increasing soil age under similar climatic conditions (Miehlich 1991). As the ash layers at the topsoil of the sites are supposed to be of similar age, and weathering conditions were similar, the higher sand content at the

disturbed sites might have been the result of drying hysteresis. From the present data, a correlation between the disturbance of the sites and the changes in the physical soil properties cannot be proven beyond doubt. Burning of the sites at the beginning of the dry season, leaving the dark topsoil bare and exposed to the direct sun, would probably have increased soil water tension. Thus it seems very likely that the clearing of the forest led to a reduction in the water tension below the permanent wilting point (pF 4.2) resulting in irreversible changes in the topsoil structure.

Considering the water storage capability of the soils, the observed differences in the matrix potential among sites were more noticeable at higher matrix potentials through the different shape of the soil water retention curves of the topsoil. Thus, the soil water content and storage at soil water tensions close to saturation was similar. But at a higher water tension of 55 kPa (which was among the highest values measured with tensiometers in the topsoil) the water content at the secondary forest sites was only 48 % of what would be expected under the mature forest at a soil depth of 0.1 m and 80 % at a soil depth of 0.2 m respectively. Assuming that the measured properties at 0.1 m soil depth were representative for between 0-0.15 m and the values measured at 0.25 m for a vertical distance between 0.15 and 0.45 m, the secondary forest only stores 69 % of the water stored under the mature forest at a soil water tension of 55 kPa.

The results showed that soil water tension was usually lowest under the mature forest sites. The soil water content at a given water tension was higher in the topsoil horizons of the mature forest compared to the other sites. Hence, the estimated average water storage of the soils was also highest under mature forest. Diverted in rainy and dry seasons by rainfall amounts, the mean estimated soil water storage of the soil profiles up to a soil depth of 1.25 m is provided in Table 3.4. Although rainfall amounts were very similar at the different altitudinal levels of the forests, the soil water storage differed significantly at all times. Mainly during drier periods, the water storage under the secondary forest sites was also significantly lower than under the clearings. Under the present conditions, the most soil water storage occurred in the mature forest.

Table 3.4 Median of the estimated soil water storage to a soil depth of 1.25 m under different vegetation types (\pm standard error, $n = 3, 4$). Different letters indicate significant differences (Scheffé-test, $p < 0.05$).

	Σ rainfall		Estimated Mean Soil Water Storage (0-1.25 m)		
	2100 m	2250 m	Mature forest	Secondary forest	Clearings
	[mm]			[mm]	
Long rainy season 05/00-07/00	460	370	928 ^a ± 4	856 ^b ± 10	875 ^b ± 6
Long dry season 8/00-10/00	130	160	893 ^a ± 4	769 ^b ± 3	804 ^c ± 4
Short rainy season 11/00-01/01	780	830	921 ^a ± 3	844 ^b ± 8	848 ^b ± 3
Short dry season 02/01-03/01	250	260	909 ^a ± 4	798 ^b ± 6	830 ^c ± 2
Long rainy season 04/01-07/01	1570	1500	925 ^a ± 2	869 ^b ± 10	868 ^b ± 14
Long dry season 08/01-10/01	150	100	851 ^a ± 6	747 ^b ± 2	777 ^b ± 10
Short rainy season 11/00-01/02	430	520	908 ^a ± 4	774 ^b ± 9	830 ^c ± 7
Short dry season 02/02-03/02	300	380	913 ^a ± 2	793 ^b ± 14	838 ^c ± 12
Long rainy season 04/02-07/02	1400	560	909 ^a ± 2	829 ^b ± 2	850 ^b ± 9

CONCLUSIONS

Since water is a valuable source in the mainly semiarid Tanzania, the control of water yields from catchment areas is of great importance. Reductions in dry season runoff have usually been ascribed to a decrease in the water storage capacity of the forest and the soil either through a reduction in infiltration rates or the soil volume (due to erosion) (Bruijnzeel 1996). Andosols, which represent the dominant soil in the forest belt of the southwestern slopes of Mt. Kilimanjaro, are known to have a high water infiltration capacity and permeability as well as a high water storage capacity. As erosivity of the soils is low and infiltration rates probably maintain high after removal of the forest, the effects of vegetation transitions on water yields might be small on this soil type (Edwards, K.A. 1979). But it appears as if the high water

storage capacity of Andosols is vulnerable to drying because of irreversible sand-size aggregate formation. The present study shows that a shift in particle size distribution towards a higher content of sand size particles led to remarkable changes in the soil water content at water suctions around field capacity. Thus the capacity to store water close to saturation was similar among sites, but when dried, water release from the mature forest was lower leading to a higher soil water storage. In the present study, soil conditions under the mature forest are most suitable for a high water storage and should be maintained to preserve water yields from the mountain.

The observed differences in the soil matrix potential could not be purely attributed to changes in the vegetation cover as topographic position and soil permeability were not identical at all sites and the number of tensiometers was relatively low. Nevertheless, one should keep in mind that the fragmentation of a forest might lead to a higher spatial and seasonal variation in the soil water tension in this area. The increasing importance of edge effects with forest opening might lead to an increase in the water demand of the affected area and consequently to drier soil conditions. Within clearings, the soil water content is supposed to increase due to reduced evapotranspiration and interception. The effect of these probably controversial effects on water yields are not easily predictable. More detailed analyses using transects from clearings to the forest need to be established at similar topographic positions to quantify these effects.

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4 Internal Nutrient Cycling in a Tropical Mountain Rainforest at Mt. Kilimanjaro

INTRODUCTION

Tropical mountain rainforests have received increasing scientific attention during past decades due to their high biodiversity and importance as water catchment areas. The latter is especially of interest for mountain rainforests in East Africa, as they provide a permanent water source for the much drier surrounding savannah environment (Bjørndalen 1992). The forest belt of Mt. Kilimanjaro receives the highest annual amounts of rainfall in the region, and most springs also originate here. The water of Mt. Kilimanjaro enables highly productive irrigation agriculture on the drier, lower slopes. Furthermore, one of the biggest rivers in Tanzania, the Pangani River, with several hydroelectric power stations located along its banks is fed by water originating from Mt. Kilimanjaro. Similar to other areas in Africa with high population pressure, the forests of Mt. Kilimanjaro are subject to human interferences like logging and burning (Lambrechts et al. 2002). In order to understand the functioning of the forest and to detect changes related to human impact, the knowledge of the biogeochemical and hydrological cycles occurring within the intact forests is of essential importance.

Nutrient inputs via bulk precipitation are of special interest for forests on nutrient depleted soils. These typically occur in lowland, but also in some mountain rainforests (Forti & Neal 1992). With the exception of NH_4 and NO_3 , other nutrients are usually enriched during their passage through the canopy of mountain rainforests (Edwards 1982, Liu et al. 2002, Veneklaas 1990b, Wilcke et al. 2001). Cavelier et al. (1996), on the other hand, reported an absorption of SO_4 in the canopy of a mountain rainforest in Panama, while concentrations of nitrogen remained more or less unchanged. Some attempts have been made to distinguish between external (wet and dry deposition) and internal (canopy leaching, ion exchange) sources of net throughfall fluxes, but all of these have strong limitations (Lovett & Lindberg 1984).

Nutrient concentrations in stemflow usually exceed throughfall, while overall stemflow fluxes contribute little to total fluxes and are only of interest in the close vicinity of tree trunks (Bruijnzeel 1989, Hafkenschied 2000, Proctor 1987, Wilcke et al. 2001). The relevance of cloud and fog precipitation as additional sources of water and nutrients in mountain rainforests has been emphasised, but its quantification remains

difficult (Cavelier & Goldstein 1989, Clark et al. 1998). A high density of epiphytes in tree crowns is a characteristic feature of tropical mountain rainforests, and their ability to store extensive amounts of water has been confirmed by many authors (Cavelier & Goldstein 1989, Pócs 1980, Veneklaas 1990b). Net absorption of some nutrient ions like nitrate in the canopy is also partly attributed to epiphytes (Liu et al. 2002).

The amount and quality of litter fall has been widely used as a measure of nutrient status of tropical forest ecosystems (Heaney & Proctor 1989, Tanner 1980, Vitousek 1984). Nutrient fluxes via litterfall were often seasonal, with the highest amounts of litterfall occurring during dry periods (Hafkenschied 2000, Lisanewick & Michelsen 1994). Nadkarni & Matelson (1992) emphasised the importance of epiphyte litter fall for the availability of nutrients in small forest gaps.

As compared to aboveground nutrient fluxes, much less is known about nutrient release by mineralisation of organic material or mineral weathering, nutrient uptake by plants, nutrient translocation and fixation within the soil and nutrient output via drainage water in tropical forest ecosystems. Bruijnzeel & Proctor (1995) summarised the soil properties of various tropical mountain rainforests, and concluded that generalisations about soil nutrient status are very difficult to make. Low temperature, frequent water saturation of the soil, and low litter quality due to high amounts of phenols and low N content often lead to reduced nutrient release by decomposition in mountain rainforests as compared to lowland rainforests (Bruijnzeel et al. 1993, Edwards & Grubb 1982, Grubb 1977, Vitousek 1984). Marrs et al. (1988) observed a decrease in the N mineralisation rates with increasing elevation. Experiments on litter decomposition along rainfall gradients in Hawaii led to contradictory results (Austin 2002, Schuur et al. 2001). Studies on belowground nutrient fluxes are still rare in tropical and especially in mountain tropical forests. Bruijnzeel et al. (1993) and Hafkenschied (2000) both recorded a nutrient increase in the litter percolate compared to throughfall water. In the mineral soil, seepage nutrient concentrations were low. To estimate the nutrient output by stream water, usually catchment studies were applied (McDowell & Asbury 1994, Wilcke et al. 2001).

Most studies on biogeochemical cycling in mountain rainforests were conducted in Central and South America and Asia where these forests cover large areas, while information about East African forests is scarce. In natural forests and forest plantations on Mt. Meru and in the Usambara Mts., above and belowground

biomass, litterfall, rainfall and soil properties were studied by Lundgren (1978) and Lundgren & Lundgren (1979). On Mt. Kilimanjaro, soil properties and changes in the runoff regime have so far only been analysed in the cultivated zone (Iseki et al. 1981, Mizota et al. 1988, Sarmett & Faraji 1991).

Mountain forests on volcanoes within the East African Rift Valley system usually form isolated humid ecosystems surrounded by semiarid environments with a potential for salt accumulation at the soil surface, and salt lakes are regularly found in the vicinity of these volcanoes. As the African savannah plains are strongly affected by wind erosion (Prospero 1999), deposition of salts to the forest canopies during the dry season might be higher compared to other mountain rainforests encountered in more humid regions. The rainfall regime in the Kilimanjaro region is characterised by a high variability in annual amounts of rainfall, with minor rainy seasons sometimes failing (Hedberg 1964). Thus, nutrient inputs via rainfall, dry deposition and overall nutrient cycling will similarly vary from year to year and differ from other mountain forest ecosystems in the humid tropics.

In this study, biogeochemical cycles in a mature mountain rainforest at Mt. Kilimanjaro were investigated. Nutrient contents (K, Mg, Ca, Na, NO₃, NH₄) in rainfall, throughfall, percolate through the forest floor, soil solution and stream water were analysed for two consecutive years. Special emphasis was given to comparisons with other mountain rainforests and the possibility of nutrient limitations.

MATERIALS AND METHODS

SITE DESCRIPTION

The study was conducted on the humid southwestern slopes of Mt. Kilimanjaro above the village Machame. Since the forest close to the settlements is already widely depleted of valuable timber, ongoing illegal logging extends far into the forest belt. Hence, even the forest at higher altitudes is no longer undisturbed (Lambrechts et al. 2002). Four plots of mature forest with an intact closed canopy were chosen at an altitudinal range between 2250 and 2350 m, bordered to the east and west by the deeply incised rivers Kikafu and Weru-Weru. For the exact location of the plots see Figure 3.1.

VEGETATION

According to Hemp (2002), the mature forest in the study area can be classified as *Ocotea-Podocarpus* forest dominated by *Ocotea usambarensis* trees in association with *Podocarpus latifolius*. The forest reaches a height of about 40 m and is further characterised by a high density and diversity of epiphytes (among them many mosses and Hymenophyllaceae) and large groups of the tree fern *Cyathea manniana* (Hemp et al. 1999). A high species richness and cover of Hymenophyllaceae is found here, indicating constantly high humidity throughout the year. Complete species lists of vascular plants on the plots are provided by Axmacher (2003).

CLIMATE

The Kilimanjaro region experiences a bimodal rainfall distribution with a long rainy season from March to June and a short one in November and December. Most recent observations on rainfall amounts at the central southern slopes were presented in Hemp (2001), showing a rainfall maximum of about 3000 mm at 2100 m, which decreases to 90, 70 and 50% at 2400, 2700 and 3000 m, respectively. Rainstorms are frequent in the Kilimanjaro region, especially during the rainy season (Nieuwolt 1974). They usually provide heavy precipitation in a restricted area with sharp boundaries. In years with less rainstorm activity, total amounts of precipitation fall well below average, leading to a high variability in the interannual amount of rainfall as reported by Hedberg (1964).

This variability was also reflected in the rainfall amounts of the two years studied with 2480 mm recorded in the first (June 2000-June 2001) and 1960 mm in the second year (June 2001-June 2002). Throughfall amounts ranged between 2040 and 1370 mm in both years, resulting in a total rainfall interception by the vegetation of 18% in the first and 30% in the second year. From May to October 2001, temperature measurements 1.5 m above the ground were performed using a simple thermohygrometer on 50 individual days. The results show a median daily temperature minimum of 8.7 and a maximum of 14.8 °C. The lowest daily temperatures were measured in July (daily maximum around 10 °C) and the highest temperatures above 20 °C were obtained in May, September and October. Humidity within the forest more or less constantly exceeded 95% from May to July 2001. In the preceding extensive dry season from August to October, daily minimum and maximum values dropped to 69 and 87% (median) respectively with overall minimum values in October (37%). Further information on rainfall distribution is presented in Chapter 3.

SOILS

The soils in the study area have developed in ash layers of different ages which were deposited on young lava of the Lent Group (phonolites, trachyandesites, Downie & Wilkinson 1972). Next to each of the plots, a soil profile was analysed and chemically characterised. According to Soil Survey Staff (2003), soils were classified as Epiaquands and Fulvudands. At least three buried soils could be distinguished in each profile, the youngest occurring at depths between 40 and 70 cm below the soil surface. Three out of the four profiles showed a discontinuous indurated horizon at soil depths between 85 and 135 cm below the soil surface, representing the depths of ground water fluctuation during the rainy season. The thickness of the indurated horizon varied between 0.02 and 0.20 m and showed signs of Fe accumulation, while the overlaying horizons exhibited redox depletions (see profile 2250 m in Chapter 2).

Table 4.1 Summarises soil properties of the soil horizons where suction cups were installed. For methods applied in physical and chemical soil analyses, refer to Chapter 2. The soils showed characteristically high contents of amorphous, acid-oxalate extractable Fe and Al, high carbon and clay contents and a low bulk density (see Table 4.1 and Chapter 2 and 3). Organic carbon contents in the upper soil horizons showed a high spatial variability, which is probably due to the digging activities of forest pigs. Acid pH-values led to a low effective cation exchange capacity even in humus-rich A horizons. Exchange sites were dominated by Al ions, followed by Ca, Mg, K and Na. High amounts of amorphous clay minerals and oxides led to a high P-sorption capacity of the soils (P-retention > 90 %, see Chapter 2). Thus, the status of available nutrients in the soils was rather poor.

Table 4.1 Selected soil properties (means with standard error, $n = 4$, texture: $n = 3$) at three different soil depths (0.1-0.2, 0.25-0.35 and 0.95-1.05 m, representing depths of suction cups).

Soil Depth m	pH	pH	pH	C	N	Sand > 53 μm	Silt	Clay	Alo
	H ₂ O	CaCl ₂	KCl						
0.1-0.2	4.0	3.5	3.3	188	11.3	97	156	747	9.3
	± 0.1	± 0.1	± 0.1	± 28	± 1.5	± 26	± 25	± 71	± 2.2
0.25-0.35	4.6	4.2	4.3	117	6.2	142	224	634	37.4
	± 0.1	± 0.1	± 0.1	± 12	± 0.4	± 21	± 37	± 126	± 5.5
0.95-1.05	4.7	4.8	5.0	70	3.0	179	327	494	57.5
	± 0.1	± 0.1	± 0.1	± 7	± 0.5	± 71	± 43	± 70	± 6.8

Soil Depth m	CEC	ECEC	K	Mg	Ca	Na	Al
	[cmol (+) kg ⁻¹]	[cmol (+) kg ⁻¹]					
0.1-0.2	75.3	3.0	0.23	0.24	0.40	0.09	1.13
	± 5.7	± 0.4	± 0.04	± 0.03	± 0.04	± 0.02	± 0.18
0.25-0.35	70.5*	0.7	0.06	0.03	0.10	0.05	0.38
		± 0.9	± 0.01	± 0.01	± 0.02	± 0.02	± 0.03
0.95-1.05	57.8	0.6	0.06	0.01	0.19	0.03	0.32
	± 2.5	± 0.2	± 0.02	± 0.01	± 0.17	± 0.01	± 0.07

* only two replicates, therefore no standard error was calculated.

STUDY DESIGN

The study was conducted on four plots of 400 m² each. In order to avoid the strong impact of erosion and surface runoff, all plots had an inclination of less than 10°. The homogeneity of soils on the plots was tested using soil coring. For throughfall measurement, all plots were equipped with 8-10 randomly distributed collectors consisting of a sharp rimmed funnel (115 mm diameter) and a 2 l collecting bottle (polyethylene). To avoid substantial contamination of the samples by insects or litter, the funnel outlet was covered by a 1 mm plastic net which was cleared after sampling when necessary. A table-tennis ball was placed in the funnel to reduce evaporation. In a nearby forest opening, five more raincatchers were installed 1.5 m above the ground to collect rainfall. As *Ocotea usambarensis* was the only tree in the canopy layer on the plots, three stems of representative trees were surrounded by a pipeline of foamed rubber to collect the stemflow. Since no mature *Podocarpus*

latifolius – tree, which is commonly associated with *O. usambarensis* at this altitude, was present on the plots, one *Podocarpus* tree neighbouring the plots was similarly equipped. Samples were collected in 50 l plastic containers.

Four free draining lysimeters were installed below the dense root mat in the Oa horizon of the litter layer. As the soils had a very high carbon content in the topsoil, this borderline was not necessarily identical with the beginning of the mineral soil. Nevertheless, an increase in bulk density, a decrease in root density and a change in soil colour were observed at this depth in the field. The change in soil properties was also defined as the baseline for the installation of suction cups. Lysimeters were made of plastic boxes with a side length of 285 mm and a height of 80 mm. Each box was covered with a 1 mm mesh net and connected to a polyethylene sampling bottle by a silicon tube in the ground. Suction cups (SKL100, ceramic cup K100, UMS, Munich) for soil water extraction were installed at depths of 0.15, 0.30 and 1.00 m in three replicates per plot. Cups from different depths were grouped together in a triangle with 1 m side length and the three triangles were again arranged as a larger triangle with a distance of 5 m to a pump (Vacuum case VK-3, UMS, Munich) located at the plot centre. To prevent preferential flow and to ensure contact between the ceramic cup and the soil, the surrounding of the cups was filled with suspended soil material of the corresponding soil horizon after installation, and the shaft was sealed with a silicon ring (0.1 m diameter) at the soil surface. One day before sampling, the pumps were switched on to create a constant suction of 400 hPa for 24 h. Samples of each soil depth were combined in one Duran glass bottle. All sampling bottles were regularly cleaned and brushed. Litter was collected from the litter layer at five places per plot on the ground separately for the L, Oi and Oa horizons. Furthermore, litter collectors were placed in two replicates on three of the plots to calculate litterfall amounts. They were made of a wooden frame of 0.5m x 0.5 m, covered with a polyethylene net (1 mm mesh) and placed horizontally 0.25 m above the ground.

SAMPLING PROCEDURE AND SAMPLE TREATMENT

In order to avoid pollution effects caused by installation and to wait for equilibrium conditions between the suction cups and the surrounding soil, all samples collected in the first two months were discarded. Starting from May 2000, solution from raincatchers and suction cups were sampled twice a week (alternating every three and four days). Installation of the lysimeters and stemflow devices was only completed in October 2001, so data from the first five months is missing. Water volumes were reported separately for each rain and litter percolate collector, but for

sample collection, 100 ml of a composite sample representing the whole plot were taken. After the first year, sampling frequency was reduced to weekly collections from May 2001 onwards. Litterfall samples were taken on a monthly basis starting from November 2000.

Water samples were combined to make composite samples for every fortnight and were stored frozen. Samples of rain and litter percolate were mixed volume weighted, while equal portions were used for the soil solution as no reliable information about the belowground water fluxes was available. On three sampling occasions, samples had to be excluded from mixed samples as either data or samples were missing. Suction cups extracted soil water regularly, except for a very dry period in September and October 2001 when almost all cups failed. Where soil solution was not available for individual times and soil depths, mixed samples were made of the remaining samples of the two week period. Litter samples were also combined per plot and stored in air-dried conditions.

CHEMICAL ANALYSES

Except for the determination of pH-values, all analyses were carried out at the University of Bayreuth. The pH of water samples was measured using a standard combined electrode with integrated temperature probe (WTW SenTix 41 pH 330). Values are not discussed in detail in this Chapter, but some are presented in Appendix E. Prior to analysis, solution from rain catchers and lysimeters was filtered through ash-free filter paper with a pore size $< 2 \mu\text{m}$ (Schleicher & Schuell, blue band 589³). Litter samples were separated into leaves, twigs, mosses and lichens and a rest, consisting of reproductive and undeterminable plant parts, and weighted. All the samples were then recombined, ground and digested with concentrated HNO_3 under pressure for nutrient analysis (after Heinrichs et al. 1986). Determination of total N contents was conducted on ball-milled samples using a total element analyser (Elementar Vario EL). Flame absorption spectrometry (AAS; Varian SpectrAA 400) was used to measure element concentrations of K, Mg, Ca and Na in water samples and plant extracts. $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ in rain and soil solution samples, were analysed with a Segmented Flow Analyser (SAN plus SYSTEM, SKALAR).

DATA ANALYSIS AND STATISTICAL EVALUATION

The plots were monitored for a total period of two years and four months from May 2000 to August 2002. Nutrient fluxes in rainfall and throughfall were calculated by multiplying recorded water fluxes with the respective element concentrations. Means of fluxes and concentrations were calculated on an annual basis for two consecutive years starting from June 2000. Unfortunately, the start of litter percolate and small litter collection was slightly delayed, resulting in incomplete samples for the first year. Volume weighted means were calculated for rainfall and throughfall by dividing the product of element concentration and water flux amount by the total water flux of the year for fortnight periods and subsequently summing the terms. The median concentration of fortnight samples from one year was used for litter percolate and soil solution as no reliable data on fluxes were available. Net throughfall fluxes were determined as the difference between throughfall and rainfall fluxes. The problems associated with the usage of lysimeters and suction cups for the collection of seepage water are summarised in Chapter 5.

Statistical analyses were conducted using the statistical work package STATISTICA 5.0 (Statsoft, Inc., Tulsa, UK). Correlation analyses were done as Pearson Product-Moment Correlations.

RESULTS

WATER CHEMISTRY

Mean concentrations for rainfall, throughfall, litter percolate and soil solution are given in Table 4.2 for each year. The highest concentrations in rainfall were measured for K followed by Na, and the smallest concentrations were obtained for Mg. While the concentrations of all cations increased while passing the forest canopy, $\text{NO}_3\text{-N}$ concentrations decreased so that throughfall concentrations were lowest for $\text{NO}_3\text{-N}$. As litter percolate values were missing for the first months, annual mean concentrations were only calculated for the second year. In the litter percolate, concentrations exceeded throughfall values for all nutrients except for K and Na. The greatest concentration increase was observed for $\text{NO}_3\text{-N}$. In the soil solution, all concentrations except for $\text{NO}_3\text{-N}$ were distinctly lower than in the litter percolate. Concentrations in the soil solution decreased in the order $\text{NO}_3\text{-N} > \text{Na} > \text{Ca} > \text{K}, \text{Mg} > \text{NH}_4\text{-N}$. Overall, cation concentrations in the soil solution were very low and sometimes close to the detection limit. $\text{NO}_3\text{-N}$ concentrations tended to decrease with increasing soil depths, while for the cations no general trend was observed. $\text{NO}_3\text{-N}$,

Ca and Mg concentrations were lower in the stream water than in the soil solution, indicating that these ions were further absorbed in deeper soil layers. Na, K and NH₄-N concentrations, on the other hand, increased.

A comparison of the two study years reveals an increase in K, Mg, Ca and Na concentrations in throughfall from the first to the second year. For K and Ca, mean concentrations of both years differed significantly ($p < 0.05$). Concentrations of N-forms in throughfall remained constant for both years. In the soil solution, no differences in nutrient concentrations were observed between the study years.

Table 4.2 Annual means of nutrient concentrations in different ecosystem compartments (\pm standard error, $n = 4$). For rainwater and throughfall, volume weighted mean concentrations for each year were calculated, while the median concentration was used for litter leachates, soil solution and stream water.

		Nutrient Concentrations					
		K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N
		[mg l ⁻¹]					
Rainfall	Year 1	0.30	0.04	0.09	0.30	0.16	0.13
	Year 2	0.50	0.05	0.15	0.36	0.16	0.17
Throughfall	Year 1	1.50 ± 0.20	0.08 ± 0.02	0.13 ± 0.01	0.53 ± 0.09	0.19 ± 0.02	0.05 ± 0.01
	Year 2	2.97 ± 0.15	0.16 ± 0.03	0.34 ± 0.05	0.90 ± 0.11	0.19 ± 0.01	0.05 ± 0.01
Litter Percolate	Year 1	-	-	-	-	-	-
	Year 2	1.44 ± 0.50	0.32 ± 0.06	0.79 ± 0.15	0.81 ± 0.05	0.27 ± 0.04	0.92 ± 0.25
Soil Solution 0.15 m	Year 1	0.15 ± 0.04	0.15 ± 0.06	0.27 ± 0.10	0.42 ± 0.07	0.03 ± 0.00	1.48 ± 0.34
	Year 2	0.19 ± 0.04	0.11 ± 0.02	0.25 ± 0.06	0.41 ± 0.08	0.04 ± 0.00	1.54 ± 0.55
0.30 m	Year 1	0.16 ± 0.04	0.14 ± 0.06	0.25 ± 0.08	0.35 ± 0.07	0.02 ± 0.00	1.42 ± 0.13
	Year 2	0.18 ± 0.03	0.15 ± 0.06	0.26 ± 0.08	0.038 ± 0.09	0.04 ± 0.00	1.41 ± 0.31
1.00 m	Year 1	0.15 ± 0.02	0.13 ± 0.02	0.21 ± 0.06	0.31 ± 0.03	0.03 ± 0.00	1.11 ± 0.12
	Year 2	0.21 ± 0.04	0.13 ± 0.03	0.27 ± 0.08	0.40 ± 0.05	0.04 ± 0.00	1.07 ± 0.17
Runoff	Year 1	0.70	0.07	0.14	1.18	0.05	0.60
	Year 2	0.84	0.08	0.16	1.25	0.06	0.56

Throughfall, litter percolate and soil solution in the topsoil all exhibited a similar seasonal pattern in nutrient concentrations (Fig. 4.1). Maximum concentrations in the soil solution tended to be slightly delayed compared to the other solutions. For both years, the highest concentrations were observed during dry periods with maximum values at the dry season in September and October. During the moderately dry period from February to March 2001 between the two rainy seasons, nutrient concentrations also increased. The rainfall distribution did not show a similar dry period in 2002, and concentrations of basic cations reached a maximum in January and February, hence a bit earlier than the year before (Fig. 4.1).

The highest seasonal variability of Mg, Ca and $\text{NH}_4\text{-N}$ concentrations occurred in litter leachates. For K and Na on the other hand, throughfall concentrations were similar or even more variable than in the litter percolate. $\text{NO}_3\text{-N}$ was the only nutrient exhibiting higher soil solution concentrations compared to the litter percolate. Still seasonal fluctuation of $\text{NO}_3\text{-N}$ was also greatest in the litter percolate. Overall, seasonal fluctuation in the soil solution composition was low compared to throughfall and litter percolate (Fig. 4.2). With the exception of $\text{NO}_3\text{-N}$, nutrient concentrations in the soil solution were low and differences at various soil depths were small. The highest concentrations were obtained during the prominent dry season 2001 for all soil depths. Notably, the soil solution from 1.0 m depth might have been influenced by high groundwater levels. While concentrations of Mg and Ca in stream water were low and did not indicate a seasonal trend, K and Na concentrations showed broad maxima during drier periods.

The composition of stemflow revealed tree species specific differences in ion concentrations for K, Mg and Ca, but not for Na. Figure 4.3 presents box whisker plots of fortnight stemflow samples of four individual trees for a period of one year. The results indicate that median concentrations of K, Mg and Ca were higher for the Podocarpus tree compared to the three Ocotea trees. Na concentrations were more or less similar among the different trees.

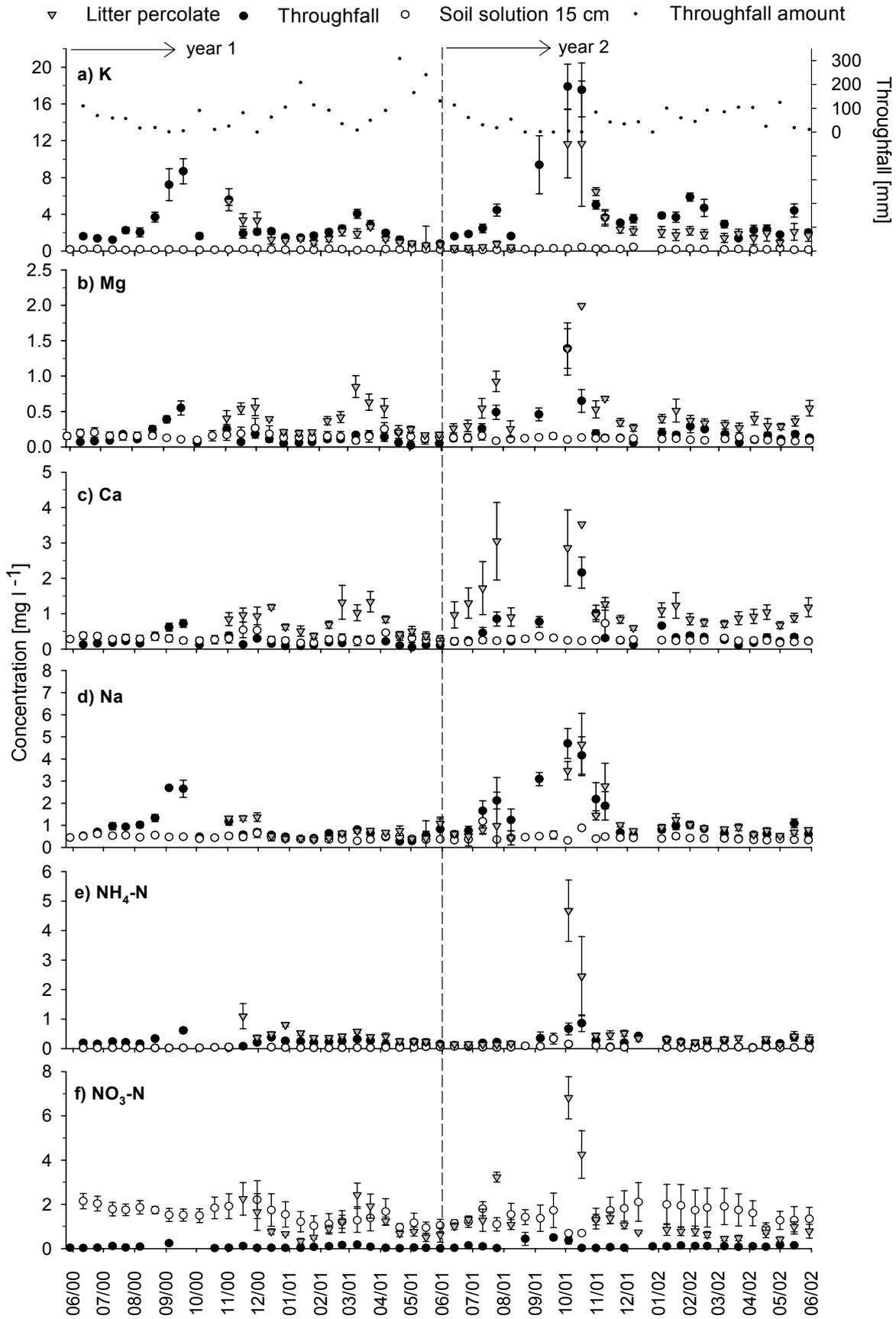


Fig. 4.1 Seasonal variation of concentrations in throughfall, litter percolate and soil solution for two consecutive years from June 2000 to May 2002 (\pm standard error, $n = 4$).

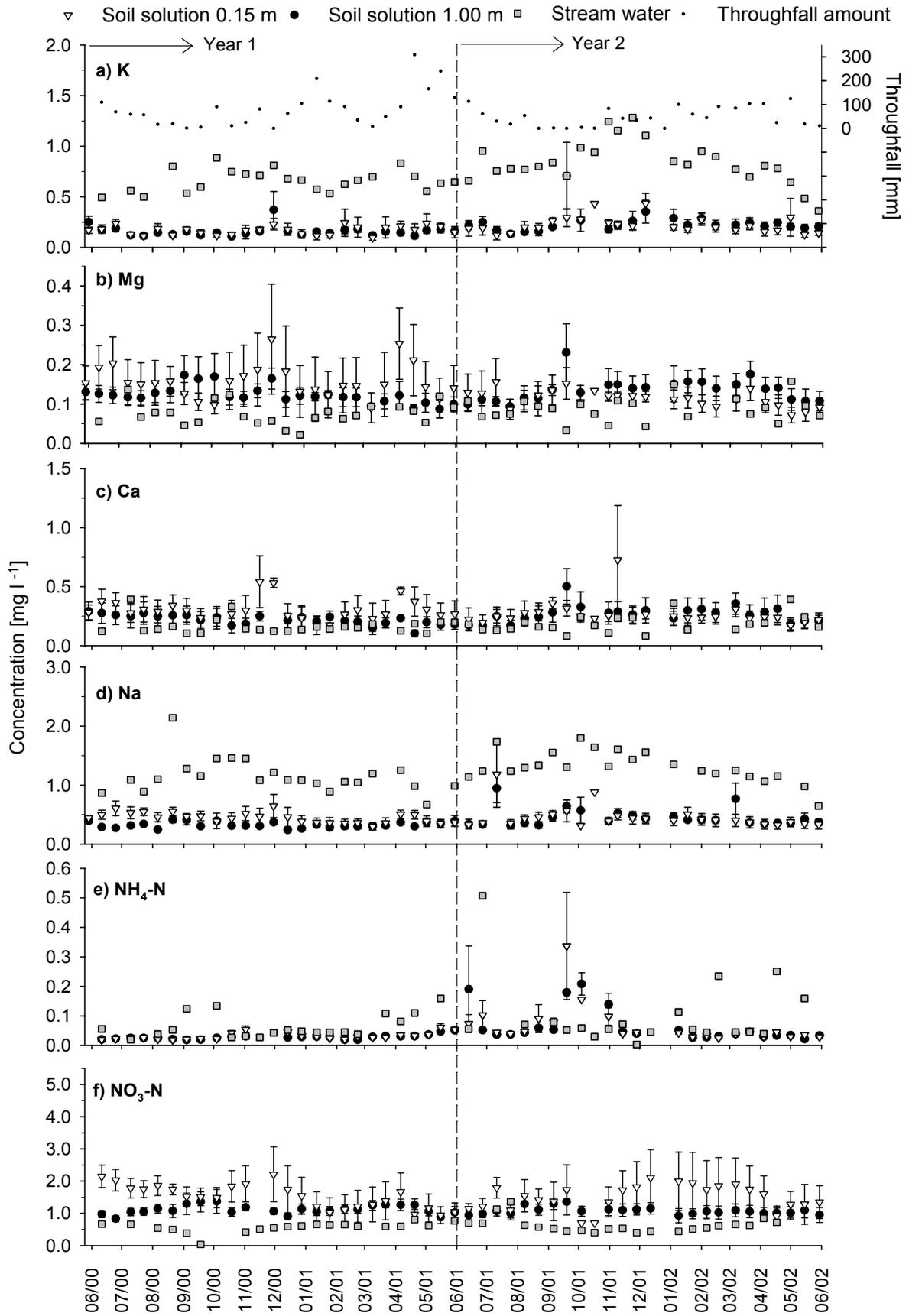


Fig. 4.2 Seasonal variation of nutrient concentrations in soil solution (0.15, 1.00 m) and in stream water from June 2000 until May 2002 (\pm standard error for soil solution, $n = 4$).

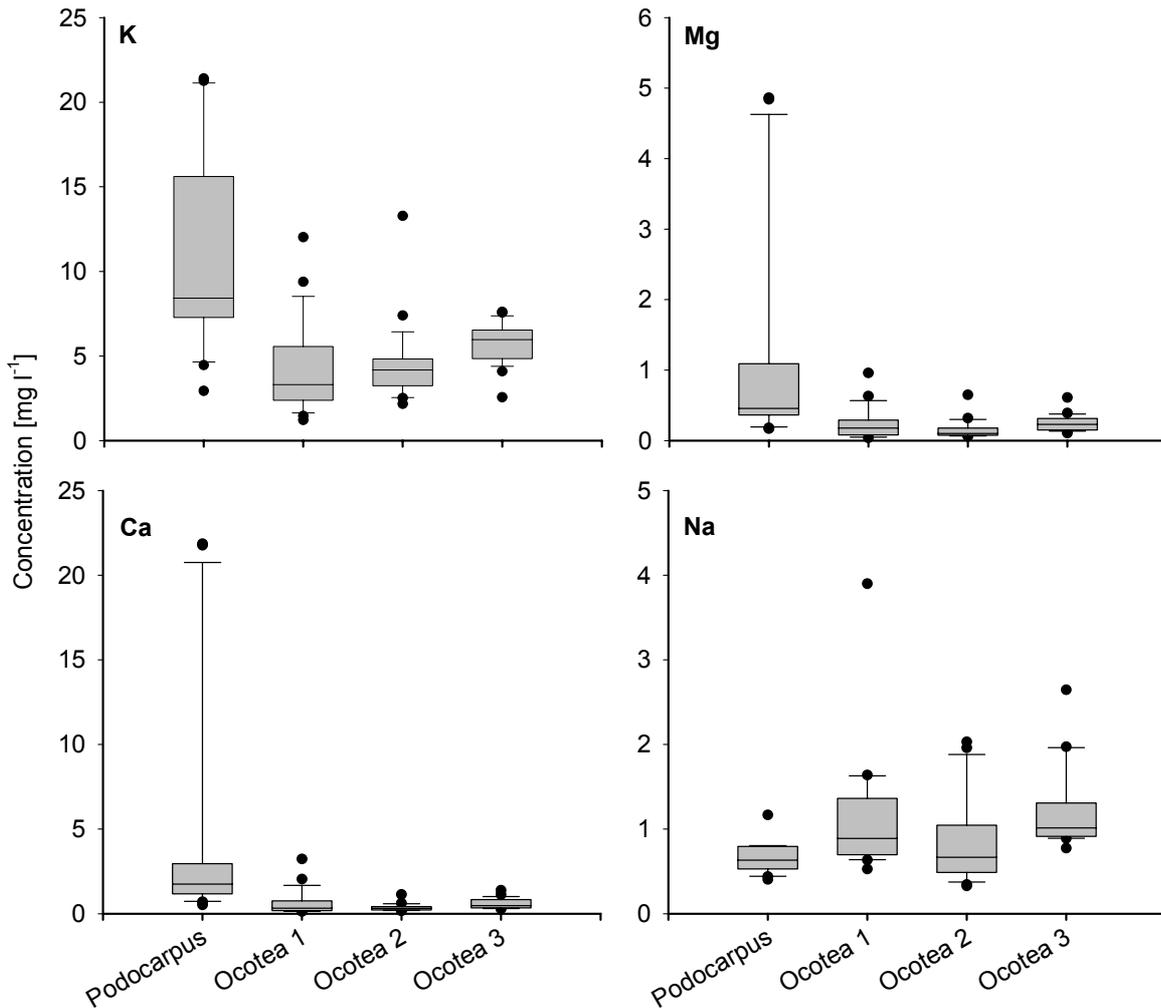


Fig. 4.3 Concentrations of basic cations in the stemflow of four trees. Box plots include measurements in fortnight samples from November 2000 until November 2001.

A correlation between rainfall and throughfall concentration was found for the basic cations in both years (Table 4.4). $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ only exhibited significant correlations in the second year. The similar seasonal fluctuation pattern of the nutrient concentrations in throughfall and litter percolate resulted in significant correlations between the concentrations of throughfall and litter percolate ($p < 0.05$). Information on litter percolate is missing for the first five months of the first year, so the data base of this year was incomplete. Furthermore, the relevant time period included the long dry season during which the concentrations were usually highest. These high concentrations were responsible for the close correlations between throughfall and litter percolate concentrations in the second year. Thus, correlations in the first year were less strong and for $\text{NH}_4\text{-N}$ not significant. In the soil solution, only $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ exhibited significant correlations between the soil solution at

0.15 and 0.30 m in both years ($r = 0.53$, $p < 0.01$ and $r = 0.70$, $p < 0.001$ in the first and $r = 0.93$, $p < 0.001$ and $r = 0.40$, $p < 0.05$ in the second year, respectively).

Dilution effects by high rainfall and throughfall amounts result in a linear relation between water amounts and inverse concentrations (concentration⁻¹). Between rainfall amounts and inverse concentrations, only weak correlations were obtained. These were not significant for K and NH₄-N for the total study period. Except for some outliers, close correlations between throughfall amounts and inverse concentrations were obtained for basic cations in the first year (Fig. 4.4). In the second year, correlations were weaker and for Ca not significant. Fortnight periods with rainfall amounts > 150 mm, which were partly responsible for stronger dilution effects in the first year, were missing in the second one leading to lower correlations. For inverse NH₄-N and NO₃-N concentrations, correlations with throughfall amounts were weak if present at all.

The similar patterns in seasonal changes of nutrient concentrations in the litter percolate, observable in Figure 4.1, is reflected in correlations between the concentrations of individual ion species (Table 4.4). In the soil solution at 0.15 m soil depth, these correlations were much weaker and in most cases not detectable (Table 4.5).

NUTRIENT FLUXES IN BULK PRECIPITATION

Annual nutrient inputs from bulk precipitation decreased in the order K > Na > NH₄-N, NO₃-N > Ca > Mg (Table 4.6). Although the second year received around 500 mm less rain, the nutrient fluxes did not respectively decline. The higher rainfall concentrations for K and Ca outweighed the decline in rainfall amounts, so that their fluxes even increased, while fluxes of other nutrients were lesser in the second year. Throughfall fluxes for K, Mg and Na did not show distinct differences between the years. Ca fluxes on the other hand were more than 60% greater in the second year compared to the first, while N fluxes declined. Net fluxes give an idea about nutrient enrichment or depletion on the passage of water through the forest canopy. Net fluxes of all basic cations were positive, indicating a net enrichment. The highest accumulation rates were obtained for K followed by Mg > Na > Ca. NH₄-N showed net fluxes close to zero, while negative net fluxes of NO₃-N indicated a net retention in the forest canopy for both years.

Table 4.3 Correlation coefficients of Pearson Product-Moment Correlations between concentrations in rainfall and throughfall, throughfall and litter percolate and litter percolate and soil solution in 0.15 m soil depth. Correlation coefficients (r) are given together with the level of significance.

	Correlation Coefficients			
	Rainfall vs. Throughfall		Throughfall vs. Litter Percolate	
	Year 1 n = 22	Year 2 ⁺ n = 22	Year 1 ⁺⁺ n = 15	Year 2 n = 22
K	0.70 ****	0.94 ****	0.79 ****	0.94 ****
Mg	0.95 ****	0.82 ****	0.63 ***	0.77 ****
Ca	0.93 ****	0.78 ****	0.54 *	0.81 ****
Na	0.61 ****	0.88 ****	0.62 *	0.88 ****
NH ₄ -N	0.36 n.s.	0.79 ****	-0.02 n.s.	0.77 ****
NO ₃ -N	0.29 n.s.	0.60 ***	0.73 ***	0.83 ****

**** p < 0.001, *** p < 0.005, ** p < 0.01, * p < 0.05, (*) p < 0.1 n.s. not significant

⁺ Three times data set for rainfall were incomplete and excluded from the calculation

⁺⁺ Data exclude the first five months of the year as collection of litter percolate only started in December 2000.

Table 4.4 Correlations between the concentrations of individual nutrients in litter percolate (correlation coefficient r, n = 21).

	K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N
K	---	0.85 ****	0.64 ***	0.91 ****	0.92 ****	0.80 ****
Mg		---	0.92 ****	0.92 ****	0.92 ****	0.85 ****
Ca			---	0.73 ****	0.76 ****	0.86 ****
Na				---	0.91 ****	0.76 ****
NH ₄ -N					---	0.83 ****
NO ₃ -N						---

**** p < 0.001, *** p < 0.005, ** p < 0.01, * p < 0.05, (*) p < 0.1 n.s. not significant

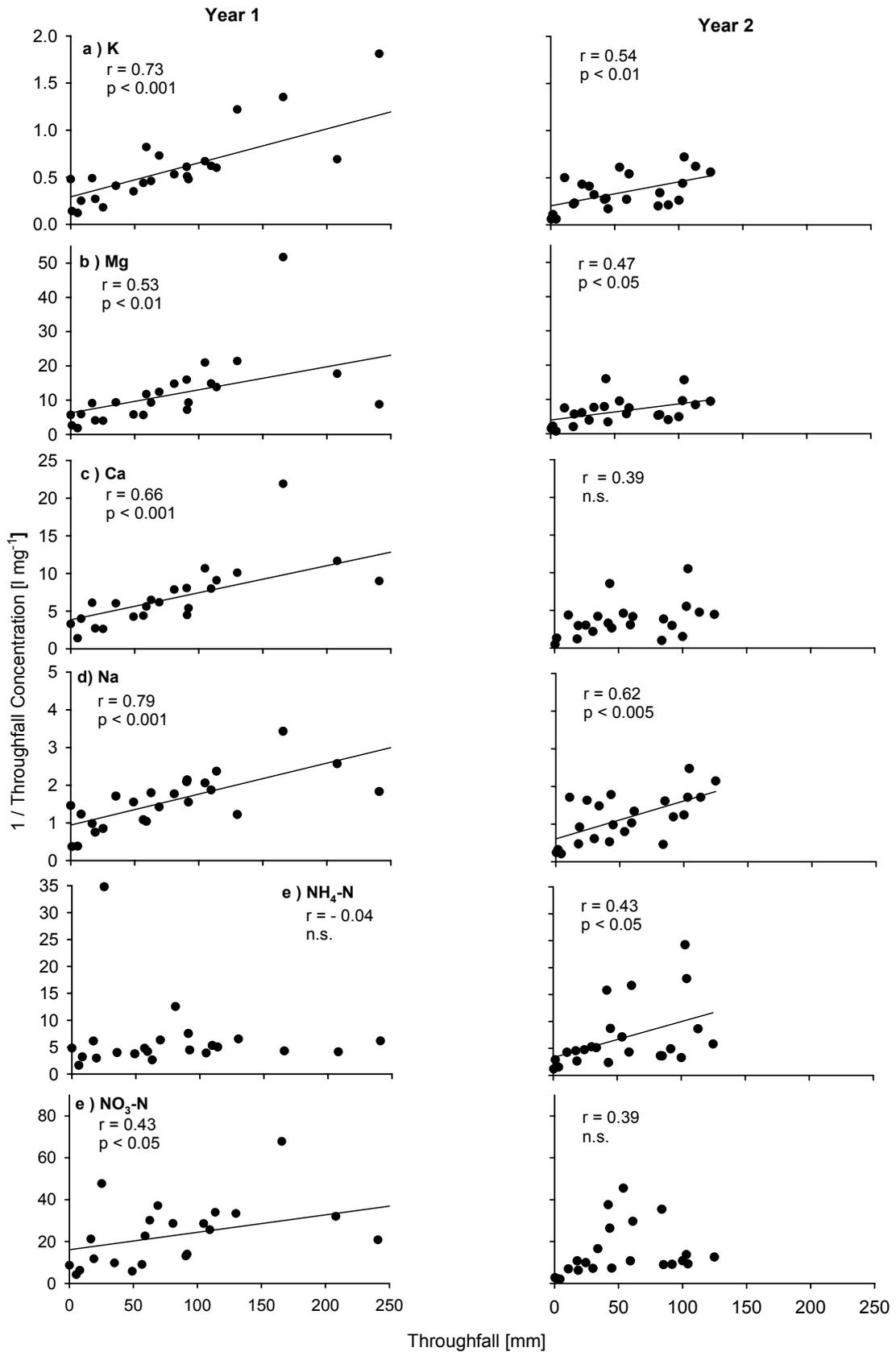


Fig 4.4 Linear correlations between the inverse nutrient concentrations (concentration⁻¹) and the amounts of throughfall in the first and second year.

Table 4.5 Correlations between the concentrations of individual nutrients in soil solution (correlation coefficient r). The upper right part represents the first study year ($n = 24$), the lower left part the second ($n = 23$).

	K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N
K	---	0.45 *	0.49 *	0.06 n.s.	0.13 n.s.	-0.06 n.s.
Mg	0.12 n.s.	---	0.81 ****	0.61 ***	0.06 n.s.	0.40 n.s.
Ca	0.17 n.s.	0.26 n.s.	---	0.63 ****	-0.05 n.s.	0.39 n.s.
Na	-0.18 n.s.	0.59 ***	0.14 n.s.	---	-0.19 n.s.	0.72 ****
NH ₄ -N	0.50 *	0.49 *	0.06 n.s.	0.08 n.s.	---	-0.24 n.s.
NO ₃ -N	-0.05 n.s.	0.33 n.s.	0.23 n.s.	0.39 n.s.	-0.15 n.s.	---

**** $p < 0.001$, *** $p < 0.005$, ** $p < 0.01$, * $p < 0.05$, (*) $p < 0.1$ n.s. not significant

Table 4.6 Mean nutrient fluxes via precipitation and throughfall. Net fluxes were calculated as difference between throughfall and rainfall fluxes (\pm standard error, $n = 4$)

		Nutrient Fluxes					
		K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N
		[kg ha ⁻¹ a ⁻¹]					
Rainfall	year 1	6.9	0.9	2.1	6.7	3.6	3.0
	year 2	8.0	0.8	2.4	5.7	2.5	2.7
Throughfall	year 1	32.2 ± 4.0	1.8 ± 0.4	2.8 ± 0.3	11.5 ± 2.0	4.2 ± 0.4	1.0 ± 0.3
	year 2	37.2 ± 1.8	2.0 ± 0.3	4.2 ± 0.6	11.2 ± 1.2	2.4 ± 0.1	0.7 ± 0.2
Net throughfall	year 1	25.3	0.9	0.7	4.8	0.6	-2
	year 2	29.2	1.2	1.8	5.5	-0.1	-2

Figure 4.5 shows that nutrient fluxes followed seasonal pattern. The greatest nutrient fluxes in throughfall were observed during high rainfall periods. This can best be seen in the first year when rainy seasons were more distinct compared to the second year. Rainfall at the end of October 2001 ended a long dry period and resulted in exceptionally high peaks for K, Ca and Na.

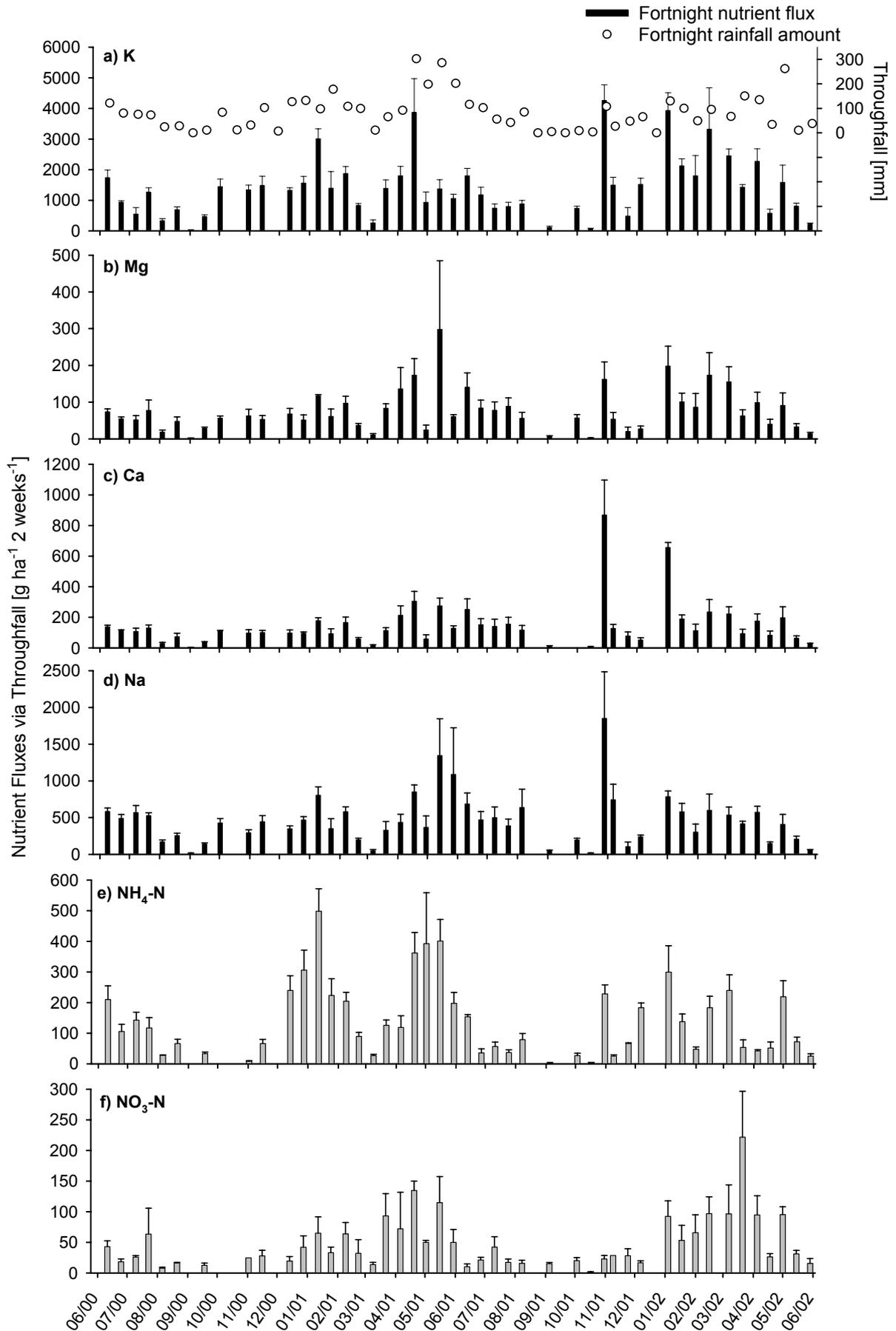


Fig. 4.5 Seasonal variation in nutrient fluxes via throughfall (\pm standard error, $n = 4$).

The observation that the highest throughfall fluxes were accompanied by great amounts of rainfall was confirmed by positive correlations between the amount of throughfall water and nutrient fluxes for all nutrients. The closest correlations for both years were obtained for $\text{NH}_4\text{-N}$ ($r = 0.84$, $p < 0.001$), the weakest for Ca ($r = 0.45$, $p < 0.001$). Analysis of net throughfall fluxes give information on the origin and fate of nutrient ions in the forest canopy. While both N forms did not show any correlations to rainfall amounts, basic cations did in the first year. In the second year, correlations were weaker and only significant for K and Mg. The net gain and loss of nutrients in the canopy might also be related to the rainfall concentrations of individual nutrients. Veneklaas (1990) used correlations between rainfall concentrations and net throughfall fluxes per mm rain to test this hypothesis. At Mt. Kilimanjaro, no correlations between rainfall concentrations and net fluxes per mm rain were obtained for K and Mg, but for $\text{NO}_3\text{-N}$, correlations were very strong. This indicates that net K and Mg fluxes were determined more by rainfall amounts, while net $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ fluxes were more dependent upon their respective concentration in rainfall. Ca and Na showed intermediate trends.

Table 4.7 Results of Pearson Product-Moment correlations between net throughfall fluxes and rainfall amounts at the left side and net throughfall fluxes per mm rain and rainfall concentrations at the right side. Correlation coefficients (r) are given together with the level of significance ($n = 17\text{-}23$).

	Correlation Coefficients			
	Net throughfall fluxes vs. rainfall amounts		Net throughfall flux per mm rain vs. rainfall concentrations	
	Year 1	Year 2	Year 1	Year 2
K	0.77 ****	0.62 ****	0.31 n.s.	-0.17 n.s.
Mg	0.72 ****	0.60 ***	-0.07 n.s.	-0.49 *
Ca	0.63 ****	0.36 n.s.	-0.81 ****	-0.73 ****
Na	0.65 ****	0.37 n.s.	-0.69 ****	-0.39 n.s.
$\text{NH}_4\text{-N}$	0.37 n.s.	0.19 n.s.	-0.62 ****	-0.76 ****
$\text{NO}_3\text{-N}$	0.11 n.s.	-0.05 n.s.	-0.95 ****	-0.97 ****

**** $p < 0.001$, *** $p < 0.005$, ** $p < 0.01$, * $p < 0.05$, n.s. not significant

Correlations between rainfall fluxes of individual nutrients were weak (Table 4.8). The closest correlations were obtained for Mg and Na. The correlations of NO₃-N to other nutrients were usually weakest. Considering net throughfall fluxes, all base cations were correlated with each other, while correlations for both N forms were weaker and especially for NO₃-N, in most cases, not significant (Table 4.9).

Table 4.8 Correlation between rainfall fluxes of different nutrients.

	K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N
K	---	0.52 ****	0.40 ***	0.51 ****	0.41 ***	0.13 n.s.
Mg		---	0.57 ****	0.75 ****	0.49 ****	0.55 ****
Ca			---	0.39 ***	0.44 ***	0.18 n.s.
Na				---	0.43 ***	0.44 ***
NH ₄ -N					---	0.22 n.s.
NO ₃ -N						---

**** p < 0.001, *** p < 0.005, ** p < 0.01, * p < 0.05, (*) p < 0.1 n.s. not significant

Table 4.9 Correlation between net throughfall fluxes of different nutrients.

	K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N
K	---	0.73 ****	0.64 ***	0.66 ****	0.37 **	0.07 n.s.
Mg		---	0.53 ****	0.61 ****	0.42 ***	0.28 n.s.
Ca			---	0.72 ****	0.28 n.s.	0.19 n.s.
Na				---	0.38 **	0.09 n.s.
NH ₄ -N					---	0.03 n.s.
NO ₃ -N						---

**** p < 0.001, *** p < 0.005, ** p < 0.01, * p < 0.05, (*) p < 0.1 n.s. not significant

NUTRIENT INPUT VIA LITTERFALL

Besides throughfall fluxes, another path by which nutrients are returned to the forest floor is litter. The total amounts of small litterfall (leaves, mosses, lichens, reproductive parts and twigs < 0.02 m diameter) exhibited seasonality with the highest inputs towards the end of the dry season and the lowest after the rainy season. Nutrient contents in total small litter samples did not show a relation to the corresponding amounts of litter fall. Highest mean contents for nutrients were obtained for N followed by Ca > K > Mg > Na (Tab 4.10). In the Oi horizon of the litter layer, concentrations for K were smaller, whereas Ca concentrations tended to be higher compared to those in freshly fallen litter. As mineralisation proceeded from the Oi to the Oa layer, concentrations of K, Mg and Ca decreased while concentrations of N and Na increased towards the Oa layer. Fresh leaves were collected from *Ocotea usambarensis* trees which dominated the upper tree layer and from *Podocarpus latifolius*, the trees of which were not yet fully grown at the study sites. Concentrations of K, Ca and to a lesser extent also N and Na tended to be slightly higher in fresh leaves compared to fallen litter.

Table 4.10 Volume weighted mean concentrations of small litter and nutrient fluxes via small litter (\pm standard error, n = 3).

	Nutrient Content					
	Litterfall [g kg ⁻¹]	Fresh Leaves [g kg ⁻¹]		Litter Layer [g kg ⁻¹]		
		Ocotea	Podocarpus	Oi	Oe	Oa
K	3.45 \pm 0.23	7.21	11.94	1.54 \pm 0.10	1.31 \pm 0.16	0.96 \pm 0.08
Mg	2.17 \pm 0.11	1.95	1.96	1.92 \pm 0.05	1.22 \pm 0.12	0.61 \pm 0.08
Ca	9.42 \pm 0.95	12.21	12.72	12.60 \pm 1.09	5.61 \pm 0.86	1.34 \pm 0.35
Na	0.49 \pm 0.05	1.21	0.15	0.36 \pm 0.06	0.36 \pm 0.04	0.57 \pm 0.02
N	16.35 \pm 1.12	19.4	17.6	16.2 \pm 0.2	23.9 \pm 0.9	26.2 \pm 0.1
P	0.82 \pm 0.09	1.47	1.63	1.10 \pm 0.15	2.07 \pm 0.52	1.59 \pm 0.12

The seasonal pattern of nutrient fluxes through small litterfall followed the scheme of the monthly amounts of litterfall with highest inputs towards the end of the dry season and the beginning of the small rains in December 2001 and January 2002 (Fig.

4.6). While annual nutrient fluxes in small litter exceeded the fluxes in throughfall for Ca and Mg, more K and Na reaches the forest floor by throughfall. The highest inputs from small litter fall occurred slightly earlier in the year than for throughfall, but both occurred around the same time of the year. N is not shown separately in the graph since fluxes from litterfall exceeded throughfall fluxes of inorganic N by a factor of 30. Annual fluxes via small litterfall are presented in Table 4.11.

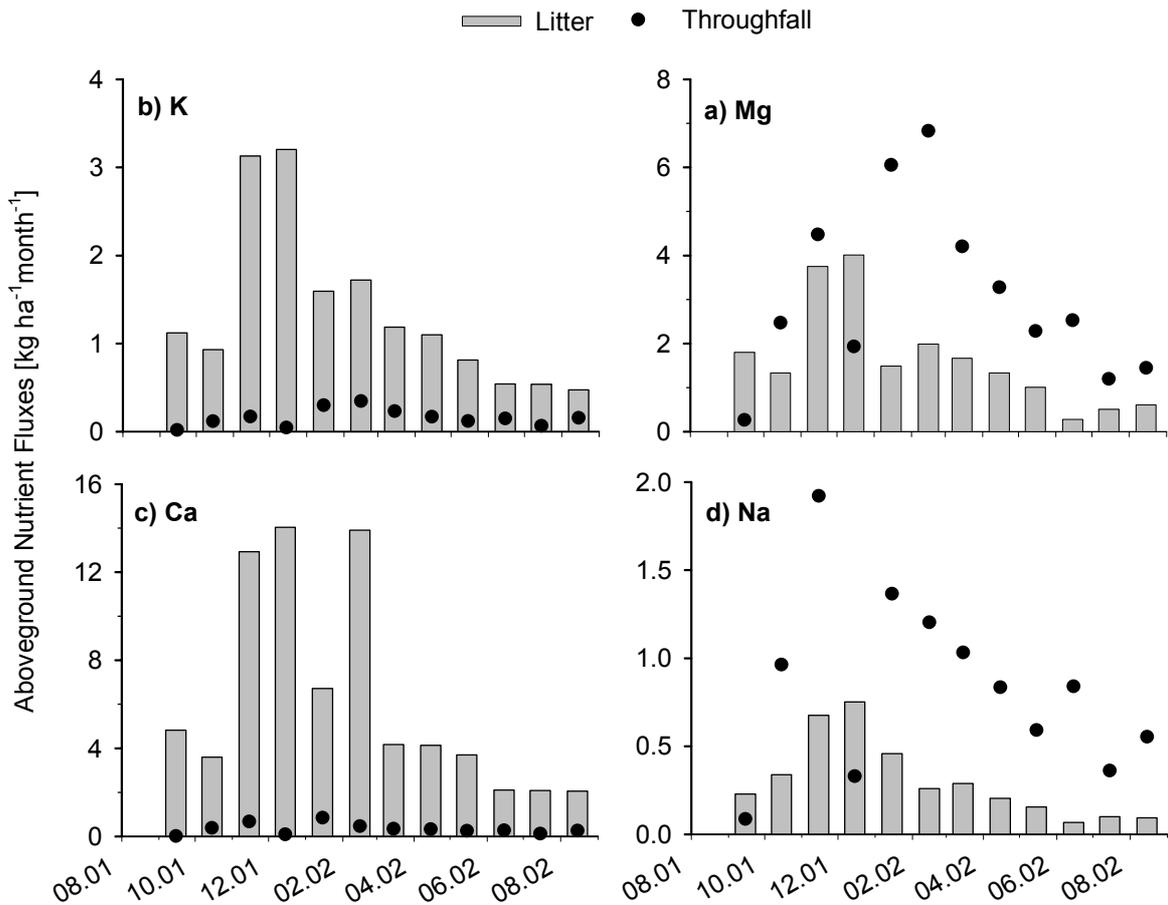


Fig. 4.6 Comparison of the seasonal distribution of monthly fluxes in small litterfall and throughfall in the second year.

Table 4.11 Annual nutrient fluxes via litterfall (August 2001-August 2002, \pm standard error, $n = 3$).

	Total Amount [t ha ⁻¹ a ⁻¹]	Nutrient Fluxes					
		K	Mg	Ca	Na	N	P
		[kg ha ⁻¹ a ⁻¹]					
Litterfall	7.4 ± 0.9	25.3 ± 3.6	15.8 ± 1.4	68.5 ± 9.1	3.6 ± 0.7	118.7 ± 12.8	5.9 ± 0.61

DISCUSSION

COMPARISON OF WATER CHEMISTRY WITH OTHER MOUNTAIN RAINFORESTS

As compared to other tropical mountain rainforests, aboveground nutrient fluxes of basic cations were low in the forest at Mt. Kilimanjaro. Tables 4.8 and 4.9 summarise recently published data on nutrient concentrations and fluxes in rainfall and throughfall at different tropical mountain rainforests. Most of these forests grew on soils which developed on volcanic ash material, similar to the conditions at Mt. Kilimanjaro. The two exceptions were studies by Hafkenscheid (2000) and Wilcke et al. (2001) which were chosen because these studies also analysed belowground water chemistry and stream water.

Rainfall K concentrations at Mt. Kilimanjaro were at the higher end compared to those of other mountain rainforests, while Mg, Ca and Na concentrations were small and N forms exhibited intermediate values. The comparison of fluxes among forests reveals a similar picture with small fluxes of Mg, Ca and Na in the present study and intermediate fluxes for K, NH₄-N and NO₃-N. Considering throughfall fluxes, K and inorganic N forms at Mt. Kilimanjaro are within the range observed at other sites where especially NH₄-N and NO₃-N fluxes varied over a wide range (Table 4.12). On the other hand, Ca and Mg fluxes in throughfall exhibited the lowest overall values recorded for these two cations (Table 4.13). The Mg and Ca fluxes in rainfall and throughfall were also below values measured at other mountain rainforests summarised in Veneklaas (1990a) and Hafkenscheid (2000). The Na fluxes were also at the lower end. This came as a surprise since higher rainfall and throughfall fluxes of these cations were expected due to extensive dust depositions of wind-eroded savannah material, especially during the dry season.

The comparison of literature data on litter percolate is more difficult. The reasons for this are that firstly, only very few studies on tropical mountain ecosystems exist and secondly, the litter layer is often not clearly defined. Most authors do not specify whether they studied only the leaf litter layer (Oi), or if they collected solution from the total organic soil layer (Oa). While in the first case mainly the litter percolate of the fresh fallen litter is considered, uptake by roots and mineralisation processes lead to an additional alteration of the solution in the second, thus limiting direct comparisons of solutions. Wilcke et al. (2001) analysed litter percolate collected below the root mat of the trees, however, the source of the litter percolate was not further specified in the two other studies presented in Table 4.14. Keeping that problem in mind, the concentrations of NH₄-N and NO₃-N in the litter percolate of

the study forest at Mt. Kilimanjaro were within the lower range observed for mountain rainforests. Mean K and Ca concentrations were at the lower end of the concentration range observed in a rainforest in Ecuador and lower than concentrations presented for Jamaica and Malaysia. Mean Mg concentrations in litter percolate measured at Mt. Kilimanjaro were below values from other tropical mountain rainforests. Nutrient concentrations in stream water give information about nutrient exports from the forested catchments. Again, Ca and Mg concentrations in stream water were lower at Mt. Kilimanjaro than in the other studies presented in Table 4.14.

Table 4.12 Nutrient concentrations and fluxes in rainfall of mountain rainforest ecosystems.

	Rainfall Concentration						Rainfall Flux					
	K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N	K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N
	[mg l ⁻¹]						[kg ha ⁻¹ a ⁻¹]					
Colombia ¹⁾ Andepts, Aquepts												
2550 m	0.38	0.15	0.48	1.14	0.86		7.9	3.2	10.1	24.1	18.3	
3370 m	0.48	0.17	0.51	1.10	0.77		6.9	2.5	7.3	15.9	11.2	
Costa Rica ²⁾ Dystrandeps												
1500 m	0.09	0.07	0.18	0.63	0.05	0.05	3.0	2.4	5.8	19.5	1.6	1.6
Ecuador ³⁾ Dystrudepts, Eutrudepts												
1900- 2010 m	0.17	0.06	0.18	0.86	0.12	0.14	3.7	1.2	3.9	19	2.6	3.0
Jamaica ⁴⁾ Dystric Cambisols, Folic Histosols												
1800	0.27	0.07	0.29	0.67	0.13	0.06	8.3	2.0	9.0	20.6	3.90	1.68
Malaysia ^{5)*} Dystropepts												
870	0.3	0.04	0.19	1.0	0.2	1.4	4	1.2	4		2.5	5
Tanzania ⁶⁾ Endoaquands, Fulvaquands												
2300	0.3- 0.5	0.04- 0.05	0.1- 0.2	0.3- 0.4	0.2	0.1- 0.2	6.9- 8.0	0.9- 0.8	2.1- 2.4	6.7- 5.7	3.6- 2.5	3.0-2.2

¹⁾ Veneklaas 1990, ²⁾ Clark et al. 1998 ³⁾ Wilcke 2002, ⁴⁾ Hafkenscheid 2000, ⁵⁾ Bruijnzeel et al. 1993 ⁶⁾ this study, *approximation from 6 weeks

K concentrations in stream water, on the other hand, were highest on Mt. Kilimanjaro. As K concentrations in the soil solution at 1 m soil depth were approximately four times lower than in streamwater, a K release at deeper soil layers due to weathering might be responsible for this observation. NH₄-N concentrations were low in all studies, while NO₃-N concentrations showed a high heterogeneity

with values at Mt. Kilimanjaro being greater than in Ecuador but lower than in Malaysia. Thus, the forest at Mt. Kilimanjaro is characterised by low Mg and Ca fluxes via rainfall and throughfall. Concentrations in litter percolate and stream water indicate that also belowground fluxes and outputs are low. Similarly, Na concentrations and fluxes were usually low, although not to the same extent as for Mg and Ca. With the exception of stream water, the same was true for K. $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$, on the other hand, were usually within the range observed at other tropical mountain rainforests.

Table 4.13 Nutrient concentrations and fluxes in throughfall of mountain rainforest ecosystems.

	Throughfall Concentration						Throughfall Flux					
	K	Mg	Ca	Na	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	K	Mg	Ca	Na	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$
	[mg l^{-1}]						[$\text{kg ha}^{-1} \text{ a}^{-1}$]					
Colombia ¹⁾ Andepts, Aquepts												
2550 m	5.1	0.6	1.5	1.5	1.2		95	11	27	27	22	
3370 m	2.8	0.6	1.6	1.2	1.0		33	7	19	14	12	
Costa Rica ²⁾ Dystrandeps												
1500 m	3.5- 4.4	0.4 -0.5	1.2- 1.6	2.1- 2.8	0.1	0.04	64	8	23.7	41	1	0.6
Ecuador ³⁾ Dystrudepts, Eutrudepts												
1900- 2010 m	5.3- 12.5	0.4- 1.7	0.9- 2.3	1.1- 1.6	0.3- 0.4	0.43- 0.99	76- 166	7-21	15-28	10-22	3-7	5.9- 8.6
Jamaica ⁴⁾ Dystric Cambisols, Folic Histosols												
1800 m	1.3- 1.5	0.2- 0.2	0.5	0.9- 1.1	0.2	0.02- 0.03	23- 34	4-5	9-11	17-24	3-4	0.5
Malaysia ^{5)*} Dystropepts												
870 m	1.1	0.3	0.6	2.0	0.5	2.0	23	7	12		9	10
Tanzania ⁶⁾ Endoaquands, Fulvaquands												
2300 m	1.5- 3.0	0.1- 0.2	0.13- 0.34	0.5- 0.9	0.2	0.05	32- 37	2.0	3-4	11	2-4	0.7- 1.0

¹⁾ Veneklaas 1990, ²⁾ Clark et al. 1998 ³⁾ Wilcke 2002, ⁴⁾ Hafkenscheid 2000, ⁵⁾ Brujinzeel et al.1993, ⁶⁾ this study, *approximation from 6 weeks

Table 4.14 Nutrient concentration in litter leachate and stream water of mountain rainforests.

	Litter Percolate Concentration						Stream Concentration					
	K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N	K	Mg	Ca	Na	NH ₄ -N	NO ₃ -N
	[mg l ⁻¹]						[mg l ⁻¹]					
Ecuador ³⁾ Dystrudepts, Eutrudepts												
1900-	0.4-	1.4-	0.3-	1.4-	0.3-	0.6-	0.3-	0.4-	0.5-	2.8-	0.1	0.1
2010 m	28	5.0	8.0	1.5	0.7	5.7	0.4	0.5	1.0	4.0		
Jamaica ⁴⁾ Dystric Cambisols, Folic Histosols												
1800 m	2.9-	0.9-	1.7-	1.6-	0.1-	0.0-						
	4.1	1.1	2.5	2.0	0.2	0.2						
Malaysia ^{5)*} Dystrupepts												
680 m	5.1	2.5	4.6	5.2	1.0	8.4	<0.1	12.5	0.5	2.0	0.1	3.1
870 m	3.6	2.7	5.7	3.6	1.0	6.5						
Tanzania ⁶⁾ Endoaquands, Fulvaquands												
2300 m	1.4	0.3	0.8	0.8	0.3	0.9	0.7-	0.1	0.1-	1.2-	0.1	0.6
							0.8		0.2	1.3		

³⁾ Wilcke 2002, ⁴⁾ Hafkenscheid 2000, ⁵⁾ Brujinzeel et al. 1993 *approximation from 6 weeks, ⁶⁾ this study

NUTRIENT FLUXES VIA LITTERFALL AND NUTRIENT LIMITATIONS

Nutrient concentrations in small litterfall are said to give an idea about the nutrient status of a forest and the closeness of the nutrient cycle (Vitousek 1984). The concentrations of K, Mg, Ca and Na in litterfall at Mt. Kilimanjaro were within the range observed at other tropical mountain rainforests summarised in Table 4.11 and in Brujinzeel & Proctor (1995). With 1.6%, N contents were higher than the range of 0.6-1.5% presented in Brujinzeel & Proctor (1995) for a number of mountain rainforests. But litter N contents of a mountain rainforest in Ecuador were even higher (Wilcke et al. 2002) and similar contents were measured by Lundgren (1978) in a mountain forest in the Usambara Mountains, around 300 km southeast of Mt. Kilimanjaro. Table 4.15 shows that also the nutrient fluxes via litterfall were also within the range of other forests, with Na fluxes being slightly higher.

Of special interest was a study presented by Lundgren (1978), who analysed acid soils in the Usambara Mts. under a natural forest which was dominated by *O. usambarensis* similar to the studied forest at Mt. Kilimanjaro. The concentrations in the litter layer were around the same order of magnitude with higher Ca and slightly higher Mg concentrations at the Usambara Mts. and higher K concentrations at Mt. Kilimanjaro.

Table 4.15 Nutrient contents and annual fluxes in small litterfall at different mountain rainforests.

	Nutrient content in litterfall					Nutrient flux via litterfall				
	K	Mg	Ca	Na	N	K	Mg	Ca	Na	N
	[g kg ⁻¹]					[kg ha ⁻¹ a ⁻¹]				
Colombia ¹⁾ Andepts, Aquepts										
2550 m	8.4				12	59				82
3370 m	3.1				9	14				34
Costa Rica ²⁾ Humitropepts, Topofibrists, Vitrandepts										
1000 m	1.4*	1.9*	7*	0.4*	11*	9	12	45	2.6	65
2000 m	2.2*	1.9*	11*	0.3*	9*	12	10	61	1.6	46
2600 m	3.0*	2.3*	10*	0.2*	7*	15	11	52	1.1	34
Ecuador ³⁾ Dystrudepts, Eutrudepts										
1900-	6.1-	3.5-	12-18	0.1-	19-22	57-	34-	117-	0.8-	165-
2010 m	9.1	5.8		0.1		77	52	154	1.1	201
Jamaica ⁴⁾ Dystric Cambisols, Folic Histosols										
1800 m	1.3-	2.1-	7-8**		6-8**	8-	12-	40-		39-53
	1.7**	2.2**				11	12	50		
Tanzania ⁵⁾ Usambara Mts.										
1400 m	4.3**	3.0**	13**		18	35	23	104		142
1800 m+	1.2	2.5	16							
Tanzania ⁶⁾ Endoaquands, Fulvaquands										
2300 m	3.5	2.2	9	0.5	16	25	16	69	4	119
2300 m +	1.5	1.9	13	0.4	16					

* non-woody litter, ** leaf litter + Oi layer

¹⁾ Veneklaas 1990, ²⁾ Heaney & Proctor 1989 ³⁾ Wilcke 2002, ⁴⁾ Hafkenscheid 2000, ⁵⁾ Lundgren 1978, ⁶⁾ this study

An overall tendency of mountain rainforest for low N concentrations in litterfall compared to lowland rainforests (Bruijnzeel & Proctor 1995) and lower N mineralisation rates (Marrs et al. 1988) led to the assumption that tropical mountain rainforests might be N limited. Similarly, the possibility of P limitation was discussed especially for old, intensively weathered soils (Tanner et al. 1998). This was further supported by fertilisation experiments in which N and P additions or a combination of both increased forest growth rates (Tanner et al. 1992, Tanner et al. 1990). Vitousek (1984) suggested the litter-amount/nutrient-flux ratio as a measure for the nutrient use efficiency of a forest. According to his reference forests, the forest at Mt. Kilimanjaro resembles lowland rainforests for N and P, characterised by high circulation and low within-stand efficiency, while other mountain rainforests usually

have lower N and P cycling rates. The study of Tanner et al. (1998) revealed that N and P concentrations of high mountain rainforests (> 1500 m) were comparatively low, while forests of intermediate altitude (1000-1500) exhibited a wide range of N and P contents. With canopy heights of over 40 m for some *Ocotea* trees, the stature of the forest at Mt. Kilimanjaro also resembles statures of lower mountain rainforests despite being located at a high altitude (Stadtmüller 1986).

Tanner et al. (1998) found a correlation between canopy height and N contents in leaves. A similar, but weaker correlation was obtained for P contents. The combination of canopy height and N and P contents of the litter at Mt. Kilimanjaro fits well with the presented correlations. Higher N contents in fresh leaves compared to litter indicate that some N is retranslocated before the leaves are shed. But with 16%, retranslocation is low compared to other mountain rainforests (Bruijnzeel & Proctor 1995). For P, retranslocation was 44% of original fresh leaf contents, which is in the range of the forests summarised in Bruijnzeel & Proctor (1995). The interpretation of differences in fresh fallen leaves and litter contents as retranslocation might be limited by the fact that for reasons of accessibility, only leaves of comparatively young trees in an old forest opening were sampled and might differ in element composition from leaves of mature trees. Canopy height and high annual litterfall masses indicate high biomass production, and together with high average N contents in litter, serious N limitation does not appear to occur in these forests. Nevertheless the usage of litter N contents for the determination of the nutrient status of a forest is limited by the fact that the litter N content varies not only with N supply, but is also related to tree species (Drechsel & Zech 1991). Furthermore, leaf N contents sometimes do not respond to N fertilisation although growth rates increase, indicating that leaf N contents do also not always reflect the N supply of trees (Tanner et al. 1998). Referring to P, low P availability at Mt. Kilimanjaro seems most likely due to the high P fixation capacity of the soils (see Chapter 2). But a comparison of P contents of fresh litter at Mt. Kilimanjaro with values presented in Drechsel & Zech (1991) reveals that P contents are higher compared to the summarised trees exhibiting P deficiency, also indicating that P is probably not a growth limiting factor for the forest at Mt. Kilimanjaro.

An overall low availability of basic cations in the forest is indicated by low K and especially Mg and Ca inputs via rainfall and throughfall, low concentrations in litter percolate and the soil solution as well as the low effective cation exchange capacity together with a low base saturation. Thus, basic cations might be growth limiting in this forest. The possibility of Ca limitation in a mountain rainforest in Ecuador was

also discussed by Wilcke et al. (2002) based on mineralisation experiments and turnover rates. Drechsel & Zech (1991) concluded that most tropical and subtropical tree species have similar foliar nutrient contents with the exception of N and that it should be possible to compare different tree species within crude ranges. They reported K deficiency symptoms between 1.0-5.7 g kg⁻¹ and low values from 1.5-9.2 g kg⁻¹, for Mg 0.7-1.3 and 0.8-1.5 g kg⁻¹, respectively and for Ca, low values ranged between 1.6 and 5.1 g kg⁻¹. For the leaves of the two tree species collected at Mt. Kilimanjaro, Mg and Ca concentrations were higher, but K concentrations in *O. usambarensis* leaves were low.

Similar to N, the retranslocation of basic cations might also be an indicator for economic nutrient cycling. As *O. usambarensis* was the only tree species in the canopy layer at the studied plots, the majority of the collected litter should have originated from this species. The comparison between the nutrient content in fresh and fallen litter revealed comparable concentrations for Mg, a decrease of 20% for Ca and of 45% for K. Na concentrations were 60% lower in the fallen litter. But these values do not represent absolute retranslocation ratios, as firstly, sampling of fresh litter was not optimal (see above) and secondly, low K and Na concentrations in the litter were partly derived from leaching before sample collection. Due to the monthly sampling scheme, the litter had mean residence times of two weeks in the traps, during which substantial losses would already have occurred (Lundgren 1978). Thus, soil properties indicate a low availability of K, Mg and Ca, but from the litter quality, no limitation can be proven.

As with the litter composition, the solo usage of soil properties for the indication of nutrient deficiencies is also limited by the fact that most soil extraction methods usually applied do not represent plant available nutrient contents (Sollins 1998). That is especially the case as plants have developed different strategies to be able to cope with low nutrient availability such as associations with miccorrhiza. Thus, according to Tanner et al. (1998), fertilization experiments might be the most suitable method to detect nutrient limitations, but as these are time-consuming, they were only very rarely applied in tropical mountains.

NUTRIENT FLUXES IN RAINFALL

Wet and dry deposition both influence rainfall concentrations at Mt. Kilimanjaro. Since the rainfall collectors were permanently open, funnel surfaces probably accumulated some dry deposited material during rain-free periods. Sources for base cations at Mt. Kilimanjaro might be oceanic sprays, terrestrial dust or volcanic emissions. As volcanic activity at Mt. Kilimanjaro and the nearby Mt. Meru is now reduced to scarce fumaroles and hydrothermal springs, these processes are not supposed to influence the base cation composition of rainfall any more. During the main rainy season, the prevailing wind systems until October are tradewinds from the south-east, which bring wet air masses from the Indian Ocean. Thus, ion additions from oceanic sources might contribute to the ion composition of rainfall, especially during the rainy season.

Terrestrial dust sources are ashes from burning of organic material (forest fires, burning of harvest residuals, house fires) or eroded soil particles. These sources are therefore not located within the study area itself. The plots are located at the most humid part of the mountain and the soil is constantly covered by vegetation so that wind erosion is unlikely and fires are scarce in normal years. Most natural forest and savannah fires occur at the end of the dry seasons, and that is also the time when vegetation residues are burnt on the fields, leaving them unprotected against wind erosion. Thus, this is the time of the year when the highest dust particle concentrations in the atmosphere are expected.

Mt. Kilimanjaro is surrounded by a semiarid environment where salt accumulations frequently occur at ephemeric ponds, at the edges of salt lakes and at irrigated fields (Wakatsuki & Mizota 1992). As shown in Prospero (1999), the African savannah plains have a high wind erosion potential and dust is often transported over great distances. Thus, additions of salt-rich particles to dry deposition seem likely at Mt. Kilimanjaro. Mizota et al. (1988) detected an addition of soil particles from the savannah plains to a soil profile in Machame at 1600 m by studying the oxygen isotope composition of quartz minerals and supposed that wind erosion was responsible for the particle translocation. Their results were supported by the frequent occurrence of dust storms and vortices of different magnitudes in the savannah, especially in the dry season.

Despite the wealth of possible sources for dry deposition, the nutrient inputs observed at the forest site, especially for Mg and Ca, were very low. This seems to be

related to a decrease in dry deposition with increasing elevation. With about 1400 m, the vertical distance between the savannah plains and the study forest is quite high. As the lower slopes of Mt. Kilimanjaro are cultivated by agroforestry, the soil surface is permanently covered and protected against erosion. At the same time, this vegetation cover represents an aerodynamically rough surface which acts as a sink for particles in ascending air masses. The same holds true for the mountain forest at lower elevations, which is heavily dissected due to human impacts.

This would explain low overall cation concentrations from particle sources, but still the K concentrations were comparatively high. Many authors explain high K concentrations in rainfall with internal sources from the forest itself (Crozat 1979, Gosz 1980, Lovett & Lindberg 1984). Crozat 1979 attributed the occurrence of K enriched aerosols in a lowland rainforest at the Ivory Coast with guttation during periods with permanently high humidity and low windspeeds in the rainy season and subsequent evaporation, resulting in K-rich salts at the leaf surfaces, which are then redeposited in and around the forest canopy. Rain collectors located in forest gaps were expected to be affected. High humidity was also observed inside the study forest (Chapter 3), but still it seems unlikely that the movement of the air is low enough in a mountainous region for trees being hindered to transpire for a sufficient time to make guttation necessary. But possibly transpiration might also leave some salts behind at the leaf surfaces. Still, from the data available, the unusual ion distribution in rainfall samples at Mt. Kilimanjaro cannot be fully explained.

NUTRIENT FLUXES IN THROUGHFALL

Characteristics of atmosphere and biosphere both determine the nutrient composition of throughfall water. By passing through the forest canopy, rainwater washes off dry deposition that has been accumulated since the last rainfall event. These ions and particles consist either of deposited aerosols or insect debris. Furthermore, decomposition of dead organic material leads to the release of nutrients in the canopy. Also the canopy itself can act as a source for nutrients because ions can passively diffuse from the apoplast of canopy tissue to surface water, and ion exchange also occurs (Schaefer & Reiners 1990). At the same time, the canopy can act as a sink for nutrients since plants have the ability to take up nutrients directly with their canopy leaves, as has often been reported for $\text{NO}_3\text{-N}$.

For the interpretation of net throughfall fluxes in the terms of nutrient cycling, it is interesting to differentiate between external and internal sources for net throughfall

fluxes. As summarised in Parker (1983) and Lovett & Lindberg (1984), several direct and indirect approaches have been proposed to separate net throughfall fluxes, but all of them have limitations. The studies of Parker (1983), Schaefer & Reiners (1990) and Puckett 1990 concluded that K in the throughfall of temperate forests mainly derived from canopy exchange. For net Ca and Mg fluxes, a combination of leaching from leaves and ion exchange as well as dry deposition wash-off were responsible, with a higher contribution of dry deposited material. In a lowland rainforest in the Amazon Basin with low nutrient fluxes in rainfall, Filoso et al. (1999) observed a higher contribution from canopy leaching for Mg and Ca in net throughfall fluxes than from dry deposition.

The close correlation between net fluxes of base cations at Mt. Kilimanjaro suggests that similar processes determined their fluxes. Ion additions to throughfall water by dry deposition are not expected to depend on the rainfall amount as long as the rainfall amount is high enough to remove all the deposited material. Thus, the dependency of net throughfall fluxes of base cations on rainfall amounts observed in this study indicates that passive leaching processes from leaves or ion exchange were also involved. Assumed that dry deposition is a linear function of time as was used as prerequisite in the model of Lovett & Lindberg (1984), one might expect similar nutrient additions per fortnight sampling period as long as the deposited material is regularly washed away. Therefore, the dry deposited material that is dissolved in rainfall passing through the canopy and solute concentrations are determined by rainfall amounts via dilution. That would result in a correlation between inverse throughfall concentrations ($\text{concentration}^{-1}$) and throughfall amounts as was observed for the base cations in the first, and with lower correlation coefficients also in the second study year. This indicates a certain contribution of external sources to throughfall fluxes. However, the correlation coefficient cannot be used as a measure for the contribution of dry depositions. Firstly, the assumption of homogenous deposition rates throughout the year probably can not be made in a region exhibiting high seasonality. Natural fires, harvest fires and wind erosion, which all present possible sources for aerosols, are most probable during drier periods of the year. Secondly, the fortnight samples do not always include just the material accumulated during that time period if longer rain-free periods occur. Thus, a certain variability in nutrient fluxes would be expected, even if dry deposition would be the only ion source in the forest canopy. Summarising the results suggest that both dry deposition and leaching from canopy tissues contribute to net throughfall fluxes. For further differentiations between both processes, event-based sample collections would have been necessary.

Both N forms studied showed a contrasting behaviour compared to the base cations, as especially $\text{NO}_3\text{-N}$ was not released, but absorbed in the forest canopy. A $\text{NO}_3\text{-N}$ absorption in the canopy was also reported from various other mountain rainforests and usually mainly ascribed to absorption by epiphytes (Clark et al. 1998, Liu et al. 2002, Veneklaas 1990b). That different processes determined net throughfall fluxes of N and base cations at Mt. Kilimanjaro was also reflected by the observation that net $\text{NO}_3\text{-N}$ fluxes and, to a lesser extent, also net $\text{NH}_4\text{-N}$ fluxes in throughfall did not exhibit close correlations with base cations. In contrast to the base cations, net throughfall fluxes of $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ also did not show a dependency on water fluxes. But the negative correlation with rainfall concentrations indicates that ion uptake or release depends on N concentrations. High rainfall N concentrations obviously result in a net absorption of N in the canopy, while lower concentrations lead to net leaching. Veneklaas (1990) made similar observations in a tropical mountain rainforest in Colombia.

BELOWGROUND NUTRIENT DYNAMICS

With the exception of K and Na, the mean nutrient concentrations in the litter percolate exceeded the throughfall concentrations. Among possible nutrient sources are direct leaching from freshly fallen litter and mineralisation of organic soil material. As the litter percolate was collected below the root mat of the vegetation, ion uptake by roots, which would result in a decrease in nutrient concentrations, or water uptake, resulting in higher concentrations in the remaining solution, also have to be considered. Ion exchange processes and adsorption to soil particles might further alter the ion composition.

For Mg, Ca and $\text{NO}_3\text{-N}$, the ion concentrations in litter percolate were higher than in throughfall at nearly any given time, indicating that the additional ion release in the litter layer exceeded the ion uptake by roots. The picture for K and Na, on the other hand, was different since for both ions the annual mean ion concentrations in litter percolate were even lower than in the throughfall water. This came as a surprise since especially K is easily leached from freshly fallen litter (Lundgren 1978, Tukey 1970) and should thus be further enriched in the litter percolate. Potential sinks for K are adsorption and exchange processes with soil organic material or ion uptake by plants or mycorrhiza. As organic matter preferentially binds polyvalent cations, the ion exchange sites were dominated by Al, Mg and Ca (Al: 10.45, Ca: 6.08, Mg: 3.15, K: 0.89 and Na 0.33 $\text{cmol}_c \text{ kg}^{-1}$). Therefore, cation exchange is not likely to be a sink for K. This indicates that a large quantity of K has probably already been taken up by

plants or micorrhiza in the litter layer. Since K concentrations in the soil solution were very low, this indicates a close nutrient cycle where K is leached from the canopy, reaches the ground as throughfall water, and is then directly taken up again by roots in the litter layer. In a mountain rainforest in Ecuador, K concentrations were also not increased in the litter percolate compared to throughfall water, while this was the case for Mg, Ca and Na (Wilcke 2001). Thus, K uptake possibly already occurred in the litter layer at this site.

Besides differences in enrichment of individual ions from throughfall water to litter percolate, nutrient concentrations were correlated to each other in the litter percolate. This might partly be explained by a similar dilution or concentration by either rainfall inputs or evapotranspiration. As the correlations were comparatively close for most elements, it also seems probable that the consumption and release of individual nutrients in the litter layer are determined by similar processes.

Usually, the highest concentrations in litter percolate were obtained towards the end of the dry season. That is also the time when differences in ion concentrations between throughfall and litter percolate were greatest for most nutrients. As mineralization probably continues at least for some time, even if the rainfall amounts are not high enough to release percolating water in the zero-tension lysimeters, this effect is probably the result of an accumulation of mineralised ions in the litter layer. These are then dissolved and translocated during the first high rainfall events at the end of dry periods.

In the mineral soil at 0.15 m, nutrient concentrations were already distinctly smaller than in the litter percolate with the exception of $\text{NO}_3\text{-N}$. A pronounced decrease in ion concentrations from the litter layer to the mineral soil was similarly observed at other sites with nutrient-depleted, weathered soils in the humid tropics (Bruijnzeel et al. 1993, Hafkenschied 2000, Lilienfein et al. 2000). This decrease was mainly related to higher nutrient stocks and available nutrients in the organic soil layers, the sorption of ions to minerals and organic material and plant uptake. The increase in $\text{NO}_3\text{-N}$ concentration from litter percolate to the soil solution is probably the result of further N mineralization and nitrification of $\text{NH}_4\text{-N}$ below the litter layer. Since the concentration of base cations in the soil solution was low, Al and H are most likely the cations accompanying $\text{NO}_3\text{-N}$ for charge compensation.

Some nutrients might still be released by the destruction of primary minerals in deeper or less intensively weathered soil layers at Mt. Kilimanjaro, such enriching

the nutrient content in ground and stream water. The results suggest that Ca and Mg remained unchanged or were further absorbed while passing the mineral phase until they reached the streams, as their stream concentration was equal to or below the soil solution concentration at 1.0 m soil depth. K concentrations in the stream water, on the other hand, were increased, which might be attributable to release from minerals at deeper soil layers. Another reason for the higher K concentration in the streams compared to the deepest suction cups might also be the presence of less weathered soils at higher altitudes. These soils feed the stream with ground water richer in K than the studied site.

DIFFERENCES BETWEEN BOTH STUDY YEARS

Although the annual amount of rainfall in the second year was 20% less than the year before, the nutrient fluxes in rainfall and throughfall did not change significantly for K, Mg, Ca and Na as their concentration in the solutes increased. Rainfall fluxes of K and Ca were even greater in the drier year, and net fluxes were greater for all base cations. Differences in the nutrient concentrations between both years were most pronounced during the dry season. Towards the end of the dry season, concentrations were distinctly higher in the second compared to the first year. This was probably the result of an increase in dry deposition as during extended dry periods, wind erosion might be more important. At the same time, forest fires and subsequent ash depositions most likely occur during that time of the year and plant residuals are burned at the fields which afterwards lie bare.

For K, the differences in rainfall and net throughfall fluxes between both years were of the same order of magnitude. In contrast, net throughfall fluxes of Mg, Ca and Na showed a stronger increase from the first to the second year than did rainfall fluxes. As the canopy has a higher surface area for the collection of particles from the atmosphere than the rainfall collectors, it seems likely that a higher deposition of particles led to the increase in net throughfall fluxes of base cations in the second year. Still, it is also possible that leaching rates and especially ion exchange processes were enhanced in the drier second year. Lower amounts of rainfall have a longer residence time on the leaf surfaces, resulting in more time for the creation of equilibrium conditions and the apoplast ion depot is probably not as much depleted as during continuous rainfall periods.

Both N forms differed from the pattern observed for basic cations, since rainfall as well as throughfall fluxes were lower in the second year. For $\text{NO}_3\text{-N}$, net fluxes

remained constant for both years. The quality of the correlation between net throughfall fluxes and rainfall amount as well as rainfall concentration also did not exhibit differences. These observations indicate that in both years, the same mechanism led to the depletion of $\text{NO}_3\text{-N}$ during the passage through the canopy. Net $\text{NH}_4\text{-N}$ fluxes, in contrast, were lower in the second year when $\text{NH}_4\text{-N}$ was not leached, but partly absorbed in the forest canopy.

Thus, results indicate that longer monitoring periods are necessary in areas with high rainfall variability to get reliable estimates of fluxes. Although net throughfall fluxes were correlated to rainfall amounts, the interpretation that overall higher rainfall amounts would lead to higher nutrient fluxes is not acceptable since the second study year exhibited higher net fluxes. Consequently, for the determination of dominant processes, longer study periods are necessary as was further indicated by differences in correlation coefficients among the years.

SUMMARY AND CONCLUSIONS

Contrary to first expectations, aboveground nutrient fluxes of base cations in rainfall and throughfall were very low at Mt. Kilimanjaro compared to other tropical mountain rainforests. This is especially true for Mg and Ca. These low fluxes are most likely attributable to the high altitudinal distance between the forest and the savannah plains, which form a potential source for terrestrial dust in the atmosphere around the mountain. Thus, the amount of base cations reaching the soil via throughfall was comparatively low. Given that the availability of basic cations in the soil was also small as indicated by a low ECEC and base saturation, base cations will become in short supply if they are not retained in the ecosystem. There were indications that especially K is held in a close cycle between the forest canopy and the soil litter layer. $\text{NO}_3\text{-N}$ was the only studied nutrient which was retained in the canopy. Mineralisation processes increased $\text{NO}_3\text{-N}$ concentrations in seepage water of the upper soil layers. In the soil solution, $\text{NO}_3\text{-N}$ was probably accompanied by Al and H as concentrations of other cations were too small for charge equilibrium. Nutrient concentrations in the soil solution were low, especially for base cations, and decreased with increasing soil depths, indicating either uptake by plants or adsorption to soil particles. Analysis of litter nutrient contents did not indicate strong nutrient limitations. The distinct difference in annual rainfall amounts, nutrient fluxes and calculated correlation coefficients between both study years indicates that

longer measuring periods would be necessary to draw general conclusions about the magnitude of ecosystem processes.

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5 Long Term Effects of Disturbances on Internal Nutrient Cycling in a Tropical Mountain Rainforest at Mt. Kilimanjaro

INTRODUCTION

Due to its richness in natural resources, Mt. Kilimanjaro is the most densely populated rural area of Tanzania. One of Mt. Kilimanjaro's most valuable resources is the water it provides to the surrounding semiarid savannah, enabling a highly productive irrigation agriculture at its slopes and feeding the rivers which supply water for hydroelectric power stations (Bjørndalen 1991). The remaining natural forest belt between 1800 and 3000 m receives the greatest amounts of annual rainfall, and most springs occur in this region. A high density of bryophytes with a high water storage capacity helps to ensure that streams are constantly flowing even during drier periods (Pócs 1991). Thus, besides its value for a number of endemic species, the forest is of great importance for the water supply. But selective logging and fire during the past decades has led to an opening of the forest especially at lower elevations (Lambrechts et al. 2002). A mosaic of secondary vegetation of varying ages was created with a species composition differing from the former natural forests (Mwasaga 1991, Wood 1964a). At some large openings created by logging, regeneration seems to be suppressed by shrub vegetation consisting mainly of *Pteridium aquilinum* and *Rubus steudneri* which have been present for many years up to decades. As the forests at lower elevations have been depleted of mature trees, including the valuable tree species *Ocotea usambarensis*, ongoing illegal logging has extended to higher elevations (Lambrechts et al. 2002). At the same time, the soils of the south western slopes are already in an advanced stage of weathering, and therefore have only a low retention capacity for nutrient cations (see Chapter 2). The question arises whether the nutrient cycle of the different secondary vegetation types occurring at the lower slopes of Mt. Kilimanjaro is stable enough to prevent major nutrient losses that might further hinder the regeneration of the natural forest.

Direct effects of logging and burning practices on nutrient cycling have been studied for a number of tropical lowland rainforests, mainly in the Amazon Basin. After disturbances, a general increase in nutrient concentrations in the soil and the soil solution was observed (Eden et al. 1991, Klinge 1997, Uhl & Jordan 1984), N mineralisation and nitrification, as well as P availability were enhanced (Giardina et al. 2000, Matson et al. 1987, Palm et al. 1996) and stream water concentrations were finally affected (Malmer 1996). The peak of these effects usually occurred within six

months after disturbance and declined soon afterwards to initial levels (Klinge 1997). The effects of selective logging were usually less severe, and differed from natural forest gaps in the way that the majority of the fallen wood was taken out of the system. In openings created by logging, the ground vegetation was usually destroyed and often the upper part of the soil was affected as well, leading to a change in species composition of the regrowth and in nutrient fluxes (Chandrashekara & Ramakrishnan 1994). Denslow et al. (1998) emphasised the influence of gap size on nutrient release, which is also probably important for clearings created by selective logging.

After disturbed forest sites have been abandoned, natural regeneration starts. Information on long term changes in nutrient fluxes during natural regeneration processes is still scarce, somewhat contradictory and restricted mostly to lowland rain forests. Five years after burning the rain forest, Uhl & Jordan (1984) found higher nutrient contents in the standing biomass, while nutrient concentrations in the soil solution had returned to postburn levels. At other sites, higher N mineralisation rates after eight years of fallow (Robertson 1984) and greater contents of exchangeable bases, especially K, as well as higher organic matter contents in soils of elder succession stages were reported (Chandrashekara & Ramakrishnan 1994, Rajesh et al. 1996). Werner (1984) also found an increase in total soil N and P during the first eight years of forest regeneration, but a decline in exchangeable bases and ammonium. These results indicate that long term changes in soil nutrient contents occur during forest regeneration. However, different sites did not always react in a similar manner, probably depending on site history (type and severeness of actual and past disturbances), site conditions (climate and soil) and the regenerating vegetation. Nevertheless, the changes observed in the solid soil phase indicate that nutrient cycling under secondary vegetation differs from mature forests. This is probably due to differences in canopy interception, the amount and quality of litter, and the water and nutrient demand.

In order to study differences in the nutrient dynamics between sites, the use of bulk soil samples is somewhat limited since overall changes in soil nutrient stocks are slow and always represent an average of past processes. Also, the high spatial variability of soil properties makes it hard to detect minor changes. Thus, for the analysis of ongoing soil processes, studying changes in the composition of the soil solution has proven to be a more sensible and useful tool (Jenny 1980). For this reason, an ecosystem approach was used in this study to determine the differences in

the nutrient cycle between mature forests, secondary forests and clearings at Mt. Kilimanjaro.

The aim of this study was to investigate whether the sites with regenerating vegetation in the forest belt of Mt. Kilimanjaro exhibit internal nutrient cycles that differ detectably from mature forest sites. The results are discussed in light of the impeded regeneration observed at clearings and the overall regeneration potential of the natural forest.

MATERIALS AND METHODS

STUDY AREA

The study site is located at the southwestern slopes of Mt. Kilimanjaro above Machame village between the deeply incised rivers Kikafu and Weru-Weru. In February 2000, ten permanent sampling sites were selected in more or less undisturbed mature forest (4 x), secondary forests (3 x, approximately 60 years old) and in forest clearings (3 x, about ten years old). In spring 2001, three more plots were identified in clearings. All plots had a size of 400 m² and were situated between 2075 and 2320 m a.s.l. As the lower slopes up to a distinct borderline at around 2150 m consisted mainly of old secondary forest and clearings, the mature forest plots had to be selected at slightly higher altitudes. Thus, the least vertical distance between the mature forest sites and the others was 140 m, while the greatest distance was 245 m. The exact location of the plots is provided in Chapter 3 and Appendix B. Only plots with an inclination of less than 10° were chosen in order to avoid the substantial influences of erosion.

VEGETATION

The forest belt at Mt. Kilimanjaro is currently restricted to an area between 1800 and 3100 m at the southwestern slopes. In the study area, the most important tree species was *Ocotea usambarensis* which occurred in all forested plots. In a method of zoning of the natural forest as defined by Hemp (2001a), the lower, disturbed plots are situated in a transition zone between an Agauria–*Ocotea* forest (1800–2000 m, lower montane forest) and an *Ocotea*–*Podocarpus* forest (2100–2300 m, middle montane forest), while the upper plots of mature forest belong completely to the *Ocotea*–*Podocarpus* forest.

In the canopy layer of the mature forest plots, *O. usambarensis* was the dominant tree species. The mature forest was further characterised by a high epiphyte density and great diversity. Among the epiphytes were a lot of pteridophytes and bryophytes. Hymenophyllaceae and thick moss layers indicated a constant high humidity within the forest. In the shrub vegetation, the afro-montane tree fern *Cyathea manniana* as well as *Podocarpus latifolius*, *Ilex mitis*, *Dracaena afro-montana* and several Rubiaceae were common. The secondary forest plots had an estimated age of 60 years, as the main logging phase in the region occurred during the Second World War. At that time, a sawmill was operating at 2000 m a.s.l. above Machame village (DOS 1968, Wood 1964b). The canopy layer of these plots was constituted mainly of the pioneer tree species *Macaranga kilimanjarica* and *Ocotea usambarensis*. Overall tree stem diameters were smaller, the number and diversity of epiphytes were reduced and the moss layer at the tree trunks was thinner compared to mature forest plots.

With an age of probably over ten years (pers. comm. with regional foresters), the forest clearings were older than initially expected. Obviously, the forest regeneration was hindered at these sites, which did not exhibit major changes in species composition or stand biomass during the monitored 2.5 years. The fern *Pteridium aquilinum* dominated these sites together with *Rubus steudneri*, which was more important in apparently older clearings, where the liana *Begonia meyeri-johannis* was also abundant. A tree layer and subsequently epiphytes were missing at these plots.

A complete species list of the vascular plants at the plots is presented in Axmacher (2003).

CLIMATE

Northern Tanzania has a bimodal rainfall distribution with a short rainfall period from November to December and a long rainfall period from March to May. Especially because the short rainy season often fails, the annual rainfall variability is high. According to Hedberg (1964), the annual amounts of rainfall at 2100 m at Mt. Kilimanjaro averaged 1840 mm from 1945 to 1958 with values varying between 1200 and 3820 mm. A great quantity of the annual rainfall also occurs during rainstorm events with restricted regional extension, leading to a high temporal as well as spatial variability in monthly and annual rainfall amounts (Nieuwolt 1974). From savannah plains to the rain forest zone, rainfall amounts increase and reach a maximum within the forest belt. But the altitude of this maximum is still a matter of

controversy since it varies with exposition, and there is an overall lack of long term rainfall measurements within the forest. One of the most recent publications on rainfall amounts at the southern slopes of Mt. Kilimanjaro was provided by Hemp (2001b), who reported maximum rainfall amounts of ca. 3000 mm at 2100 m.

At the study sites, the amount of rainfall in the first year was 2600 mm at 2100 m and 2480 mm at 2300 m. The second year was remarkably drier with rainfall amounts of 2210 and 1960 mm at 2100 and 2300 m respectively, indicating that 2300 m might already be above the rainfall maximum. Interception was low at the clearings but reached up to 30% of incident rainfall in the forests. For further information on rainfall and throughfall fluxes see Chapter 3. Periodic temperature measurements at 50 days between May and October 2001 using a simple hygro thermometer 1.5 meter above the ground resulted in a median of 8.7 °C for the daily minimum temperature and of 14.8 °C for maximum temperatures in the mature forest at 2330 m. At 18 days in February 2001, temperature was compared among treatments. In the secondary forests at around 2100 m, temperatures were on average 1.6 °C higher than in the mature forest. Highest variability between day and night temperatures was found at the clearings, where daily maximum temperatures in this comparatively dry month were on average 14 °C warmer than in the adjacent secondary forest.

STUDY DESIGN

Soil analyses were performed to test the prerequisite of comparable soil conditions prior to disturbances. A soil profile was established in the vicinity of each plot to a maximum depth of 2.3 m in order to assess main soil properties. Horizon designation and soil classification were made in accordance with the US Soil Taxonomy (Soil Survey Staff 2003). Samples were taken by horizon from three sides of the pit walls for laboratory analyses. For the determination of the bulk density, three undisturbed soil cores with a volume of 100 cm³ were taken from each horizon. The homogeneity of the soil in the plots was tested afterwards to 1 m soil depth using a soil auger.

The internal nutrient cycle at the plots was studied by monitoring rainfall, throughfall, litter percolate and soil solution for two consecutive years. Rainfall was collected at three forest clearings, two at lower elevations and one close to the mature forest plots. At each clearing, five raincatchers were installed 1.5 m above the ground and shrub vegetation was reduced to approximately 1 m height in the surrounding of the collectors. Furthermore, all plots were equipped with eight to ten randomly distributed throughfall collectors. Rain collectors as well as throughfall collectors

consisted of 2 l collection bottles and a sharp-rimmed funnel with a diameter of 115 mm, all made of polyethylene. The collection bottles of the throughfall collectors were partly buried in the ground so that the rims of the funnels were approximately 0.3 m above the ground surface. Hence, herbal vegetation close to the ground was not considered in throughfall. The ground of the funnel was covered by a 0.5 mm polyethylene net to reduce the contamination of the samples with litter and insects. Additionally, a table-tennis ball was placed in the funnel mouth to reduce evaporation losses.

Litter percolate was collected using four zero-tension lysimeters per plot, which were placed below the root mat within the organic layer. The lysimeters consisted of plastic boxes (28.5 cm side length, 8 cm height), covered with a 0.5 mm polyethylene mesh. A silicon tube connected the lysimeter to a buried 2 l polyethylene sampling bottle in a closeable bucket. Soil solution from deeper soil layers was extracted by ceramic suction cups (SKL 100, ceramic cup K100, UMS Munich) in 0.15, 0.30 and 1.00 m depths. Three cups, one at each depth, were installed in the form of a triangle with 1 m side length in three replicates at each plot. The groups were arranged at maximal distance to each other, and all had a horizontal distance of 5 m from the pump system (Vacuum case VK-3, UMS Munich), which was placed in a closeable box in the center of the plot together with the 1 l sampling bottles (Duranglass). The soil solution collected by the suction cups was stored in one bottle for each soil depth. Litterfall was collected in litter traps of 0.5 m × 0.5 m made of a wooden frame covered by a 0.5 mm mesh net. Two of these were placed horizontally 0.25 m above the ground in all forested plots. To get an idea of the nutrient concentrations in the surface runoff, a stream close to the mature forest was regularly sampled.

Soil samples were taken from four different depths (0-0.15, 0.15-0.30, 0.30-0.60, 0.60-1.0 m) at twelve randomly chosen sites per plot. Every three samples of each depth were combined to get four composite soil samples per plot and depth unit.

SAMPLING PROCEDURE FOR WATER SAMPLES

After a calibration period of two months, the sampling of the raincatchers, suction cups and stream water was started in May 2000. Lysimeters and litter collectors were added in November 2000. In the first study year, samples were taken twice a week in the following manner: On one date, the raincatcher and lysimeter samples were taken. Water volumes were recorded for all individual collectors, and a composite

sample of 100 ml was taken from each plot. Stream water samples were taken on the same date. Pumps for the suction cups were turned on to create a constant under-pressure of 400 hPa until the next day when these samples were taken. Sampling of the litter traps was carried out on a monthly basis and was always conducted within the first three days of a month.

Starting from the end of May 2001, three more forest clearings were included in the study to obtain a total of six replicates. Three of these sites were burned in November 2001 and were thus not included in this study. As a consequence, one clearing sampled in the first year was replaced by another in the second. Samples were taken on a weekly basis from May until October 2001, with two days between measurements in the mature forests and the regenerating sites. From November until the end of the second study year, samples of the lower plots were again taken on a biweekly basis, while the weekly mode was continued at the mature forest plots.

Soil solution was obtained continuously in all plots at soil depths between 0.15 and 0.30 m with the exception of a very dry period in 2001 when no solution could be extracted for up to five weeks at some plots. The suction cups at 1.00 m were less effective in extracting soil solution so that sampling, especially at the overall drier secondary forest sites, failed frequently during drier periods.

SAMPLE TREATMENT

Composite samples were made for fortnight periods. While rain and litter percolate samples were mixed volume weighted, the soil solution samples were equally weighted as no reliable data on the belowground water fluxes existed. Missing soil solution samples due to dry soils were ignored in the mixed samples. Three times when either rain samples or data were missing for individual plots, samples were excluded. Composite samples were made for the whole period independent of the sampling frequency. One exception was the time from November 2001 to February 2002 when samples from the clearings and the secondary forests were not mixed but analysed individually. For that time, volume weighted means for fortnight periods were calculated for rainfall, throughfall and litter percolate samples, and means were used for soil solution and stream water. Water samples were stored frozen and litter and soil samples were kept in an air-dried condition until analysis.

CHEMICAL AND PHYSICAL ANALYSES

Analyses of the mineral soil were carried out on air-dried samples (40° C) of the fraction < 2 mm. Of the soil profiles, pH was determined using H₂O and 0.01 M CaCl₂ at a soil : solution ratio of 1 (m) : 2.5 (v) with a standard combined electrode with integrated temperature probe (WTW SenTix 41 pH 330). Total carbon (C_t) and nitrogen (N_t) contents were analysed on ball-milled samples using a total element analyser (Elementar Vario EL). Exchangeable cations (K, Ca, Mg, Na, Al) were extracted by a 0.5 M NH₄Cl solution (Trüby & Aldinger 1989) and measured by atomic absorption (Varian SpectrAA 400). The CEC was calculated as the sum of the exchangeable base cations and exchangeable Al. Dissolution of Al and Fe was tested in a 0.2 M oxalate solution at pH 3 (Schwertmann 1964) to get Fe and Al bound in metal-humus complexes, allophane, imogolite and ferrihydrite (Fe_o, Al_o). Following the procedure of Holmgren (1967), cold dithionite-citrate was used to extract Fe and Al in crystalline oxides and fractions of metal-humus complexes and amorphous constituents (Fe_d, Al_d). Al and Fe in extracts were again measured by atomic absorption (Varian SpectrAA 400). Particle size distributions were analysed using field moist samples, which were stored at temperatures around 4 °C. Soil samples were dispersed by shaking 5 g of soil in 20 ml 0.1 M Na₄P₂O₇ solution added to 500 ml water overnight. Sand-size particles were removed by sieving, silt and clay contents were determined using the pipette method (Gee & Bauder 1986). In the composite soil samples of each plot, mineral N content was determined by extracting 20 g of field moist samples less than four hours after sampling with 100 ml 1 M KCl solution. Extracts were stored frozen and analysed using a Segmented Flow Analyser (Skalar, SA 2000/4000).

The pH measurement of water samples was conducted in Tanzania on separates of the composite samples using a standard combined electrode with integrated temperature probe (WTW SenTix 41 pH 330). Prior to further analysis, rain and litter percolate samples were filtered through an ash-free paper filter, pore size < 2 µm (Schleicher & Schuell, blueband 589³). NH₄-N as well as NO₃-N and NO₂-N were measured using a Segmented Flow Analyser (SKALAR, SA 2000/4000). As NO₂-N concentrations were considered to be negligible, it is not referred to separately but included in the term NO₃-N in this paper. Litter samples were separated in leaves, twigs and branches (< 20 mm diameter), mosses, lichens and a rest, composed of reproductive parts and unidentified plant material, and subsequently weighed. For nutrient analysis, samples were mixed, ground and digested with concentrated HNO₃ under pressure (Heinrichs et al. 1986). The same procedure was used to

dissolve nutrients of the ground litter layer. To determine the element concentrations of Mg, K, Ca and Na in water samples and litter extracts, Flame absorption spectrometry (AAS; Varian SpectrAA 400) was used.

LIMITATIONS OF THE STUDY DESIGN

The usage of lysimeter and suction cups for the determination of soil solution results in inherent problems that have to be considered when interpreting the data. For the determination of the litter percolate, zero tension lysimeters were installed from a small soil pit and set laterally below the root mat in the organic soil layer. The first uncertainty in using lysimeters is that water collected in the lysimeter could either come from the zone directly above the lysimeter, or it could be laterally transported water that was deposited elsewhere (Addiscott 1994). Since the studied plots all had inclinations of less than 10° and there were no dense horizons within or below the root mat favouring lateral flow along its borders, it can safely be assumed that most water collected in the lysimeters derived from water deposited directly above the collectors. Another problem that cannot be overcome by zero tension lysimeters is the creation of an air-water interface at the base of the soil above the collector, where otherwise continuous soil pores are interrupted. Thus, due to surface tensions, water is held back above the lysimeter until the soil becomes saturated. Water accumulates and eventually moves laterally away from the lysimeters, thus reducing the water flux and eventually also altering the nutrient concentration of the water finally entering the collectors. Therefore, the amount of water collected in the lysimeters is in most cases not totally equal to the amount of water percolating through the litter layer in the undisturbed soil next to the lysimeter. These devices are therefore not suitable for calculating absolute fluxes. As the same type of lysimeter was installed at all plots and at comparable soil depths, any errors induced by the sampling method should be similar, making comparisons of concentrations between sites possible.

Similar problems arise with the usage of suction cups. The area of soil that is sampled is usually not well defined (Warrick & Amoozegar-Fard 1977) as it depends on soil hydraulic properties, soil moisture and the suction applied. Depending on the water suction applied, different soil pore sizes with different ion compositions are affected. By using under-pressure, additional solution is extracted that would not be obtained with free draining lysimeters, probably leading to different concentrations (Marques et al. 1996). Therefore, direct comparisons of results obtained by different water extraction methods are problematic. In contrast to zero tension lysimeters,

suction cups also usually do not collect water when no suction is applied unless the water tension in the soil is low enough to let the water diffuse passively into the ceramic cups. The area surrounding the suction cups is depleted of water due to the applied suction and a diffusion gradient towards the cups is created and may interfere with the natural flow pattern of the soil. In this study, pressure pumps were only switched on once or twice a week for 24 h and it was assumed that the natural flow pattern returned to near natural conditions in between readings. Hence, soil solution with suction cups was not collected the entire time, as was the case for the lysimeters, but only at specific periods of the week. Therefore there was a risk of missing singular peaks in amounts and composition of water fluxes. This leads to another general problem because suction cups usually extract only a minor soil volume and can be by-passed by the water flow in the soil particularly during high rainfall events (Addiscott 1994), and when fluxes mainly occur in macro-pores. In summary, water extracted by suction cups is probably not completely equal to the free percolating gravimetric soil water. However, with 400 hPa, applied pressures were comparatively low and as soil properties were overall comparable among sites, the determined concentrations can nevertheless be used to assess possible vegetation effects.

For the comparison of different vegetation types, the first year was most suitable, since during that time the water samples at all plots were taken on the same day and the annual amounts of rainfall were similar at all sites. For the interpretation of the data of the second year, some restrictions have to be made. Firstly because the sampling scheme in the second year differed between mature forest plots and regenerating sites. As raincatchers and lysimeters accumulate water and nutrient fluxes for a given period, effects on annual flux amounts are not considered to be substantial, assuming that no conversion of the samples took place during the longer time period they have spent in the field (such as microbial decay or losses due to evaporation). Soil solution gained by the suction cups depends on soil water conditions during the time when water is extracted from the soil. As rainfall regimes and thus soil water contents and composition might change within a few hours, the comparison of samples taken at different days certainly inherits some problems. But analyses of individual samples at higher resolution for some periods and the measurement of composite samples of the first year revealed that the seasonal variation of the soil solution concentrations in the mature forests was low compared to the secondary forest sites and especially the clearings. Thus, the assumption was made that the median concentration of the composite samples obtained from weekly measurements in the mature forest during the second year should be very close to

the median that might have been obtained by sampling on a higher resolution as was done at the secondary forest sites and the clearings. Therefore, only median concentrations for total years but no individual fortnight samples or time series were statistically compared between vegetation types.

Another problem that arose in the second year was that overall amounts of rainfall were considerably less than the year before. This decline was greater in the area of the mature forest sites than at the regenerating sites due to less rainstorm activity during the rainy season. Therefore, overall water fluxes by rainfall and throughfall and probably also in the soil solution were expected to be smaller in the mature forests and might result in higher nutrient concentrations. This effect also has to be considered when the data of the mature forests are compared to those of the regenerating plots.

CALCULATIONS AND STATISTICAL EVALUATION

Fluxes of rainfall and throughfall were calculated by multiplying the depths collected with the respective element concentrations. Volume weighted means were calculated by dividing the product of element concentration and flux depths by the total flux depth of the year for each two week period and summing the terms. Net throughfall fluxes were determined as difference between throughfall and rainfall fluxes.

Statistical analyses were conducted using the program Statistica 5.0 (Statsoft, Inc., Tulsa, UK). If the analysis of variance (ANOVA) resulted in significant differences between the studied vegetation types, Scheffé-Tests were used to analyse differences between the treatments. ANOVA was conducted on log-transformed data to avoid a correlation between mean values and respective standard deviations. Correlation analyses were performed using Pearson Product-Moment correlations.

RESULTS

COMPARABILITY OF SOIL PROPERTIES PRIOR TO DISTURBANCE

The possibility of effects caused by differences in soil properties should be ruled out in order to be able to ascribe differences in the nutrient cycle to changes in the vegetation cover. But it is not only the soil that affects the vegetation composition: The vegetation itself has a feedback effect on a range of soil properties such as

amount and composition of soil organic matter and soil acidity. In order to test the prerequisite of similar soil conditions prior to vegetation changes, it is necessary to use parameters which are only slightly affected by the vegetation cover, such as soil type, particle size distribution and concentrations of pedogene oxides.

All soils investigated met the requirements of Andisols according to Soil Survey Staff (2003). Soils were further classified as Fulvudands or Epiaquands, depending on whether the accumulated soil organic material reached the requirements for a histic epipedon or not. Buried soils were found in nearly every profile, with fossil A horizons being most pronounced and having higher C contents in the mature forest. These buried horizons induce a high spatial heterogeneity of the soils, especially below 0.5 m. But particle size distribution did not reveal significant differences with the exception of the topsoil between 0.05 and 0.10 m (Fig. 5.1). In this depth, clay contents were significantly lower in the secondary forest as compared to the mature forest, and sand contents were significantly higher. Analyses of the water content of the samples revealed that topsoil samples of secondary forests were significantly drier than samples from clearings or the mature forest. Hence differences in texture might have been caused by an irreversible hardening of soil particles upon drying, resulting in a reduction of clay, and an increase in sand size particles in the topsoil of the secondary forest. In the soil profiles under mature forest, hydromorphic properties were more strongly expressed at depths below 0.5 m than at the other plots, as can be seen by their low contents of active Fe (Table 5.2). Similar to the dissolution results of Fe and Al, also pH (H₂O, CaCl₂) and total C and N values did not vary significantly between the treatments. C contents in the upper mineral horizons showed a high variability in all studied soils. These small scale differences were probably attributable to the frequent activity of wild pigs, which locally mixed the soil up to a depth of 0.3 m in their search for food.

As the ECEC was correlated with C contents in the topsoil, ECEC values also exhibited a high variability (Table 5.3). But despite high C contents, the ECEC was very low in all profiles except for the uppermost A and Oa horizons as all soils were acidic and in an advanced stage of weathering. Since high rainfall amounts also favour leaching, the content of exchangeable bases was low compared to exchangeable Al, resulting in a low base saturation. Hence, the overall availability of base cations in these soils was scarce and best in A and Oi horizons, where the highest root density was also found. No significant differences between the different treatments were obtained. These results indicate a generally low base retention capacity of the mineral soil.

Nutrient stocks of C and N did not exhibit significant differences in the mineral soil to a depth of 1.0 m (Table 5.1). But in the organic layers, total C and N stocks were lowest under secondary forests. This difference was significant between mature and secondary forest plots ($p < 0.05$).

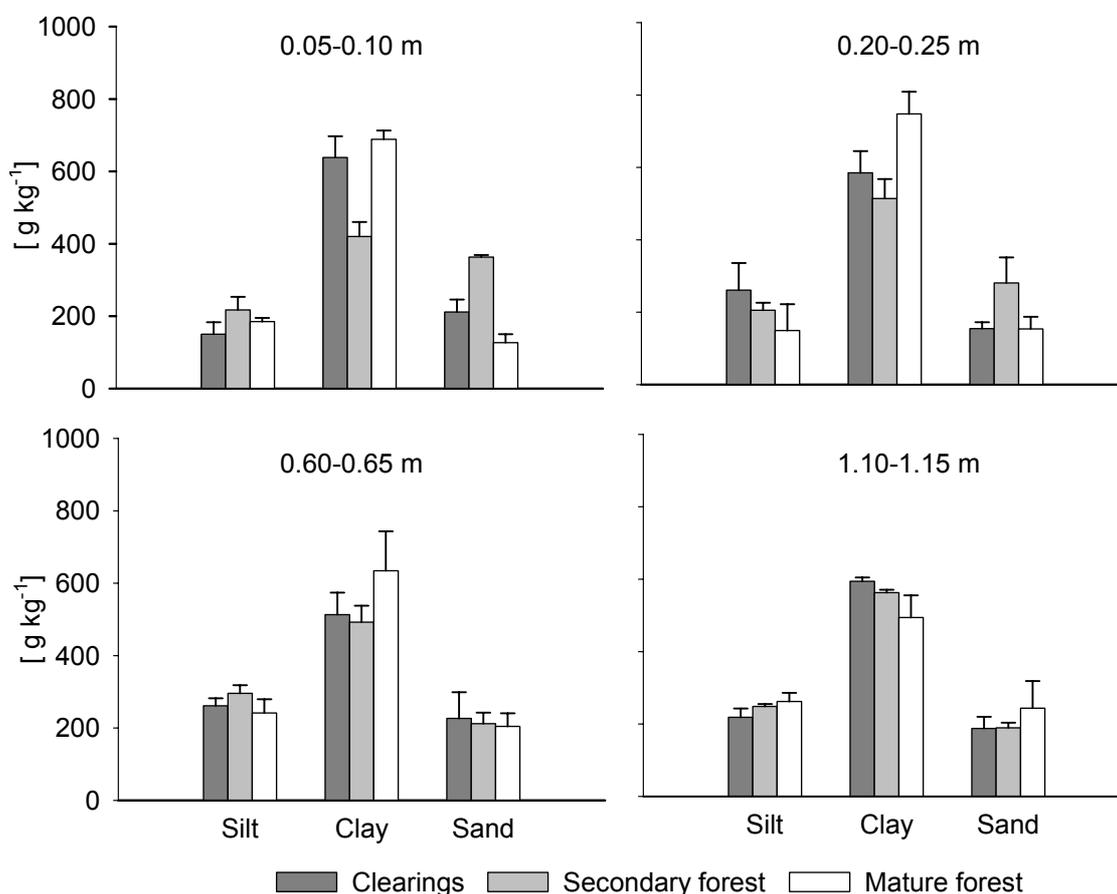


Fig. 5.1 Particle size distribution at different soil depths under clearings, secondary and mature forests (error bars provide the standard error).

Table 5.1 Mean C and N stocks in the organic soil horizons and the mineral soil up to a soil depth of 1.0 m (\pm standard error). Different letters indicate significant differences between vegetation types (Scheffé-test, $p < 0.05$).

	Organic Soil Horizons			Mineral Soil			Total		
	Cl	Sf	Mf	Cl	Sf	Mf	Cl	Sf	Mf
	[t ha ⁻¹]			[t ha ⁻¹]			[t ha ⁻¹]		
C	98 ^{ab} ± 18	62 ^a ± 13	164 ^b ± 22	474 ^a ± 8	471 ^a ± 33	565 ^a ± 44	572 ^{ab} ± 13	533 ^a ± 35	729 ^b ± 54
N	6.3 ^{ab} ± 1.3	3.7 ^a ± 0.8	10.3 ^b ± 1.2	30.0 ^a ± 1.4	27.4 ^a ± 0.4	25.6 ^a ± 2.8	36.4 ^a ± 1.1	31.1 ^a ± 0.9	35.9 ^a ± 3.1

Cl: clearings, Sf: Secondary forest, Mf: Mature forest

Table 5.2 Mean soil characteristics of clearings (Cl), secondary (Sf) and mature forests (Mf) at soil depths of 0.10-0.20, 0.25-0.35 and 0.95-1.05 m, where instruments were installed.

Soil Depth [m]		pH	pH	C	N	Fe _o	Fe _d	Al _d
		H ₂ O	CaCl ₂					
				[g kg ⁻¹]		[g kg ⁻¹]		
0.10-0.20	Cl	4.1 ± 0.1	3.9 ± 0.1	162.5 ± 13.1	10.6 ± 0.4	41.8 ± 1.02	70.1 ± 1.0	26.5 ± 2.1
	Sf	4.6 ± 0.3	4.0 ± 0.2	138.9 ± 14.6	9.0 ± 1.2	29.0 ± 3.8	71.5 ± 2.5	38.9 ± 9.4
	Mf	4.4 ± 0.1	4.0 ± 0.1	143.9 ± 21.0	8.1 ± 1.4	44.8 ± 4.2	68.3 ± 2.9	31.48 ± 9.62
0.25-0.35	Cl	4.7 ± 0.1	4.4 ± 0.3	101.6 ± 2.7	6.8 ± 0.4	31.2 ± 0.4	62.5 ± 1.3	45.3 ± 0.6
	Sf	4.7 ± 0.1	4.5 ± 0.1	106.0 ± 7.0	6.1 ± 0.1	25.7 ± 1.4	64.2 ± 2.7	43.7 ± 6.0
	Mf	4.7 ± 0.1	4.3 ± 0.1	123.0 ± 13.3	6.2 ± 0.4	42.1 ± 8.2	69.3 ± 9.2	44.8 ± 5.6
0.95-1.05	Cl	5.0 ± 0.1	5.0 ± 0.1	74.8 ± 9.3	3.7 ± 0.6	31.9 ± 3.6	79.3 ± 7.1	40.2 ± 2.2
	Sf	4.9 ± 0.1	5.0 ± 0.1	57.2 ± 6.1	2.9 ± 0.1	36.2 ± 1.1	91.4 ± 7.4	39.3 ± 4.7
	Mf	4.6 ± 0.1	4.9 ± 0.0	58.8 ± 9.3	2.6 ± 0.5	24.9 ± 5.3	47.7 ± 10.6	27.0 ± 6.2

Table 5.3 Mean cation exchange characteristics of clearings (Cl), secondary (Sf) and mature forests (Mf) at soil depths of 0.10-0.20, 0.25-0.35 and 0.95-1.05 m, where instruments were installed.

Soil Depth [m]		ECEC	K	Mg	Ca	Na	Al
		[cmol _c kg ⁻¹]					
		[cmol _c kg ⁻¹]					
0.10-0.20	Cl	8.54 ± 0.82	0.35 ± 0.04	0.24 ± 0.01	0.57 ± 0.12	0.06 ± 0.01	7.11 ± 0.84
	Sf	6.53 ± 2.04	0.19 ± 0.06	0.12 ± 0.04	0.18 ± 0.02	0.09 ± 0.01	5.71 ± 1.8
	Mf	6.16 ± 2.35	0.13 ± 0.06	0.11 ± 0.07	0.21 ± 0.08	0.08 ± 0.02	5.22 ± 1.85
0.25-0.35	Cl	1.36 ± 0.37	0.14 ± 0.03	0.03 ± 0.01	0.09 ± 0.01	0.03 ± 0.01	1.07 ± 0.36
	Sf	1.93 ± 0.07	0.09 ± 0.00	0.05 ± 0.02	0.12 ± 0.02	0.06 ± 0.01	1.57 ± 0.04
	Mf	2.52 ± 0.51	0.05 ± 0.01	0.03 ± 0.01	0.10 ± 0.02	0.04 ± 0.01	2.23 ± 0.43
0.95-1.05	Cl	0.37 ± 0.12	0.05 ± 0.02	0.00 ± 0.00	0.06 ± 0.02	0.02 ± 0.00	0.24 ± 0.11
	Sf	0.70 ± 0.14	0.03 ± 0.00	0.02 ± 0.001	0.06 ± 0.02	0.05 ± 0.02	0.51 ± 0.13
	Mf	0.48 ± 0.05	0.11 ± 0.02	0.01 ± 0.00	0.02 ± 0.00	0.03 ± 0.01	0.31 ± 0.06

SEASONAL CHANGES IN THE ION CONCENTRATION OF WATER PERCOLATING THROUGH THE ECOSYSTEM

In the forest belt at Mt. Kilimanjaro, the bimodal rainfall distribution leads to a seasonality in nutrient concentrations in most water pathways. As can be seen in Fig. 5.2, K concentrations in water from throughfall and litter percolate were always highest during drier periods as were concentrations in precipitation, not depicted in the graph. The same pattern that is shown here for K and $\text{NO}_3\text{-N}$ in the mature forest was also observed with different intensities for other nutrients. As $\text{NO}_3\text{-N}$ was absorbed in the canopy of the forested plots, the concentration in throughfall was very low and exhibited comparably minor seasonal changes (Fig. 5.2). In the soil solution, seasonal fluctuations in concentrations were generally damped and only increased during extended dry periods (Fig. 5.3).

THROUGHFALL COMPOSITION AND FLUXES AT INDIVIDUAL VEGETATION TYPES

Nutrient concentrations generally increased upon passage through the vegetation cover as can be seen from the volume weighted mean concentrations in rainfall and throughfall in Table 5.4. One exception was the $\text{NO}_3\text{-N}$ concentrations. $\text{NO}_3\text{-N}$ was apparently absorbed in the canopy of the forests but not in the vegetation of the clearings so that throughfall concentrations in the clearings were significantly higher in the first, although not in the second year. In the first year, K concentrations in the throughfall of the mature forests were also significantly lower than in the secondary forests and the clearings, but this effect was not observed in the second year. For the other elements, no significant differences in throughfall concentrations between the treatments were obtained.

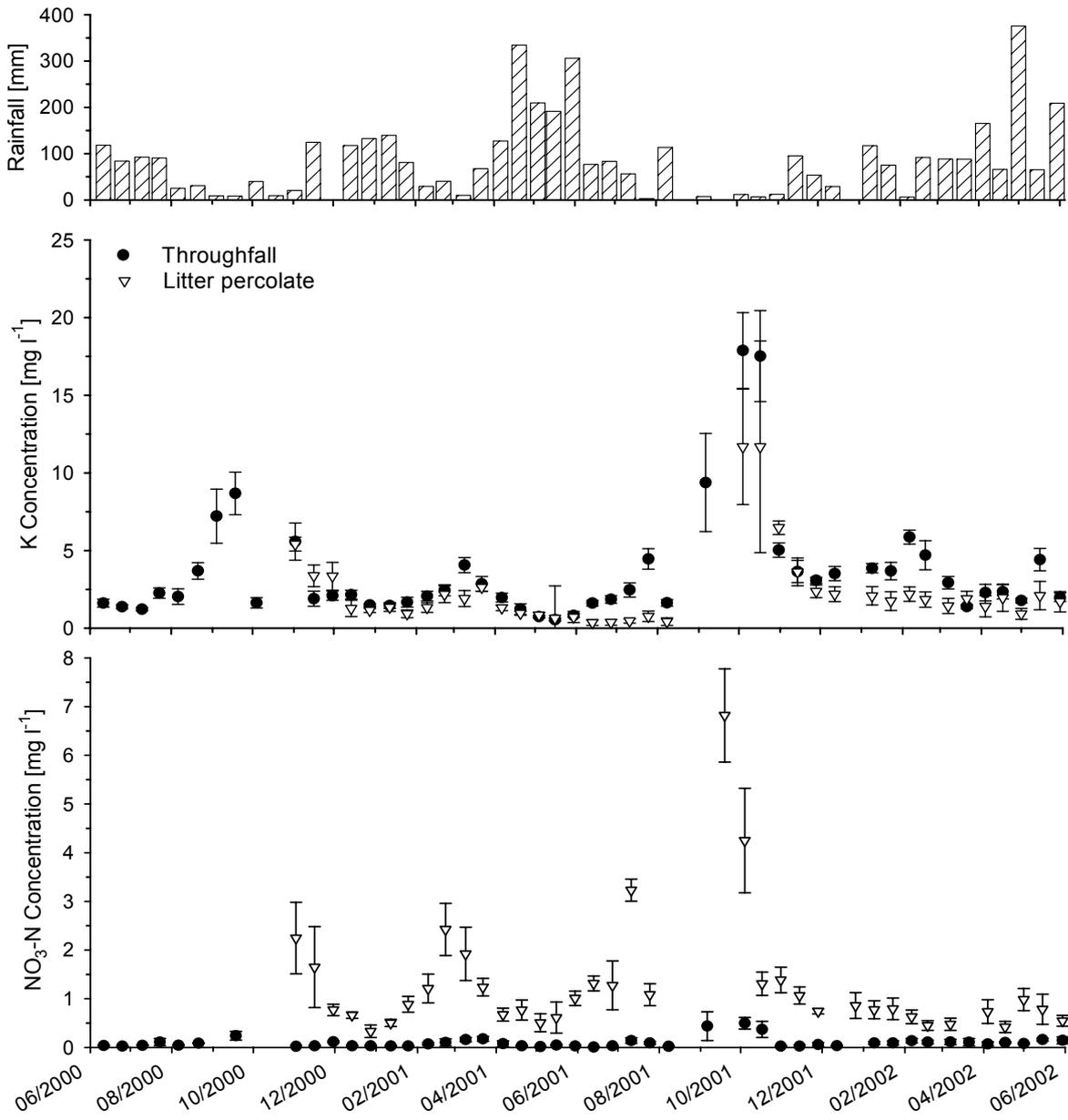


Fig. 5.2 Seasonal variation in K and $\text{NO}_3\text{-N}$ concentrations in throughfall and litter percolate of mature forests. Error bars represent standard errors. Rainfall amounts of fortnight periods at 2300 m a.s.l. are presented for comparison.

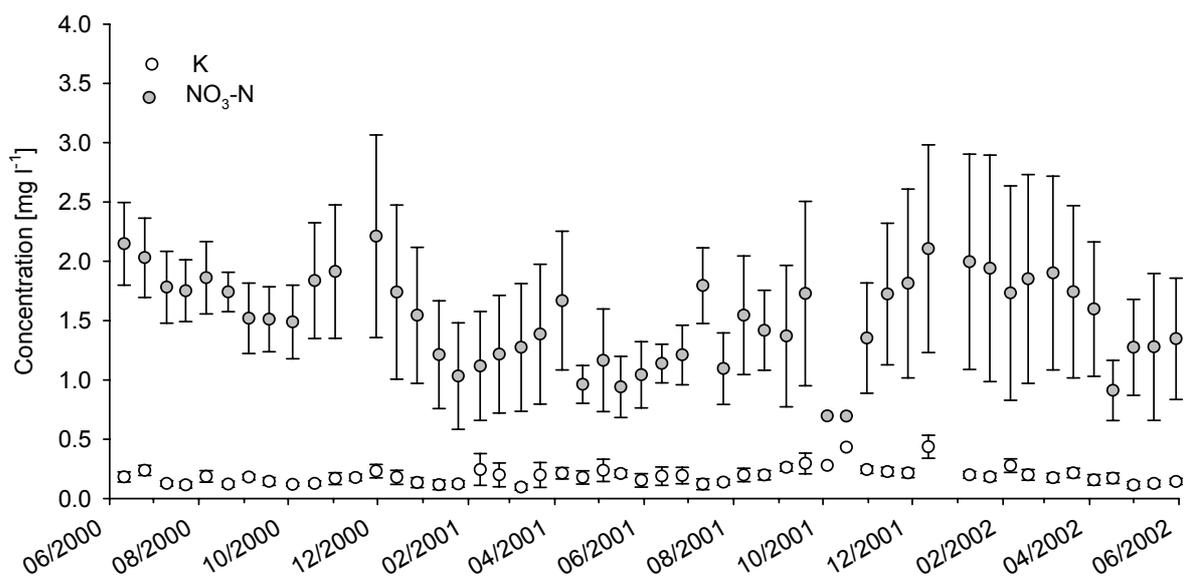


Fig. 5.3 Seasonal variation in $\text{NO}_3\text{-N}$ and K concentrations in the soil solution at 15 cm depth.

Table 5.4 Volume weighted mean concentrations and standard errors ($n = 3\text{-}4$) in rainfall and throughfall for two consecutive years (June 2000 to June 2002). Different subscripts within rows (but not within columns) indicate significant differences among the means ($p < 0.05$).

	Year 1					Year 2				
	Rainfall		Throughfall			Rainfall		Throughfall		
	2100 m	2300 m	Cl	Sf	Mf	2100 m	2300 m	Cl	Sf	Mf
	[mg l ⁻¹]					[mg l ⁻¹]				
K	0.65	0.30	3.06 ^a ± 0.09	2.98 ^a ± 0.07	1.50 ^b ± 0.20	0.33	0.50	3.04 ^a ± 0.27	4.41 ^b ± 0.24	2.97 ^a ± 0.15
Mg	0.03	0.04	0.09 ^a ± 0.01	0.09 ^a ± 0.01	0.08 ^a ± 0.02	0.05	0.05	0.12 ^a ± 0.04	0.14 ^a ± 0.03	0.16 ^a ± 0.03
Ca	0.08	0.09	0.14 ^a ± 0.01	0.16 ^a ± 0.01	0.13 ^a ± 0.01	0.11	0.15	0.25 ^a ± 0.11	0.24 ^a ± 0.05	0.34 ^a ± 0.05
Na	0.33	0.30	0.43 ^a ± 0.06	0.51 ^a ± 0.04	0.53 ^a ± 0.09	0.35	0.36	0.59 ^a ± 0.06	0.93 ^a ± 0.05	0.90 ^a ± 0.11
$\text{NH}_4\text{-N}$	0.15	0.16	0.23 ^a ± 0.03	0.21 ^a ± 0.01	0.19 ^a ± 0.02	0.15	0.16	0.18 ^a ± <0.01	0.21 ^a ± 0.02	0.19 ^a ± 0.01
$\text{NO}_3\text{-N}$	0.09	0.13	0.15 ^a ± 0.03	0.04 ^b ± <0.01	0.05 ^b ± 0.01	0.15	0.17	0.14 ^a ± 0.02	0.05 ^a ± 0.01	0.05 ^a ± 0.01

Cl: Clearings, Sf: Secondary forest, Mf: Mature forest

The nutrient fluxes via rainfall and throughfall reflected the results obtained for nutrient concentrations. Higher throughfall $\text{NO}_3\text{-N}$ concentrations at the clearings compared to the forests led to significantly higher throughfall fluxes at the clearings for both years (Table 5.5). $\text{NH}_4\text{-N}$ fluxes were also higher at the clearings, although this difference was not significant. K fluxes via throughfall were significantly lower in mature forest compared to clearings and secondary forest in both years. In the first year, also clearings and secondary forests differed significantly in K throughfall fluxes, but that was not the case in the second year.

Table 5.5 Nutrient fluxes via rainfall and throughfall and standard errors ($n = 3\text{-}4$) for two consecutive years (June 2000 to June 2002). Different subscripts within rows (but not within columns) indicate significant differences among means ($p < 0,05$).

	Year 1					Year 2				
	Rainfall		Throughfall			Rainfall		Throughfall		
	2100	2300	Cl	Sf	Mf	2100	2300	Cl	Sf	Mf
	m	m				m	m			
	[kg ha ⁻¹ a ⁻¹]					[kg ha ⁻¹ a ⁻¹]				
K	15.8	6.9	83.0 ^a	62.5 ^b	32.2 ^c	6.2	8.0	57.2 ^a	61.6 ^a	37.2 ^b
			±3.0	±1.9	±4.0			±4.3	±3.8	±1.8
Mg	0.8	0.9	2.5 ^a	1.9 ^a	1.8 ^a	1.0	0.8	1.9 ^a	1.9 ^a	2.0 ^a
			±0.3	±0.1	±0.4			±0.4	±0.4	±0.3
Ca	1.9	2.1	3.9 ^a	3.2 ^a	2.8 ^a	2.2	2.4	4.7 ^a	3.3 ^a	4.2 ^a
			±0.4	±0.2	±0.3			±1.9	±0.6	±0.6
Na	8.0	6.7	11.5 ^a	10.5 ^a	11.5 ^a	6.7	5.7	11.1 ^a	12.9 ^a	11.2 ^a
			±1.1	±0.5	±2.0			±1.5	±0.9	±1.2
$\text{NH}_4\text{-N}$	3.6	3.6	6.1 ^a	4.5 ^a	4.2 ^a	2.8	2.5	3.3 ^a	2.9 ^{ab}	2.4 ^b
			±0.6	±0.3	±0.4			±0.1	±0.2	±0.1
$\text{NO}_3\text{-N}$	2.1	3.0	4.1 ^a	0.8 ^b	1.0 ^b	2.8	2.7	2.6 ^a	0.7 ^b	0.7 ^b
			±0.6	±0.1	±0.3			±0.3	±0.2	±0.2

Cl: Clearings, Sf: Secondary forest, Mf: Mature forest

COMPOSITION OF WATER PERCOLATING THROUGH THE SOIL UNDER DIFFERENT REGENERATION STAGES

Nutrient concentrations in litter percolate and soil solution differed among the studied vegetation types with respect to both total amount and spatial heterogeneity. As sampling of litter percolate only started in late November 2000, data for the first five months are missing. K concentrations in litter percolate were highest in the clearings (Fig. 5.4). Differences between clearings and forest plots were most pronounced in the dry seasons, as K concentrations at the clearings greatly increased

during drier periods. The high standard error for K concentrations at the clearings compared to the two forest types indicates that the spatial variability was also higher at the clearings. Similar results with higher overall concentrations as well as seasonal and spatial variability at clearings were obtained for Mg (Fig. 5.4) and Ca, whereas Na concentrations did not show major differences. Regarding nitrogen compounds, $\text{NH}_4\text{-N}$ concentrations did not exhibit differences between the treatments. But for $\text{NO}_3\text{-N}$ in the litter percolate, the highest concentrations were again measured at the clearings, where the highest variability was also observed.

In the soil solution at 0.15 m, most patterns observed in the litter percolate were repeated (Fig. 5.5). K and Mg concentrations were higher at the clearings compared to the forest. The highest variability was also found there. Overall, seasonal changes induced by rainy and dry seasons were less pronounced compared to the litter percolate. $\text{NH}_4\text{-N}$ concentrations were in the same order of magnitude for all vegetation types, while $\text{NO}_3\text{-N}$ concentrations again had highest values under the clearings.

Table 5.6 presents the median concentrations for the litter percolate in the second study year. For all nutrients with the exception of Na, the highest median concentrations were found in the clearings. Despite the high standard error obtained for the clearings, the means of the vegetation type nutrient concentrations were significantly different for Mg, K, Ca and $\text{NH}_4\text{-N}$, but not for $\text{NO}_3\text{-N}$. The Scheffé-Test revealed that significant differences mainly occurred between clearings and mature forest. The secondary forest usually exhibited nutrient concentrations similar to those of the mature forest or values between those of the mature forest and the clearings, but still no significant differences were obtained.

In the soil solution at 0.15 and 1.00 m depth, the highest mean nutrient concentrations were again generally obtained at the clearings (Table 5.7, 5.8). Due to a high variability within field replicates, K concentrations at 15 cm soil depth were significantly higher than in the forests in the first year. Ca concentrations in both years were significantly higher in the clearings, while Mg concentrations only showed significant differences to the mature forest in the second year. Mean $\text{NO}_3\text{-N}$ concentrations in the soil solution at 15 cm depth only differed significantly between the vegetation types in the first year. As overall nutrient concentrations were low in the soil solution at 100 cm soil depth, differences were not significant except for $\text{NO}_3\text{-N}$, which exhibited higher concentrations under mature forest in the first year.

While the mature forest usually exhibited the lowest nutrient concentrations in litter percolate as well as in soil solution, for $\text{NO}_3\text{-N}$, the secondary forest plots had the lowest concentrations.

CHANGES IN THE NUTRIENT COMPOSITION OF THE WATER DURING ITS PASSAGE THROUGH THE DIFFERENT REGENERATION STAGES

On its way from rainfall to the streams, the chemical composition of water undergoes numerous changes as it passes through the vegetation, percolates through the litter layer and finally through the mineral soil. In Fig. 5.6, mean nutrient concentrations of each vegetation type during the second year were used to create box-whisker-plots. These show the annual medium concentrations as well as the annual variability of the nutrient concentrations in different ecosystem compounds. The first example of Mg in mature forests shows that throughfall water was enriched with Mg while passing through the vegetation as compared to precipitation. A further increase in Mg concentrations was observed in the litter percolate, while it decreased in the mineral soil, probably due to adsorption to soil constituents or uptake by plants. Mg concentrations in stream water were on average higher than in precipitation, but smaller than at the sampling site for soil solution at 1 m. The same pattern was observed for all three regeneration stages and - with the exception of throughfall water - overall concentrations were highest in the clearings. For K, the concentration increase from precipitation to throughfall was more pronounced than for Mg. In the natural forest, K concentrations did not increase further from throughfall to litter percolate. Very low K concentrations were observed in the soil solution, which increased slightly again in the stream water. Different from in the mature forest, K concentrations in the clearings were highest in the litter percolate. In the soil solution at 0.15 m depth, K concentrations at the clearings were again considerably higher than in both forested plots, but also decreased with increasing soil depth. Concentrations in the secondary forest showed intermediate values between the low concentrations in mature forest and the considerably higher ones in the clearings.

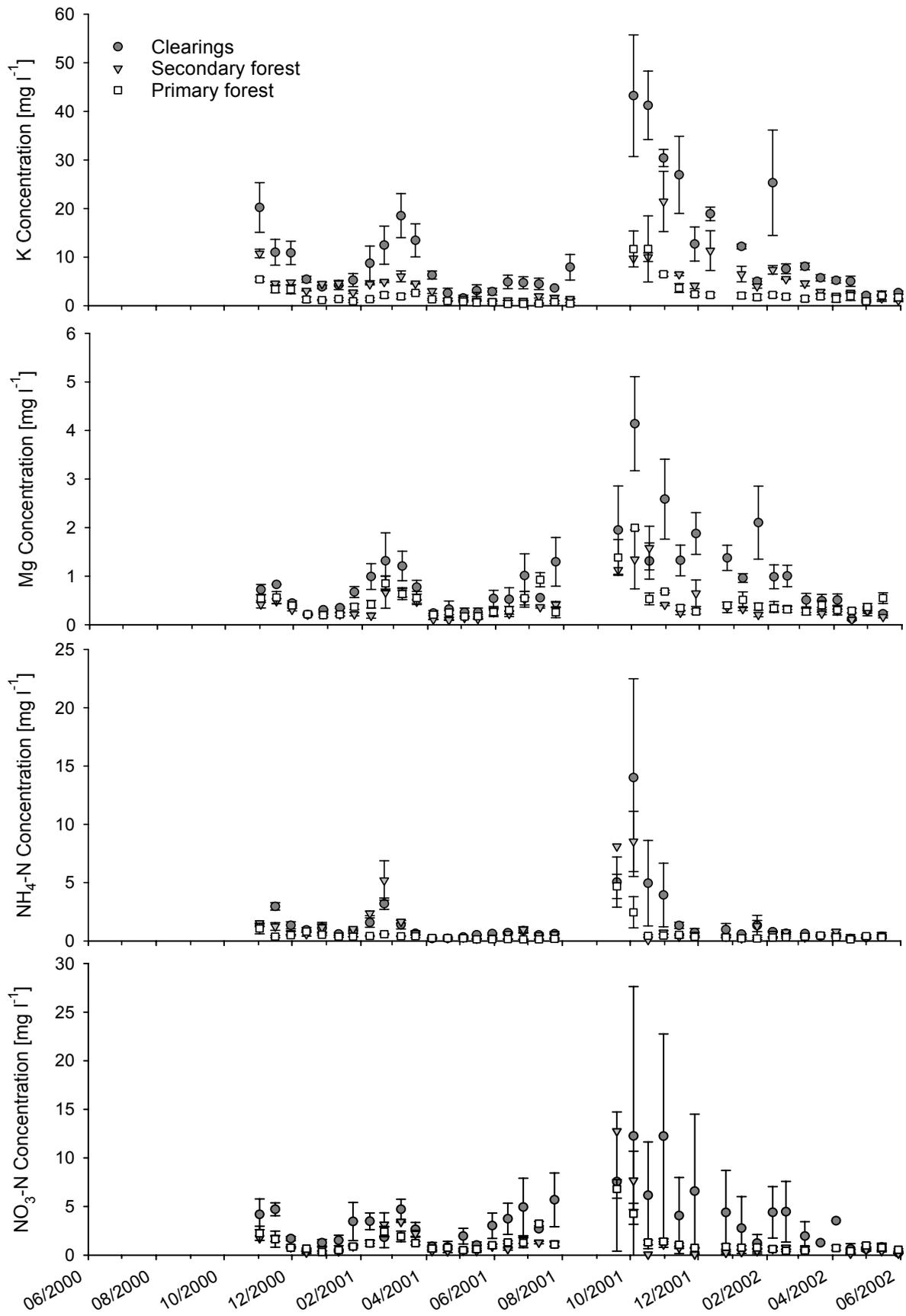


Fig 5.4 Nutrient concentrations in litter percolates under different vegetation types. Error bars provide standard errors ($n = 3-4$).

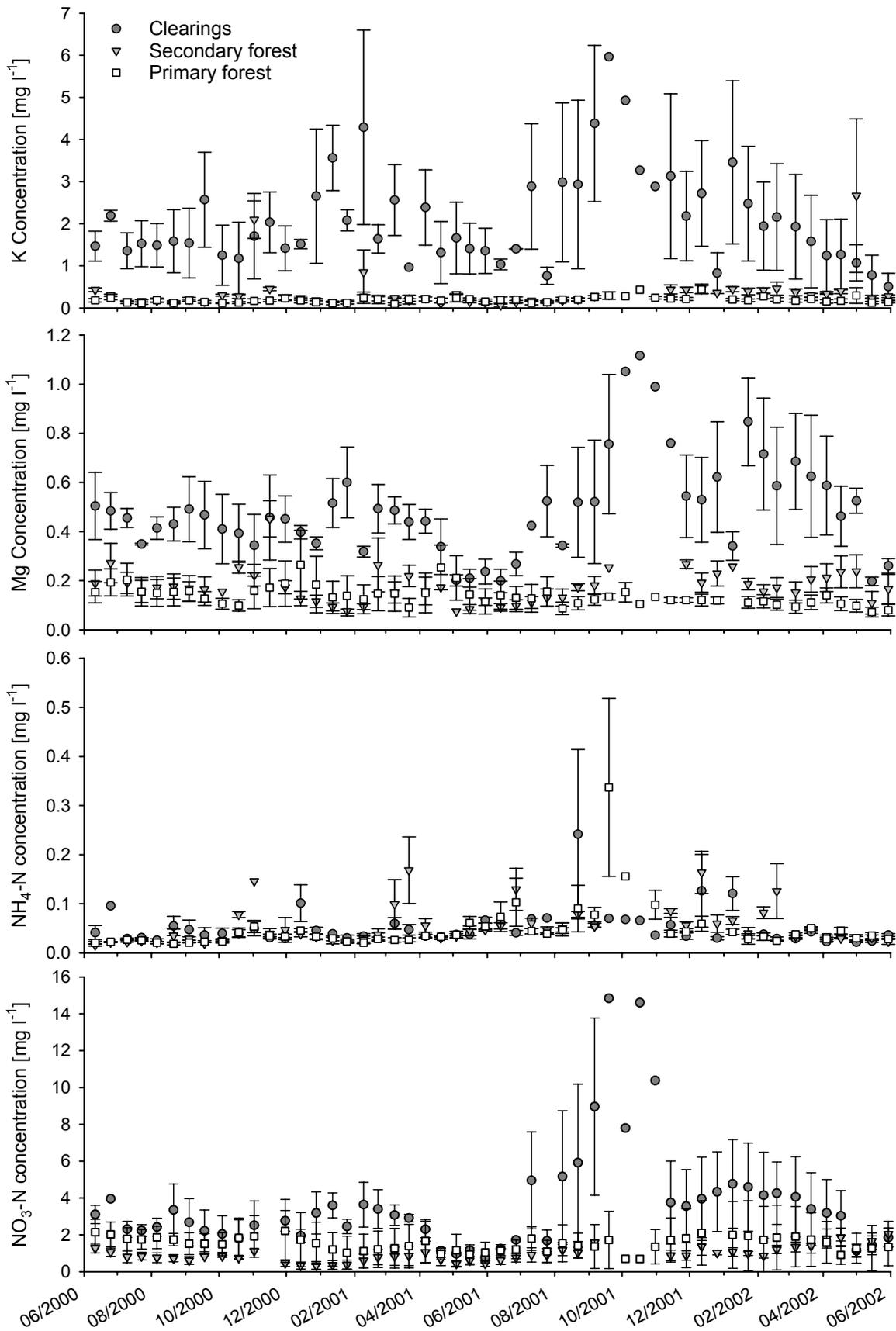


Fig. 5.5 Nutrient concentrations in the soil solution (0.15 m) under different vegetation types. Error bars provide standard errors (n = 3,4).

Table 5.6 Means of the median nutrient concentrations in the litter percolate under different vegetation types for the second year (\pm standard errors for field replicates, $n = 3, 4$). Different subscripts within rows indicate significant differences among the means ($p < 0.05$).

	Year 2		
	Litter Percolate		
	Cl	Sf	Mf
	[mg l ⁻¹]		
K	7.41 ^a ± 0.61	3.21 ^{ab} ± 0.36	1.44 ^b ± 0.50
Mg	0.92 ^a ± 0.20	0.31 ^{ab} ± 0.01	0.32 ^b ± 0.06
Ca	1.95 ^a ± 0.48	0.80 ^{ab} ± 0.05	0.79 ^b ± 0.15
Na	0.93 ^a ± 0.09	0.93 ^a ± 0.06	0.81 ^a ± 0.05
NH ₄ -N	0.64 ^a ± 0.02	0.45 ^{ab} ± 0.07	0.27 ^b ± 0.04
NO ₃ -N	3.08 ^a ± 1.69	0.62 ^a ± 0.07	0.92 ^a ± 0.25

Cl: Clearings, Sf: Secondary forest, Mf: Mature forest

Table 5.7 Means of the median nutrient concentrations in the soil solution in 0.15 m depth for two years (June 2000 to June 2002) and standard errors for field replicates ($n = 3, 4$). Different subscripts within rows indicate significant differences among means ($p < 0.05$).

	Year 1			Year 2		
	Soil Solution 0.15 m			Soil Solution 0.15 m		
	Cl	Sf	Mf	Cl	Sf	Mf
	[mg l ⁻¹]			[mg l ⁻¹]		
K	1.53 ^a ± 0.44	0.20 ^b ± 0.04	0.15 ^b ± 0.04	2.09 ^a ± 1.22	0.29 ^a ± 0.03	0.19 ^a ± 0.04
Mg	0.40 ^a ± 0.05	0.14 ^a ± 0.03	0.15 ^a ± 0.06	0.57 ^a ± 0.20	0.18 ^{ab} ± 0.04	0.11 ^b ± 0.02
Ca	1.41 ^a ± 0.45	0.16 ^b ± 0.02	0.27 ^b ± 0.10	1.59 ^a ± 0.45	0.28 ^b ± 0.05	0.25 ^b ± 0.06
Na	0.43 ^a ± 0.03	0.51 ^a ± 0.09	0.42 ^a ± 0.07	0.36 ^a ± 0.10	0.74 ^a ± 0.12	0.41 ^a ± 0.08
NH ₄ -N	0.04 ^a ± 0.01	0.03 ^a $\pm <0.01$	0.03 ^a $\pm <0.01$	0.04 ^a $\pm <0.01$	0.05 ^a $\pm <0.01$	0.04 ^a $\pm <0.01$
NO ₃ -N	2.18 ^a ± 0.32	0.62 ^b ± 0.23	1.48 ^a ± 0.34	3.92 ^a ± 2.25	1.07 ^a ± 0.17	1.54 ^a ± 0.55

Cl: Clearings, Sf: Secondary forest, Mf: Mature forest

Table 5.8 Means of the median nutrient concentrations in the soil solution in 100 cm depth as well as in stream water of the mature forests for two years (June 2000 to June 2002) and standard errors for field replicates (n = 3, 4). Different subscripts within rows indicate significant differences among the means ($p < 0.05$).

	Year 1				Year 2			
	Soil Solution 1 m			Stream	Soil Solution 1 m			Stream
	CI	SF	MF		CI	SF	MF	
[mg l ⁻¹]				[mg l ⁻¹]				
K	0.35 ^a ± 0.11	0.21 ^a ± 0.02	0.15 ^a ± 0.02	0.70	0.43 ^a ± 0.18	0.21 ^a ± 0.02	0.21 ^a ± 0.04	0.84
Mg	0.29 ^a ± 0.05	0.20 ^a ± 0.05	0.13 ^a ± 0.02	0.07	0.34 ^a ± 0.09	0.18 ^a ± 0.04	0.13 ^a ± 0.03	0.08
Ca	0.59 ^a ± 0.17	0.21 ^a ± 0.04	0.21 ^a ± 0.06	0.14	0.77 ^a ± 0.20	0.25 ^a ± 0.05	0.27 ^a ± 0.08	0.16
Na	0.31 ^a ± 0.02	0.40 ^a ± 0.04	0.31 ^a ± 0.03	1.18	0.46 ^a ± 0.05	0.57 ^a ± 0.01	0.40 ^a ± 0.05	1.25
NH ₄ -N	0.07 ^a ± 0.01	0.07 ^a ± <0.01	0.03 ^a ± <0.01	0.05	0.08 ^a ± 0.02	0.13 ^a ± 0.03	0.04 ^a ± <0.01	0.06
NO ₃ -N	0.42 ^a ± 0.11	0.34 ^{ab} ± 0.14	1.11 ^b ± 0.12	0.60	0.99 ^a ± 0.55	0.40 ^a ± 0.14	1.07 ^a ± 0.17	0.56

CI: Clearings, SF: Secondary forest, MF: Mature forest

NO₃-N was the only nutrient studied displaying decreasing concentrations from rainfall to throughfall in the forests. Concentrations increased again in the litter percolate and were highest in the topsoil solution. With increasing soil depth, concentrations declined with lowest concentrations found in the stream water. Again, the highest concentrations by far were found in the clearings, where high NO₃-N concentrations were found even at deeper soil layers. For NH₄-N on average, no shift in the concentration between rainfall and throughfall was observed. Similar to Mg, the highest values were measured in the litter percolate, declining in the soil solution at all treatments. In stream water as well as soil solution measured at 1 m soil depth, NH₄-N concentrations raised slightly again.

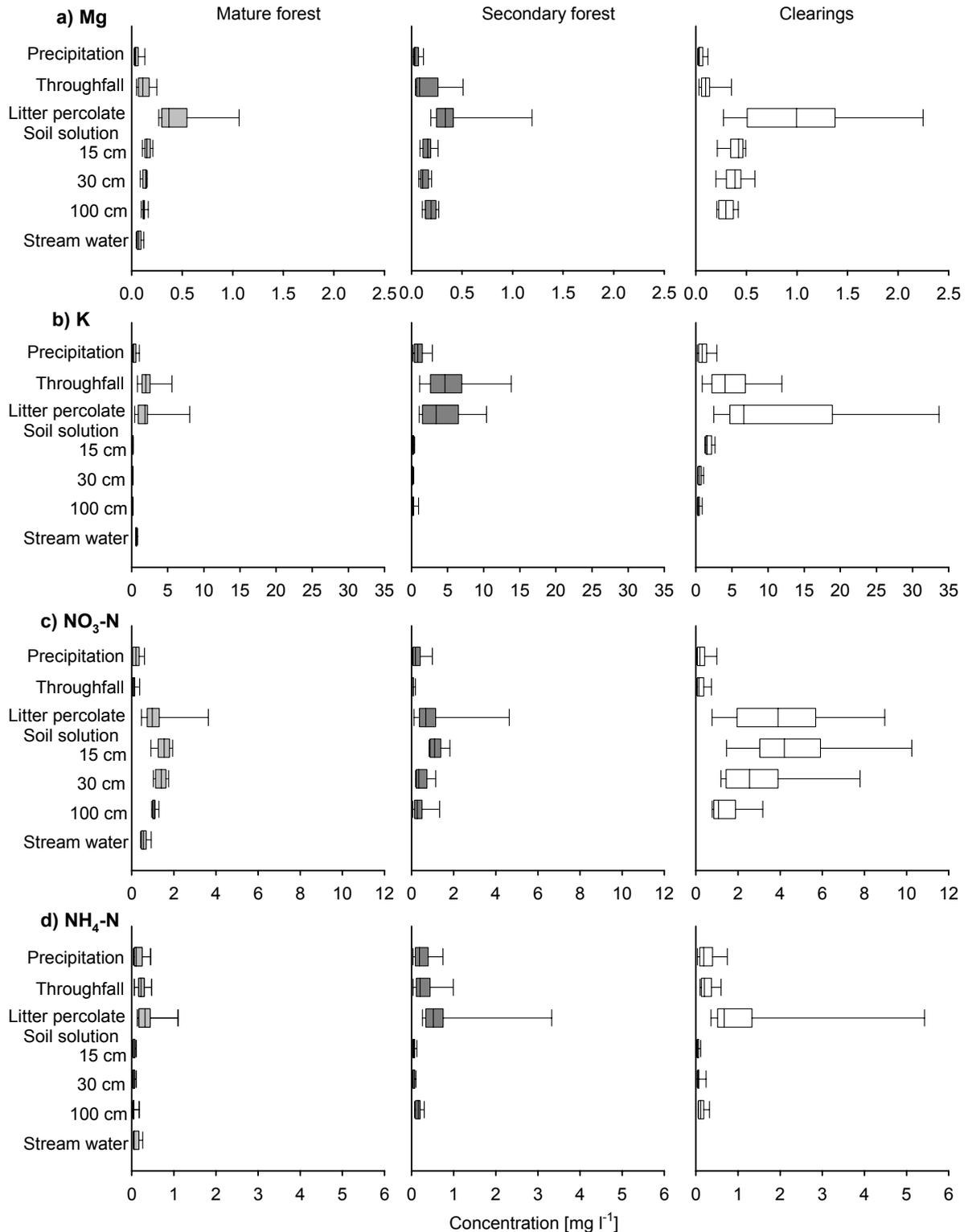


Fig. 5.6 Annual variability of nutrient concentrations in water flow, following its way through the ecosystem compartments from rainfall to stream water in the natural forest. Box-whisker diagrams include the means of fortnight samples of the different vegetation types in the second year, with vertical lines showing the median, boxes the 25 and 75% quantiles and whiskers showing the 5 and 95 % quantiles.

NITROGEN POOLS IN THE MINERAL SOIL

Similar to the soil solution, the KCl-extractable mineral N pools were also highest at the clearings. Secondary forest plots usually showed the lowest N concentrations at each of the four soil depths (Fig. 5.7). Differences were especially pronounced for $\text{NO}_3\text{-N}$, where secondary forests had significantly lower concentrations than the clearings for all except the deepest studied soil layer. Also for total N, secondary forests exhibited significantly lower concentrations between 0.15 and 0.60 m. Total N and $\text{NH}_4\text{-N}$ contents decreased with increasing soil depth, while $\text{NO}_3\text{-N}$ showed a trend towards increasing concentrations at higher soil depth, which was probably attributable to the high anion exchange capacity of the soils. In the upper soil layers, concentrations of $\text{NH}_4\text{-N}$ were higher as compared to $\text{NO}_3\text{-N}$, but the proportion of $\text{NO}_3\text{-N}$ increased at higher soil depths.

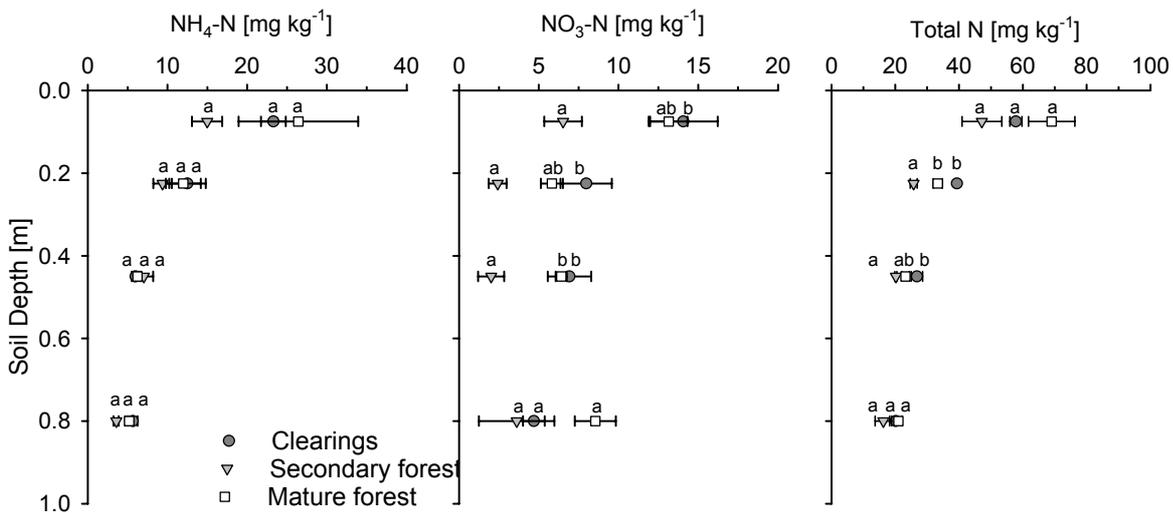


Fig. 5.7 Mean KCl extractable $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and total N contents of the three vegetation types at soil depths between 0-0.15, 0.15-0.3, 0.3-0.6 and 0.6-1.0 m. Error bars represent standard errors, different letters indicate significant differences after Scheffé-test ($n = 3$, $p < 0.05$).

NUTRIENT CONTENTS IN THE LITTER LAYER AND FLUXES VIA LITTER FALL

The nutrient composition of litter fall and the litter layer gives information on the decomposability of the litter produced by different vegetation types. Since it was not possible to properly install litter traps at the clearings where the vegetation mainly consisted of ferns and lianas, which tend to build up several layers of dead organic material within the live vegetation, litterfall was only collected in the forests. No significant differences in the nutrient content of the small litterfall were obtained for the two forest types (Table 5.10). As amounts of litterfall were on average higher in the secondary forest (Table 5.9), the annual fluxes via litter fall were higher than in the mature forest. But due to a high variability, these differences were not significant.

Also in the litter layer, nutrient concentrations were not significantly different between mature and secondary forest, but K and N contents in the litter layer of the clearings were significantly higher than in both forest types (Table 5.11). Consequently, the C/N ratios were also significantly lower in the clearings. Ca concentrations differed between clearings and secondary forests, while differences compared to the mature forest were not significant.

Table 5.9 Mean amounts of small litter fall in primary and secondary forests and proportions of leaves, twigs (< 2 cm diameter), mosses and the rest, consisting of reproductive parts, bark and unidentifiable leaf fragments.

	Total Small Litter	Leaves	Twigs < 20 mm	Mosses and Lichens	Rest
	[t ha ⁻¹ a ⁻¹]	[%]			
Secondary Forest	12.0 ± 2.1	76 ± 1	11 ± 2	1 ± 0	12 ± 2
Mature Forest	7.4 ± 0.9	68 ± 1	10 ± 1	4 ± 1	18 ± 4

Table 5.10 Mean nutrient concentrations and annual fluxes in the small litter of the secondary and mature forests (\pm standard error, $n = 3$).

	K	Mg	Ca	Na	N	P	S
	[g kg ⁻¹]						
Secondary forest	4.55 ± 0.41	2.06 ± 0.14	7.51 ± 0.13	0.40 ± 0.06	13.89 ± 0.72	0.81 ± 0.06	1.64 ± 0.08
Mature forest	3.45 ± 0.20	2.17 ± 0.10	9.42 ± 0.82	0.49 ± 0.05	16.35 ± 1.12	0.82 ± 0.08	1.69 ± 0.09
	[kg ha ⁻¹ a ⁻¹]						
Secondary forest	57.1 ± 15.0	24.8 ± 5.0	89.7 ± 14.5	5.0 ± 1.6	169.8 ± 37.4	10.1 ± 2.5	20.0 ± 4.4
Mature forest	25.3 ± 3.2	15.8 ± 1.2	68.5 ± 7.9	3.6 ± 0.6	118.7 ± 11.0	5.9 ± 0.5	12.4 ± 1.5

Table 5.11 Nutrient concentrations in the litter layer (Oi) (\pm standard errors for field replicates, $n = 3-4$). Different subscripts within columns (but not within rows) indicate significant differences among means ($p < 0.05$).

	K	Mg	Ca	Na	N	P	S	C/N
	[g kg ⁻¹]							
Clearings	2.92 ^a ± 0.34	0.45 ^a ± 0.04	2.22 ^a ± 0.36	7.93 ^a ± 1.37	2.12 ^a ± 0.17	1.19 ^a ± 0.07	0.181 ^a ± 0.014	22.3 ^a ± 2.2
Secondary forest	1.59 ^b ± 0.04	0.28 ^a ± 0.01	1.61 ^b ± 0.13	6.98 ^a ± 0.22	1.51 ^b ± 0.08	1.31 ^a ± 0.24	0.166 ^a ± 0.003	31.0 ^b ± 1.9
Mature forest	1.54 ^b ± 0.10	0.36 ^a ± 0.06	1.92 ^{ab} ± 0.05	12.60 ^a ± 1.09	1.62 ^b ± 0.02	1.09 ^a ± 0.15	0.182 ^a ± 0.003	30.1 ^b ± 0.34

DISCUSSION

DIFFERENCES IN ABOVEGROUND NUTRIENT FLUXES

Nitrate was the only nutrient studied that showed a net absorption in the canopy of the forest. Net nitrogen losses in the canopy have already been reported for a number of tropical montane rain forests and were usually attributed to uptake by epiphytes (Clark et al. 1998, Liu et al. 2002). This is probably also the case at Mt. Kilimanjaro, as the same effect was not observed in the clearings where epiphytes are missing. Thus, higher amounts of NO₃-N reach the forest floor via throughfall in the clearings as compared to the adjacent forest. NH₄-N did not exhibit major differences, while all

other nutrients were enriched during their passage through the vegetation. It was quite surprising that the nutrient concentrations in the throughfall water of the clearings matched the concentrations in the forests. Due to lower interception losses, the total amounts of throughfall were also higher at the clearings, resulting in higher nutrient fluxes via throughfall for K compared to the forests. As the canopies of the forests have a higher biomass and also surface area than the clearings, a higher accumulation of dry deposited material and higher leaching rates in the forest canopy were expected. Several factors might have been responsible for the high throughfall fluxes on the clearings compared to the forests.

Firstly, with a coverage of 70-95% of the tree layer (canopies >10 m height) on the secondary forest sites and of 45-85% on the mature forest plots, the forest canopies were not that close. The ability of plants to comb aerosols and dust particles from the atmosphere also depends on leaf structure. As fern leaves have a high surface area, they are probably effective in removing particles from the atmosphere. Furthermore, the fragmentation of the forest also probably influences the air circulation and local wind speeds, thus affecting total dry deposition in this area. However, as overall deposition ratios were probably low (see Chapter 4), differences due to vegetation structure might have been less detectable.

Furthermore, leaves of the vegetation at the clearings might be more susceptible to leaching than the mostly sclerophyllous leaves of the forest trees. The greatest difference in throughfall fluxes among all three vegetation types was measured for K, which is an element that is easily leached out of leaves (Parker 1983). The dominant tree species of the mature forest is the Lauraceae *Ocotea usambarensis* with mostly scleromorphous leaves. Leaves of *Macaranga kilimanjarica*, the most abundant tree in the canopy of the secondary forests, are larger and thinner, and hence are probably more susceptible to leaching than *O. usambarensis* leaves. The leaves of the vegetation at the clearings, which were dominated by *Pteridium aquilinum*, *Rubus steudneri* and other lianas might have had the highest leaching rates. Moreover, a comparatively great amount of standing dead biomass in the clearings might have increased the nutrient content in throughfall by the leaching of nutrients from the decomposing material.

Besides high leaching rates from the vegetation of the clearings, low nutrient losses from the forest canopies are another possible explanation. As has been shown in chapter 4, nutrient concentrations as well as fluxes in rainfall and throughfall in the mature forest were at the lower limit compared to other tropical mountain rainforests

for K, Ca and Mg. Low nutrient concentrations in rainfall indicate that these elements might be in short supply to the high epiphytic biomass in the canopy. In a rainforest in China, Liu et al. (2002) reported an uptake of $\text{NO}_3\text{-N}$, K, P and Ca from stemflow by epiphytic mosses. Thus, it seems possible that a large quantity of nutrients released by leaching from the canopy is directly taken up by epiphytes in the canopy and does not reach the ground. This hypothesis suggests a redistribution of nutrients within the canopy of the forests induced by rainfall. On the other hand, at the clearings where epiphytic biomass is negligible, all leached nutrients reach the ground. Nevertheless, from the present data this hypothesis cannot be proven. Further studies on the effects of epiphytes on stemflow and throughfall composition would be necessary.

HIGH NUTRIENT CONCENTRATIONS IN SEEPAGE WATER ON THE CLEARINGS

Overall, the highest nutrient concentrations were measured in the litter percolate under the clearings. As the water fluxes via throughfall were higher at the clearings due to the reduced interception compared to the forests, the water fluxes via litter percolate are also supposed to be higher in the clearings. This was confirmed by the water amounts collected in the lysimeters, but due to the above mentioned problems involved in the calculation of water fluxes from lysimeter collectors, nutrient fluxes were not determined. But since both water fluxes and concentrations were higher at the clearings, nutrient fluxes in the litter percolate would probably make differences between vegetation types more apparent.

The litter percolate was collected below the root mat at the lower end of the Oa horizon. This implies that the concentration of the analysed seepage water is the result of nutrients released by mineralisation and nutrient uptake by plants, mycorrhiza or microorganisms as well as ion exchange with soil constituents. The nutrient demand of the forest, especially the secondary forest, is supposed to be higher than that of the clearings. Consequently, the nutrient uptake by roots should also be smaller at the clearings, resulting in higher concentrations of the soil solution.

Another reason for the high nutrient concentrations in the litter percolate of the clearings are probably higher mineralisation rates. Temperatures in the forest were usually below 20 °C, which is below optimum conditions for microbial activities. Thus, the higher temperatures observed in the clearings enhance the decomposition of soil organic material. Also the nutrient content of the decomposing litter was higher in the clearings, further enhancing mineralization. Nevertheless, the stocks of

organic material were higher at the clearings as compared to the adjacent secondary forest, which further enhances the mineralization rates. The high organic matter stocks of the clearings compared to the secondary forests together with higher mineralization rates indicate that either one of them or both are not in a steady state condition between formation and mineralisation of SOM. That besides mineralisation, the accumulation of SOM also occurred at some clearings was indicated by one younger clearing dominated by *P. aquilinum*. In this plot, high amounts of hardly decomposed fern litter accumulated at the soil surface. Following the invasion of *P. aquilinum*, Johnson-Maynard et al. (1997) observed higher organic matter enrichment at respective sites compared to forests. This indicates that the litter of *P. aquilinum* at Mt. Kilimnajaro is not as easily decomposed as e.g. *R. steudneri* and other lianas and has thus accumulated at the soil surface.

In the soil solution, concentrations of the topsoil still differed significantly for some ions, while differences decreased with increasing soil depths and overall decreasing concentrations. This was probably due to further plant uptake, presumably also by tree roots invading the clearings, or absorption by soil constituents.

HIGH VARIABILITY OF NUTRIENT CONCENTRATIONS ON CLEARINGS

At the clearings, a high seasonality in nutrient concentrations of seepage water as well as a high variability of nutrient concentrations among sites was observed. Great differences between the mean daily temperatures of rainy days and days with prolonged sunshine in the clearings might also explain the higher seasonality of nutrient concentrations observed in the clearings compared to the forests. Hence, clearings reacted more sensitively to changes in climatic conditions than the forested plots do, where climatic extremes were usually buffered. The high variability among the clearings might have been the result of different histories of disturbances and of the different sizes of the clearings. The smallest study clearing (ca. 600 m²) exhibited nutrient concentrations in the soil that most closely resembled the forest plots. Considering seasonal trends in nutrient concentrations in the seepage water, the clearings did not always react in a similar manner. During heavy rainstorms for example, the fern vegetation tended to be pressed down by wind and rain and was afterwards overgrown by young fern leaves, leaving the old ones for decomposition on the ground. This process might have led to a nutrient flush at affected clearings but not at others.

DIFFERENCES IN N DYNAMICS BETWEEN SECONDARY AND MATURE FOREST

The mature forest usually exhibited the lowest nutrient concentrations, but for $\text{NO}_3\text{-N}$ it was the secondary forests. These results were supported by the amounts of KCl-extractable $\text{NO}_3\text{-N}$ in the soil, which were also significantly lower in secondary forests. One possible explanation might be differences in lateral leaching rates as the secondary plots were mainly located on ridges. Because two of the mature forest sites were in upslope position, this is not supposed to be the main reason. Another explanation for the low available N contents at the secondary forest sites might include low N mineralisation rates. N mineralisation depends on total N stocks, the C/N ratio, temperature, pH, and soil humidity (Rowell 1994). Total N stocks in the organic soil layer of the secondary forest were significantly lower than in the mature forest which might reduce N mineralisation rates. Annual amounts of litterfall and subsequent N fluxes, on the other hand, tended to be higher in the secondary forest compared with the mature forest. McDonald & Healey (2000) compared annual amounts of litterfall between mature and secondary mountain rainforests. They obtained similar litterfall amounts between mature and a 20 year old secondary forest in Jamaica. A literature review presented in the same paper revealed on average higher litterfall amounts at secondary as compared to mature forest sites (9.8 and 6.2 t ha⁻¹ respectively). With 7.4 t ha⁻¹, litterfall at the mature forest of Mt. Kilimanjaro was within the range of values presented in McDonald & Healey (2002) (3.6-11 t ha⁻¹), while the secondary forest was more at the higher end (secondary forest Mt. Kilimanjaro: 12.0 t ha⁻¹, others: 7.0-12.5 t ha⁻¹). Leaves of early successional species are said to decompose faster than late successional species (Ewel 1975). This is probably also the case at Mt. Kilimanjaro, as the litter accumulation on the ground of the secondary forest does not exceed that of the mature forest. As other factors influencing mineralisation did not differ between the forests or were, like temperature, even more favourable at the secondary forest sites. These results indicate that litter mineralisation at the secondary forest sites is probably faster than at the mature forest sites.

The high C/N ratios around 30 in the litter of the forests suggest that also immobilisation of N can occur at these sites (Norton 2000), and the possibility of N limitation was often discussed for tropical mountain forest sites (Bruijnzeel & Proctor 1995, Tanner et al. 1998). KCl extractable N (N_{min}) is supposed to represent a plant available N pool in the soil (Blackmer 2000). Vitousek & Matson (1988) measured N_{min} pools for a variety of tropical lowland and montane sites. Overall contents at Mt. Kilimanjaro were at the upper end of the values cited (2.5-8.5 g kg⁻¹ $\text{NH}_4\text{-N}$ and

0.5-11.7 g kg⁻¹ NO₃-N in the upper 15 cm of the soil and 22-102 g kg⁻¹ NH₄-N and 0-2 g kg⁻¹ NO₃-N in the organic layers). As the concentration of mineral nitrogen in the soil undergoes seasonal changes, single measurements - as was the case at Mt. Kilimanjaro - have their limitations when being compared to other values cited in literature. Samples from the topsoil at Mt. Kilimanjaro were taken in the dry season, when N concentrations are supposed to be high due to reduced leaching. Thus, the available N contents measured probably resulted in the overestimation of annual means.

Leaf litter N concentrations in the mature forest were higher as compared to other montane forest sites summarised in Tanner et al. (1998). The secondary forest showed a lower N concentration-to-amount ratio in litterfall, which might be an indication of N limitation according to Vitousek (1984). However, as the annual amount of litter was high at the secondary forest, overall amounts of N cycled in litterfall were higher than in other tropical mountain rainforests (Tanner et al. 1998). With maximum canopy heights of up to 35 m in the secondary forest and up to 40 m in the mature forest, both forests are less stunted than most other tropical mountain forests at a similar altitude (Stadtmüller 1986), which probably is also attributed to higher annual amounts of litterfall and subsequent N fluxes.

Summarising, the low NO₃-N content in the seepage water of the secondary forest is probably not only a result of lower mineralisation rates at these sites as compared to the mature forest sites. Although severe N limitations are not expected for both forests due to high N contents in the litter as compared to other mountain rainforests, the lower concentration-to-amount ratio in litterfall of the secondary forest might be an indication of a lower N supply of these sites. Thus, the lower available NO₃-N concentrations at the secondary forest sites might partly be the result of a higher N demand of the probably faster growing secondary vegetation accompanied by higher plant uptake. This hypothesis suggests that the N cycle of the secondary forest should be slightly more closed than that of the mature forest.

DIFFERENCES IN NUTRIENT CYCLING AMONG VEGETATION TYPES

As discussed in Chapter 4, K in the mature forest is held in a closed cycle between the canopy and the litter layer. Also most other base cations exhibited low concentrations in the soil solution of the mature forest, indicating low losses. Contrary to this, in the clearings, K as well as other nutrient concentrations were

higher in the litter percolate and the soil solution than at the forest sites. Also for both N forms analysed, concentrations were higher in the seepage water of the clearings. This indicates that overall more nutrients are cycled per unit biomass in the clearings as compared to the forests. Thus, it seems that the nutrient cycle of the clearings was overall more open compared to the mature forest, reflecting a different strategy of nutrient budgeting of the pioneer vegetation. Secondary forests usually took a position between mature forests and clearings with the exception of $\text{NO}_3\text{-N}$.

POSSIBLE EFFECTS OF THE MORE OPEN NUTRIENT CYCLE IN CLEARINGS ON FOREST REGENERATION

The question is whether the less closed nutrient cycling of the pioneer vegetation influences the site conditions in a way that forest regeneration is suppressed due to changes in soil fertility in the long run. In most studies in the humid tropics, a decline in nutrient stocks was observed directly after forest disturbance. Stocks were generally restored within a few years of regeneration (McDonald & Healey 2000, Rajesh et al. 1996, Uhl & Jordan 1984). Hughes et al. (1999), on the other hand, did not find significant changes in soil nutrient contents of vitric Andepts in Mexico, neither during cropping periods, nor during the following forest regeneration. They attributed this to the organic matter conservation of Andosols, which enabled the accumulation of large amounts of C, N and S in the soil and also prevented substantial nutrient losses after disturbance. Soils at Mt. Kilimanjaro are older and more intensively weathered and leached than the soils of the study in Mexico. Nevertheless, C and N stocks in the mineral soil are even higher at Mt. Kilimanjaro (Mexico: C 139-269 t ha⁻¹, N 14-24 t ha⁻¹, Mt. Kilimanjaro: C 471-565 t ha⁻¹, N 26-30 t ha⁻¹). These high nutrient contents, which are partly protected by organo-mineral complexes, might limit the risk of considerable N losses after disturbances. Although N mineralisation in the clearings is apparently enhanced as compared to the forest, it is not likely that N losses are substantial as stocks are still high. Furthermore, differences in N concentrations in deeper soil layers were not significant. Assuming that no major lateral transport of solutes occurred, most $\text{NO}_3\text{-N}$ was adsorbed at deeper soil layers or taken up by plants, so that no enhanced leaching of $\text{NO}_3\text{-N}$ out of the system is to be expected for the clearings compared to the mature forest sites. As a result, it is not likely that the clearings will become depleted in soil N in a such a way that no regeneration of natural forest is possible. For basic cations, the situation might be different as their availability seems to be limited in the leached soils. The closed cycle of the mature forest for K also indicates that it is in short supply. K

concentrations at 1.0 m soil depth were still higher at clearings than in the adjacent forest, but the difference was not significant at $p < 0.05$. As throughfall amounts at the clearings were generally higher compared to at the secondary forest sites and soils were usually wetter (see Chapter 3), the water fluxes in the soil are supposed to be higher at the clearing although they have not been determined. Thus, higher concentrations together with higher fluxes might lead to K losses at the clearings. Nevertheless, decreasing K concentrations with increasing soil depths at the clearings indicate either K removal from the soil solution by plant uptake at deeper soil layers or adsorption to soil particles. To summarise, the leaching losses of basic cations following disturbances are expected to be more severe due to the low retention capacity of the soil. However, high N stocks could buffer higher mineralisation rates for some time and the protection of SOM in Andisols prevents its rapid and complete decay.

POSSIBLE CAUSES FOR THE SUPPRESSED FOREST SUCCESSION AT THE CLEARINGS

This problem involves two questions. First, how was the present stage of herb and shrub vegetation achieved, and second, why can it maintain itself? Forest gaps created by the fall of branches or trees are natural early regeneration stages of forests. Usually, tree establishment in these gaps occurs very fast with species composition depending on the frequency of gap formations and the size of the created gap. While small gaps favour the upcoming of seedlings already present in the undergrowth, larger gaps can be colonised by pioneer species which mainly germinate in the open and were not present below the canopy before (Whitmore 1989). The monitored clearings in the forest ranged in size from approximately 600 m² to far more than 1000 m². Since tree trunks are still present on almost all of the clearings, it can be ruled out that the areas are not potentially suitable for tree growth. From the present results, a degeneration of the soil following forest clearance can be excluded as a possible reason for the impeded forest regeneration. No soil compaction was observed at the sites (see soil bulk densities in Chapter 3) and overall nutrient availability was even higher at the clearings. Because the tree trunks left in the clearings show signs of cutting, it can be concluded that the clearings were not formed naturally, but originated from illegal logging. Chandrashekara & Ramakrishnan (1994) pointed out that clearings created by selective felled trees differ from natural gaps with respect to population dynamics, biomass accumulation and nutrient cycling, as the logging of trees is usually accompanied by a heavy disturbance of the undergrowth. Trees felled at Mt. Kilimanjaro are usually cut into planks directly in the forests, and undergrowth in the clearing is actively destroyed

to improve accessibility. Thus, an upcoming of tree seedlings which were formerly present in the forest, as in small natural gaps, is impossible. Hence, forest regeneration relies mainly on tree seedlings that come up after the disturbance. But these are in strong competition for light with the fast growing herb and shrub vegetation. Once the vegetation cover has closed above the tree seedlings, regeneration of the clearings can take a long time because the shade tolerant non-pioneer species had already been cut and probably did not germinate within the open clearings, while the seedlings of pioneer trees can hardly survive for a long time in the shadow of the shrub vegetation. So regeneration has to start from the edges of the clearings in the shadow of the remaining trees, whose crowns slowly extend into the open space of the clearings.

The case of arrested succession in forest glades has often been reported in East Africa (Chapman & Chapman 1997, Kasenene 1987). Chapman et al. (1999) suggested that Africa lacks aggressive pioneer tree species that could invade large openings quickly before these are closed by shrub vegetation. They assume that this deficit might be the result of the evolutionary history as African wet forests lack large-scale natural hazards such as hurricanes or wildfires that necessitate the rapid reforestation of larger forest plots in other tropical regions. Pioneer species like *Macaranga kilimanjarica* nevertheless exist at Mt. Kilimanjaro and are dominant in the secondary forests of the lower southwestern slopes (Axmacher 2003). Ongoing disturbances might also have prevented these species from invading the clearings. On the much drier lower western slopes of Mt. Kilimanjaro and at the nearby Mt. Meru, large forest glades were identified which showed no signs of forest recovery even on long time-scales (Lundgren & Lundgren 1972, Wood 1964a). These clearings are dominated by grass species, and there is evidence that they were formerly used for agriculture and are now kept open by grazing buffaloes and fire. The clearings analysed in my study are much younger since some tree trunks are still left in the openings and no indications of former landuse were found. Grazing can also be excluded as a reason for the long-term persistence of the clearings, as the clearings do not provide high fodder quality and no evidence of the presence of animals other than wild pigs, which use tunnels under the shrub vegetation to access the clearings, has been observed. The presence of the geophytic bracken fern *Pteridium aquilinum* in all clearings with varying abundance is an indicator for reoccurring fires (Hemp & Beck 2001, Kramer et al. 1995). Especially during the El Niño year 1996-1997, forest fires also occurred at the wettest southern side of Mt. Kilimanjaro. Hemp (2001b) observed an increase in the cover of *P. aquilinum* from less than 1 % in the postburn forest to up to 80 % in the following years. Therefore, bracken fern seems highly

competitive after fires due to its rhizom system and the good environmental conditions for fast growth after the fire. Once bracken fern is established, it is hard to supersede as it is fast-growing and therefore shadows out seedlings in addition to producing an allelopathic toxin during the decomposition of the fern leaves which hinders the germination of other plants. Only very few plant species such as the lianas *Rubus steudneri* and *Begonia meyeri-johannis* are able to successfully compete with the bracken fern on the clearings. As lianas, they can overgrow the fern, so that older clearings were dominated by *R. steudneri* and lianas rather than *P. aquilinum*. Due to higher temperatures in the clearings, the vegetation dries faster during the dry season than in the intact forest. The vegetation accumulates high amounts of standing dead organic material that is easily flammable when dry, so that the clearings themselves probably enhance the risk of further fires. So the crucial point in the regeneration of the forests seems to be reoccurring fires together with the presence of aggressive shrub and herbal species rather than soil deterioration or an overall lack of pioneer forest species.

SUMMARY AND CONCLUSIONS

Nutrient dynamics in the clearings differed in many respects from the studied forests. Aboveground N fluxes in the clearings were higher compared to the mature forest due to N absorption in the canopy of the trees. Comparatively high throughfall fluxes of base cations in the clearings compared to the forests might have been the result of some absorption of base cations by epiphytes in the canopy of trees or differences in the surface structure and leaching properties of leaves from the different vegetation types. Belowground nutrient concentrations were higher in the clearings compared to both forests, probably because of higher mineralisation rates in the clearings and less plant uptake. These results indicate a different strategy of the climax vegetation at the mature forest sites with more closed nutrient cycles, especially for base cations and the pioneer vegetation in the clearings which exhibit overall more open nutrient cycles.

Concentrations in the soil solution under the clearings declined with increasing soil depth and homogenised between sites. Furthermore, the nutrient stocks associated with SOM in the soil were high so that nutrient losses via leaching are not expected to be substantially higher in clearings than in the forest. Nevertheless, as clearings also exhibited the greatest seasonality in seepage water concentrations, some enhanced leaching losses at the end of the dry seasons, when highest concentrations

occurred, are conceivable. Belowground nutrient fluxes would provide more meaningful insight on nutrient losses than do concentrations. Thus, the analyses of water runoff in streams and more information on climatic conditions on high resolution (rainfall, evapotranspiration) would be necessary in future studies for reasonable modelling of belowground water fluxes. As the clearings showed a high variability among sites, in future studies it would be beneficial to increase the number of field replicates in order to get more significant results.

Overall results indicated that limitations of major nutrients are not supposed to be the reason for the impeded regeneration on the clearings. The reasons for the conservation of the clearings might be ongoing disturbance, probably by fire, together with the presence of aggressive shrubs, which compete with the natural forest vegetation. Since illegal logging is still going on at Mt. Kilimanjaro (Lambrechts et al. 2002), the number of clearings is presently increasing. Considering the large areas involved and the poor accessibility, the control of the shrub and liana vegetation on already existing clearings by the forest management seems unrealistic. Measures to prevent further logging should be improved so that sites where forest regeneration has been arrested will not increase in the coming decades.

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6 The Role of Total Organic Matter in the Nutrient Cycle of Tropical a Mountain Forest Succession

INTRODUCTION

Nutrient cycles in forests are closely linked to the hydrological cycle because water acts as the main transporting agent, solvent and catalyst (Bruijnzeel 1989). Besides diluted inorganic nutrients, the importance of dissolved organic matter (DOM) in nutrient cycles was increasingly emphasized in the last two decades. Dissolved forms of organic N (DON), P (DOP) and S (DOS) contribute significantly to dissolved N, P and S in throughfall, litter percolate and soil solution, and their fluxes often exceed the fluxes of corresponding inorganic forms (Homann et al. 1990, Michalzik et al. 2001, Qualls & Haines 1991). While nitrate was thought to be particularly mobile and the main form of N to migrate to deeper soil layers and streams, Hedin et al. (1995) and Perakis & Hedin (2002) showed that N losses in unpolluted watersheds in southern Chile were nearly exclusively due to DON (> 95%), which was formerly not included in forest ecosystem models. Smolander & Kitunen (2002) pointed out that DON comprised about 62-83% of total N in the soil solution of a Norway spruce stand. But the role of DON in forest ecosystems is probably twofold: on the one side it may contribute to N losses due to leaching, and on the other side it is a potential N source for plants, which can directly assimilate amino acids (Neff et al. 2003). Besides DON, also DOP proved to be a major P form in forest floor leachates and in soil solutions of temperate forests (Kaiser et al. 2003, Qualls et al. 2000).

Humus and the litter layer were identified as main sources for DOM in forest ecosystems, with some contribution also from microbial biomass and root exudates (Kalbitz et al. 2000). DOM concentrations and fluxes are controlled by abiotic factors like temperature, soil moisture and pH (Andersson et al. 2000, Kalbitz et al. 2000, Solinger et al. 2001) as well as by biotic factors such as microbial activity and the abundance of fungi (Guggenberger et al. 1994, Kalbitz et al. 2000). The effect of the vegetation cover on fluxes and quality of DOM is still a matter of controversy (Michalzik et al. 2001). While Currie et al. (1996) found larger DOC and DON concentrations under coniferous trees as compared to hardwood forests, Matzner (1988) did not observe differences in DON fluxes in litter percolates of beech and spruce stands. Also Smolander & Kitunen (2002) and Strobel et al. (2001) could not identify effects of tree species on DOC composition. In contrast, Magill & Aber (2000) showed a correlation between plant species, accompanied litter chemistries and DOC

concentrations in litter leachates. Similarly, Kuiters (1993) measured higher DOC concentrations in leachates from deciduous leaves as compared to coniferous needles and ascribed this to differences in leaf properties.

Land use changes can lead to long-term effects on DOM concentrations since accompanied changes in the vegetation cover alter the amount and quality of litter, which in turn affect DOM leaching from the canopy as well as from the forest floor (Chantigny 2003). Short-term effects induced by clearcutting usually lead to an initial increase in DOM concentrations and fluxes in litter percolate as well as in soil solution. This can be explained by additional wood debris decaying on the soil, stimulation of microbial activity, soil disturbance or larger water fluxes (Qualls et al. 2000, Smolander et al. 2001). Some authors also reported little overall changes in DOM concentrations (summarised in Chantigny 2003) which was attributed to differences in the amount of plant residues left at the disturbed sites and effects of subsequent burning. Also afforestation of agricultural soils results in an increase in DOM concentrations in the soil solution which is accompanied by an increase in the amount of organic Al-complexes and chelating organic acids (Quideau & Bockheim 1997).

In his review, Chantigny (2003) draws attention to the knowledge gap about the role of DOM in the nutrient cycle of tropical forest ecosystems. Most studies on DOM in the tropics focussed on DOC, while less is known about fluxes of DON, DOP and DOS. In a Puerto Rican lowland rain forest for example, internal DOC fluxes (throughfall and soil water) and DOC fluxes in streams were analysed by McDowell & Asbury (1994) and McDowell (1998). Also Wilcke et al. (2001) analysed DOC in rainfall, throughfall and stream water fluxes in an Ecuadorian mountain rain forest. Möller (2001) studied DON and showed that $\text{NO}_3\text{-N}$ concentrations exceeded DON in the soil solution of a tropical mountain rain forest in Thailand. Except for a study by Roose & Lelong (1981) in West Africa, no studies on the relevancy of DOM have been conducted in Sub-Saharan Africa. To my knowledge, so far DOP and DOS were not included in studies on nutrient cycling in the tropics.

Deforestation, slash and burn agriculture and other land use changes are common practice in the humid tropics and often inherit the risk of land degradation. Studies on soil chemical changes accompanying these conversions were reviewed by Bruijnzeel (1998), but most of them excluded DOM. The effect of forest cutting and burning on DON concentrations in the soil solution was studied by Klinge (1997) in a tropical lowland rainforest in the Amazon basin. He observed an increase in DON

concentrations after forest clearing, which was further enhanced after the plots were burned.

The forests of Mt. Kilimanjaro in Tanzania were subject to selective logging during the past decades, which led to a fragmentation of the lower forest belt and changes in plant species composition (Lambrechts et al. 2002, Lamprey et al. 1991, Mwasaga 1991). Also fires are a common threat for the forest. The aim of this study was to analyse the role of DOM in the nutrient cycle of this tropical mountain rain forest and to assess possible effects of forest conversions by comparing mature forest, secondary forest and clearings. In order to get information about OM release in the soil solution immediately after disturbance, some clearings were cut and burnt during the study.

MATERIAL AND METHODS

STUDY AREA

The study site was located in the forest belt at the south-western slopes of Mt. Kilimanjaro above Machame village at an altitude between 2100 and 2300 m. The soils developed on layered volcanic ashes that overlay phonolites and trachytes of the Lent group (Downie & Wilkinson 1972) and were classified as Fulvudands, Epiaquands and Placaquands (Soil Survey Staff 2003). For soil properties and comparability of soils see Chapter 2, 3 and 4. Precipitation ranged from 2480 to 2600 mm (at 2250 and 2100 m respectively) in the first year of the study from June 2000 to May 2001. In the following year, rainfall amounts were lower and varied between 1960 and 2210 mm. Further information on the hydrology of the study sites is presented in Chapter 3.

The mature forest was dominated by the tree species *Ocotea usambarensis* and characterised by a high epiphyte density and diversity. The secondary forest (around 60 years of age) had smaller stem diameters, a lower stand height and a lower epiphyte density compared to the mature forest. The dominant tree species in the canopy layer was the pioneer *Macaranga kilimanjarica*, accompanied by young *Ocotea usambarensis* trees. The clearings (approximately more than ten years old) were dominated by shrubs and lianas such as *Rubus steudneri*, *Pteridium aquilinum* and *Begonia meyeri-johannis*. Regeneration of forest vegetation is seemingly impeded on these sites.

STUDY DESIGN

Clearings and secondary forests were studied at three plots and mature forests at four plots. Each plot had a size of 400 m² and an inclination < 10°. As the lower slopes of the study area up to a borderline around 2150 m were depleted of undisturbed mature forest, these plots had to be chosen at slightly elevated altitudes than the secondary forest and the clearings. Thus, the minimum vertical distance between the mature forest plots to the other plots was 140 m. As recurrent fires are probably responsible for the impeded regeneration at the clearings (see Chapter 5), three more clearings were included in the study from May 2001 so that later on a fire experiment could be conducted at the clearings. For more detailed information on the location of the plots see also Chapter 3. Next to each plot, a soil pit was dug, described and chemically characterised. All plots were tested for homogeneity using soil coring and equipped with collectors for throughfall (ten per plot) and litter percolate (four to five per plot, installed below the root mat in the Oa layer). Suction cups were used to collect the soil solution from three soil depths in three replicates (0.15, 0.30 and 1.00 m). Rainfall was collected at 2100 and 2250 m using five collectors placed in clearings 1.5 m above the ground. Most equipment was installed in March 2000, and sampling started in May 2000. Sampling of lysimeters was only possible from November 2000 on. As a consequence, lysimeter data is missing for the first half year. Close to the mature forest sites, streamwater was collected also to get additional information about the output. For further descriptions of the equipment used see also Chapter 3 and 4.

Sampling was done twice a week in the first study year. Water amounts were separately registered for all collectors, while for chemical analysis, a composite sample of each site was prepared for rainfall, throughfall and litter percolate. Soil solution was extracted using a constant pressure of 400 hPa overnight (for about 24 hours). Samples for each soil depth were combined in one collection bottle so that no individual analysis of single suction cups was feasible. From June 2001 onwards, sampling was continued on a weekly basis. During this time, mature forest sites were sampled two days after the other sites. In November 2001, three of the clearings were cut and subsequently burned in December during rain-free periods. During the fire, suction cups were protected using wet pottery as coverage but left in the field whereas rainfall collectors and lysimeters were removed. Immediately after the fire, they were reinstalled, causing as little disturbance as possible. Clearings and the secondary forest sites were sampled again twice a week starting from November. At the mature forest sites, sampling was continued on weekly base.

The water samples were combined into biweekly samples irrespective of sampling scheme. For rainfall, throughfall and litter percolate, volume weighted samples were prepared, while equal portions were combined for soil solutions and the stream water samples, for no reliable data on fluxes was available. Samples were stored frozen. Prior to analysis, rain and litter percolate samples were filtered through ash-free filter papers with a pore size $< 2 \mu\text{m}$ (Schleicher & Schuell, blue band 589³). Thus, measured concentrations of organic forms of C, N, S and P could not be referred to as dissolved. Instead the term "total organic" (TO) was used. Total organic carbon was determined using a TOC analyser (Elementar High TOC and Shimadzu TOC-5050). For the determination of total N, $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{NO}_2\text{-N}$, a Segmented Flow Analyser (Skalar SANplus, SA 2000/4000) was used. The same equipment was used for analysis of total P (P_{tot}) and $\text{PO}_4\text{-P}$. Total S (S_{tot}) was measured using an ICP-AES (GBC Integra XMP) and for the determination of $\text{SO}_4\text{-S}$, an IC was applied.

Total organic nitrogen (TON), total organic phosphorus (TOP) and total organic sulphur (TOS) were calculated as difference between total amounts and inorganic forms ($\text{TON} = N_{\text{tot}} - \text{NH}_4\text{-N} - (\text{NO}_3\text{-N} + \text{NO}_2\text{-N})$, $\text{TOP} = P_{\text{tot}} - \text{PO}_4\text{-P}$, $\text{TOS} = S_{\text{tot}} - \text{SO}_4\text{-S}$).

DATA ANALYSES AND STATISTICS

Means were calculated on annual basis. TOC and TON concentrations were analysed for the whole sampling period from May 2000 to September 2002. TOS was only measured for one year, starting from December 2000. That was the time, when lysimeters were installed and calibrated. Thus, for comparisons among all dissolved elements, the latter time period (December 2000-December 2001) was used. Means were calculated as flux weighted means for rainfall and throughfall, while for litter percolate, soil solution and stream water, the median was used as no reliable data on the corresponding water fluxes was available. If values were below the detection limit, they were set as zero for the calculation of means. The same was done when calculations of organically bound elements resulted in negative values. This results in a potential underestimation of means. The annual means of the different sites were compared by solution type using one-way analyses of variance (ANOVA), followed by a post-hoc separation of means by the Scheffé-test ($p < 0.05$). Correlation analyses were conducted as Pearson Product-Moment Correlations. For these analyses, values below the detection limit were excluded. Statistical analysis were all conducted using the program STATISTICA 5.0 (Statsoft, Inc., Tulsa, UK).

RESULTS

ABOVEGROUND CONCENTRATIONS AND FLUXES OF TOTAL ORGANICALLY BOUND ELEMENTS

Concentrations of all dissolved organic elements in rainfall increased during the passage through the vegetation cover (Table 6.1). With a threefold increase, the enrichment was greatest for TOC under forest vegetation. Throughfall concentrations exhibited a strong seasonal variability with largest values occurring during dry periods. This was reflected by a significant correlation between rainfall and inverse throughfall concentrations (concentration⁻¹) of TOC, TON and TOS for all three types of vegetation cover (Figure 6.1), but correlations were weakest for TOS. Although water fluxes via throughfall were higher at clearings, TOC fluxes were significantly smaller as compared to the two forest types (Table 6.2). TON concentrations and fluxes with throughfall were also slightly smaller at the clearings, while TOS concentrations as well as fluxes were slightly larger for clearings than for the forests. As half of the analysed rainfall samples were below the detection limit for TOS, total fluxes on an annual basis are likely to be underestimated. In even more samples, TOP was not detectable and thus it was not included in rainfall and throughfall analyses.

Table 6.1 Volume-weighted mean concentrations of total organically bound elements in rainfall and throughfall (\pm standard error, $n = 3$ for clearings and secondary forest, $n = 4$ for mature forest).

	Rainfall		Mature forest	Throughfall	
	2100 m	2250 m		Secondary forest	Clearings
	[mg l ⁻¹]			[mg l ⁻¹]	
TOC					
1.6.00-1.6.01	5.18	4.34	7.40 ^a ± 0.76	10.9 ^b ± 0.20	5.22 ^a ± 0.27
1.6.01-1.6.02	4.29	3.41	11.4 ^a ± 1.14	13.1 ^a ± 0.96	5.26 ^b ± 0.66
TON					
1.6.00-1.6.01	0.21	0.13	0.39 ^a ± 0.06	0.49 ^a ± 0.07	0.35 ^a ± 0.03
1.6.01-1.6.02	0.30	0.24	0.50 ^a ± 0.05	0.58 ^a ± 0.04	0.43 ^a ± 0.04
TOS					
15.12.00-15.12.01	0.04	0.04	0.06 ^a ± 0.02	0.08 ^a ± 0.01	0.09 ^a ± 0.01

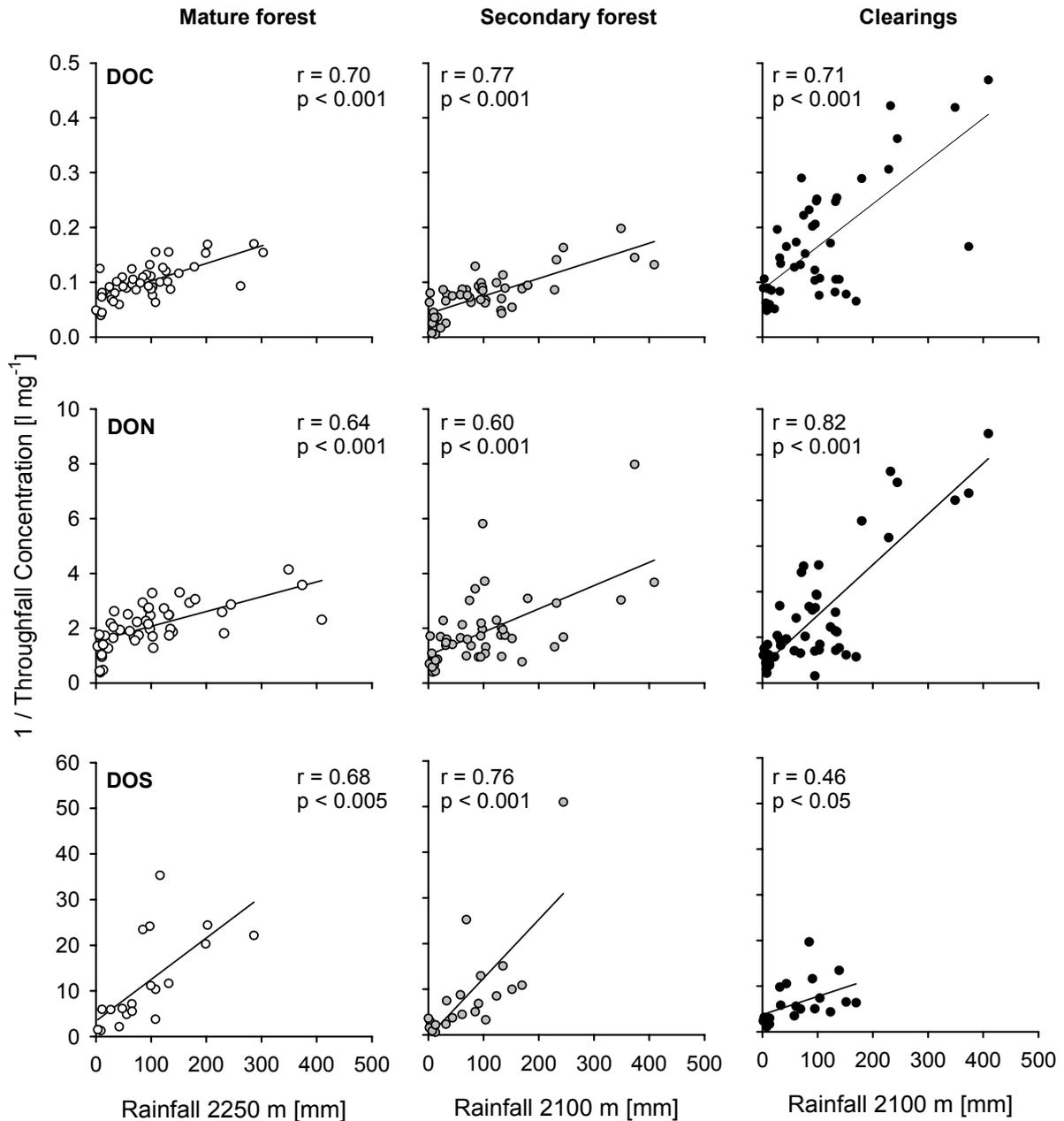


Fig. 6.1 Relation between inverse throughfall concentrations (concentration⁻¹) of total organically bound elements and rainfall amounts. Time periods considered were: TOC 11/00-5/02, TON 6/00-5/02, TOS 12/00-11/01.

TOC fluxes in rainwater were strongly correlated with rainfall amounts ($r = 0.87$ for 2100 m and $r = 0.82$ for 2250 m, $p < 0.001$). Correlations for TOS fluxes were less strong ($r = 0.75$, $p < 0.005$ and $r = 0.79$, $p < 0.01$ respectively). For TON only weak correlations were found ($r = 0.31$ and $r = 0.28$, $p < 0.05$). Net throughfall fluxes were calculated as the difference between throughfall and rainfall fluxes of individual elements and represent the amount of total organically bound elements added during the passage through the canopy. That flux was only weakly correlated with

rainfall amounts and concentrations for TOC at the forest sites (Table 6.3). Net TON fluxes on the other hand showed stronger correlations with rainfall amounts and concentrations for both forest types, indicating increasing net fluxes with increasing precipitation and subsequent lower rainfall concentrations. Such a relationship was not found for the clearings. For net TOS fluxes, the number of valid fluxes was low as rainfall concentrations were often below the detection limit ($n = 13$ for 2100 m and $n = 10$ for 2250 m). Net TOS fluxes were negatively correlated to rainfall amounts at the mature forest and the clearings, but not at the secondary forest sites. No correlation with rainfall concentrations was observed for net TOS fluxes (Table 6.3).

Table 6.2 Fluxes of total organically bound elements in rainfall and throughfall (\pm standard error, $n = 3$ for clearings and secondary forest, $n = 4$ for mature forest).

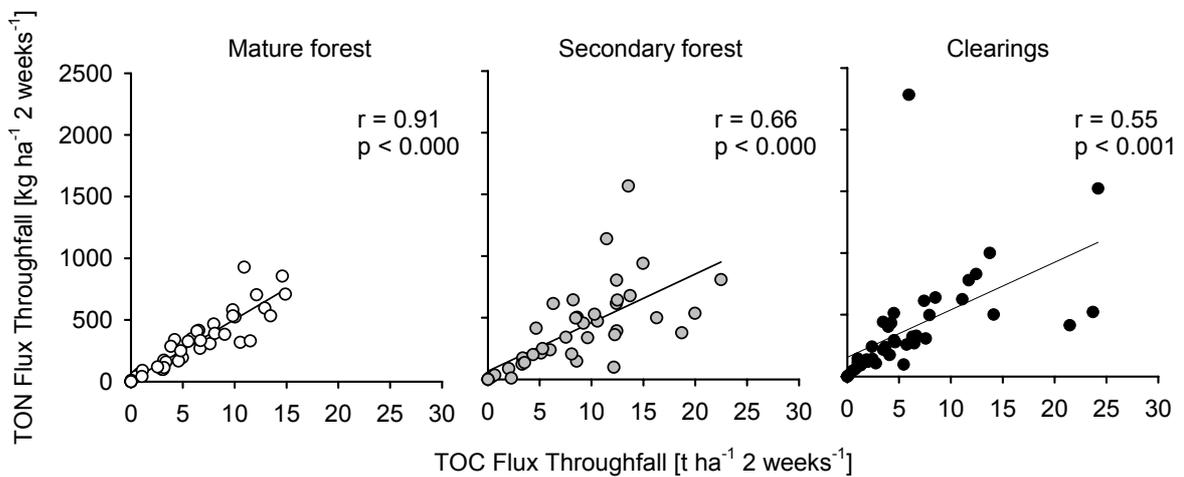
	Rainfall		Mature forest	Throughfall	
	2100 m	2250 m		Secondary forest	Clearings
	[kg ha ⁻¹ a ⁻¹]			[kg ha ⁻¹ a ⁻¹]	
DOC					
1.6.00-1.6.01	143.9	110.9	160.0 ^{ab} ± 17.3	218.5 ^a ± 6.03	137.4 ^b ± 0.26
1.6.01-1.6.02	88.9	59.4	142.2 ^a ± 13.6	182.3 ^a ± 9.1	102.8 ^b ± 8.0
DON					
1.6.00-1.6.01	5.97	3.36	8.31 ^a ± 1.23	10.31 ^a ± 1.42	9.59 ^a ± 0.84
1.6.01-1.6.02	6.18	4.15	6.24 ^a ± 0.60	8.06 ^a ± 0.35	8.11 ^a ± 0.34
DOS					
15.12.00-15.12.01	0.99	1.05	1.34 ^a ± 0.49	1.57 ^a ± 0.19	2.39 ^a ± 0.20

The analyses of throughfall fluxes of TOC and respective fluxes of TON revealed a close correlation for mature forests (Fig. 6.2). For secondary forests, the correlation was weaker and at the clearings, one outlier also led to a weak relation. A positive correlation was also observed between TOC fluxes in throughfall and TOS fluxes for mature forests and clearings while for secondary forests they were not significant (Fig 6.3). Organic and inorganic fluxes were significantly correlated in throughfall for N and S (Fig. 6.4, 6.5). Overall, closest correlations were found for the mature forest sites. For rainfall, no correlations between organic and inorganic fluxes were found for S and N. The same was true for net throughfall fluxes.

Table 6.3 Correlation coefficients between net throughfall fluxes (throughfall – rainfall fluxes) of TOC, TON and TOS and rainfall amount and concentration.

	Rainfall Amount			Rainfall Concentrations of Total Organically Bound Elements		
	Mature forest	Secondary forest [mg l ⁻¹]	Clearings	Mature forest	Secondary forest [mg l ⁻¹]	Clearings
Net throughfall flux						
TOC						
r (n= 40-45) #	0.53	0.56	0.01	-0.45	-0.38	-0.09
p	< 0.001	< 0.001	n.s.	< 0.005	< 0.05	n.s.
TON						
r (n= 48)	0.65	0.66	0.11	-0.67	-0.52	0.26
p	< 0.001	< 0.001	n.s.	< 0.001	< 0.001	n.s.
TOS						
r (n = 10-13)	-0.77	-0.45	-0.87	-0.087	0.09	0.21
p	< 0.01	n.s.	< 0.005	n.s.	n.s.	n.s.

Excluding one outlier

**Fig. 6.2** Correlation between TOC and TON fluxes in throughfall for two-week-periods (n = 40).

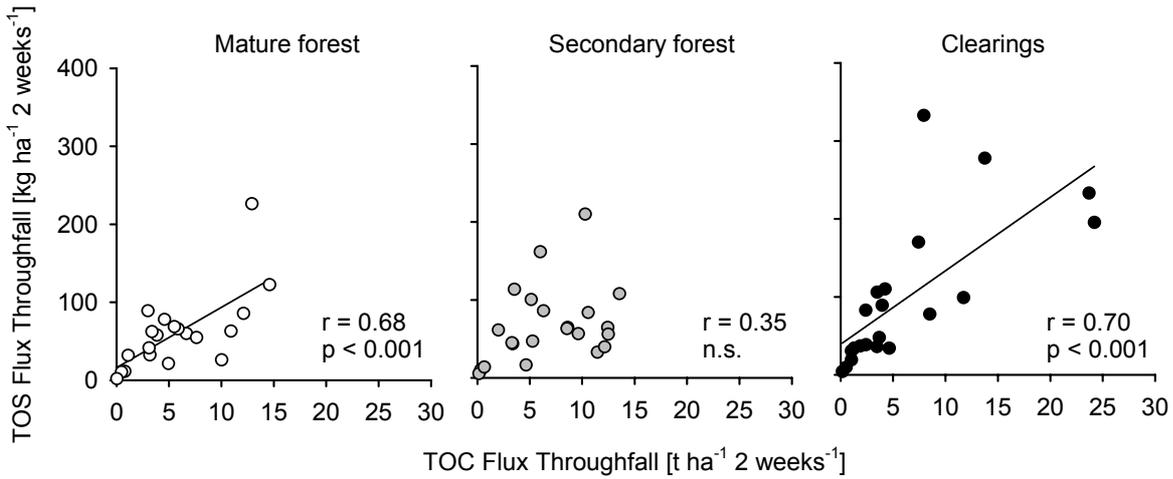


Fig 6.3 Correlation between TOC and TOS fluxes in throughfall for two-week-periods (n = 20).

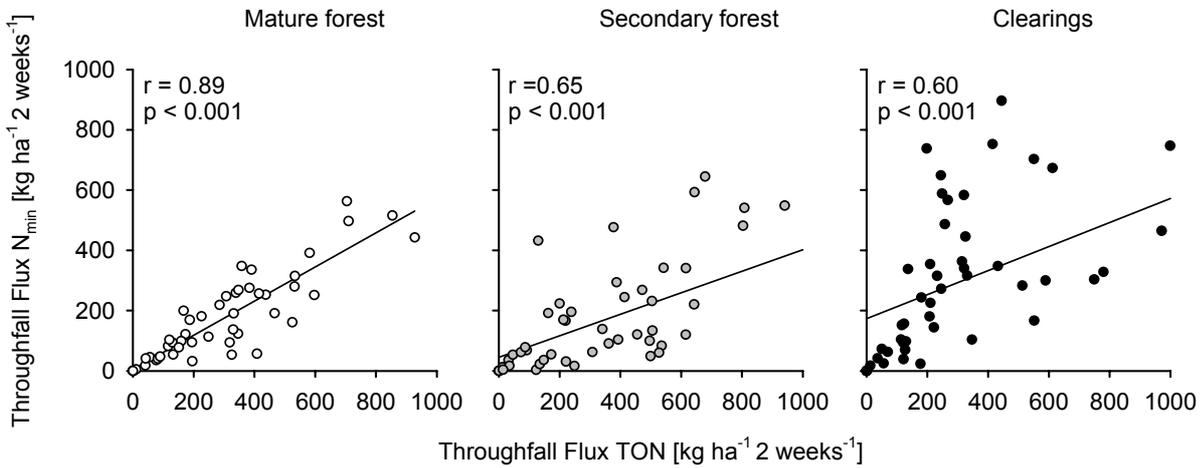


Fig. 6.4 Relation between organic (TON) and inorganic (N_{min} = NH₄-N + NO₃-N) N fluxes in throughfall. Time period considered: 6/00-6/02.

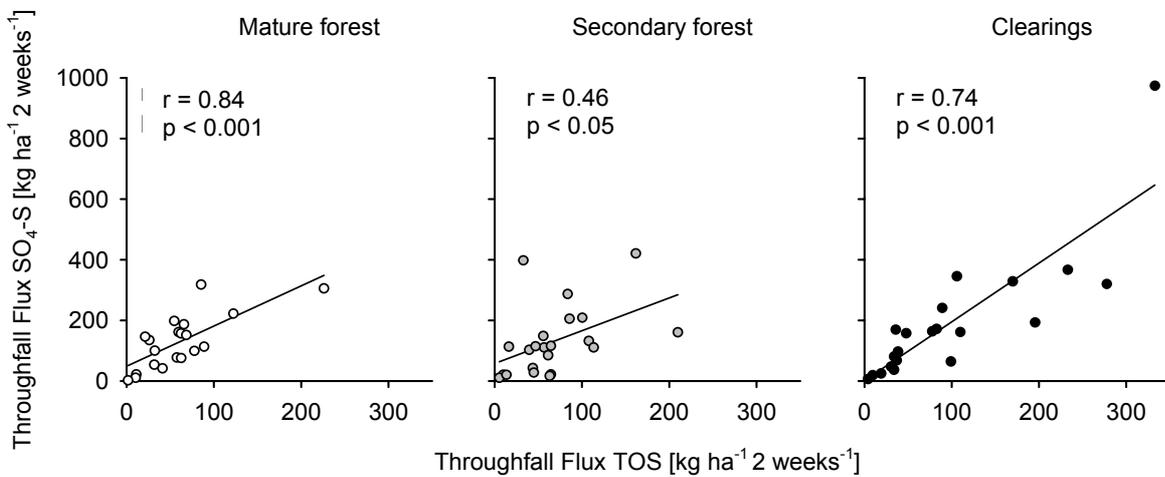


Fig. 6.5 Relation between organic and inorganic S fluxes in throughfall. Time period considered: 12/00-11/01.

BELOWGROUND CONCENTRATIONS OF TOTAL ORGANICALLY BOUND ELEMENTS IN SEEPAGE WATER

Largest concentrations of total organically bound elements were measured in the litter percolate (Table 6.4). At the clearings, TOC, TON and TOP concentrations in litter percolate were significantly larger than under mature forest. TOP was not detectable at any depth. Also the median TOS concentration was in the range of the detection limit only for the clearings. For TOC and TON, concentrations declined by a factor of 5-10 from litter percolate to soil solution, and tended to decrease with soil depth (Table 6.5). Median concentrations of TOC and TON in stream water sampled close to the mature forest sites were slightly larger than concentrations measured in solutions sampled with the deepest suction cups under mature forest (Table 6.4). While TOC and especially TON concentrations in the topsoil differed between the forest sites and the clearings, such differences were not significant for the deeper soil.

Table 6.4 Mean concentrations of total organically bound elements in litter percolate and stream water under mature forests, secondary forests and clearings. The mean was calculated from annual median concentrations at individual sites (\pm standard error, $n = 3$ for clearings and secondary forest, $n = 4$ for mature forest).

	Litter Percolate			Stream water [mg l ⁻¹]
	Mature forest	Secondary forest [mg l ⁻¹]	Clearings	
TOC				
1.6.01-1.6.02	21.22 ^a ± 2.08	24.43 ^{ab} ± 2.09	30.81 ^b ± 0.51	2.88
TON				
1.6.01-1.6.02	0.77 ^a ± 0.07	0.88 ^a ± 0.11	1.48 ^b ± 0.12	0.09
TOP				
1.6.01-1.6.02	0.04 ^a ± 0.00	0.06 ^{ab} ± 0.01	0.09 ^b ± 0.01	
TOS				
15.12.00-15.12.01	0.18 ^a ± 0.03	0.23 ^a ± 0.02	0.29 ^a ± 0.03	

Table 6.5 Mean concentrations of total organically bound elements in the soil solution under mature forests, secondary forests and clearings. The mean was calculated from annual median concentrations at individual sites (\pm standard error, $n = 3$ for clearings and secondary forest, $n = 4$ for mature forest).

	Soil Solution 0.15 m			Soil Solution 1 m		
	Mature forest	Secondary forest	Clearings	Mature forest	Secondary forest	Clearings
	[mg l ⁻¹]			[mg l ⁻¹]		
TOC						
1.6.00-1.6.01	2.33 ^a ± 0.20	2.97 ^a ± 0.67	4.36 ^a ± 0.62	1.54 ^a ± 0.05	3.19 ^a ± 0.54	3.69 ^a ± 1.55
1.6.01-1.6.02	2.67 ^{ab} ± 0.25	2.02 ^a ± 0.28	4.30 ^b ± 0.71	1.26 ^a ± 0.15	1.73 ^a ± 0.25	1.99 ^a ± 0.46
TON						
1.6.00-1.6.01	0.09 ^a ± 0.01	0.05 ^b ± 0.01	0.17 ^c ± 0.01	0.03 ^a ± 0.01	0.04 ^a ± 0.02	0.04 ^a ± 0.02
1.6.01-1.6.02	0.14 ^{ab} ± 0.02	0.09 ^a ± 0.01	0.31 ^b ± 0.11	0.06 ^a ± 0.01	0.08 ^a ± 0.02	0.14 ^a ± 0.07
TOP*						
1.6.01-1.6.02	ND	ND	ND	ND	ND	ND
1.6.01-1.6.02	ND	ND	ND	ND	ND	ND
TOS						
15.12.00-15.12.01	ND	ND	0.07 ± 0.01	ND	ND	0.08 ± 0.04

ND: Median concentration was below the detection limit of S and P.

*: As nearly all samples were below the detection limit, only one quarter of the samples was analysed at random.

Median TON, TOP and TOS concentrations in the litter percolate of all sites were significantly correlated to TOC concentrations, with the closest correlation for TON. This result indicates that the release of organically bound nutrients into the litter percolate was related to the release of TOC, independently of the vegetation type. Nevertheless, mature forests, secondary forests and clearings showed different amounts of total organically bound nutrients released as can be seen in Figure 6.6. In the soil solution at 0.15 m, a similar but weaker correlation was found for TOC and TON ($r = 0.64$, $p < 0.05$). At 1 m soil depth, the correlation was only significant at $p < 0.1$ ($r = 0.60$). As for TOP and TOS most concentrations were below the detection limit, no correlation analyses were possible for the soil solution.

Correlations between concentrations of inorganic and organic N in litter percolate were closest for the clearings ($r = 0.82$, $p < 0.001$) and weakest for the secondary forest ($r = 0.53$, $p < 0.001$). The mature forest exhibited intermediate correlations ($r = 0.71$, $p < 0.001$).

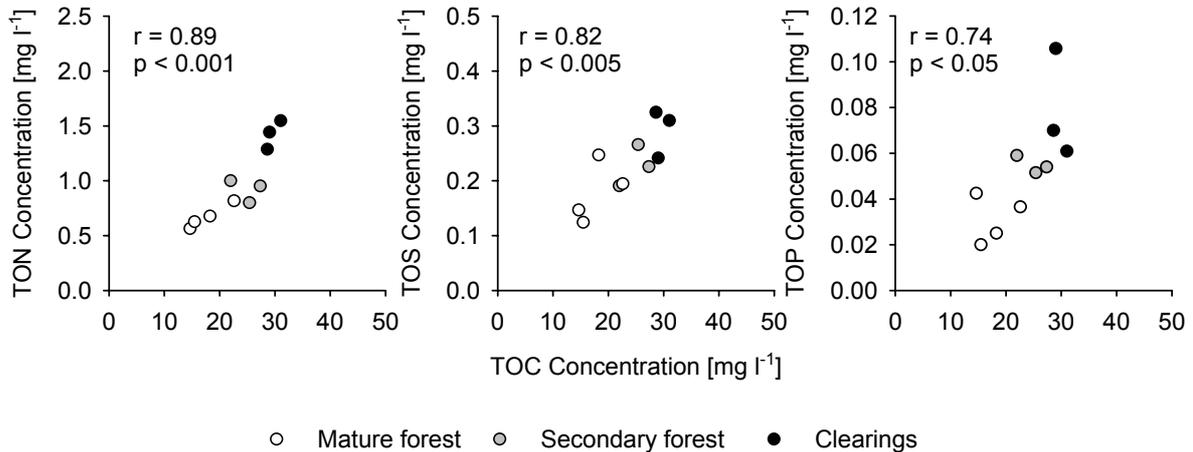


Fig. 6.6 Correlation between median concentrations of TOC and TON, TOC and TOP at individual plots for the time from 1.12.00-1.12.01 ($n = 10$).

CHANGES IN THE CONCENTRATION OF TOTAL ORGANICALLY BOUND ELEMENTS IN WATER ON THE PASSAGE THROUGH VEGETATION AND SOIL

Mean concentrations between field replicates of the fortnight mixed samples for one year formed the basis for the box-whisker-plots in Figures 6.7-6.9. Hence, the diagrams show the temporal variability of concentrations but not their spatial distribution. As rainfall concentrations were not volume weighted in these graphs, the median concentrations tended to larger values as compared to the volume weighted means presented in Table 6.1.

In general, concentrations of total organically bound elements increased from rainfall over throughfall to the litter percolate for both forest types, with a tendency for higher concentrations at the secondary forest sites. The increase in total organically bound elements from throughfall to litter percolate appeared to be stronger for TOC than for TON and TOS. Concentrations showed a pronounced decline towards the mineral soil layers and the stream water. Smallest TON concentrations were measured in the mineral soil solution under secondary forest. The concentration profile for clearings was similar, but for TOC and TON, throughfall concentrations

increased less during the passage of water through the vegetation cover as compared to the forests. Thus, the increase in concentration towards the litter percolate was more pronounced and indicates a larger TOC and TON release in the litter percolate of the clearings. The wider boxes for the secondary forest sites and the clearings, especially for TON, indicate a stronger seasonality of the litter percolate concentrations at these sites than at the mature forests.

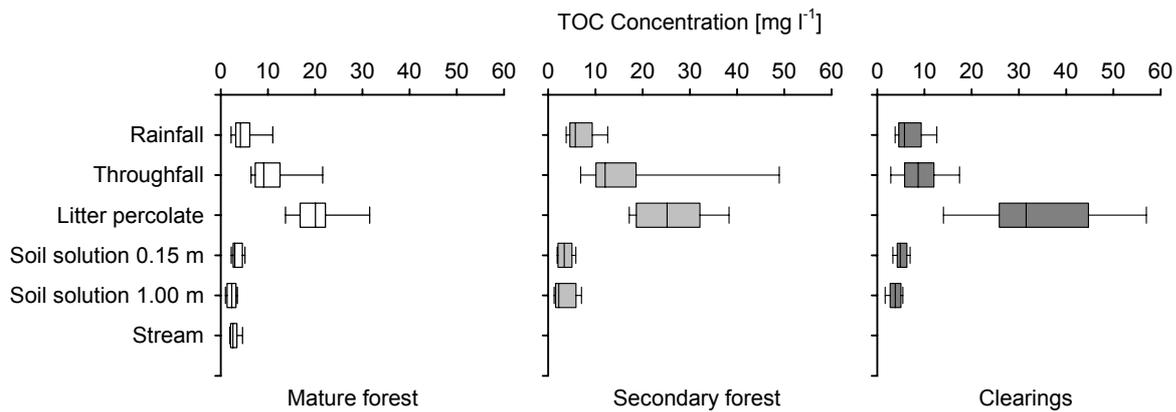


Fig. 6.7 Changes in TOC concentrations in percolating water on the passage through three vegetation types. Boxes include mean concentrations per vegetation type of two-week mixed samples from 1.12.00-1.12.01. Outliers above and below the 90th and 10th percentile are not shown.

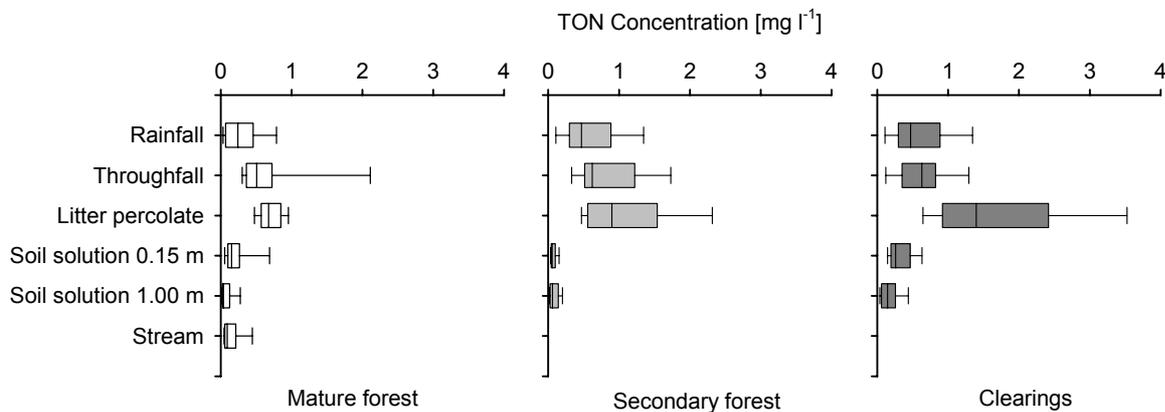


Fig. 6.8 Changes in TON concentrations in percolating water on the passage through three vegetation types. Boxes include mean concentrations per vegetation type of two-week mixed samples from 1.12.00-1.12.01. Outliers above and below the 90th and 10th percentile are not shown.

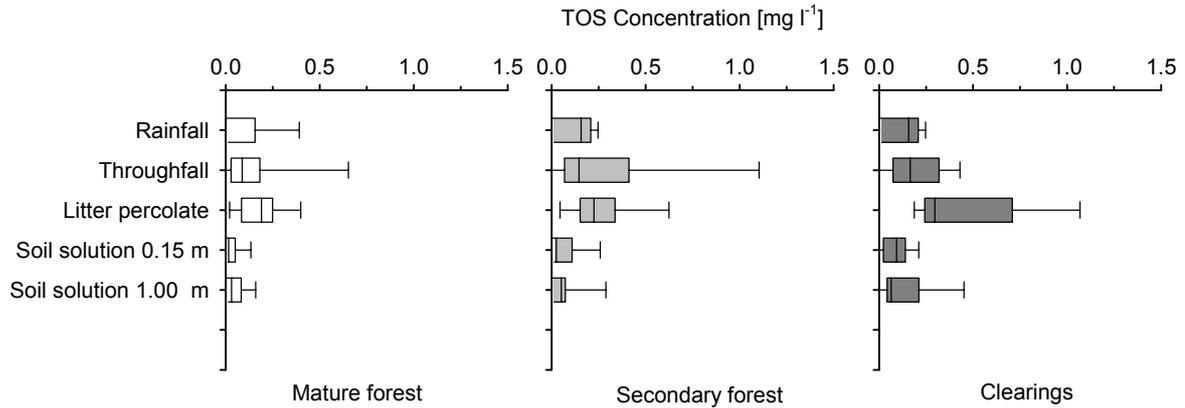


Fig. 6.9 Changes in TOS concentrations in percolating water on the passage through three vegetation types. Boxes include mean concentrations per vegetation type of two-week mixed samples from 1.12.00-1.12.01. Outliers above and below the 90th and 10th percentile are not shown.

THE RELEVANCE OF ORGANIC FORMS OF AS COMPARED TO INORGANIC N, S AND P FORMS

As DOM contributes significantly to total amounts of N, S and P in temperate soils, it is important to analyse whether this holds also true for a tropical mountain environment. In case of TON, the largest contribution to total N (N_{tot}) was found for throughfall in the forests (Table 6.6). At the bottom of the forest floor, the contribution of TON to N_{tot} was < 50% and it further decreased in the mineral soil, where its proportion was often < 10%. In the secondary forests and the clearings, it seemed as if the contribution of TON increased with increasing soil depth (see also Fig. 6.10) and in the stream water. Here, the contribution of TON to N_{tot} was larger than in the soil solution under the mature forest. However, overall concentrations were low. Except for throughfall, where the contribution of TON to total N was lower at the clearings, no vegetation effect on the partitioning of TON in organic and inorganic forms was found.

The contribution of TOS to total S (S_{tot}) in throughfall was lower as compared to the litter percolate. The percentages of TON and TOS in the litter percolate were similar and those of TOP were only slightly less. The contribution of TOS to total S at the clearings was less in the mineral soil than in percolates from the organic horizons. No effect of the vegetation type on the percentage of TOS was detectable. For TOP most concentrations were below the detection limit so that no information on its contribution in throughfall and the soil solution is available.

Table 6.6: Mean percentage of total N, S and P present as TON, TOS and TOP in different water pathways under different vegetation types. Percentages were calculated from volume weighted mean concentrations for rainfall and throughfall and median values for other water samples. Means for the period from 1.6.01-1.6.02 were used for TON and TOP, while 1.12.00-1.12.01 was used for TOS (\pm standard error, $n = 3$ for clearings and secondary forest, $n = 4$ for mature forest).

	Percentages of N_{tot} , S_{tot} and P_{tot} as TON, TOS and TOP								
	TON			TOS			TOP		
	MF	SF	CI	MF	SF	CI	MF	SF	CI
	[%]			[%]			[%]		
Rainfall	48	53	53	34	34	34	ND	ND	ND
Throughfall	66 ± 3	77 ± 9	57 ± 3	34 ± 3	37 ± 2	36 ± 1	ND	ND	ND
Litter Percolate	39 ± 2	43 ± 3	33 ± 11	43 ± 5	42 ± 2	44 ± 9	34 ± 4	35 ± 9	21 ± 5
Soil Solution 0.15 m	8 ± 2	7 ± 1	11 ± 3	ND	ND	17 ± 5	ND	ND	ND
Soil Solution 0.30 m	7 ± 1	10 ± 3	7 ± 1	-	-	-	ND	ND	ND
Soil Solution 1.00 m	5 ± 1	14 ± 4	16 ± 5	ND	ND	23 $\pm 2^*$	ND	ND	ND
Stream Water	12	-	-	-	-	-	-	-	-

ND: Not detectable, MF: Mature forest, SF: Secondary forest, CI: Clearings, *: $n = 2$

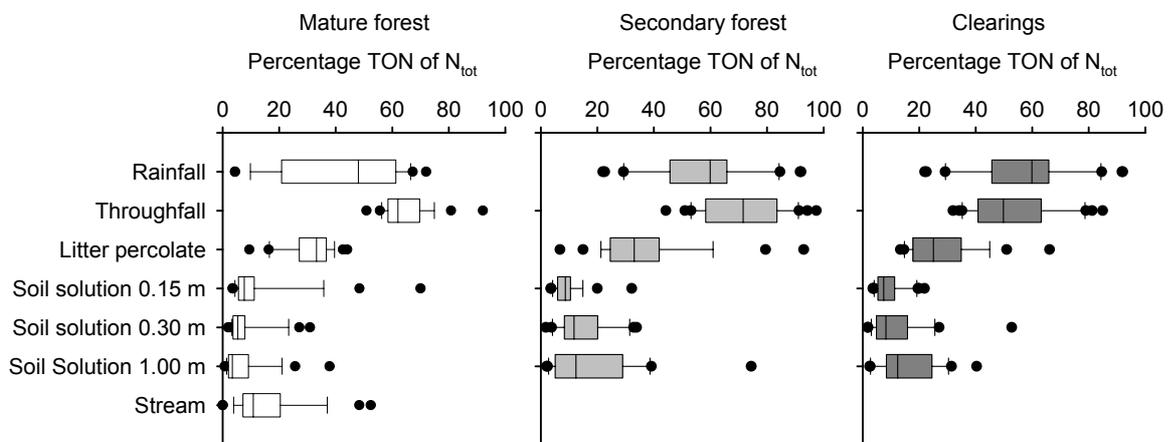


Fig. 6.10 Percentage of total N present as TON in different water pathways. Boxes include mean percentages per vegetation treatment of two-week mixed samples from 1.12.00-1.12.01.

EFFECT OF FIRE ON CONCENTRATIONS OF TOTAL ORGANICALLY BOUND ELEMENTS

Fires are a common phenomenon on Mt. Kilimanjaro. They occur towards the end of the dry season at higher altitudes in the ericaceous belt, but also in the forest on the lower slopes, where they are probably partly responsible for the impeded regeneration at some clearings. Thus, the vegetation of three out of six clearings was first cut and then the dry plant residues were burned at the end of the dry season in order to investigate the effects of fire on organic matter in the soil solution. The dry season was very pronounced that year. Nutrient concentrations at the end of the dry season were already at a high level due to accumulation of mineralised matter. No marked effects of cutting and burning of the vegetation were observed for the TOC concentrations in the litter percolate except for one fortnight sampling period (Figure 6.11). In the soil solution, no differences were observed either. For TON, a concentration maximum occurred at the end of the dry season and after the clearing of the sites. The second maximum was not observed at the reference sites. The concentration maximum for TON induced by the disturbance was most pronounced in the soil solution at 0.15 m. Concentrations remained on an elevated level for approximately five months after the clearing until May 2002 (Figure 6.12). Also the TOP concentrations in litter percolate showed a maximum after the clearing. Despite the large concentrations of inorganic P in the litter percolate during the postburn period, total P concentrations remained below the detection limit in the mineral soil, indicating a high P fixation by allophane.

No change in the contribution of organic N to total N was observed in the postburn period. The same was true for TOP. The contribution of TOP to total P was highly variable among disturbed as well as undisturbed clearings. From May 2002 until the end of the study period, the proportion of TOP tended to be larger at the undisturbed clearings than at the burned sites (median of 43 and 17% respectively). After May 2002, concentrations of TOP and TON were smaller under burned clearings than for the reference clearings.

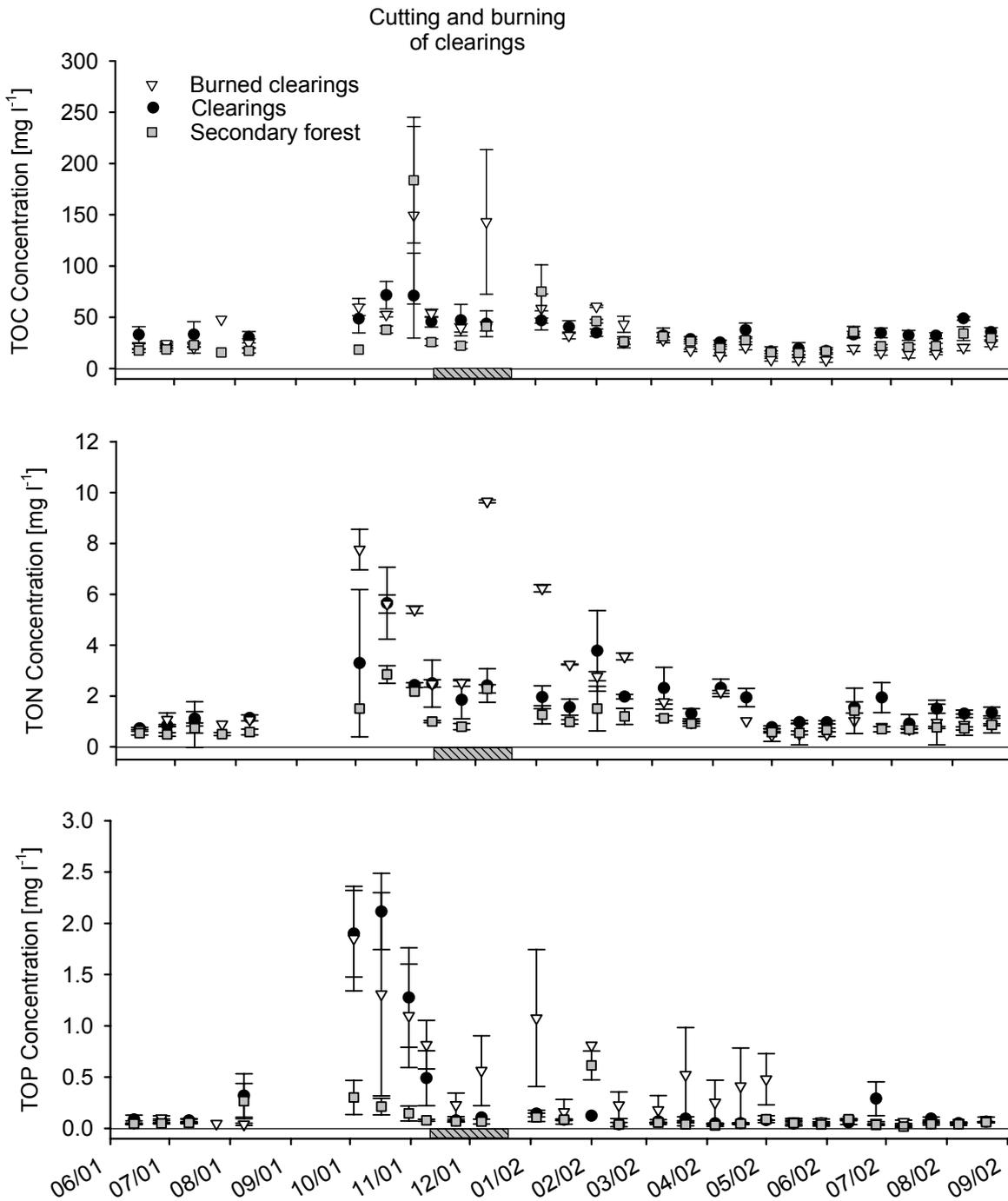


Fig. 6.11: Concentrations of total organically bound elements in litter percolate of clearings and secondary forest (\pm standard error, $n = 3$). Between November and December 2001, three out of six clearings were first cut and then burned; the relevant period is marked by a grey bar at the bottom of the graph.

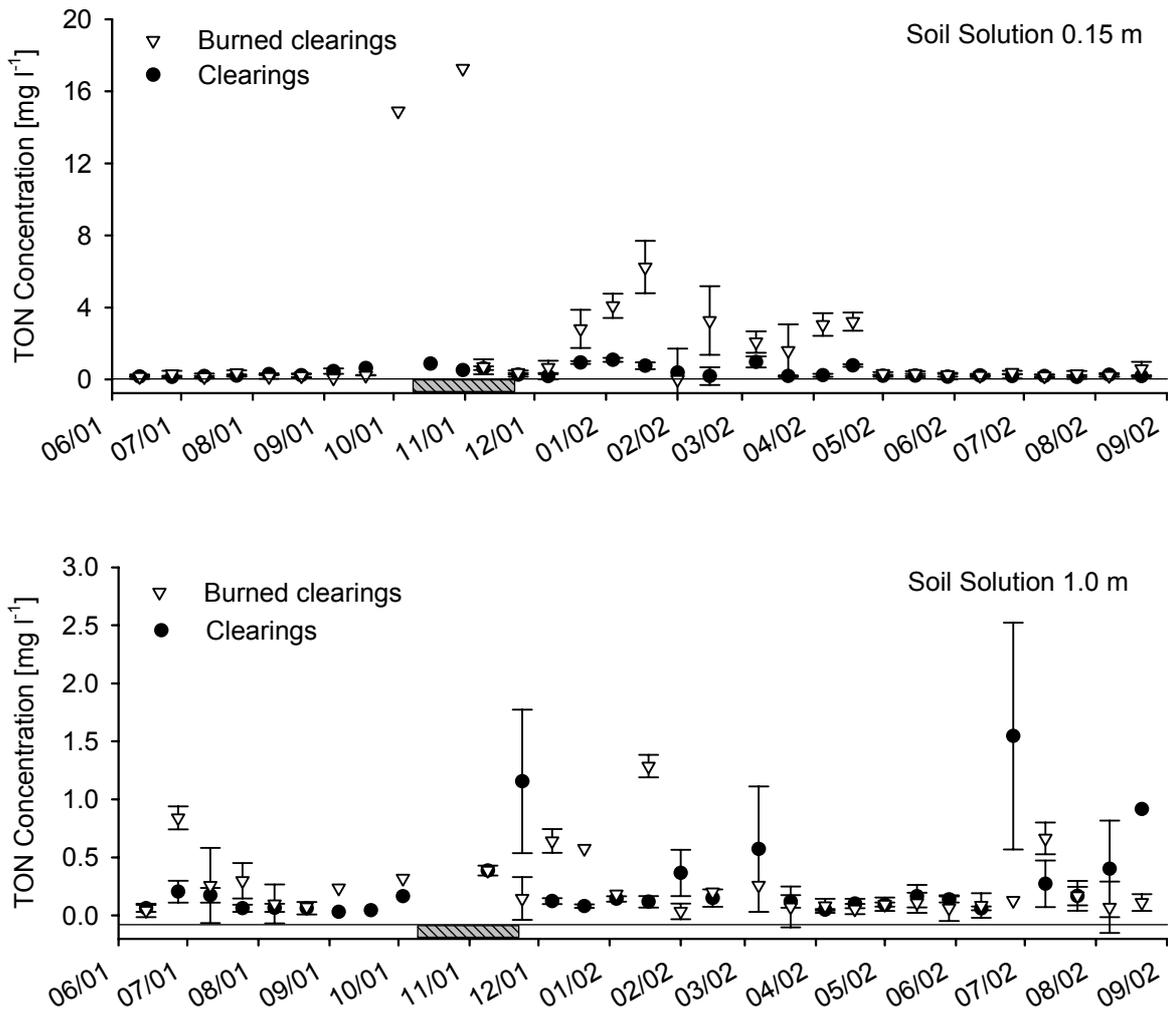


Fig. 6.12 TON concentrations (\pm standard error, $n = 3$) of the soil solution (0.15 and 1.0 m) under two groups of clearings, one of which was cut and burned between November and December 2001. The relevant period is marked by a grey bar at the bottom of the graph.

DISCUSSION

COMPARISON OF THE RESULTS OBTAINED AT MT. KILIMANJARO WITH THOSE FROM OTHER TEMPERATE AND TROPICAL FOREST SITES

For the temperate zone and especially the northern hemisphere, a number of studies have examined concentrations and fluxes of DOC and DON in forest ecosystems (McDowell & Likens 1988, Michalzik & Matzner 1999, Qualls et al. 1991). An overview of current knowledge is given by Michalzik et al. (2001). Throughfall TOC concentrations in the temperate forests show a high variability in the same order of magnitude as the throughfall concentrations of tropical forests presented in Table 6.7. TOC concentrations in litter percolate at Mt. Kilimanjaro were at the lower end of values measured for temperate forests and are also smaller than in a tropical mountain rain forest in Ecuador at similar altitude. The larger TOC concentrations in the litter percolate of the Ecuadorian forest might be due to the extraordinarily high accumulation of organic material in the litter layer of these forests (Schrumpf et al. 2001). In the soil solution, concentrations in A horizons at Mt. Kilimanjaro were an order of magnitude lower compared to temperate sites. In the deeper mineral soil, the concentrations were more similar, indicating a stronger decrease with soil depths at temperate sites. The TOC concentration in the soil solution at Mt. Kilimanjaro was smaller compared to other tropical sites. Still, overall TOC concentrations of soil solutions at the tropical sites were less than the concentrations in temperate regions. The stream concentrations at Mt. Kilimanjaro were in the same range as streams studied in mountain forests in Ecuador and Thailand, but higher than in lowland rainforests at the Ivory Coast and in Puerto Rico (Table 6.7).

The higher TOC concentrations in both, Ecuadorian and Tanzanian rainwater might be caused by differences in pore sizes of filters used prior to analyses. Ecuadorian and Tanzanian samples were filtered using a coarser filter (4-7 and 2 μm respectively) compared to the studies in Thailand and Puerto Rico (0.45 and 0.7 μm). Hence, a larger quantity of particles was included in the first two studies. Another reason might be the environment of the rainfall collectors. At Mt. Kilimanjaro, collectors were located in forest clearings. Thus, it seems probable that small amounts of spray water created in the canopy of the adjacent forest during heavy rainstorms could have reached the collectors and increased rainfall TOC concentrations by the addition of canopy-derived compounds.

Table 6.7 DOC and DON concentrations in temperate and tropical forest ecosystems.

	RF	TF	LP	SS	SS [mg l ⁻¹]	S
DOC						
Temperate Forests ¹		3-35	20-90	18-75 A horizons	2-35 B horizons	
LRF Ivory Coast ² #	1.3	7.4		8.7 0.3m	8.1 2.0 m	1.0 spring
LRM Puerto Rico ³	1.0	6.2		5.3 0.4 m	2.4 0.8 m	1.9
MRF Thailand ⁴	1.5	3.3-4.4		4-6 ⁺ 0.15 m	2-3 ⁺ 0.8 m	2-3 ⁺
MRF Ecuador ⁵ #	4.1	12.9-17.6	35.6-63.7			2.3-3.1
MRF Tanzania ⁷ #	3.4-5.2	7.4-13.1	21.2-24.4	2.0-3.0 0.15 m	1.3-3.2 1.0 m	2.9
DON						
Temperate Forests ¹		0.25-1.11	0.4-2.45		0.2-1.1 B horizons	
LRF Brazil ⁶ *	0.15	0.48		0.4 ⁺ 0.25m	0.2-0.3 ⁺ 1.1m	0.08
MRF Thailand ⁴	0.22	0.22-0.25		0.2-0.3 ⁺		0.06-0.13
MRF Tanzania ⁷ #	0.13- 0.30	0.39-0.58	0.77-0.88	0.05-0.14	0.03-0.08	0.09

RF: rainfall, TF: throughfall, LP: litter percolate, SS: soil solution, S: stream, ND: not detectable
LRF: Lowland rainforest, MRF: Mountain rain forest, # total organic C and N, + values taken from graph

¹Michalzik et al. (2001), ²Roose & Lelong (1981), ³McDowell (1998), ⁴Möller (2001), ⁵Wilcke et al. (2001), ⁶Klinge (1997)* values calculated as difference between total N and inorganic forms presented in the study, ⁷ this study

The number of ecosystem studies in the humid tropics which include DON measurements is rare. One example is the study of Möller (2001) in Thailand. Klinge (1997) only presented DON concentrations in the soil solution of an Amazon rainforest, but for rainfall and throughfall, DON concentrations could be obtained by calculation using means of total and inorganic N (Table 6.7). Rainfall concentrations in both studies were in the same order of magnitude as at Mt. Kilimanjaro. The sites in Thailand had lowest DON throughfall concentrations, but all tropical sites were within the range of concentrations observed for temperate forest ecosystems (Table 6.7). In the soil solution, TOC and TON concentrations at Mt. Kilimanjaro were

smallest of all tropical sites studied so far. In contrast, TON concentrations in the streams were similar for all tropical sites.

So far, no detailed study on DOP or DOS is available from the humid tropics. For a temperate deciduous forest, Qualls et al. (1991) obtained DOP concentrations in the leachate of the Oa horizon of nearly $25 \mu\text{g l}^{-1}$. The study of Kaiser et al. (2003) revealed a high seasonality of DOP concentrations in the litter percolate of a European beech forest. Highest DOP concentrations were obtained in summer and autumn when they reached concentrations of up to $330\text{-}400 \mu\text{g l}^{-1}$ following drier periods. Concentration in the litter percolate at Mt. Kilimanjaro similarly peaked at the end of the dry season and reached maximum values of $330 \mu\text{g l}^{-1}$ in the mature forest, $610 \mu\text{g l}^{-1}$ in the secondary forest and $2110 \mu\text{g l}^{-1}$ at the clearings. With an average of $40\text{-}60 \mu\text{g l}^{-1}$ (median), the TOP concentrations in the litter percolate (Oa horizon) of the two forest types studied at Mt. Kilimanjaro were lower than the range of $200\text{-}300 \mu\text{g l}^{-1}$ reported in Michalzik et al. (2001) for five temperate forest soils.

Fluxes of DOC and DON in rainfall and throughfall of tropical and temperate forests are provided in Table 6.8. DOC and DON fluxes in rainfall at tropical sites were within the range of values measured for temperate forests while the throughfall fluxes were at the upper end of values found in temperate forests.

CONTRIBUTION OF ORGANIC MATTER TO ABOVEGROUND NUTRIENT FLUXES

DOM is already present in rainfall before it reaches the ground. Organic acids in rainfall at remote, vegetated areas can derive from the oxidation of isoprene or direct emission from the vegetation (Andreae et al. 1986). DON was found to comprise more than half of total N in rainfall samples of Costa Rica, Brazil and Thailand (Hendry et al. 1984, Klinge 1997, Möller 2001) and aerosols, ash and other particles in wet and dry deposition are usually attributed to be the source. DOM usually increases during the passage of rainwater through the forest canopy (Table 6.7, 6.8). Tukey (1970) reported that several organic substances including carbohydrates and amino acids can be leached from plant tissues. Also Parker (1983) attributed the DOC increase during the passage of water through a forest canopy to leaching but argued that decomposition of dead organic material in the canopy may also contribute to DOC in throughfall. This might be of special importance in tropical mountain rain forests with a high density of epiphytes. These plants lead to the accumulation of considerable amounts of decaying organic material and humus in the forest canopy (Lüttge 1997). Nadkarni & Matelson (1992) reported, that dead organic matter

comprised 13% of total epiphytic litterfall in a mountain rainforest in Costa Rica. The microbial biomass in canopy humus was similar to that of the forest floor (Vance & Nadkarni 1990). Thus, leaching of decomposing parts of epiphytes as well as from canopy humus is likely to contribute to DOM concentrations in throughfall.

Table 6.8 DON and TON fluxes in rainfall and throughfall of selected temperate and tropical forest sites.

	RF	TF	LP	SS	SS	S
	[kg ha ⁻¹ a ⁻¹]					
DOC						
Temperate Forests ¹		40-160	100-400		10-200	B horizons
LRF Puerto Rico ³	33.6	127		92.0	42.7	32.5
MRF Ecuador ⁵ #	90	143-266				
MRF Tanzania ⁷ #	59.4-88.9	142-182				
DON						
Temperate Forests ¹		1.2-11.5	0.2-18.0		0.1-9.4	B horizons
LRF Brazil ^{6*}	4.6	11.9				
MRF Tanzania ⁷ #	3.4-6.2	6.2-10.3				

For the legend see Table 6.7.

The observed negative correlation between rainfall amounts and throughfall concentrations of organic matter at Mt. Kilimanjaro indicates dilution of rainfall and throughfall concentrations by large amounts of rain. A simple dilution would occur if the wash-off of dry deposition, which constantly accumulates in the forest canopy, would be responsible for the increase in OM in throughfall. But correlations between rainfall amounts and throughfall concentrations were not strong, and the relation between net throughfall fluxes and rainfall amounts indicates that also leaching sources seem to be important (Parker 1983). The relation between organic and inorganic N fluxes in throughfall points out that both fluxes might be determined by similar processes. Nitrate is said to be accumulated due to dry deposition and retained by canopy uptake. Ammonia can similarly be retained by forest canopies (Schaefer & Reiners 1990). At the study sites, net NO₃-N fluxes were negative, indicating retention of NO₃-N in the canopy, whereas NH₄-N fluxes remained more or less unchanged (Chapter 5). Processes that include ion adsorption and exchange are probably influenced by solute concentrations. The negative correlation between net TON throughfall fluxes and rainfall TON concentrations supports this

hypothesis. Since net throughfall TON fluxes at the clearings were neither correlated to rainfall amounts nor to rainfall concentrations, the processes might be related to specific properties of the forested sites like presence of epiphytes and properties of tree leaves.

According to Schaefer & Reiners (1990), net $\text{SO}_4\text{-S}$ -fluxes in forest canopies probably derive from a combination of wash-off of dry deposit and diffusion from apoplastic pools. At most fortnight intervals with sufficiently high rainfall concentrations, net throughfall fluxes of TOS were negative and negative correlations with rainfall amounts indicate that the higher the rainfall amounts, the higher was the net canopy retention of TOS. Also $\text{SO}_4\text{-S}$ showed a net retention in the forest canopy, but no correlations to rainfall variables. For most mountain rainforests, a net S release from the canopy was observed (Hafkenscheid 2000, Wilcke et al. 2001), but Cavelier et al. (1997) also found a net retention of S in the canopy of a mountain rainforest in Panama. The present results indicate that beside inorganic S, also organically bound S might be retained by the forest canopy but due to the low number of detectable valid samples, this needs to be investigated in further studies.

The correlation between net TOC fluxes and rainfall amounts indicates that besides wash-off from the canopy also leaching from plant tissues contributes to organic matter in throughfall. In the mature forest, a close correlation between throughfall fluxes of TOC and TON suggests that both variables are under the control of similar factors. Considering only net fluxes, correlations were weaker, indicating some differences in canopy processes.

SOURCES AND SINKS FOR TOTAL ORGANICALLY BOUND ELEMENTS IN THE SOIL

Concentrations of TOC as well as of TON in the litter percolate at Mt. Kilimanjaro were at the lower limit of respective concentrations measured at other sites. In the soil solution, concentrations were less than values obtained in temperate forests. Also, the relative contribution of TON to total N in litter percolate and soil solution was smaller than the proportions in temperate (Qualls et al. 1991, Smolander et al. 2001) and other tropical (Klinge 1997) forest ecosystems. This result may be due to little release of organic matter in the forest floor, rapid mineralisation of organic compounds, plant uptake or adsorption to minerals.

Up to now it is not quite clear which horizon of the forest floor layers (Oi, Oe, Oa) is mainly responsible for DOM release. While Michalzik & Matzner (1999) assumed the

Oi horizon to be the main source of DOM in the forest floor, other studies found the Oe and Oa horizons to be of greater importance (Fröberg et al. 2003, Solinger et al. 2001). In the present study, forest floor percolate was sampled in the Oa horizon below the root mat of the trees. For this reason, an estimation of the contribution of individual horizons is not possible. Root exudates and decomposing dead roots might be additional sources for organic matter in forest floor percolates. Plant roots probably do not only present a source, but also a sink for DOM due to direct uptake of DON (Neff et al. 2003). Schmidt & Stewart (1997) showed that the vegetation of a wet subtropical heathland takes up amino acids directly. Therefore, it cannot be ruled out that tropical mountain forest plants also use DON constituents directly or via micorrhiza, which is so far only poorly understood (Murphy et al. 2000, Neff et al. 2003). Consequently, plant or micorrhiza uptake might have reduced organic matter concentrations in the litter percolate. Furthermore, as the Oa horizons already contain a significant amount of mineral particles, sorption processes may have affected the organic matter concentrations in the deeper litter layers.

According to studies of Kaiser & Guggenberger (1996), Fe and Al hydrous oxides are major sorbents for DOM in soils. Andosols being the dominant soil type in the study area, usually contain huge amounts of oxalate-extractable Fe and Al and are thus expected to have a high sorption capacity for DOM. This was also confirmed by studies of Dahlgren et al. (1991) in nonallophanic Andosols of Japan, where large quantities of DOM were immobilized or decomposed in the A1 horizons. In batch experiments, Nambu & Yonebayashi (2000) similarly measured more DOM sorption to Andosols as compared to Inceptisols and Entisols. Neff et al. 2000 studied the influence of soil age on DOM fluxes in a laboratory experiment using O horizons of volcanic ash soils of varying age (from 300 to 4.100.000 years). The soils with an intermediate soil age of 20.000 years had the largest contents of noncrystalline minerals and exhibited the strongest physical control on DOC fluxes. At the oldest sites, the authors observed an increase of biological control on DOM release which was attributed to a decrease in the amorphous constituents at advanced stages of Andosol weathering. Radiocarbon ages (^{14}C) of charcoal in fossil A horizons at the study sites ranged from 10.000 to 16.000 years (see Chapter 2), indicating that the recent topsoil material is comparably young. The soils contained considerable amounts of oxalate-extractable Al and Si and dithionite-citrate-extractable Al, and there was evidence for a considerable anion sorption in the deeper mineral soil (see chapter 2). These results indicate in summary that a major part of the DOM released in the litter layer and canopy was probably retained by sorption in the mineral soil.

The analysis of the degradability of DOM in different ecosystem fluxes revealed that DOM in throughfall was more readily mineralisable than DOM in litter percolate or in the soil solution (Qualls & Haines 1992). Even though there were indications that biodegradation occurs at deeper soil layers, adsorption to soil particles appears to be the process determining the retention of DOM in the subsoil (Kalbitz et al. 2000). Although no analyses on the DOM composition and DOM mineralisation were conducted in this study, it can be assumed that these general observations were also valid for the study sites at Mt. Kilimanjaro.

VEGETATION EFFECTS

The vegetation cover may influence organic matter concentrations and fluxes through differences in leaching properties of plant tissue and decomposability of litter. The contribution of TON on total N in throughfall was larger at forested sites than for clearings, although TON fluxes did not exhibit differences. This can be explained by the retention of inorganic N, especially of $\text{NO}_3\text{-N}$, in the forest canopies, while N was leached from the shrub vegetation of the clearings (see Chapter 5), leading to increased throughfall TON at the forest sites. Also TOC concentrations and fluxes were significantly larger in throughfall of forest sites, indicating stronger release or additional sources of organic matter in the forest canopies. Beside stronger leaching due to the larger biomass of the forest canopy, epiphytic humus may contribute to organic matter in throughfall of the forests.

Under forests as well as at clearings, organic matter increased from throughfall to litter percolate. The increase was more pronounced for the clearings, indicating a stronger release of organic matter in the litter layer at these sites. Some studies showed that DOM concentrations and fluxes in leachates from Oa horizons may be controlled by pH (Andersson et al. 2000, Michalzik et al. 2001), microbial biomass and activity (Smolander & Kitunen 2002), or dominant tree species (Strobel et al. 2001). A trend for increasing DOM concentrations with increasing temperature was observed in laboratory studies, but could not be confirmed in the field (Kalbitz et al. 2000). Larger inorganic N concentrations in the litter percolate at the clearings indicate higher N-mineralisation rates and higher microbial activity. This is probably by higher temperatures and closer C/N ratios of the litter in the clearings (Chapter 5). Inorganic and organic N concentrations were significantly correlated in the litter percolate which points at increased turnover of the litter material at the clearings.

Johnson-Maynard et al. (1998) studied a suppressed secondary succession of a coniferous forest after the invasion of bracken on Andisols. They observed significant larger DOC concentrations in the soil solution of fern dominated clearings than under undisturbed forest and suggested that bracken fern is responsible for an increase in Al-humus complexes in the subsoil (Johnson-Maynard et al. 1997). These results indicate that also the litter of the bracken, which was dominant at the younger clearings at Mt. Kilimanjaro, could have influenced the release of organic matter in litter percolate. Similar to the observations of Johnson-Maynard et al. (1997), litter accumulation and organic matter concentrations in the topsoil were higher in clearings as compared to adjacent secondary forest (see Chapter 5). Higher amounts of soil organic matter might also lead to increased release of DOM in volcanic ash soils (Neff et al. 2000). Differences in solution concentrations vanished with depths, likely due to the strongly sorbing soil mineral matrix.

IMPORTANCE OF ORGANIC MATTER

The forest at Mt. Kilimanjaro showed the largest contribution of TON to total N in throughfall among the studied solution types. In the litter percolate, the contribution of organic matter to total N, P, and S was generally < 50% and was even smaller in the mineral soil. This is in contrast to observations made in temperate forest ecosystems. In a deciduous forest in the Appalachian Mountains, DON and DOP concentrations in litter percolate and the soil solution exceeded inorganic forms (Qualls et al. 2000). Similar results were obtained for DON in a Norway spruce stand (Smolander et al. 2001) and for DOP in a German beech forest (Kaiser et al. 2003). With 30-50% also the contribution of DON to total N in the mineral soil of a lowland rainforest in the Amazon Basin was larger (Klinge 1997). The small contribution of TON to total N at Mt. Kilimanjaro was probably due to the high content of amorphous minerals in the soils, which act as a strong sorbent. This partly contradicts the observations of Hedin et al. (1995) and Perakis & Hedin (2002), who studied stream N concentrations in a number of Chilean streams and found consistently DON to represent > 95% of total N. Some of the streams were sampled in areas with soils that developed on tephra. These soils probably also contain high amounts of amorphous soil material and thus have a high retention capacity for organic nutrients. Perakis & Hedin (2002) ascribe the high contribution of DON to total N to low input of inorganic N as the study areas were widely unpolluted. The canopy of the forest at Mt. Kilimanjaro retains significant amounts of the deposited N and thus input of inorganic N via throughfall is low. This discrepancy cannot be solved from the data available.

Larger DON concentrations in the stream as compared to the soil solution of the mature forest might be caused by sources within the stream channel (e.g. litter falling into the stream, decaying organisms) or due to additions of throughfall water. Local inputs by laterally transported water also form a potential DON source in streams.

RELATIONS BETWEEN TOC, TON, TOP AND TOS

In the mature forest, TOC concentrations were closely correlated to TON in throughfall, litter percolate and the soil solution in the upper mineral soil. Relations between DOC and DON concentrations and fluxes in different compartments of forest ecosystems have frequently been observed in temperate forests (Michalzik et al. 2001). Nevertheless, there are also hints that release and fate of DON might be independent of DOC (Kalbitz et al. 2000, Solinger et al. 2001). In litter percolate, mean annual TOC concentrations relate to mean TON, TOS and TOP concentrations at different sites. The results indicated that despite different amounts of organic matter being released in the forest floor under the different vegetation types, there are no major changes in its composition. Correlations between TOC and TOP concentrations in fortnight samples were much weaker than those obtained by Kaiser et al. (2003) in a temperate forest. This might be partly due to overall low OP concentrations at the sites studied here. Small errors in the determination of either total P or PO₄-P therefore might have a large effect on calculated OP concentrations. Studies on DOS are rare. Kaiser & Guggenberger (pers. comm.) found a strong correlation between DOS and DOC concentrations in litter percolate as well as in soil solution of two European forests.

THE EFFECT OF DISTURBANCE ON ORGANIC MATTER CONCENTRATIONS

Cutting and burning of the vegetation usually induces increased DOM concentrations immediately after the disturbance (Chantigny 2003, Qualls et al. 2000, Smolander et al. 2001). Meyer & Tate (1983) found reduced DOC exports two years after the clearcutting of a forested watershed. They attributed the result to reduced inputs of TOC with throughfall and lower annual production of litter as compared to undisturbed forested areas. The duration of elevated organic matter concentrations in seepage water following disturbance show a wide range. Even 8-10 years after clear-cut, Moore (1989) found elevated DOC concentrations in catchment water of a hardwood-forest in New Zealand and ascribed them to organic debris in the stream

channel. On the other hand, Klinge (1997) found elevated DON concentrations in the soil solution following cutting and burning of tropical rainforest in the Amazon basin only over a period of 4-5 months. The biomass cut and burned at the clearings of Mt. Kilimanjaro was little compared to that of a mature forest and consequently also the effects on OM concentrations were less strong than in other studies. In the study of Klinge (1997), cutting of secondary vegetation half a year after the main disturbance induced a minor increase in soil solution DON for less than one month. At Mt. Kilimanjaro, elevated concentrations were detectable for up to five months for TON and TOP, while effects on TOC concentrations were less pronounced. The secondary vegetation at Mt. Kilimanjaro recovered within three months after the disturbance except for one site where the recovery of the vegetation cover was less rapid in some small areas. Overall, leaching of organic matter from the sites following disturbance was not substantial. Because OP and to a larger extent also for $\text{PO}_4\text{-P}$, concentrations in litter percolate increased following disturbance, while those in the mineral soil solution remained below the detection limit. Although TON concentrations increased in the topsoil after disturbance, the effect vanished with soil depth, probably due to the strong sorption of OM. The reduced organic matter concentrations in litter percolate some weeks after disturbance might be due to the depletion of easily leachable and decomposable organic material and the low litter production of the regenerating vegetation.

CONCLUSIONS

In the studied mountain rainforest at Mt. Kilimanjaro, highest OM concentrations were measured in the litter percolate. As $\text{NO}_3\text{-N}$ is retained in the forest canopy, most N in throughfall reaches the ground as ON. There are some indices that differences in plant tissues among forests and clearings lead to differences in TOC and TON leaching. Epiphytic biomass and canopy humus were thought to contribute to throughfall TOM fluxes in the forests. The relative contribution of OM to total belowground concentrations of N, S and P was low compared to other tropical and temperate sites, probably because of strong sorption by the mineral soils. Hence, leaching losses of nutrients associated with OM are not supposed to be high and for N, inorganic forms seem to be more mobile in the analysed soils.

Increased organic matter release following disturbance by fires was buffered by the mineral soil. Consequently, losses of organic matter to streams following minor disturbances are supposed to be low. The fact that organic matter concentrations in litter percolate and the topsoil solution at clearings were larger than at forest sites

indicates possible long-term effects of forest disturbances at Mt. Kilimanjaro. Sorption analyses need to be conducted to test the hypothesis of the large sorption capacity of the soils and their ability to control organic matter concentrations in the soil solution at the study sites.

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7 Summary and General Conclusions

Tropical mountain rainforests are among the most diverse ecosystems in the world (Myers et al. 2000) and are often located in important headwater areas, which supply water to lowland areas. The latter is of special importance in East Africa, where regions covered with mountain rainforests form basic catchment areas for rivers in the savannah. A continuous water supply to these rivers is essential for driving hydroelectric plants and enabling irrigation agriculture. The rainforest belt of Mt. Kilimanjaro is one of the major catchment areas in Tanzania. Nevertheless, the natural forest has been intensively dissected during the past decades by transformation into forest plantations by logging and fires (Lambrechts et al. 2002, Newmark 1991). Especially at the lower boundary, ongoing logging has led to a highly fragmented forest where a mosaic of secondary vegetation of various ages is encountered today. In some larger clearings covered by bracken and lianas, the regeneration of the natural forest seems to be impeded so that these clearings may persist for years or even up to decades. Despite the accepted importance of forest protection in order to maintain various forest functions ranging from attracting tourism to water conservation, hardly anything is known about the biogeochemical cycles in the intact forest and possible impacts of forest disturbance.

The aim of this study is to provide basic information on soils as well as on the water and nutrient cycle in old growth forests on Mt. Kilimanjaro. In order to assess the long term impact of forest disturbance, the biogeochemical characteristics of mature and disturbed sites, covered with secondary vegetation of varying age, are compared. Some emphasis is given to organically bound nutrients which have been proven to contribute significantly to the nutrient cycle of temperate forests, but which have received only little attention in tropical ecosystems so far (Chantigny 2003, Perakis & Hedin 2002).

METHODOLOGICAL ASPECTS

To get an overview of soil characteristics in the forest belt of the study area, a transect study was performed at the southwestern slopes of the mountain. The transect extended from the lower (1850 m a.s.l.) to the upper (3150 m a.s.l.) forest boundary. At each approximately 200 m altitude, one soil profile was described and chemically characterised.

The main study area ranged from 2100 to 2300 m a.s.l. and included 13 plots of 400 m² each, six of which were located in clearings, three in secondary forest and four in mature forest. The mature forest sites had to be chosen about 150 m above the other sites as no larger areas of closed old growth forest were found in the vicinity of the secondary forest and the clearings. An ecosystem approach was used to study the water and nutrient characteristics on the sites, which were equipped with collectors for rainfall, throughfall and litter percolate, suction cups (at 0.15, 0.30, 1.00 m), tensiometers (at 0.10, 0.20, 0.60, 1.10 m) and litter collectors. Samples were taken for over two years on at least a weekly basis and mixed two-week samples of the collected solutions were analysed for their contents of K, Mg, Ca, Na, NO₃-N, NH₄-N, SO₄-S, PO₄-P, DOC, DON, DOS and DOP. Litter was collected monthly, weighed and analysed for nutrient contents. Next to each plot, a soil profile was also analysed.

Aboveground water chemistry and fluxes were compared among the sites. For belowground seepage water, only the water chemistry was interpreted since water flux models did not result in reliable estimates of belowground water fluxes with the data available.

RESULTS

1 GENESIS AND NUTRIENT STATUS OF SOILS

All soils were classified as sil-andic Andisols with Hapludands at lower elevations, Placaquands at around 2300 m a.s.l., Melanudands at 2500 m a.s.l., followed by Fulvudands and Haplustands with increasing elevation. The highest profile was classified as an Endoaquand. Hydromorphic features were mainly observed between 2300 and 2500 m and at the highest profile, where impermeable bedrock below 0.5 m from the soil surface led to water stagnation. Up to five buried soils were found in the profiles. Very dark fossil A horizons were most pronounced at mid elevations of the transect. The soils exhibited typical properties derived from volcanic ash such as high contents of amorphous clays, low bulk densities and a high accumulation of organic carbon. Positive ΔpH values and high Si_o contents indicated that profiles at lower elevations had on average higher contents of variable charge clays than at higher elevations. As all soils were acidic with low ECEC values and hence fulfilled the requirements for acrodoxic properties, they were considered to be already in an advanced stage of weathering and leaching. The exchange sites were mainly occupied by Al, resulting in a low base saturation and very low overall contents of exchangeable nutrient cations in the mineral soil. Decreasing N concentrations in the

Oi layer together with decreasing temperature with increasing elevation indicate a low N availability at higher elevations. Litter N contents and C/N ratios showed a correlation with the vegetation composition along the study transect. This might be due to a shift in the vegetation composition towards species that are better adapted to a low N availability with increasing altitude.

2 ABOVEGROUND WATER FLUXES, SOIL WATER TENSION AND SOIL WATER STORAGE

Total annual rainfall amounts at 2100 m were between 5% and 10% greater than at 2250 m a.s.l. in both years. Differences in weekly records indicated a high spatial and temporal variability of rainfall events. There was a great difference in annual rainfall amounts between both years which exceeded the difference between the altitudinal levels (2600 and 2210 mm at 2100 m a.s.l. and 2210 and 1960 mm at 2250 m a.s.l.). Rainfall interception was close to zero in the clearings, but high in the secondary as well as the mature forest sites, where it accounted for 30% of incident rainfall in the second monitored year. The matrix potential in the soils was lowest under secondary forest, while the soils in the clearings and the mature forest usually had higher water contents. Differences were most pronounced during dry periods. Higher sand contents in the topsoil of the secondary forests and the clearings compared to the mature forests led to different shapes of the soil-water-characteristic curves at the respective sites. As mature forests had both lower mean soil water tensions and higher water contents at the respective tensions, the estimated mean soil water storage in the upper 1.25 m of the mature forest sites was higher. This led to significantly higher estimated mean soil water storage values under the mature forest compared to the secondary forest and the clearings during both rainy and dry seasons.

3 CHARACTERISTICS OF THE INTERNAL NUTRIENT CYCLE IN THE MATURE FOREST

Compared to other mountain rainforests, nutrient concentrations and fluxes in rainfall and throughfall were low at Mt. Kilimanjaro. While $\text{NO}_3\text{-N}$ exhibited a net retention in the forest canopy, other nutrients in rainfall were enriched on the passage through the canopy. Correlation analyses indicated that leaching from the vegetation itself as well as wash-off of dry deposited material in the canopy both contributed to throughfall fluxes. Net $\text{NO}_3\text{-N}$ fluxes and – to a lesser degree – also $\text{NH}_4\text{-N}$ fluxes in throughfall exhibited a correlation with rainfall concentrations.

Accordingly, high N concentrations in rainfall led to a net absorption in the canopy, while low N concentrations resulted in net leaching. The highest overall nutrient concentrations were obtained in the litter percolate. Seeping further through the mineral soil, the nutrient concentrations in the leachate exhibited a pronounced decline. This was especially true for the base cations and $\text{NH}_4\text{-N}$. In contrast, the highest $\text{NO}_3\text{-N}$ concentrations were obtained in the soil solution at 0.15 m and can be attributed to nitrification and further mineralisation in the A horizon, where plant uptake was probably lower compared to the O horizon due to a lower root density. The results show that especially K is held in a closed cycle between the forest canopy and the litter layer. However, comparatively high N amounts are cycled via small litter-fall. Foliage analyses did not indicate severe limitations of major nutrients.

4 DIFFERENCES IN THE NUTRIENT CYCLE BETWEEN MATURE FOREST, SECONDARY FOREST AND CLEARINGS

Most nutrient fluxes via throughfall were nearly as high in the clearings as in the two forest types, despite the much higher biomass of the forest. Since N was not absorbed by the vegetation of the clearings, throughfall $\text{NO}_3\text{-N}$ fluxes were also significantly higher. K fluxes were significantly lower in the mature forest than in the secondary forest and in the clearings, which was probably attributable to differences in leaf properties and the associated susceptibility of leaves for leaching. In the litter percolate as well as in the soil solution at 0.15 m soil depth, nutrient concentrations were again highest in the clearings. Differences were most pronounced for K, Mg, Ca and $\text{NO}_3\text{-N}$, especially during drier periods. As indicated by higher leaching rates from the vegetation and higher belowground nutrient concentrations, the clearings exhibited overall a more open nutrient cycle than the mature forest. With the exception of $\text{NO}_3\text{-N}$, secondary forests usually took an intermediate position between mature forests and clearings, but usually more closely resembled mature forests. At deeper soil layers, soil solution concentrations did not differ significantly among the treatments.

5 RELEVANCE OF ORGANICALLY BOUND NUTRIENTS

Similar to most inorganic bound nutrients, the TOC, TON and TOS concentrations in rainfall increased during the passage through the forest canopy. The TOP concentrations were above the detection limit only in the litter leachate, where the overall highest concentrations of organically bound nutrients were measured. The fluxes of TON in throughfall were closely correlated to TOC and total inorganic N fluxes. Correlations between the TOS and TOC fluxes as well as with fluxes of inorganic S were weaker but significant. There were indications that the wash-off from the canopy, with an expected contribution of canopy humus, as well as leaching from the forest vegetation itself both contributed to net TOC and TON fluxes. In the soil solution, the TOC concentrations were nearly an order of magnitude lower than in litter percolate and the TON and TOS concentrations also exhibited a pronounced decline. This was probably due to strong sorption by the mineral soil. The highest contribution of TON to total N was obtained in throughfall, while for TOS it was in the litter percolate. Different from in many forests in the temperate region, the TON, TOS and TOP in litter percolate accounted for less than half of the amount of total N, S and P. For TON, this percentage was further reduced to less than 10% in the mineral soil.

While the TOC concentrations in throughfall were lower in the clearings as compared to the forests, the clearings exhibited the highest concentrations of organically bound nutrients in the litter percolate. These were probably either the result of higher mineralisation rates or an effect of the bracken vegetation in the clearings. Nevertheless, the seepage water concentrations at deeper soil layers did not exhibit significant differences between habitats. Following an induced fire at the clearings, the concentrations of organically bound nutrients were enhanced in the topsoil only, where the effect lasted for a few weeks.

GENERAL DISCUSSION AND CONCLUSIONS

Soils derived from volcanic ash are said to be fertile and well suitable for agriculture due to their stable soil structure, high water storage capacity, and high pool of OM. Nevertheless, the structure of these soils is fragile upon drying, which finally leads to an irreversible aggregation of soil particles. This process is accompanied by an increase in the sand content, which in turn reduces the water storage capacity of the soils. Since the water storage capacity of the forest belt at Mt. Kilimanjaro is important for maintaining a continuous dry season discharge, disturbances that lead

to an alteration of the soil structure should be avoided. The higher sand content of the soils under secondary forest vegetation as compared to soils under mature forest cannot exclusively be attributed to forest disturbance on the basis of the available data. Nevertheless, the soils under fragmented secondary forest vegetation proved to be driest, especially during the dry season. Several studies have shown that soil temperature as well as soil humidity is altered up to 40 m from the forest edge to the interior (Gelhausen et al. 2000, Jose et al. 1996), and there are also indications that evapotranspiration rates at forest edges are increased especially during drier periods (Giambelluca et al. 2003). Therefore, besides the likely effects of the topographic position and differences in soil water permeability, edge effects in the region of the fragmented secondary forests probably contribute to the difference between the soil water tension at the secondary forest and the more homogenous old growth forest. Due to lower interception and lower transpiration rates, the soil water suction at the clearings was lower than in the adjacent secondary forest. Differences between both secondary vegetation types were most pronounced during dry periods. Therefore, the opening of the forest alters soil moisture conditions in space and time as compared to a closed mature forest. Since supposed higher transpiration rates and lower soil moisture at the secondary sites oppose lower transpiration rates and higher soil moisture at the clearings, the effects on total water yields are not easily predictable.

The soils under the humid climate of the forest belt of Mt. Kilimanjaro are already in an advanced stage of weathering and are acidified. Since the major soil constituents have only a variable charge, CEC is high but ECEC is very low, indicating a low cation retention capacity of the soils. Therefore, any disturbance of the forest resulting in a nutrient release in the topsoil will automatically lead to leaching losses. The low base saturation in the mineral soil induces an overall low availability of base cations. Similarly, the high P fixing capacity of the soils on the sites studied indicates a low P availability. High C/N ratios of the litter together with comparatively low temperatures at the study sites suggest that mineralisation rates of organic material might be low and that N immobilisation might be a problem. In contrast, the stocks of organically bound nutrients like N and S were very high compared to the other mountain forest sites. Although organic soil material is somehow protected from decomposition in Andisols by the formation of stable organo-mineral complexes (Nambu & Yonebayashi 2000), the high stocks will increase overall mineralisation rates. Nevertheless, considering soil parameters, the nutrient availability at the study sites is presumably rather poor, especially for base cations.

Besides the mineral soil, other possible sources of base cations for the forest are inputs via wet and dry deposition. Globally, the African continent and especially the Sahara are among the greatest producers of dust to the atmosphere (Prospero 1999, Swap et al. 1992). For this reason it was suspected that high amounts of nutrient-rich dust particles from the savannah plains surrounding Mt. Kilimanjaro would result in a high nutrient input via wet and dry deposition. In contrast to this hypothesis, the results indicate that nutrient inputs via rainfall and throughfall were rather poor at the forest belt of Mt. Kilimanjaro as compared to other tropical mountain ecosystems. As dust-storms occur in the region, one possible explanation for this observation is the high altitudinal distance between the savannah plains and the study sites. The low element inputs further increase the need for base cation conservation in the forest.

Despite the low availability of major nutrients, foliar analyses in the mature forest did not give indications of severe limitations. For N, this might be due to the very high SOM stocks, which represent a great pool for N and other associated minerals that can be released by mineralisation. The pronounced decrease in base cation concentrations from litter leachate to the soil solution indicates high assimilation rates by either plant roots or mycorrhiza since the retention capacity for these ions in the soils is low. The leaching rates of nutrients from the canopy of the mature forest were also low. The annual amounts of litterfall were comparatively high at Mt. Kilimanjaro as compared to other tropical mountain rainforests, but this observation needs to be put into perspective since the stature of the forest rather resembled lower mountain rainforests. As a consequence, comparatively low amounts of nutrients were cycled in the mature forest, which exhibited a closed nutrient cycle, especially for K, thereby retaining nutrients within the system.

In the seepage water of the clearings, the nutrient concentrations were higher than in the adjacent forest, which can be attributed to increased mineralisation rates caused by higher temperatures and a higher nutrient content of the litter. At the same time, the nutrient demand of the vegetation in the clearings was likely to be lower, resulting in lower plant assimilation rates. Since the leaching rates from the vegetation were higher during rainfall events, the secondary vegetation in the clearings exhibited a more open nutrient cycle than the forests. This can be explained by the different strategies of both vegetation types. Pioneer vegetation is usually better adapted to take advantage of an increased nutrient supply following disturbances than late successional forest species, which are used to a constant low nutrient supply. Therefore, secondary vegetation can quickly invade disturbed areas.

The pioneer species are often not long-living and seek to grow and reproduce as long as the conditions are favourable for their growth. Thus, there is less need for nutrient conservation for the pioneer vegetation in the clearings than for the vegetation in natural forest, which is reflected by their nutrient cycles. Since no evidence was found for soil deterioration or shortages of major nutrients were observed in the clearings, the impeded forest regeneration in the clearings was probably the result of either ongoing disturbances or less competitive late successional species or a combination of both factors.

While nutrient concentrations in the seepage water of the topsoil were higher at the clearings than in the forest, differences were less distinct at deeper soil layers. This might indicate that leaching losses in the clearings are not substantially different from the forest sites, possibly due to nutrient absorption or assimilation at deeper soil layers. This conclusion is only valid under the assumption that there was no export of nutrients by lateral flow, and water fluxes at deeper soil layers at the clearings were not significantly higher than at the other sites. Since belowground water and nutrient fluxes in either direction could not be determined with sufficient accuracy with the data available, this question cannot be answered beyond doubt.

Besides inorganic nutrient forms, organically bound nutrients have also been proven to contribute significantly to the nutrient cycle in temperate forests (Perakis & Hedin 2002). Organic forms of N and P contributed more than half of the total amount of N and P in the litter percolate and the soil solution of deciduous temperate forests (Kaiser et al. 2003, Qualls et al. 2000). At Mt. Kilimanjaro in contrast, organic bound nutrients seemed to be much less susceptible to leaching than their inorganic forms. This was probably due to the formation of organo-mineral complexes in the soil because Andisols have proven to be good sorbents for DOM (Nambu & Yonebayashi 2000). Therefore, it appears that an enhanced release of organically bound nutrients in the topsoil following disturbance is counterbalanced by adsorption at deeper soil layers and hence should not result in significant nutrient losses. Still, the clearings exhibited throughfall concentrations different from the forests and again the highest concentrations of organically bound nutrients were found in seepage water of the clearings, indicating that also the cycle of these nutrients exhibits long term alterations following disturbances.

The results showed that the nutrient cycle on disturbed sites at Mt. Kilimanjaro is not only affected immediately after disturbance, but possibly altered for decades due to different strategies in nutrient usage and conservation of pioneer and late successional vegetation. Similarly, the water balance varies between clearings, secondary forest sites and old growth forests probably as a result of differences in interception and transpiration. These differences might be further intensified by edge effects at the highly fragmented lower slopes and deterioration of physical soil properties. Overall, the opening of the forest at lower elevations led to a higher spatial and seasonal variability of soil moisture as well as nutrient concentrations in seepage water. The large scale effects of these alterations require further research.

RESEARCH PERSPECTIVES

The forests of Mt. Kilimanjaro still present an open field for further research. The results of the present study revealed that the opening of forests at the lower slopes leads to a higher spatial variability in soil moisture. While some research has focussed on the effects of large scale forest clearings on water yields (Bruijnzeel 1996), much less is known about the effects of forest fragmentation, which might lead to a small-scale heterogeneity in groundwater recharge. This would make the effects on total water yield of a disturbed catchment difficult to predict. Given the importance of the water resources of Mt. Kilimanjaro for the surrounding area, further research on the level of small catchments is necessary.

The reasons for the drier soil conditions under the secondary forest as compared to the mature forest are still highly speculative. In this respect, the differences in the water demand of a primary mountain cloud forest, which is said to have low transpiration rates (Bruijnzeel 1989), and secondary vegetation would be interesting to study. Since evapotranspiration rates of a site might also be related to its proximity to the next clearing, edge effects need further attention, especially as their importance increases with ongoing illegal logging.

For the determination of nutrient losses by leaching under different successional stages of the forest, a complete water budget would be necessary which could not be provided in the present study. Any future study should include analyses of lateral flow, a factor that proved to be of major importance in an Ecuadorian rainforest (Goller, personal communication). Given the high water permeability of the soil, the

increase in bulk density from O and A horizons to B horizons might be sufficient to deflect the flow paths of the water. Areas covered with secondary vegetation in the tropics still increase due to continuing wood harvesting. Since this study showed that a tight nutrient cycle is not necessarily restored after clearings have been colonised by secondary vegetation and that also the water budget might exhibit long term changes, biogeochemical processes in secondary vegetation deserve more attention.

The fate of the organically bound nutrients released in the organic soil layers might be an interesting further research topic, since the concentration of these nutrients in the soil solution was lower than in most other forest ecosystems studied in temperate and tropical regions. Thus, the exceptional high adsorption capacity of Andisols at Mt. Kilimanjaro, which are already in an advanced stage of weathering, requires further investigation.

The high annual variability in rainfall amounts on the mountain makes long term ecosystem studies necessary in order to gain better insight into the biogeochemical cycle since many processes determining nutrient fluxes, such as dry deposition or mineralisation rates, are dependant upon rainfall amounts and the associated soil humidity.

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APPENDIX A

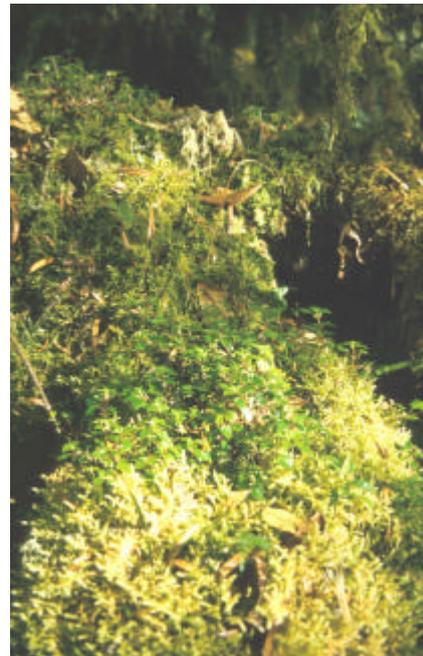
Pictures of the Study Sites



Picture 1 Clearing Plot 2.



Picture 2 Secondary forest Plot 4.



Picture 3 Mosses on branches in the mature forest.



Picture 4 Mature forest Plot 12.



Picture 5 Soil profile Plot 2265.

APPENDIX B

Description of Soil Profiles

Profile 1**Clearing****Classification: Histic Endoaquand**

Altitude: 2090 m a.s.l.

UTM coordinates: 304719 / 9651034

Inclination: < 10°

Vegetation: Shrubs, *Pteridium aquilinum*, *Rubus steudneri*

Organic soil layers

Horizon	Depths	Comments
Oi	30-150 mm	Fluctuating thickness of layers
Oe	20-50 mm	Rooted
Oa	50-150 mm	

Mineral soil layers

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [fine roots dm ⁻²]	Comments
OA	-0.25	7.5 YR 3/3 5 YR 3/3	± Granular	0.24	<5	11-20	Loosely sorted particles
Bw1	-0.60	7.5 YR 3/3-4/3	Granular-blocky	0.49	5	6-20	Some soft red stones
Bwc1	-0.75 (80)	5 YR 4/4	Blocky	0.53	5	6-10	Red concretions
Ab	-0.95 (105)	7.5 YR 4/6, 3/4	Blocky	0.64	<5	6-10	Varying horizon depth
Bwb1	-1.33	5 YR 4/6	Blocky Blocky	0.75	<5	3-10	Contains charcoal Shining ped surfaces
Bwb2	-1.54	7.5 YR 4/6	Blocky	0.58	<5	1-5	Charcoal, shining ped surfaces
Bwb3	-1.62	5 YR 4/6	Blocky	0.59	<5	1-5	Shining ped surfaces.
Bwcb	-1.79	7.5 YR 3/4, 5/8	Blocky	0.65	5-10	1-5	Shining ped surfaces, some greyish-blue stones, concretions, charcoal
BC	-1.95+	7.5 YR 4/6, 5/8	Blocky	0.65	60	1-5	Greyish-blue stones with yellow inclusions and brown stones partly covered by dark-red crusts

Profile 2**Clearing****Classification: Acrudoxic Fulvudand**

Altitude: 2135 m a.s.l.

UTM coordinates: 304868 / 9651133

Inclination: < 10°

Vegetation: Shrubs, *R. steudneri*, *P. aquilinum*,**Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	50-100 mm	Fluctuating thickness
Oe	50-100 mm	Rooted
Oa	50 mm	

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
A	-0.10	7,5 YR 2/3	Granular	0.40	<5	21-50	
AB	-0.17	7,5 YR 2/3-3/3	Granular-blocky	0.39	<5	11-50	Charcoal, transition to Bw1 horizon is undulating, probably due to activities of pigs
Bw1	-0.22	7,5 YR 3/4	Granular-blocky	0.47	<5	11-20	Fluctuating thickness
Bw2	-0.35	7,5 YR 2/3	Blocky	0.56	<5	6-20	Charcoal, shining ped surfaces, dark
Bw3	-0.92	7,5 YR 3/4	Blocky	0.51	<5	3-10	Charcoal, shining ped surfaces, lighter
Bwc1	-1.12	7,5 YR 3/3	Blocky	0.58	5	3-10	Charcoal, shining ped surfaces, greyish-blue stones
Bwc2	-1.42	5 YR 3/3	Blocky	0.55	<5	3-10	Charcoal, shining ped surfaces, some concretions
Bw4	-1.65	5 YR 3/3	Blocky	0.51	<5	6-10	Charcoal, shining ped surfaces
Bw5	-1.82	7,5 YR 3/3, 3/4	Blocky	0.52	<5	3-5	Greenish matrix with white intrusions
2Ab	-2.13	5 YR 3/3	Blocky	0.52	<5	1-2	Charcoal, more reddish
2BC	-2.30+	5 YR 3/3	± Blocky	0.62	40	1-2	Greyish-blue stones with yellow inclusions, wet ped surfaces

Profile 3**Clearing****Classification: Acrudoxic Fulvudand**

Altitude: 2140 m a.s.l.

UTM coordinates: 304882 / 9651112

Inclination: < 10°

Vegetation: Shrubs, *R. steudneri*, *P. aquilinum*,**Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	100 mm	Fluctuating thickness
Oe	50-100 mm	Rooted, smells like pig
Oa	40 mm	

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
AB	-0.25	7,5 YR 3/4	Block-granular	0.36	-	11-50	Charcoal
Bw1	-0.50	7,5 YR 4/6, 4/4	± Blocky	0.62	<5	11-20	Shining ped surfaces, charcoal
Bw2	-0.75		Blocky	0.72	<5	6-20	Shining ped surfaces, rare concretions, few charcoal
Bwc1	-1.20	7,5 YR 4/6, 5/8	Blocky	0.65	5	6-10	Reddish horizon, charcoal, concretions, shining ped surfaces
Bw3	-1.50	10 YR 4/6, 3/4	Blocky	0.53	20-30	3-5	Shining ped surfaces, greyish-blue stones differently weathered, soil matrix contains small red dots, charcoal at the transition to the CB horizon
CB	-1.75 +	10 YR 3/4 - 3/3	-	0.57	ca. 85	0-2	Greyish-blue and brown stones sometimes with yellow inclusions, soil matrix is sludgy

Profile 4**Secondary forest****Classification: Aquic Fulvudand**

Altitude: 2155 m a.s.l.

UTM coordinates: 304971 / 9651144

Inclination: < 10°

Vegetation: Forest fragment, *Macaranga kilimanjarica*,
Ocotea usambarensis

Organic soil layers

Horizon	Thickness	Comments
Oi	30-40 mm	Fluctuating thickness
Oe	10 mm	Rooted
Oa	40 mm	> 50 roots dm ²

Mineral soil layers

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
A	-0.10	5 YR 2/3	Granular	0.25	-	> 50	A red zone at the right profile site was sampled separately, charcoal
Bw1	-0.42	5 YR 3/3	± Blocky	0.52	-	6-20	
Bw2	-0.60	5 YR 3/4 - 4/4	Blocky	0.67	-	6-10	
2Ab1	-0.88	5 YR 4/4	Blocky	0.76	-	3-10	Charcoal, shining ped surfaces
2Bwcb1	-1.20	5 YR 4/6	Blocky	0.73	10	1-2	shining ped surfaces
2Bwb1	-1.50	5 YR 4/3, 3/3,	± Blocky	0.71	40-80	1-5	Stones increase towards the lower border, greenish-bluish stones with white dots
2Bwb2	-1.58	5 YR 4/4 7,5 YR 4/6	± Blocky	0.50	-	1-2	Little charcoal
3Ab2	-1.90	5 YR 3/3 - 4/3	± Blocky	0.56	-	3-10 mainly old	Charcoal, orange to yellow spots
Stoneline	-1.92						Consisting of small, dark stones, maybe concretions
3Bwb3	-2.00	5 YR 3/4 - 3/6	± Blocky		-	1-5	Comparatively dense
4AB	-2.23	5 YR 3/3	± Blocky		-	1-5 old	Charcoal, dense
4Bwb4	-2.35 +	5 YR 4/4	± Blocky		-	0	Red-spotted, stack flow

Profile 5**Secondary forest****Classification: Acrudoxic Fulvudand**

Altitude: 2090 m a.s.l.

UTM coordinates: 304705 / 9650983

Inclination: < 10°

Vegetation: Forest fragment, *M. kilimanjarica*, *O. usambarensis***Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	40 mm	
Oe	10 mm	Rooted
Oa	100 mm	> 50 roots dm ²

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
AB	-0.14	7,5 YR 3/3-4/4	Granular	0.28	-	11-20	
Bw1	-0.39	7,5 YR 4/6 5 YR 4/6	± Blocky	0.31	<5	6-20	Reddish
Bw2	-0.69	7,5 YR 3/4	Blocky	0.59	<5	3-10	Darker, some charcoal, shining ped faces, some concretions
Bw3	-0.94	7,5 YR 4/6	Blocky	0.77	<5	3-5	Charcoal, shining ped faces
Bwc	-1.04	7,5 YR 4/4	Blocky	0.73	<5	3-5	Charcoal, shining ped faces
2Ab	-1.14	7,5 YR 4/4, 5/6	Blocky	0.59	5	0-2	Reddish, some small concretions
2CB	-1.34	10 YR 5/6 - 4/4 and 4/3	-	0.54	60-70	0-2	Greyish-blue and brown stones sometimes with yellow inclusions, different weathered, ped surfaces shine wet

Profile 6**Secondary forest****Classification: Acrudoxic Fulvudand**

Altitude: 2165 m a.s.l.

UTM coordinates: 304971 / 9651216

Inclination: < 10°

Vegetation: Forest fragment, *O. usambarensis*, *M. kilimanjarica*

Organic soil layers

Horizon	Thickness	Comments
Oi	30 mm	Fluctuating thickness
Oe	15 mm	Rooted
Oa	90 mm	> 50 roots dm ²

Mineral soil layers

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
A	-0.15	7,5 YR 2/3	Granular	0.30	-	21-50	Charcoal
Bw1	-0.27	7,5 YR 4/6	± Blocky	0.33	-	11-50	
Bw2	-0.45	7,5 YR 3/3	± Blocky	0.48	<5	11-20	Some concretions
2Acb	-0.65	7,5 YR 3/2 - 2/2	± Blocky	0.70	<5	11-20	Shining ped surfaces
2Bcb	-0.70	7,5 YR 3/2	-	0.70	40	6-10	Stoneline
2Bwb1	-0.85		± Blocky	0.78	<5	3-5	Charcoal, 3 mm band of stones at the
2Bwb2	-1.15	7,5 YR 4/6	Blocky	0.62	<5	3-5	Shining ped surfaces
2Bwcb	-1.35	7,5 YR 4/6	Blocky	0.76	5-10	3-10	Shining ped surfaces
2Bwb3	-1.47	10 YR 4/6	± Blocky.	0.72	<5	3-5	White dots in new matrix
Placic h.	-1.47			0.44			1mm thickness
3Cr1	-1.59	10 YR 3/4	-	0.55	10	3-5	Many white dots in the matrix
3Cr2	-1.68	10 YR 3/4	± Blocky	0.56	30	3-5	Many white dots
4Ab1	-1.92	5 YR 4/6	± Blocky	0.64	10	1-2	reddish
4Ab2	-1.97	7,5 YR 3/4	± Blocky		-	1-5	Charcoal, more kohäsive
4Bwb4	-2.13	7,5 YR 4/4	± Blocky		10	1-5	Some concretions
4Bwb5	-2.45	7,5 YR 4/4	-		5-10	1-2	White and red spots
4Bwb6	-2.50	7,5 YR 5/6, 4/6	-		5-10	1-2	Red spots in brown matrix

Profile 8**Mature forest****Classification: Histic Placaquand**

Altitude: 2265 m a.s.l.

UTM coordinates: 305168 / 9653242

Inclination: < 10°

Vegetation: Forest, *O.Usambarensis*, *Podocarpus latifolius***Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	30 mm	Fluctuating thickness
Oe	5 mm	Rooted
Oa	210 mm	> 50 roots dm ²

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
BA	-0.19	7,5 YR 4/4	Blocky - granular	0.43	<5	6-20	Some small red stones
2Ab1	-0.32	7,5 YR 1,7/1	± Blocky	0.52	-	6-10	Many old root channels
2Bwb1	-0.40	10 YR 6/3, 5/3	± Blocky	0.60	-	1-2	Kohäsive and partly bleached
2Bwb2	-0.43	10 YR 6/2, 6/4	± Blocky	0.62	-	1-2	Pale, not continuous
3Agb	-0.52	10 YR 3/1-3/2	± Blocky	0.78	<5	1-2	Bleached
3Bgb	-0.60	10 YR 3/2, 3/3	-	0.60	5	1-2	Pale color, contains soft, yellowish stones
3Bmb	-0.67	2,5 YR 2/3, 3/4 5 YR 5/8, 2/4 10 YR 7/8					Yellow stones are included, iron bands pervade crusts
3Bwb3	-0.85	10 YR 4/2, 3/3	± Blocky	0.50	10-20	0-1	Red-brown stones, charcoal
4BA	-1.04	10 YR 3/4	± Blocky	0.70	10-20	0-1	Red-brown stones, charcoal
4Ab2	-1.35	10 YR 1,7/1	± Blocky	0.43	-	1-2	Sharp lower boundary
4Bwb4	-1.44	10 YR 5/4, 4/2	-	0.54	-	1-2	Greyish color with white dots
4Bwb5	-1.72	10 YR 6/6, 5/6	-	0.62	-	1-2	Yellowish, water is coming up

Profile 9**Mature forest****Classification: Histic Endoaquand**

Altitude: 2265 m a.s.l.

UTM coordinates: 305040 / 9653243

Inclination: < 10°

Vegetation: Forest, *O. Usambarensis*, *P. latifolius***Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	30 mm	Fluctuating thickness
Oe	5 mm	Rooted
Oa	235 mm	> 50 roots dm ²

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
Bw1	-0.20	5 YR 3/4	Blocky	0.36	<5	6-20	charcoal
Bw2	-0.30	7,5 YR 3/4	Blocky	0.44	<5	6-20	Few concretions
Bw3	-0.50	5 YR 3/3	Blocky	0.48	5	6-10	Shining peds, some red concretions
Placic h	-0.51						discontinuous
2Ab1	-0.60	7,5 YR 3/2	Blocky	0.42	-	6-20	Comparatively pale, discontinuous, charcoal
2Bwb1	-0.68	5 YR 4/3	Blocky	0.58			Shining peds, single orange-red smooth stones
2Bwb2	-0.88	7,5 YR 3/4	Blocky	0.62	<5	3-10	
3Ab2	-0.99	10 YR 2/3	± Blocky	0.58	-	3-10	Charcoal, shining peds
3Bgb1	-1.01	7,5 YR 5/3	± Blocky	0.68	<5	1-2	Bleached color, red concretions, brown and white spots
3Bwb3	-1.16	10 YR 4/6, 5/6	± Blocky	0.57	-	3-5 (old)	Yellowish matrix with white spots
3Bm1	-1.18						Thin iron crusts overlay and intrude the indurated horizon
3BCr1	-1.36	7,5 YR 3/4	± Blocky	0.93	-	3-5 (old)	Brownish with white spots
4Ab3	-1.52	7,5 YR 3/4	± Blocky	0.44	<5	3-5 (old)	Thin discontinuous iron band at the upper boarder, charcoal

**Profile 9
continued**

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
4BCr2	-1.56	7,5 YR 5/3, 5/4	-		5	0-2	Greatest extension at the left site, apparently weathered parent material with some smooth stones in a greyish/yellowish matrix
4Bm2	-160+		-				Approximately > 0.1 m thick, strongly indurated material including stones

Profile 10**Mature forest****Classification: Acrudoxic Fulvudand**

Altitude: 2250 m a.s.l.

UTM coordinates: 305021 / 9653095

Inclination: < 10°

Vegetation: Forest, *O. Usambarensis*, *P. latifolius*

Organic soil layers

Horizon	Thickness	Comments
Oi	30 mm	
Oe	5 mm	
Oa	130 mm	> 50 roots dm ²

Mineral soil layers

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
BA	-0.10	7,5 YR 4/6, auch:	Granular	0.42	-	6-10	
Bw	-0.30	7,5 YR 4/3 - 3/3	± Blocky	0.58	<5	6-10	Charcoal, small red stones at the boundary to 2Ab1
2Ab1	-0.45 (0.55)	7,5 YR 1,7/1	± Blocky	0.62	<5	3-10	Irregular lower boundary
Placic h	0.55						Discontinuous, includes yellow stones, charcoal and some concretions mainly directly below
2Bwb	-0.80 (0.90)		± Blocky	0.58	10	1-5	Seems bleached, red mottles, dark-red crusts at stone surfaces
Placic h	-0.90	2,5 YR 2/2, 5 YR 2/3					Yellow material within the crust: 10 YR 6/4, 7,5 YR 6/8, 2,5 YR 5/6
3Ab2	-1.30			0.63	<5	1-5	Dark, contains charcoal
Stoneline	-1.33	7,5 YR 6/8, 5/6, 10 YR 4/6, 4/4			80	0	Red and yellow stones, partly also bluish ones with bright inclusions
Cr	-1.80	7,5 YR 6/1, 2,5 YR 4/2, 6/1, 5/1, 10 YR 4/6			40	0	Ash-like layer with white and brown intrusions, some bluish stones. Color of red mottles: 7,5 YR 5/8

Profile 12**Mature forest****Classification: Hisitc Placaquand**

Altitude: 2135 m a.s.l.

UTM coordinates: 304868 / 9651133

Inclination: < 10°

Vegetation: Forest, *O. Usambarensis*, *P. latifolius*

Mineral soil layers

Organic soil layers

Horizon	Thickness	Comments
Oi	30 mm	Fluctuating thickness
Oe	5 mm	Rooted
Oa	300 mm	> 50 roots dm ²

Horizon	Soil depths [m]	Colour field moist	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
BA	-12	5YR 3/3	Blocky-ganular	0.55	-	6-20	Charcoal
2AB	-20	7.5YR 3/1	Blocky		-	6-10	Darker than BA
2Ab1	-38	10YR 2/1	Blocky	0.621	-	6-20	
2AB	-45	10YR 3/1	Blocky	0.67	-	3-10	Grey horizon, charcoal
Placic h	45						
2Bwb1	-58	10YR 4/2	Blocky	0.68	-	3-10	Bleached colors, charcoal
3Ab2	-65	10YR 3/1	Blocky	0.76	-	3-5	Discontinuous
Placic h	65						
3Bwb2	-90	10YR 4/6, 5/6	± Blocky	0.80	-	1-2	Contains white dots in the matrix
Placic h	90						Discontinuous
3Bwb3	-105	7.5YR 5/6 10YR 5/6	± Blocky	0.70	-	1-2	Yellowish with white dots
4Ab3	-115	10YR 3/3	Blocky	0.75	10	1-5 mainly old	Charcoal, some feldspars
4Bm	-150		-			0	Cemented horizon with high stone content, contains red crusts
4Cr	-165+	7.5YR 5/3	-		5-10	0	Weathered volcanic ash material, soft

Profile 101**Clearing****Classification: Histic Endoaquand**

Altitude: 2080 m a.s.l.

UTM coordinates: 305058 / 9651051

Inclination: < 10°

Vegetation: shrubs, *R. steudneri*, *P. aquilinum*,**Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	3	
Oe	10	
Oa	11	Densely rooted

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
BA	- 22	5YR 4/4	Clay loam	Blocky		< 5	5-10	
2BA	- 50	7.5YR 3/4	Clay loam	Blocky-ganular		< 5	3-5	Charcoal
2Bwb1	- 79	5YR 4/4	Clay loam	Blocky		< 5	3-5	Charcoal
2Bwb2	- 108		Clay loam	Blocky		< 5	1-5	Reddish stones
3ABb	- 129	5YR 3/4	Clay loam	Blocky		5-10	1-2	Small reddish stones, charcoal
3Bwb3	- 145	5YR 4/4	Clay loam	Blocky		0	0-2	Shining ped surfaces
3Bwb4	- 169	5YR 4/4-4/6	Loam	Blocky		< 5	0-2	Small red stones, charcoal
3Bwb5	- 202	7.5YR 4/4	Loam	Blocky		5	0-2	Slightly olive-brown with white dots
4Ab	- 217	7.5YR 4/4	Clay loam	Blocky		< 5	0-2	Charcoal
4Bwb6	229+	5YR 3/4	Clay loam	Blocky		< 5	0	Charcoal

Profile 102**Clearing****Classification: Histic Endoaquand**

Altitude: 2075 m a.s.l.

UTM coordinates: 305036 / 9650999

Inclination: 10°

Vegetation: shrubs, *R. steudneri*, *P. aquilinum*,**Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	2	
Oe	5-15	
Oa	10	Densely rooted

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
BA	- 17	5YR 3/3		± Granular		0	6-10	Charcoal
Bw1	- 28	10YR 4/3		± Blocky		< 5	6-10	Charcoal, small orange stones
Bw2	- 70	5YR 3/3		Blocky		5	3-10	Small orange stones, some others bueish
2Ab1	- 87	5YR 2.5/1-2		± Blocky		< 5	1-5	Wet, charcoal
2Bwb1	- 97	5YR 3/2-2.5/2		Blocky		< 5	1-5	Charcoal
3Ab2	- 144	5YR 2.5/1		Blocky		< 5	1-5	Charcoal, shining ped surfaces, old roots
3Bwb2	- 155	10YR 3/3		-		5	0-2	Small reddish stones,
3Bwb3	- 159	7.5YR 4/6		-		< 5	0-2	Discontinuous, mainly right side
4Ab3	175+	7.5YR 3/2		-		10	0-5	Charcoal, small reddish and larger bueish stones, white spots, more old root channels

Profile 103**Clearing****Classification: Acrudoxic Fulvudand**

Altitude: 2120 m a.s.l.

UTM coordinates: 305074/ 9651146

Inclination: < 10°

Vegetation: shrubs, *R. steudneri*, *P. aquilinum*,

Organic soil layers

Horizon	Thickness	Comments
Oi	4	
Oe	5-15	
Oa	7	Densely rooted

Mineral soil layers

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
AB	- 23		Loam	Granular-blocky		0	21-50	
2BA	- 51	7.5YR 3/4 – 5YR 3/4	Loam	Granular-blocky		5-10	6-10	Charcoal, red stones
2Bwb1	- 71	7.5YR 3/4	Loam	-		25	6-10	Some stones covered with dark-reddish crusts
2Bwb2	- 80	7.5YR 3/4 – 4/4	Loam	± Blocky		5	3-5	
2Bwb3	- 98	10YR 4/4 – 3/4	Loam	± Blocky		0	1-2	White dots
2Bwb4	- 110	7.5YR 4/4	Loam	Blocky		< 5	1-2	Charcoal, white dots
3Ab1	- 125	5YR 3/4	Clay Loam	Blocky		0	0-2	Charcoal, shining ped surfaces
3Bwb5	- 149	5YR 3/4	Loam	Blocky		0	1-2	Charcoal
3Bwb6	- 172	5YR 4/4	Clay loam	Blocky		0	1-5	Charcoal, shining ped surfaces
4Ab2	- 189	5YR 3/3	Clay loam	Blocky		< 5	0-2	Charcoal, shining ped surfaces, some small stones
4Bwb7	- 200	5YR 4/4	Loam	Blocky		< 5	0-2	Charcoal, shining ped surf.
5Ab3	- 211	7.5YR 4/2	Loam	Blocky		< 5	0-2	Charcoal, shining ped surf.
5BC1	- 221	10YR 5/4	Loam	Blocky		< 5	0	
5BC2	238+	10YR 5/6 – 4/6	Loam	-		5	0	Old root channels, thixotrop

Profile 1850**Agauria Forest****Classification: Acrudoxic Hapludand**

Altitude: 1850 m a.s.l.

UTM coordinates: 0304505 / 9648709

Inclination: < 10°

Vegetation: shrubs, *R. steudneri*, *P. aquilinum*,**Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	3	
Oe	4	
Oa	6	

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
A	- 5	7.5 YR 1.7/1	Silt loam	Granular	0.37	< 5	21-50	
Bw	- 8	2.5YR 2/4	Silt loam	Granular		< 5	11-50	Charcoal, mottels
Ab1	- 20	7.5R 1.7/1	Silt loam	Granular	0.40	< 5	6-10	
AB	- 62	7.5R 2/2	Silt loam	Blocky	0.58	< 5	3-10	
BA	- 88	2.5YR 2/2	Silt loam	Blocky	0.61	< 5	3-5	
Bwb1	- 157	2.5 YR 2/2	Silty clay loam	Blocky	0.74	5	1-2	
Bwb2	- 220	5 YR 2/2	Silty clay loam	Blocky	0.75	5	0-2	
2Ab2	- 237	5 YR 2/1	Clay loam	Blocky	0.63	20	0-2	Charcoal
2Bwb3	- 248	7.5YR 3/2	Silty clay loam	Blocky		< 5	0	
2BC	- 254	7.5YR 2/2	Silty clay loam	Blocky		20	0	Some stones are intensively weathered

Profile 2090**Macaranga-Ocotea Forest****Classification: Acrudoxic Hapludand**

Altitude: 2090 m a.s.l.

UTM coordinates: 304971 / 9651216

Inclination: < 10°

Vegetation: *Ocotea usambarensis***Mineral soil layers****Organic soil layers**

Horizon	Thickness	Comments
Oi	3.5	
Oe	3.5	
Oa	12	Densely rooted

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
A	- 10	7,5 YR 2/3		Granular	0.33		21-50	Charcoal
Bw	- 30	7,5 YR 4/6		Blocky	0.45		11-20	
2Ab1	- 40	7,5 YR 3/3		Blocky	0.84	< 5	11-20	Some concretions
2Ab2	- 52	7,5 YR 3/2 - 2/2		Blocky	0.75	< 5	11-20	Some concretions
2BAb1	- 65	7,5 YR 3/2		Blocky	0.88	4-40	3-5	Charcoal
2Bwb1	- 75			Blocky	0.70	< 5	3-5	
2Bwcb1	- 95			Blocky	0.73	5-10	3-10	Some concretions
2Bwb2	- 120			Blocky	0.85	< 5	3-5	White dots
Placic h	- 120.1							
3Cr1	- 127	7,5 YR 4/6		-	0.84	10	3-5	Light dots in matrix
3Cr2	- 152	10 YR 4/6		± Blocky	0.84	30	3-5	White dots
Placic h.	- 152.1							
4Bwcb2	- 164	10 YR 3/4		± Blocky	0.62	10	1-2	Some concretions
4BAb2	- 190	10 YR 3/4		± Blocky	0.85	5-10	0-2	White and red dots, reddish
4BAb3	- 215	7,5 YR 3/4		± Blocky	0.71	5-10	0-2	Some red dots in matrix
4Cr	220 +	7,5 YR 4/4		-			0-2	

Profile 2265**Ocotea Forest****Classification: Histic Placaquand**

Altitude: 2265 m a.s.l.

UTM coordinates: 305168 / 9653242

Inclination: < 10°

Vegetation: *Ocotea usambarensis*

Organic soil layers

Horizon	Thickness	Comments
Oi	3	
Oe	0.5	
Oa	21	Densely rooted

Mineral soil layers

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
BA	- 15	7,5 YR 4/4	Silty clay loam	± Blocky	0.51	0	11-20	
2BA	- 25	7,5 YR 1,7/1	Silty clay	± Blocky	0.49	0	6-10	
2AB1	- 30	7,5 YR 1,7/1		± Blocky	0.59	0	3-10	
2AB2	- 45	7,5 YR 1,7/1	Clay loam	± Blocky	0.60	3	3-5	
2AB3	- 50	7,5 YR 1,7/1		± Blocky	0.60	< 5		
2Bwb1	- 50	10 YR 6/3, 5/3	Clay loam	± Blocky	0.60	< 5	1-2	
2Bgb	- 55	10 YR 6/2, 6/4	Clay loam	± Blocky	0.73	< 5	1-2	
3AB4	- 65		Clay loam	± Blocky	0.71	< 5		
3Ab1	- 65	10 YR 3/1-3/2		± Blocky		< 5	3-5	
3Bmb	- 75	2,5 YR 2/3, ¾	Silty clay loam	± Blocky			0	Charcoal above and below
3Bwb2	- 78	5 YR 5/8, 2/4	Silty clay loam	± Blocky		< 5	0	Charcoal
3Bwb3	- 88	10 YR 4/2, 3/3	Silty clay loam	± Blocky	0.65	< 5	0	Mottled
3Bwb4	- 100	10 YR ¾	Silty clay loam	± Blocky	0.62	20-30	0	Mottled, thixotrop
4Ab2	- 110	10 YR 1,7/1	Silty clay loam	± Blocky	0.52	< 5	0	Thixotrop
4Ab3	- 125		Silty clay loam	± Blocky	0.52	< 5	0	Thixotrop
4Ab4	- 132		Silty clay loam	± Blocky	0.50	< 5	0	Thixotrop
4BA	- 152	10 YR 5/4, 4/2	Silty clay loam	± Blocky		< 5	0	Thixotrop
4Bwb5	- 192	10 YR 6/6, 5/6	Silty clay loam	± Blocky		< 5	0	Thixotrop
5Ab5	- 222 +		Silty clay loam	± Blocky		10-20	0	Light dots, Charcoal

Profile 2530**Ocotea Forest****Classification: Acrudoxic Melanudand**

Altitude: 2530 m a.s.l.

UTM coordinates: 305892 / 9655273

Inclination: < 10°

Vegetation: *Ocotea usambarensis*, *Podocarpus latifolius*

Mineral soil layers

Organic soil layers

Horizon	Thickness	Comments
Oi	3	
Oe	4	
Oa	12	

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
AB	- 14	7.5YR 2/2	Silt loam	Granular	0.53	< 5	6-20	
Bwc	- 21	7.5YR 4/6	Sandy loam	Granular - blocky		< 5	3-5	Concretions, mainly left side
2BA	- 26	7.5YR 2/1	Silt loam	Granular - blocky	0.43	0	6-10	
2Ab1	- 64	N 2/0	Clay loam	-	0.55	< 5	11-20	
2Ab2	- 72	2.5Y 2/1	Silty clay	Blocky-granular	0.54	40	3-10	Yellowish stones
2Ab3	- 86	N 2/0	Clay loam	Blocky	0.64	0	1-5	
2Bgb1	- 104	10YR 1.7/1	Silty clay loam	Blocky	0.63	15	1-5	
2Bgb2	- 114	2.5 Y 2/1	Clay loam	-		20	1-5	Yellowish stones
3Ab4	- 134	N 2/0	Clay loam	-		0	1-2	
3Ab5	- 144	N 2/0	Clay loam	-	0.63	0	1-2	
3Bgb3	- 149	N 1.5/0	Silty clay loam	Blocky	0.56	0	0-2	Discontinuous
3Bwb1	- 154	2.5Y 3/3	Loam	Blocky	0.57	0	0-2	Discontinuous, mottled
4Ab6	- 161	N 2/0	Clay loam	-	0.63	0	0-2	
4Bwb2	- 174	2.5Y 2/1	Silty clay loam	Blocky	0.62	20-30	0-2	

Profile 2700**Ocotea-Podocarpus Forest****Classification: Acrudoxic Fulvudand**

Altitude: 2700 m a.s.l.

UTM coordinates: 306382 / 9656263

Inclination: < 10°

Vegetation: *Podocarpus latifolius*, *Hagenia abyssinica*,
Agauria salicifolia

Mineral soil layers

Organic soil layers

Horizon	Thickness	Comments
Oi	3	
Oe	1	
Oa	15	

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
ABw	- 25		Clay loam	blocky	0.43	< 5	6-10	
2BA1	- 35		Silt loam	blocky	0.56	< 5	3-10	Charcoal
2BA2	- 50		Silt loam	-	0.52	< 5	3-10	Charcoal
2Bb	- 60		Silt loam	-	0,67	5	1-2	Thin greyish loam at the bottom
3Ab	- 112		Silt loam	blocky	0.52	10-40	0-2	Charcoal
3BC	112+		Loam	-	0.48	50	0	Includes dark stones, looks like tephra

Profile 2900**Podocarpus Forest****Classification: Acrudoxic Fulvudand**

Altitude: 2900 m a.s.l.

UTM coordinates: 306836 / 9657131

Inclination: < 10°

Vegetation: *Podocarpus latifolius*, *Hagenia abyssinica*,
Agauria salicifolia

Organic soil layers

Horizon	Thickness	Comments
Oi	2	
Oe	2	
Oa	10	

Mineral soil layers

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
BA	19		Silt loam	Blocky-granular	0.43	< 5	6-10	
2Ab	58		Clay loam	Ganular	0.63	< 5	6-10	
2Bwb1	65		Silty clay loam	Granular	0.72	5-10	1-2	
2Bwb2	71		Loam	-	0.78	20	0	Small white dots in matrix
2BC	105		Loam	-	0.89	40	0	Stones partly weathered

Profile 3100**Hagenia Forest****Classification: Pachic Haplustand**

Altitude: 3080 m a.s.l.

UTM coordinates: 307483 / 9657888

Inclination: < 10°

Vegetation: *Hagenia abyssinica*

Mineral soil layers

Organic soil layers

Horizon	Thickness	Comments
Oi	4	
Oe	0.5	
Oa	13	

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
AB	- 9	10YR 2/1	Silty clay loam	Granular	0.44	10	21-50	
2Ab	- 27	7.5YR 2/1	Silt loam	Blocky	0.41	20	6-20	Charcoal
2BA	- 47	10YR 2/1	Sandy loam	Blocky	0.35	30	6-20	
2BC	77+	10YR 2/1	Sandy clay loam	Blocky	0.80	70-75	1-2	

Profile 3150**Ericaceous Belt****Classification: Lithic Endoaquand**

Altitude: 3150 m a.s.l.

UTM coordinates: 304868 / 9651133

Inclination: < 10°

Vegetation: *Erica excelsa*, burned in 1997

Mineral soil layers

Organic soil layers

Horizon	Thickness	Comments
Oi	4	
Oe		
Oa	20	

Horizon	Soil depths [m]	Colour field moist	Texture	Structure	Bulk density [g cm ⁻³]	Stones [%]	Roots [number dm ⁻²]	Comments
BA	- 12		Silty clay loam	Blocky	0.91	20	6-10	
Bg	- 25	7.5YR 3/4	Loam	-	0.87	30-40	0-2	
2AB1	- 30		Loam	Blocky	0.63	50	0	Red mottles
2AB2	- 40		Loam	Blocky		50	0	Red mottles
2Bgb	45+		Loam	-		75	0	Small concretions, water stagnation

APPENDIX C

Soil Chemical Characteristics

- C, N and S contents
- Exchangeable cations (ECEC)
- pH
- Oxalate (Fe_o , Al_o , Si_o), dithionite (Fe_d , Al_d) and pyrophosphate (Al_p , Fe_p) extractable Fe, Al and Si

For methods see Chapter 2.

	C/N	C	N	S	K	Na	Mg	Ca	Al	Fe	ECEC	BS
		[g kg ⁻¹]			[cmol _c kg ⁻¹ fine earth]							[%]
P 2530												
Oa2	13.9	286	20.6	2.2	0.87	0.17	1.21	3.68	6.86	1.27	14.06	42
AB	16.3	151	9.3	1.5	0.25	0.09	0.20	0.75	6.94	0.22	8.45	15
Bwc	21.0	64	3.0	0.8	0.10	0.16	0.03	0.05	0.42	0.04	0.80	43
2BA	19.2	138	7.2	1.4	0.10	0.05	0.03	0.15	1.32	0.03	1.68	20
2Ab1	31.7	170	5.3	0.6	0.05	0.06	0.04	0.14	1.12	0.01	1.42	20
2Ab2	23.2	98	4.2	0.9	0.06	0.07	0.03	0.09	0.83	0.01	1.09	23
2Ab3	27.0	174	6.4	1.0	0.09	0.03	0.01	0.11	2.77	0.01	3.03	8
2Bgb1	31.4	96	3.1	0.6	0.07	0.03	0.01	0.08	2.16	0.01	2.36	8
2Bgb2	28.9	106	3.7	0.9	0.07	0.03	0.01	0.06	1.22	0.00	1.40	12
3Ab4	32.5	125	3.9	0.7	0.10	0.08	0.01	0.10	1.25	0.01	1.55	18
3Ab5	35.7	140	3.9	0.6	0.03	0.04	0.03	0.08	0.64	0.02	0.84	22
3Bgb3	33.2	99	3.0	0.7	0.05	0.05	0.03	0.11	0.62	0.02	0.88	27
3Bwb1	30.5	48	1.6	0.6	0.03	0.05	0.03	0.04	0.15	0.00	0.30	50
4Ab6	39.2	163	4.2	0.7	0.06	0.08	0.03	0.10	1.08	0.01	1.36	20
4Bwb2	35.0	89	2.5	1.0	0.04	0.05	0.02	0.05	0.03	0.00	0.20	81
P 2700												
Oa2	17.9	275	15.3	1.8	0.53	0.12	0.69	1.73	10.18	1.72	14.97	21
ABw	23.8	130	5.4	1.1	0.08	0.07	0.02	0.09	3.24	0.05	3.57	8
2BAb1	22.0	160	7.3	1.0	0.11	0.05	0.02	0.07	3.06	0.02	3.32	7
2BAb2	23.1	154	6.7	1.0	0.08	0.04	0.02	0.08	4.35	0.04	4.61	5
2Bb	22.7	76	3.4	0.8	0.12	0.06	0.04	0.63	1.28	0.04	2.17	39
3Ab	29.1	123	4.2	1.1	0.06	0.06	0.01	0.06	0.54	0.05	0.78	25
3BC	29.9	40	1.4	0.9	0.03	0.04	0.01	0.03	0.05	0.02	0.19	61
P 2900												
Oa2	14.4	229	15.9	1.9	0.40	0.11	0.31	0.64	16.13	1.87	19.45	7
BA	15.2	175	6.7	1.4	0.25	0.12	0.19	0.33	12.76	0.81	14.46	6
2Ab	19.7	123	6.2	1.1	0.06	0.06	0.02	0.08	1.15	0.03	1.40	15
2Bwb1	21.3	63	3.0	0.8	0.04	0.04	0.01	0.05	0.40	0.00	0.55	26
2Bwb2	19.6	39	2.0	0.6	0.06	0.05	0.01	0.04	0.50	0.00	0.66	24
2BC	16.2	40	0.6	0.2	0.26	0.05	0.01	0.07	0.64	0.00	1.02	38
P 3100												
Oa2	13.7	180	13.1	1.4	0.63	0.16	0.27	1.08	7.06	0.05	9.26	23
AB	13.8	108	7.8	1.0	0.22	0.14	0.14	0.22	1.98	0.00	2.70	26
2Ab	12.5	149	1.9	1.3	0.20	0.12	0.19	0.28	3.42	0.00	4.21	19
2BA	13.8	123	8.9	1.1	0.17	0.12	0.11	0.22	1.38	0.00	1.99	31
2BC	17.3	65	3.7	0.8	0.08	0.09	0.04	0.10	0.16	0.00	0.47	66
P 3150												
Oa	15.4	312	20.2	2.1	0.96	0.17	1.34	2.82	11.66	0.36	17.31	31
BA	25.5	141	5.5	1.2	0.07	0.04	0.01	0.08	2.13	0.08	2.41	8
Bg	24.1	115	4.7	0.9	0.11	0.03	0.01	0.12	4.21	0.11	4.59	6
2AB1	22.8	117	5.1	1.0	0.09	0.02	0.00	0.06	2.23	0.07	2.47	7
2AB2	26.7	119	4.5	1.1	0.06	0.01	0.01	0.07	0.65	0.03	0.82	18
2Bg	26.7	108	4.1	1.1	0.06	0.03	0.01	0.07	0.73	0.06	0.95	18

	C/N	C	N	S	K	Na	Mg	Ca	Al	Fe	ECEC	BS
		[g kg ⁻¹]			[cmol _c kg ⁻¹ fine earth]							[%]
P1												
Oa2	14.4	253	17.6	2.0	0.74	0.16	0.64	1.73	10.85	1.14	15.26	21
OaA	14.0	184	13.1	1.6	0.43	0.09	0.24	0.32	9.03	0.27	10.38	10
Bw1	15.7	106	6.7	1.3	0.12	0.05	0.03	0.09	1.84	0.00	2.13	13
Bwc1	17.4	64	3.7	1.8	0.04	0.01	0.01	0.06	0.44	0.01	0.57	22
Ab	17.4	92	5.3	1.7	0.03	0.02	0.01	0.08	0.48	0.00	0.62	22
Bwb1	15.8	48	3.0	2.7	0.03	0.03	0.01	0.07	0.21	0.00	0.37	41
Bwb2	17.8	51	2.9	3.4	0.04	0.02	0.01	0.05	0.17	0.00	0.30	42
Bwb3	16.7	41	2.5	3.2	0.03	0.03	0.00	0.01	0.06	0.00	0.13	56
Bwcb	21.1	49	2.3	4.2	0.01	0.02	0.00	0.04	0.45	0.00	0.52	14
BC	20.4	45	2.2	4.9	0.00	0.02	0.01	0.07	0.00	0.00	0.11	
P2												
A	12.5	161	12.9	1.5	0.51	0.11	0.23	0.97	7.50	0.10	9.43	19
AB	13.6	133	9.8	1.4	0.27	0.04	0.25	0.78	5.86	0.06	7.27	19
Bw1	14.4	118	8.2	1.3	0.29	0.07	0.14	0.41	3.86	0.05	4.82	19
Bw2	13.6	104	7.6	1.6	0.20	0.01	0.03	0.11	0.92	0.00	1.28	28
Bw3	15.0	79	5.3	1.9	0.16	0.02	0.01	0.12	0.44	0.00	0.76	42
Bwc1	15.0	77	5.1	2.2	0.08	0.02	0.00	0.07	0.16	0.00	0.34	52
Bwc2	16.1	77	4.8	2.1	0.10	0.02	0.01	0.09	0.29	0.00	0.50	43
Bw4	15.7	74	4.7	2.4	0.12	0.04	0.02	0.11	0.18	0.00	0.47	61
Bw5	17.9	61	3.4	2.8	0.05	0.02	0.02	0.07	0.14	0.00	0.31	53
2Ab	13.7	68	5.0	2.2	0.10	0.02	0.01	0.09	0.17	0.00	0.39	57
2BC	16.0	61	3.8	2.5	0.07	0.08	0.06	0.24	0.09	0.01	0.55	81
P3												
Oa2					0.64	0.07	0.88	4.25	12.81	0.79	19.44	30
AB	16.1	171	10.6	1.4	0.34	0.05	0.23	0.61	6.44	0.06	7.73	16
Bw1	16.0	95	6.0	1.2	0.09	0.03	0.01	0.06	0.45	0.01	0.65	30
Bw2	18.7	60	3.2	2.2	0.05	0.02	0.02	0.05	0.12	0.00	0.26	53
Bwc1	18.6	55	3.0	3.1	0.03	0.03	0.00	0.01	0.07	0.00	0.14	52
Bw3	23.0	45	2.0	3.2	0.01	0.03	0.00	0.01	0.00	0.00	0.06	92
CB	18.4	25	1.4	2.1	0.01	0.02	0.01	0.02	0.03	0.00	0.08	60
P4												
Oa					0.57	0.19	1.42	3.00	11.59	1.15	17.91	29
A	14.0	141	10.1	1.0	0.30	0.09	0.14	0.41	7.69	0.03	8.66	11
Bw1	16.9	105	6.2	1.0	0.16	0.04	0.01	0.08	1.27	0.00	1.56	18
Bw2	16.8	67	4.0	1.3	0.08	0.08	0.02	0.14	1.60	0.01	1.92	16
2Ab1	19.4	70	3.6	2.1	0.05	0.05	0.00	0.08	0.68	0.01	0.87	20
2Bwcb1	21.7	58	2.7	3.0	0.03	0.04	0.00	0.02	0.28	0.01	0.37	22
2Bwb1	22.0	33	1.5	3.0	0.02	0.04	0.00	0.05	0.40	0.01	0.52	21
2Bwb2	15.3	24	1.6	1.8	0.03	0.03	0.01	0.04	0.64	0.01	0.76	15
3Ab2	16.2	47	2.9	2.4	0.02	0.03	0.00	0.00	0.12	0.00	0.18	30
Stone- line												
3Bwb3	20.0	50	2.5	3.2	0.03	0.03	0.00	0.03	0.08	0.00	0.16	52
4AB	17.6	57	3.3	3.2	0.05	0.03	0.00	0.11	0.46	0.00	0.65	30
4Bwb4	17.5	48	2.7	3.3	0.04	0.03	0.00	0.06	0.02	0.00	0.15	85

	C/N	C	N	S	K	Na	Mg	Ca	Al	Fe	ECEC	BS
		[g kg ⁻¹]			[cmol _c kg ⁻¹ fine earth]							[%]
P5												
Oa					0.54	0.18	1.71	2.32	12.26	1.01	18.02	26
AB	14.6	158	10.8	1.4	0.17	0.08	0.15	0.18	7.14	0.23	7.95	7
Bw1	15.0	93	6.2	1.4	0.09	0.05	0.09	0.14	1.62	0.06	2.05	18
Bw2	14.5	92	6.4	1.2	0.03	0.06	0.00	0.04	0.66	0.00	0.80	17
Bw3	16.4	44	2.7	2.9	0.04	0.03	0.04	0.11	0.69	0.00	0.92	24
Bwc	16.0	42	2.6	3.1	0.03	0.04	0.00	0.17	0.25	0.01	0.50	48
2Ab	20.1	49	2.4	4.0	0.02	0.04	0.00	0.07	0.13	0.00	0.25	48
2CB	20.9	40	1.9	3.6	0.01	0.04	0.05	0.10	0.14	0.01	0.35	57
P6												
Oa	15.1	271	17.9	2.1	0.49	0.13	0.55	1.16	13.11	1.82	17.26	14
A	15.3	154	10.0	1.2	0.32	0.11	0.18	0.23	8.38	0.41	9.62	9
Bw1	18.5	120	6.5	1.1	0.10	0.06	0.05	0.07	1.49	0.03	1.79	15
Bw2	17.6	105	6.0	1.1	0.04	0.05	0.02	0.04	0.61	0.01	0.77	20
2Acb	18.2	104	5.7	1.2	0.06	0.04	0.01	0.02	0.44	0.00	0.57	22
2Bcb	20.2	86	4.3	1.8	0.05	0.03	0.00	0.04	0.27	0.00	0.40	30
2Bwb1	22.1	78	3.5	2.1	0.04	0.03	0.01	0.01	0.19	0.00	0.29	32
2Bwb2	21.7	69	3.2	1.9	0.03	0.10	0.01	0.04	0.21	0.01	0.40	46
2Bwcb	17.5	54	3.1	1.4	0.04	0.06	0.00	0.01	0.24	0.00	0.35	30
2Bwb3	20.6	35	1.7	1.4	0.03	0.02	0.01	0.02	0.17	0.01	0.26	33
Placic h.												
3Cr1	17.9	10	0.5	1.5	0.02	0.03	0.05	0.07	0.21	0.00	0.38	44
3Cr2	17.3	11	0.6	1.5	0.01	0.01	0.03	0.02	0.06	0.00	0.14	56
4Ab1	15.6	39	2.5	1.9	0.05	0.03	0.02	0.02	0.09	0.00	0.20	55
4Ab2	19.2	45	2.3	2.0	0.04	0.00	0.01	0.04	0.28	0.00	0.37	24
4Bwb4	19.9	42	2.1	2.0	0.03	0.00	0.04	0.00	0.03	0.00	0.11	72
4Bwb5	18.0	42	2.3	1.2	0.04	0.03	0.01	0.01	0.31	0.00	0.40	22
4Bwb6	19.2	39	2.1	1.3	0.03	0.03	0.00	0.01	0.23	0.00	0.30	24
P8												
Oa	15.4	236	15.3	2.0	0.33	0.07	0.31	0.48	7.99	0.67	9.86	12
BA	17.2	99	5.7	1.7	0.07	0.04	0.02	0.14	2.35	0.04	2.65	10
2Ab1	23.7	133	5.6	1.3	0.02	0.02	0.01	0.11	0.67	0.01	0.85	20
2Bwb1	19.3	54	2.8	1.5	0.03	0.01	0.01	0.04	0.17	0.00	0.25	33
2Bwb2	17.2	33	1.9	0.9	0.07	0.03	0.00	0.05	0.30	0.01	0.47	35
3Agb	19.9	62	3.1	1.2	0.07	0.01	0.00	0.02	0.38	0.00	0.49	22
3Bgb	22.8	85	3.7	1.6	0.03	0.02	0.03	0.68	0.14	0.00	0.90	84
3Bmb	33.1	51	1.5	3.6								
3Bwb3	17.9	39	2.2	1.4	0.15	0.01	0.01	0.03	0.25	0.00	0.45	44
4BA	22.9	71	3.1	2.3	0.06	0.02	0.01	0.10	0.13	0.00	0.32	58
4Ab2	27.2	131	4.8	0.9	0.05	0.01	0.00	0.09	1.81	0.00	1.96	8
4Bwb4	27.8	40	1.4	0.9	0.01	0.01	0.02	0.02	0.21	0.01	0.28	23
4Bwb5	24.0	27	1.1	1.0	0.58	0.03	0.04	0.05	0.11	0.00	0.82	86

	C/N	C	N	S	K	Na	Mg	Ca	Al	Fe	ECEC	BS
		[g kg ⁻¹]			[cmol _c kg ⁻¹ fine earth]							[%]
P9												
Oa1					0.49	0.37	2.57	3.55	6.81	0.93	14.73	47
Oa2	16.2	182	11.2	1.5	0.55	0.20	0.65	0.85	9.29	1.75	13.28	17
Bw1	19.7	119	6.0	1.2	0.25	0.12	0.26	0.40	9.40	1.04	11.47	9
Bw2	20.8	121	5.8	1.4	0.07	0.06	0.05	0.12	3.02	0.14	3.46	9
Bw3	23.7	104	4.4	1.8	0.06	0.04	0.01	0.06	1.08	0.03	1.28	13
Placic h	26.7	96	3.6	1.9								
2Ab1	24.1	100	4.2	1.2	0.03	0.03	0.01	0.02	0.29	0.01	0.38	21
2Bwb1	23.3	78	3.3	1.4	0.05	0.03	0.00	0.03	0.41	0.01	0.53	21
2Bwb2	20.5	77	3.7	1.6	0.06	0.04	0.00	0.03	0.36	0.01	0.50	26
3Ab2	29.5	96	3.2	1.7	0.09	0.03	0.00	0.01	0.24	0.00	0.39	36
3Bgb1	26.6	57	2.1	1.2	0.04	0.02	0.00	0.03	0.39	0.01	0.50	19
3Bwb3	31.2	48	1.6	1.5	0.03	0.02	0.02	0.02	0.14	0.00	0.23	38
3Bm	37.2	17	0.5	2.4								
3BCr1	21.3	8	0.4	1.9	0.01	0.01	0.04	0.03	0.11	0.01	0.21	47
4Ab3	19.5	49	2.5	2.8	0.01	0.02	0.02	0.02	0.07	0.01	0.15	49
4BCr2	27.9	30	1.1	2.7	0.04	0.03	0.01	0.02	0.06	0.00	0.15	61
4Bm	22.9	20	0.9	2.0	0.02	0.02	0.01	0.11	0.05	0.00	0.22	78
P10												
Oa1					1.03	0.32	2.38	5.04	7.49	0.65	16.91	52
Oa2	14.0	270	19.3	2.3	0.59	0.11	1.90	1.28	9.19	0.98	14.05	28
BA	16.4	125	7.6	1.2	0.17	0.07	0.18	0.31	6.10	0.04	6.86	11
Bw	17.8	101	5.7	1.2	0.04	0.02	0.01	0.04	0.82	0.00	0.93	11
2Ab1	21.3	127	6.0	1.2	0.03	0.03	0.03	0.25	0.61	0.00	0.95	36
Placic												
h.	25.8	65	2.5	2.2	0.03	0.02	0.01	0.04	0.15	0.00	0.26	43
2Bwb	21.1	59	2.8	1.0	0.04	0.01	0.01	0.03	0.06	0.00	0.15	63
Placic												
h.	28.4	78	2.7	1.8	0.03	0.02	0.02	0.04	0.08	0.00	0.19	56
3Ab2	24.1	98	4.1	1.2	0.07	0.03	0.01	0.04	0.38	0.00	0.53	28
Stone-												
line	22.0	22	1.0	1.1	0.07	0.05	0.01	0.06	0.13	0.00	0.32	59
Cr	15.3	8	0.5	0.7	0.12	0.08	0.16	0.10	3.19	0.00	3.65	13
P12												
Oa1	15.5	308	19.9	2.3	0.39	0.20	0.47	0.99	10.97	1.90	14.92	14
Oa2	18.8	210	11.2	1.5	0.18	0.11	0.19	0.43	11.66	1.61	14.17	6
BA	20.3	151	7.4	1.4	0.06	0.08	0.03	0.10	3.92	0.12	4.31	6
2AB	21.7	152	7.0	1.4	0.02	0.03	0.00	0.05	1.32	0.02	1.45	8
2Ab1	23.4	154	6.6	1.2	0.04	0.04	0.00	0.07	1.42	0.01	1.59	10
2AB	21.7	93	4.3	0.8	0.07	0.06	0.01	0.07	1.16	0.01	1.37	15
Placic h	27.2	77	2.8	1.2								
2Bwb1	21.9	61	2.8	0.8	0.06	0.04	0.00	0.04	1.14	0.01	1.30	12
3Ab2	29.2	102	3.5	1.0	0.04	0.02	0.00	0.03	1.25	0.01	1.35	7
Placic h	45.3	75	1.6	1.6								
3Bwb2	32.6	60	1.9	1.1	0.08	0.04	0.01	0.02	0.44	0.01	0.59	25
Placic h	39.7	51	1.3	1.4								
3Bwb3	28.6	41	1.4	0.8	0.00	0.01	0.02	0.02	0.21	0.00	0.26	19
4Ab3	24.4	66	2.7	1.5	0.03	0.03	0.01	0.01	0.20	0.00	0.28	30
4Bm												
4Cr	17.1	9	0.6	0.5	0.13	0.08	0.01	0.06	1.68	0.00	1.97	14

	C/N	C	N	S	K	Na	Mg	Ca	Al	Fe	ECEC	BS
		[g kg ⁻¹]			[cmol _c kg ⁻¹ fine earth]						[%]	
P101*												
BA	15.3	111	7.3	1.1	1.65	0.21	0.67	0.63	9.93	0.20	13.30	24
2BA	15.5	99	6.4	1.5	0.87	0.00	0.09	0.22	2.48	0.00	3.67	32
2Bwb1	17.8	78	4.4	2.1	0.49	0.46	0.05	0.06	2.26	0.00	3.32	32
2Bwb2	19.6	73	3.7	2.5	0.49	0.09	0.10	0.09	1.48	0.00	2.26	34
3ABb	17.2	77	4.5	1.8	0.51	0.04	0.03	0.07	0.59	0.00	1.25	52
3Bwb3	18.7	68	3.6	2.0	0.70	0.14	0.06	0.97	1.26	0.00	3.13	60
3Bwb4	16.0	56	3.5	2.1	0.60	0.03	0.08	0.10	1.51	0.00	2.32	35
3Bwb5	19.6	42	2.2	3.9	0.24	0.08	0.07	0.10	1.12	0.00	1.60	30
4Ab	19.4	82	4.3	1.9	0.47	0.19	0.00	0.00	0.82	0.00	1.48	45
4Bwb6	12.7	48	3.8	4.1	0.48	0.04	0.02	0.00	0.98	0.00	1.52	35
P102*												
Oa2	12.8	185	14.4	1.8	7.39	0.21	3.49	1.97	8.60	1.16	22.82	57
BA	14.8	118	8.0	1.1	3.06	0.06	0.82	0.55	5.93	0.06	10.47	43
Bw1	14.8	92	6.2	1.2	1.95	0.08	0.21	0.24	8.29	0.14	10.92	23
Bw2	15.7	104	6.7	1.6	1.33	0.09	0.21	0.32	3.68	0.00	5.62	34
2Ab1	17.6	129	7.3	1.6	1.07	0.03	0.19	0.08	2.62	0.05	4.05	34
2Bwb1	18.4	115	6.2	2.0	0.82	0.30	0.11	0.12	2.09	0.00	3.43	39
3Ab2	16.2	118	7.3	2.4	0.81	0.06	0.09	0.15	2.68	0.00	3.79	29
3Bwb2	16.1	39	2.4	3.0	0.47	0.03	0.11	0.25	1.51	0.00	2.37	36
3Bwb3	11.4	53	4.6	2.5	1.38	0.05	0.08	0.06	1.54	0.00	3.11	51
4Ab3	15.0	101	6.7	2.1	1.02	0.10	0.12	0.18	2.57	0.00	3.99	36
P103*												
Oa2	13.3	221	16.6	1.7	6.52	0.57	4.66	6.16	5.37	1.85	25.14	71
AB	15.8	123	7.8	1.1	2.46	0.65	1.16	2.27	2.93	0.49	9.97	66
2BA	17.5	103	5.9	1.2	0.62	0.03	0.08	0.06	3.04	0.11	3.94	20
2Bwb1	21.1	80	3.8	1.5	0.35	0.06	0.17	0.15	3.73	0.12	4.58	16
2Bwb2	20.6	57	2.8	1.1	0.20	0.06	0.12	0.07	3.21	0.00	3.65	12
2Bwb3	19.1	39	2.1	1.6	0.32	0.00	0.11	0.12	3.54	0.19	4.29	13
2Bwb4	15.1	52	3.5	2.3	0.60	0.13	0.11	0.18	2.32	0.23	3.56	29
3Ab1	13.7	61	4.4	2.8	0.88	0.01	0.05	0.00	2.40	0.00	3.34	28
3Bwb5	15.5	53	3.4	2.2	1.04	0.04	0.06	0.04	0.62	0.00	1.80	66
3Bwb6	17.1	72	4.2	2.7	0.71	0.08	0.04	0.00	1.54	0.00	2.36	35
4Ab2	19.2	80	4.2	2.1	0.90	0.27	0.11	0.14	1.45	0.00	2.88	49
4Bwb7	18.3	67	3.7	2.7	0.63	0.02	0.04	0.03	2.59	0.00	3.32	22
5Ab3	18.6	70	3.8	2.2	0.70	0.00	0.06	0.06	1.79	0.00	2.61	31
5BC1	17.4	40	2.3	1.8	0.55	0.04	0.08	0.00	0.84	0.00	1.52	45

* Exchangeable cations were determined in 1M CH₃COO-NH₄, pH 7

	pH		Al _o	Al _d	Fe _o	Fe _d	Si _o
	H ₂ O	KCl					
	[g kg ⁻¹]						
P 1850							
A	5.1	4.5	32.0	46.1	24.5	78.3	1.8
Bw	5.2	4.6	26.5	26.5	13.8	83.0	2.8
Ab1	5.3	4.7	34.8	48.0	45.3	96.2	1.9
AB	5.4	4.9	44.6	50.6	21.5	68.5	4.9
BA	5.2	5.1	51.1	38.9	21.7	65.2	6.0
Bwb1	5.2	5.1	66.4	39.5	27.5	70.6	5.9
Bwb2	5.0	5.1	35.3	53.2	31.4	96.3	3.4
2Ab2	4.9	5.1	54.1	55.8	27.5	96.8	5.9
2Bwb3	5.1	5.3	61.1	47.5	18.9	92.0	7.3
2BC	5.1	5.3	71.4	37.9	18.4	91.1	7.8
P 2090							
A	4.1	3.7	16.5	26.1	47.9	91.0	0.1
Bw	4.9	4.4	51.3	50.9	42.8	82.0	2.2
2Ab1	5.1	4.9	70.2	42.4	23.2	57.1	6.1
2Ab2	5.0	4.9	53.4	43.1	43.5	106.2	2.9
2BAb1	5.0	5.0	56.9	49.5	32.6	86.8	5.2
2Bwb1	5.0	4.9	49.3	50.1	46.1	90.7	3.7
2Bwcb1	4.9	4.9	58.4	43.7	26.0	82.2	5.5
2Bwb2	4.9	5.2	55.4	35.7	23.0	78.6	6.7
Placic h.							
3Crb1	5.1	5.4	25.8	23.0	20.7	65.5	3.4
3Crb2	5.2	5.4	14.5	22.9	14.1	63.5	1.7
Placic h.							
4Bwcb2	4.9	5.1	36.6	34.9	44.3	112.3	3.2
4BAb2	4.9	5.1	48.8	37.5	50.6	94.3	4.8
4BAb3	4.7	5.0	55.4	27.9	18.2	53.4	6.4
4Cr	4.9	5.2	44.6	36.2	17.1	142.8	5.5
P 2265							
	3.9	3.3					
BA	4.5	4.4	32.8	37.9	46.1	85.7	1.1
2BA	4.3	4.6	48.6	34.6	26.3	50.7	4.1
2AB1	4.4	4.7	60.6	19.7	11.3	18.7	7.3
2AB2	4.4	4.8	71.4	21.1	4.2	9.6	8.9
2AB3	4.5	4.9	73.7	10.0	3.4	7.4	11.4
2Bwb1	4.8	5.2	65.4	4.9	3.4	6.4	9.9
2Bgb2	4.7	5.1	56.6	7.1	0.9	2.1	8.8
3AB4	4.5	4.9	68.7	14.0	3.7	8.3	10.3
3Ab1	4.5	4.9	62.4	13.3	3.9	8.9	8.6
3Bmb	4.6	5.3	54.1	27.7	32.9	127.3	7.9
3Bwb2	4.4	4.9	55.4	21.4	17.7	37.7	8.4
3Bwb3	4.4	4.8	43.1	21.0	17.7	40.7	5.3
3Bwb4	4.4	4.9	59.1	31.7	30.1	73.5	7.9
4Ab2	4.5	4.7	61.6	23.4	14.1	31.7	7.9
4Ab3	4.5	4.5	54.4	17.9	5.5	8.6	5.8
4Ab4	4.7	4.7	56.1	19.8	3.4	4.8	7.1
4BA	4.7	4.8	52.1	8.1	5.0	8.6	8.1
4Bwb5			50.6	1.0	5.7	6.2	8.5
5Ab5	4.8	4.9	63.1	7.8	1.9	3.7	9.1
5Ab6	4.9	5.1	65.1	5.8	1.4	2.4	10.5

	pH		Al _o	Al _d	Fe _o	Fe _d	Si _o
	H ₂ O	KCl					
[g kg ⁻¹]							
P 2530							
Oa2	4.0	3.3					
AB	4.4	3.9	21.8	31.2	53.4	94.7	0.3
Bwc	4.7	4.5	59.6	42.3	16.6	68.0	6.0
2BA	4.8	4.5	45.1	57.4	40.0	84.3	2.2
2Ab1	5.2	5.0	70.7	33.2	6.0	12.9	4.4
2Ab2	5.1	4.5	78.4	17.3	4.5	9.5	8.3
2Ab3	5.1	4.6	87.2	39.4	12.6	26.9	6.6
2Bgb1	5.2	4.8	55.4	31.1	3.2	6.4	4.0
2Bgb2	5.1	4.7	77.2	14.1	3.4	7.3	7.7
3Ab4	5.1	4.7	82.7	23.5	2.4	3.0	8.2
3Ab5	5.1	4.7	63.9	31.9	1.2	7.5	6.4
3Bgb3	5.2	5.0	53.4	25.1	1.2	4.8	5.4
3Bwb1	5.1	4.7	58.6	8.4	5.5	4.6	7.3
4Ab6	5.1	5.0	74.2	18.1	0.1	1.4	7.2
4Bwb2	4.9	4.9	72.7	11.7	0.6	1.7	9.2
P 2700							
Oa2	3.7	3.1					
ABw	4.7	4.3	34.0	50.6	48.9	87.2	1.1
2BAb1	4.6	4.3	37.3	46.3	35.2	66.9	0.8
2BAb2	4.5	4.2	41.6	54.4	32.4	64.3	1.2
2Bb	4.9	4.5	48.1	47.4	17.1	49.3	4.1
3Ab	4.9	4.5	54.1	33.0	25.8	43.8	4.6
3BC	5.1	4.9	60.4	16.9	10.0	22.2	4.5
P 2900							
Oa2	3.6	3.2					
BA	4.1	3.5	12.0	12.9	45.6	60.5	0.8
2Ab	5.0	4.5	58.6	42.6	16.1	30.7	6.8
2Bwb1	4.9	4.7	49.1	29.4	15.4	36.9	6.5
2Bwb2	5.0	4.7	36.8	20.1	12.8	30.0	5.7
2BC	5.2	4.6	21.0	8.5	5.5	20.4	5.2
P 3100							
Oa2	4.7	4.0					
AB	5.1	4.4	40.6	33.7	17.9	39.1	4.4
2Ab	4.9	4.3	20.0	20.5	22.5	45.2	0.7
2BA	5.1	4.5	33.5	26.9	22.2	43.3	2.5
2BC	5.2	4.9	61.9	21.3	11.1	24.3	7.9
P 3150							
Oa	4.3	3.5					
BA	5.1	4.4	55.9	42.1	22.2	43.7	4.1
Bg	5.0	4.4	50.6	47.8	25.5	52.8	3.8
2AB1	5.0	4.5	50.6	29.4	32.1	48.1	4.0
2AB2	5.2	4.6	58.9	25.4	14.1	28.1	5.5
2Bg	5.2	4.7	60.9	21.7	10.5	20.5	6.4

	pH			Al _p	Al _o	Al _d	Fe _p	Fe _o	Fe _d	Si _o
	H ₂ O	KCl	CaCl ₂							
[g kg ⁻¹]										
P1										
Oa2	3.7		3.2							
OaA	3.8		3.8	8.2	28.6		3.2			9.2
Bw1	4.9		4.6	6.9	62.4		0.5			21.9
Bwc1	5.03		5.0	5.3	62.6		0.5			24.7
Ab	5.09		4.8	6.2	60.9		0.4			23.4
Bwb1	4.8		4.9	4.1	51.1		0.4			18.1
Bwb2	4.8		5.1	3.3	61.0		0.2			25.3
Bwb3	5.1		5.1		63.4					27.5
Bwcb	5.0		5.4		77.9					27.7
BC	5.14		5.4		71.9					28.2
P2										
A	4.3	3.8	3.8	10.0	25.1	19.0	5.3	41.1	61.0	3.0
AB	4.4	4.0	4.0	14.1	31.6	29.5	7.1	40.4	68.7	5.8
Bw1	4.4	4.3	4.0	9.1	32.6	37.8	2.4	49.1	69.8	8.3
Bw2	4.5	4.7	4.6	10.1	48.1	46.1	1.9	30.7	60.6	14.9
Bw3	4.6	4.8	4.7	5.0	34.9	39.4	2.8	47.6	77.1	9.4
Bwc1	4.8	5.0	5.0	8.0	50.8	37.1	1.3	26.8	69.3	15.8
Bwc2	4.5	4.8	4.7	8.5	59.4	35.5	0.8	30.4	64.6	16.4
Bw4	4.7	5.0	5.0		60.6	36.8		22.9	61.0	21.4
Bw5	4.8	5.2	5.1		70.5	29.8		12.5	49.9	25.7
2Ab	4.8	5.0	4.9		63.7	32.0		23.9	74.4	20.5
2BC	4.54	5.1	5.1		64.7	34.4		19.1	64.8	23.9
P3										
Oa2	3.6									
AB	4.2		3.8	13.0	23.4	23.6		43.3	71.5	9.7
Bw1	4.7		4.7	12.9	66.4	44.5	6.0	31.7	64.4	20.4
Bw2	5.0		5.0	6.4	69.4	38.3	0.9	31.8	72.0	23.6
Bwc1	5.1		5.1	5.8	77.6	43.3	0.8	37.1	89.3	26.8
Bw3	5.2		5.3	5.6	72.1	30.8	0.5	12.0	52.3	30.4
CB	5.3		5.3		48.9	19.2		21.5	43.0	25.8
P4										
Oa										
A	4.0	3.7	3.9	3.1	16.0	22.7	0.6	38.0	95.3	
Bw1	4.5	4.5	4.7	9.8	71.6	52.3	1.4	23.7	68.0	
Bw2	5.3	4.9	5.0	1.8	67.5	37.2	0.2	23.1	83.3	
2Ab1	5.3	4.9	5.2	3.3	66.7	38.3	0.2	24.2	71.7	
2Bwcb1	5.3	5.1	5.1	3.8	10.8	46.0	0.2	37.7	101.5	
2Bwb1	4.9	5.1	5.4			45.9			212.8	
2Bwb2	5.3	5.1	5.2	4.4	88.8	29.3	0.0	22.2	58.3	
3Ab2	5.0	4.9	5.0	1.0	29.0			26.3		
Stone-line				1.6		38.2			84.6	
3Bwb3	5.4	5.1	5.2		62.8	47.1		40.7	99.8	
4AB	5.2	5.2	5.2			31.3			64.3	
4Bwb4	5.3	5.2	5.4		70.8	36.5		18.5	86.2	

	pH			Al _p	Al _o	Al _d	Fe _p	Fe _o	Fe _d	Si _o
	H ₂ O	KCl	CaCl ₂							
[g kg ⁻¹]										
P5										
Oa										
AB	4.5		4.0	10.1	16.8	25.6	3.2	34.4	75.0	
Bw1	4.6		4.4	5.9			1.6			
Bw2	5.0		4.8	10.9	37.5	35.2	1.3	27.8	60.3	
Bw3	4.8		5.0	5.2	48.7	32.6	0.6	34.6	81.3	
Bwc	4.8		5.0	3.9			0.4			
2Ab	5.0		5.2	5.2			0.2			
2CB	5.3		5.3	6.1	56.6	10.0	0.2	2.0	32.8	
P6										
Oa	3.7		3.2							
A	4.0		3.7		8.2					1.3
Bw1	4.9				18.3					1.3
Bw2	4.9		4.8		44.3					8.5
2Acb	4.9		5.0		64.5					18.8
2Bcb	5.0		5.0		63.9					19.5
2Bwb1	4.9		4.9		60.5					17.1
2Bwb2	4.9		4.9		53.5					13.8
2Bwcb	5.0		5.0		54.5					17.2
2Bwb3	5.0		5.3		50.9					18.8
Placic h.										
3Cr1	4.9		5.2		26.2					10.8
3Cr2	5.0		5.3		27.6					11.7
4Ab1	4.7		5.0		42.1					13.0
4Ab2	5.0		5.0		53.8					18.5
4Bwb4	5.2		5.1		53.5					18.7
4Bwb5	5.0		4.9		44.3					14.6
4Bwb6	5.2		5.2							
P8										
Oa	3.7	3.3	3.3							
BA	4.6	4.3	4.3	6.4	34.7	34.6	5.0	54.5	74.7	10.8
2Ab1	4.9	4.7	4.8	7.7	68.3	25.5	0.8	9.2	16.1	22.2
2Bwb1	4.7	5.1	5.1	5.0	68.3	14.3	0.3	2.8	8.0	31.8
2Bwb2	4.8	4.9		3.4	51.5	15.8	0.1	1.7	3.4	25.6
3Agb	4.6	4.9	5.0	5.7		22.0	0.6	2.9	5.6	
3Bgb	4.8	5.0	5.0	8.9	72.0	10.9	0.5	4.3	11.8	32.0
3Bmb				3.5	43.7	31.8	0.5	72.2	157.7	17.0
3Bwb3	4.6	4.9	4.9	4.4		16.0	0.9	20.9	33.1	
4BA	4.7	5.0	4.9	7.3	58.5	31.9	1.1	27.6	49.8	25.0
4Ab2	4.6	4.4	4.6	14.9	52.0	19.1	1.1	4.6	11.9	21.7
4Bwb4	4.8	5.0	5.0		52.9	10.8		5.9	10.1	26.4
4Bwb5	5.0	5.1	5.2		56.3	20.2		6.2	9.5	

	pH			Al _p	Al _o	Al _d	Fe _p	Fe _o	Fe _d	Si _o
	H ₂ O	KCl	CaCl ₂							
[g kg ⁻¹]										
P9										
Oa1	4.2	3.0	3.5							
Oa2	4.3	3.4	3.6	8.0	7.4	10.9	23.5	40.2	66.9	
Bw1	4.7	4.2	4.2	13.3	31.2	43.3	7.8	48.4	84.3	
Bw2	4.7	4.5	4.3	15.6	70.0	55.5	5.1	35.8	66.6	
Bw3	4.7	4.9	4.7	10.7	51.2	21.3	4.7	36.1	54.6	
Placic h				11.1		43.9	3.5	34.9	92.0	
2Ab1	4.5	4.8	4.8	10.4	44.3	33.9	2.1	23.4	44.2	
2Bwb1	4.6	4.8	4.8	9.5	44.4	48.3	3.6	42.7	85.8	
2Bwb2	4.7	5.0	4.8	7.7	45.5	40.3	0.8	36.9	72.0	
3Ab2	4.8	4.8	4.7	11.2	46.0	43.3	1.9	33.4	59.0	
3Bgb1	4.7	5.0	4.8	6.8	41.9	24.5	1.0	18.9	41.9	
3Bwb3		5.1	4.9	7.1	78.1	26.3	1.2	19.0	39.9	
3Bm				3.8		27.1	0.5	46.2	116.5	
3BCr1	4.7	5.2	5.1	4.0	39.4	58.3	0.3	29.8	73.3	
4Ab3	4.6	5.4	5.0		41.7	18.5		5.7	47.5	
4BCr2	4.7	5.4	5.1			10.9		3.7	29.0	
4Bm						31.7		22.6	78.7	
P10										
Oa1										
Oa2	4.0		3.6	10.7	30.3		4.2	22.0		
BA	4.0		3.8		15.5	17.0		38.2	66.6	
Bw				8.2	30.1	26.8	3.7	22.5	32.6	
2Ab1	4.6		4.7	10.2	38.9	20.0	0.5	3.9	4.8	
Placic h.					30.1	20.3		38.7	101.2	
2Bwb	4.5		5.1	4.7	52.0	21.1	0.9	22.7	41.9	
Placic h.	4.8		4.7			29.7		39.3	100.4	
3Ab2	4.8		4.7	8.3	53.0	20.4	1.3	19.9	33.0	
Stone-										
line	4.7		5.2		43.9	11.8		12.8	45.9	
Cr	4.6		4.2		6.9	6.4		8.0	33.4	
P12										
Oa1	3.6	2.9	3.1							
Oa2	3.9	3.3	3.4		9.2	8.6		55.5	62.5	
BA	4.4	4.3	4.0	9.1	53.5	49.0	1.3	39.8	63.2	17.2
2AB	4.8	4.7	4.6		65.4	56.7		23.4	48.9	24.6
2Ab1	4.9	4.6	4.5	13.8	57.3	34.3	1.7	16.1	30.0	22.3
2AB	4.6	4.6	4.5	9.6	58.3	31.0	0.4	7.5	14.2	
Placic h					50.7	40.4		72.4	178.7	24.5
2Bwb1	4.7	4.7	4.7	9.1	46.5	24.1		9.2	15.7	22.6
3Ab2	4.8	4.7	4.5		77.1	24.9	0.9	4.8	10.2	
Placic h					41.0	42.1		82.0	161.5	
3Bwb2	4.5	4.9	4.9	9.2	66.2	24.6	1.4	16.9	38.0	
Placic h					73.4	26.0		42.6	81.1	26.3
3Bwb3	4.5	5.1	5.0	6.0	85.6	15.3	0.4	14.6	25.4	
4Ab3	4.5	5.2	5.1	9.0	66.5	15.7	0.1	1.4	9.3	34.6
4Bm										
4Cr	4.4	4.3	4.3		35.3	13.7		2.4	13.4	20.9

	pH			Al _p	Al _o	Al _d	Fe _p	Fe _o	Fe _d	Si _o
	H ₂ O	KCl	CaCl ₂							
	[g kg ⁻¹]									
P101										
BA	4.5	4.4		9.1	36.7	28.9	5.2	44.1	65.7	10.9
2BA	4.5	4.9		7.2	34.8	38.9	0.9	29.3	86.0	10.8
2Bwb1	4.7	5.0		8.7	39.2	44.3	0.6	53.6	87.7	9.4
2Bwb2	4.7	5.1		6.0	39.9	33.7	0.6	57.4	87.9	10.9
3ABb	4.7	5.1		4.7	46.4	34.4	0.4	42.2	61.7	14.9
3Bwb3	4.7	5.1		5.6	39.8	29.1	5.2	49.8	68.0	11.3
3Bwb4	4.6	5.2		5.1	31.1	24.2	0.6	54.1	96.7	8.8
3Bwb5	4.6	5.4		3.6	41.6	40.8	0.2	55.1	95.5	11.5
4Ab	4.7	5.4		2.4	48.5	29.7	0.1	40.8	61.7	16.5
4Bwb6	4.6	5.6		2.5	40.3	30.2	0.2	50.3	76.1	12.9
P102										
Oa2										
BA	4.3	3.6								
Bw1	4.7	4.3		9.7	30.6	27.4	3.3	50.2	69.1	5.9
Bw2	4.6	4.7		7.8	44.6	38.2	1.4	38.0	66.1	11.7
2Ab1	4.8	4.9		6.9	43.5	41.4	1.0	34.5	74.5	14.6
2Bwb1	4.8	4.8		8.7	46.8	32.3	0.6	34.9	53.0	14.6
3Ab2	4.8	4.8		8.9	44.6	8.4	1.0	24.9	19.8	16.9
3Bwb2	4.9	5.0		3.5	56.0	22.5	0.3	22.5	43.9	22.9
3Bwb3	4.9	5.6		2.9	55.8	14.8	0.1	13.8	34.5	26.9
4Ab3	4.8	5.3		4.3	49.3	15.6	0.2	19.6	47.0	20.7
	5.0	5.0		3.3	51.5	31.1	0.2	23.3	75.7	20.7
P103										
Oa2										
AB	3.6	3.0								
2BA	4.7	3.9		6.2	10.7	19.5	5.3	40.7	76.0	
2Bwb1	4.5	4.8		9.0	36.4	33.1	1.2	26.1	67.7	11.0
2Bwb2	5.0	5.0		6.3	38.0	36.2	0.8	36.5	96.3	
2Bwb3	6.0	5.1		5.6	41.2	26.1	0.8	30.3	67.9	
2Bwb4	5.0	5.2		4.7	43.5	21.3	0.2	39.6	52.7	18.3
3Ab1	5.0	5.2		3.7	35.1	32.5	0.3	33.1	72.5	13.7
3Bwb5	4.8	5.2		3.8	43.6	26.2	0.3	40.1	76.1	15.8
3Bwb6	4.9	5.0		4.0	27.4	34.2	0.3	40.0	102.0	9.4
4Ab2	4.9	5.1		4.4	39.5	33.3	0.3	28.8	70.8	14.7
4Bwb7	4.9	5.0		3.5	45.4	33.0	0.8	33.7	68.3	
5Ab3	5.0	5.2		3.4	43.2	36.7	0.3	41.1	84.6	15.1
5BC1	5.0	5.2		7.2	40.5	25.2	1.4	27.8	48.0	15.6
P101*	4.8	5.3		2.2	60.4	12.8	0.0	3.8	13.9	27.8
BA	5.1	5.3		3.9	66.5	11.9	0.1	4.0	18.7	30.9

APPENDIX D

Rainfall, Throughfall, Interception

Vegetation: **Cl:** Clearings, **Sf:** Secondary forest, **Mf:** Mature forest

B Cl: Clearings burned in November 2001

	Rainfall		CI	SE	Throughfall				CI	Interception	
	2100 m	2250 m			Sf	SE	Mf	SE		Sf	Mf
	[mm]	[mm]			[mm]	[mm]	[mm]	[mm]		[mm]	[mm]
28.11.2000	16.6	7.2							16.6	16.6	7.2
05.12.2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.12.2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.12.2000	49.0	28.8	41.0	2.1	34.9	2.6	17.6	1.8	8.0	14.2	11.2
15.12.2000	25.9	31.1	16.3	1.1	20.6	1.4	17.7	0.4	9.5	5.3	13.4
19.12.2000	64.0	67.1	63.0	5.6	51.2	4.1	27.5	3.2	1.0	12.9	39.6
22.12.2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29.12.2000	35.6	29.7	38.8	13.0	28.3	5.6	29.7	5.2	-3.1	7.3	0.0
02.01.2001	116.2	102.3	152.0	11.0	37.0	9.2	75.2	11.3	-35.8	79.2	27.1
05.01.2001	37.9	41.6	21.2	2.1	32.2	3.1	26.2	2.0	16.7	5.7	15.4
09.01.2001	48.7	56.1	26.6	3.3	20.1	1.2	37.8	5.4	22.0	28.6	18.3
12.01.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.01.2001	83.0	187.1	113.5	18.3	66.7	3.4	144.1	5.5	-30.4	16.4	43.0
19.01.2001	53.6	14.8	47.0	5.6	42.2	0.9	9.0	1.3	6.6	11.5	5.8
23.01.2001	5.6	19.5	5.3	0.5	2.8	0.4	17.6	0.9	0.3	2.9	1.9
26.01.2001	35.6	26.5	32.0	1.2	21.3	1.8	22.1	1.5	3.7	14.4	4.3
30.01.2001	57.7	82.0	54.3	4.1	42.6	3.4	65.3	1.7	3.4	15.2	16.7
02.02.2001	17.1	32.7	26.0	8.4	14.7	7.9	25.1	1.4	-8.9	2.4	7.6
06.02.2001	45.9	28.0	34.9	3.5	25.0	1.5	21.3	1.3	11.0	20.8	6.7
09.02.2001	35.6	27.7	29.5	1.9	25.0	1.1	22.8	1.4	6.1	10.6	4.8
13.02.2001	16.0	22.8	10.0	0.6	7.4	0.4	22.7	1.2	6.1	8.6	0.1
16.02.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.02.2001	16.0	26.7	13.1	0.1	7.7	0.6	20.4	1.5	2.9	8.4	6.3
23.02.2001	23.6	8.2	23.4	1.4	16.2	1.0	5.8	0.4	0.2	7.4	2.4
27.02.2001	4.0	8.7	3.6	0.3	0.8	0.2	9.0	1.6	0.4	3.2	-0.3
02.03.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
06.03.2001	10.7	11.0	9.0	0.4	8.0	0.1	8.2	0.5	1.7	2.7	2.8
09.03.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.03.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.03.2001	27.1	13.1	20.0	0.1	14.5	2.1	10.8	0.5	7.1	12.6	2.3
20.03.2001	3.8	5.1	3.7	0.1	0.9	0.2	3.4	0.5	0.1	2.9	1.7
23.03.2001	2.2	0.0	1.5	0.3	1.0	0.3	1.5	0.2	0.7	1.2	-1.5
27.03.2001	39.8	65.4	30.8	1.9	23.0	1.5	33.4	6.7	9.0	16.8	32.0
30.03.2001	6.8	12.8	7.3	0.9	6.4	0.5	27.5	6.8	-0.6	0.4	-14.7
03.04.2001	33.2	27.8	30.9	2.3	25.0	1.9	24.3	1.0	2.3	8.2	3.5
06.04.2001	47.2	29.1	36.2	3.3	31.4	1.4	25.8	1.7	11.0	15.8	3.2
10.04.2001	47.9	22.2	41.8	1.8	34.8	4.0	13.2	1.5	6.1	13.2	9.0
14.04.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.04.2001	110.3	68.8	96.0	6.7	77.2	15.9	60.9	2.5	14.4	33.1	8.0
20.04.2001	15.9	38.5	15.1	0.2	13.0	0.3	21.4	1.3	0.7	2.9	17.1
24.04.2001	247.5	195.4	242.5	13.1	201.7	25.1	226.7	7.4	5.0	45.8	-31.3
27.04.2001	101.1	76.5	106.1	4.8	87.9	4.5	60.5	2.6	-5.0	13.2	16.1
01.05.2001	34.2	34.9	36.7	3.1	28.5	0.6	25.9	1.2	-2.5	5.7	9.0
04.05.2001	80.1	78.3	82.6	4.0	67.0	4.7	75.2	3.1	-2.4	13.1	3.1
08.05.2001	16.6	8.9	15.9	3.0	11.2	0.3	4.4	0.7	0.8	5.5	4.5
11.05.2001	51.3	0.0	57.4	1.6	44.5	2.5	0.0	0.0	-6.1	6.8	0.0
15.05.2001	0.0	175.0	0.0	0.0	0.0	0.0	148.4	13.3	0.0	0.0	26.6
18.05.2001	193.2	0.0	176.6	5.2	142.4	12.6	0.0	0.0	16.6	50.8	0.0
22.05.2001	0.0	111.2	0.0	0.0	0.0	0.0	92.6	6.2	0.0	0.0	18.6

	Rainfall			Throughfall				Interception		
	2100 m	CI	SE	B CI	SE	Sf	SE	CI	B CI	Sf
	[mm]			[mm]				[mm]		
11.05.2001	51.3	55.4	1.8			44.5	3.8	-4.1		6.8
15.05.2001	0.0	0.0	0.0			0.0	0.0	0.0		0.0
18.05.2001	193.2	155.1	6.0			142.4	0.7	38.1		50.8
22.05.2001	0.0	0.0	0.0			0.0	0.0	0.0		0.0
25.05.2001	195.3	119.7	3.4			129.9	1.2	75.6		65.4
01.06.2001	153.6	142.9	18.0			115.0	8.4	10.7		38.6
08.06.2001	45.6	34.3	9.5			24.6	0.0	11.4		21.0
15.06.2001	39.0	47.5	3.5			55.8	2.4	-8.5		-16.7
22.06.2001	58.6	53.2	3.5			41.1	1.5	5.4		17.6
29.06.2001	32.0	28.6	1.1			17.9	0.6	3.3		14.1
06.07.2001	25.1	24.3	0.5			18.9	1.0	0.8		6.2
13.07.2001	36.1	33.0	2.2			26.4	1.7	3.1		9.7
20.07.2001	3.2	5.0	1.1			2.8	0.6	-1.9		0.3
27.07.2001	0.0	0.0	0.0			0.0	0.0	0.0		0.0
03.08.2001	122.8	136.0	19.3			108.2	11.4	-13.2		14.6
10.08.2001	0.8	0.3	0.2			0.2		0.5		0.5
17.08.2001	1.8	1.1	0.1			0.8	0.1	0.7		1.0
24.08.2001	0.0	0.0	0.0			0.0	0.0	0.0		0.0
31.08.2001	4.9	4.0	0.2			0.9	0.3	0.8		4.0
07.09.2001	3.2	2.3	0.2			0.5	0.1	0.9		2.7
14.09.2001	0.0	0.0	0.0			0.0	0.0	0.0		0.0
21.09.2001	0.0	0.0	0.0			0.0	0.0	0.0		0.0
28.09.2001	0.0	0.0	0.0			0.0	0.0	0.0		0.0
05.10.2001	12.8	12.9	1.6	12.2	1.2	6.9	0.3	-0.1	-0.5	5.9
12.10.2001	6.7	6.7	0.7	7.4	0.7	4.8	0.3	0.1	0.7	1.9
19.10.2001	0.4	0.6	0.2	0.4	0.1	0.2	0.0	-0.1	-0.1	0.3
26.10.2001	0.2	0.1	0.1	0.1	0.0	0.1	0.0	0.1	-0.1	0.1
02.11.2001	12.9	9.8	1.3	11.3	0.5	8.5	0.3	3.1	-1.6	4.4
09.11.2001	67.5	60.1	3.3	60.7	2.6	47.0	1.0	7.4	-6.8	20.5
16.11.2001	36.5	33.2	0.5	36.5	0.3	21.8	0.4	3.3	0.0	14.7
23.11.2001	45.6	37.3	3.1	44.3	2.1	34.6	0.3	8.4	-1.3	11.1
01.12.2001	12.4	13.8	3.4	16.8	3.1	6.1	1.5	-1.3	4.3	6.4
07.12.2001	15.4	12.8	2.2	14.6	5.5	5.8	0.9	2.6	-0.8	9.6
11.12.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.12.2001	2.4	2.9	0.9	4.7	0.8	0.6	0.0	-0.4	2.3	1.8
18.12.2001	29.3	24.5	4.0	25.8	2.4	15.9	0.3	4.8	-3.5	13.3
21.12.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.12.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.12.2001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
01.01.2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
04.01.2002	34.3	30.3	3.1	31.5	1.2	21.9	1.1	3.9	-2.8	12.4
08.01.2002	25.3	32.9	7.5	28.7	9.5	17.1	1.6	-7.6	3.5	8.2
11.01.2002	16.6	11.3	1.3	14.3	2.4	7.5	0.9	5.3	-2.4	9.2
15.01.2002	56.6	61.7	1.8	59.9	8.2	38.6	10.5	-5.1	3.3	18.0
18.01.2002	1.6	1.8	0.6	1.9	0.3	1.0	0.2	-0.1	0.3	0.6
22.01.2002	6.5	5.6	0.7	6.7	0.1	2.9	0.3	0.9	0.2	3.6
25.01.2002	44.2	43.2	1.8	41.0	1.2	27.4	3.0	1.0	-3.2	16.8
29.01.2002	25.2	17.7	1.1	30.6	3.1	17.1	0.9	7.5	5.5	8.1
01.02.2002	0.3	0.3	0.0	0.2	0.0	0.2	0.0	0.0	-0.1	0.1
05.02.2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.02.2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.02.2002	6.1	4.6	0.3	6.4	0.2	1.1	0.6	1.5	0.3	5.0

	Rainfall			Throughfall				Interception		
	2100 m	CI	SE	B CI	SE	Sf	SE	CI	B CI	Sf
	[mm]			[mm]				[mm]		
15.02.2002	33.2	29.0	3.8	36.2	2.8	26.6	0.3	4.2	3.0	6.6
19.02.2002	60.3	47.5	2.4	47.8	4.3	20.7	3.7	12.8	-12.5	39.6
22.02.2002	0.6	0.5	0.1	0.3	0.1	0.3	0.0	0.1	-0.2	0.2
26.02.2002	8.7	8.4	0.7	8.7	0.2	4.5	1.1	0.4	-0.1	4.3
01.03.2002	17.6	14.4	0.5	15.0	1.2	12.8	2.6	3.2	-2.6	4.8
05.03.2002	50.4	37.4	4.3	48.5	0.9	32.4	2.5	13.1	-2.0	18.0
08.03.2002	11.8	10.7	1.8	11.8	1.1	5.8	1.6	1.1	0.0	6.0
12.03.2002	15.2	19.8	6.5	29.8	8.1	9.7	2.8	-4.6	14.6	5.5
15.03.2002	28.3	30.6	2.7	35.7	3.4	24.0	2.3	-2.3	7.4	4.3
19.03.2002	41.5	27.5	6.8	25.6	5.8	26.7	0.8	14.0	-15.9	14.8
22.03.2002	25.1	24.8	1.4	28.2	2.5	20.9	0.0	0.4	3.1	4.2
26.03.2002	0.8	0.7	0.2	0.4	0.1	0.4	0.1	0.1	-0.4	0.4
02.04.2002	108.8	93.1	4.4	102.8	2.2	77.3	6.1	15.7	-6.0	31.5
05.04.2002	26.4	28.3	2.5	31.3	6.2	18.4	0.1	-1.9	4.9	8.0
09.04.2002	44.7	37.3	0.8	43.3	1.0	30.4	1.2	7.4	-1.4	14.2
12.04.2002	4.9	4.9	0.9	10.9	5.9	2.2	0.6	0.1	6.0	2.7
16.04.2002	31.8	25.1	1.5	29.0	0.6	20.5	1.9	6.7	-2.8	11.4
19.04.2002	37.7	32.0	2.8	41.3	0.8	24.4	0.3	5.7	3.6	13.3
23.04.2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26.04.2002	248.8	214.4	13.8	212.2	30.8	180.9	1.5	34.4	-36.6	67.8
30.04.2002	40.5	38.1	2.3	42.0	0.9	30.0	2.5	2.4	1.5	10.5
03.05.2002	119.9	104.6	14.1	119.3	14.2	85.7	4.2	15.3	-0.5	34.2
07.05.2002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.05.2002	26.9	22.0	2.1	25.9	0.4	15.0	1.3	4.8	-0.9	11.8
14.05.2002	0.2	0.3	0.0	0.2	0.0	0.3	0.2	-0.1	0.0	-0.2
17.05.2002	0.3	0.6	0.2	0.8	0.0	0.8	0.2	-0.3	0.5	-0.5
21.05.2002	43.5	35.0	11.5	34.5	5.9	25.1	4.0	8.4	-9.0	18.4
24.05.2002	180.6	167.2	23.8	154.0	19.2	79.3	1.9	13.4	-26.6	101.3
28.05.2002	8.1	7.3	0.5	7.9	0.5	7.6	0.9	0.8	-0.2	0.5
31.05.2002	6.0	3.5	1.5	4.6	1.2	3.1	0.3	2.5	-1.3	2.9
04.06.2002	34.1	25.4	1.0	28.5	1.7	19.7	0.2	8.8	-5.6	14.5
07.06.2002	37,1	32,4	3,1	28,6	2,4	16,4	0,9	4,7	-8,6	20,7
11.06.2002	35,1	34,2	4,1	33,5	4,4	18,9	1,7	0,9	-1,7	16,2
14.06.2002		29,6	6,0	35,5	9,9	26,0	0,0	-29,6	35,5	-26,0
18.06.2002	40,4	41,2	2,3	40,0	9,7	22,8	3,9	-0,8	-0,5	17,7
21.06.2002	28,1	15,3	1,8	18,3	0,6	11,7	1,9	12,7	-9,8	16,3
25.06.2002	8,4	5,6	1,5	6,0	1,2	5,2	1,0	2,8	-2,4	3,2
28.06.2002	73,7	33,9	1,5	56,2	10,6	26,4	5,4	39,8	-17,5	47,3
02.07.2002		63,3	1,0	50,8	6,7	43,7	26,0	-63,3	50,8	-43,7
05.07.2002	138,6	73,6	6,7	79,0	18,4	73,8	2,5	64,9	-59,6	64,8
09.07.2002		2,1	0,5	2,9	0,9	1,9	0,4	-2,1	2,9	-1,9
12.07.2002	0,5	0,2	0,0	0,3	0,1	0,0	0,0	0,3	-0,2	0,5
16.07.2002	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
19.07.2002	0,4	0,7	0,1	0,4	0,1	0,4	0,1	-0,3	0,0	0,0
23.07.2002	10,8	8,6	0,8	9,2	0,7	3,9	1,5	2,2	-1,6	6,9
26.07.2002	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
30.07.2002	28,2	21,5	2,1	25,9	3,3	17,1	2,5	6,7	-2,3	11,2
02.08.2002	12,3	14,0	1,4	11,3	1,3	6,9	0,3	-1,8	-0,9	5,3
06.08.2002	38,2	35,9	0,6	27,3	1,5	22,5	4,9	2,3	-10,9	15,8
09.08.2002	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13.08.2002	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16.08.2002	82,1	56,9	6,1	56,1	5,4	51,7	13,3	25,3	-26,0	30,4
20.08.2002	20,9	11,8	1,7	11,6	1,6	9,3	1,9	9,1	-9,4	11,7
23.08.2002	9,2	6,5	0,4	7,1	0,8	3,8	0,2	2,8	-2,1	5,5
27.08.2002	6,4	4,7	0,2	5,7	0,4	2,6	0,2	1,7	-0,7	3,8

	Rainfall 2250 m	Throughfall Mf	SE	Interception Mf		Rainfall 2250 m	Throughfall Mf	SE	Interception Mf
	[mm]					[mm]			
11.05.2001	0	0	0	0	01.01.2002	0,0	0,0	0,0	0,0
15.05.2001	175,0	148,4	13,3	26,6	08.01.2002	63,7	56,7	3,9	7,0
18.05.2001	0,0	0,0	0,0	0,0	15.01.2002	66,2	43,4	3,4	22,9
22.05.2001	111,2	92,6	6,2	18,6	22.01.2002	45,1	29,7	1,8	15,3
27.05.2001	162,7	114,9	5,5	47,8	29.01.2002	55,3	29,4	2,9	25,8
05.06.2001	39,5	15,3	1,6	24,2	05.02.2002	17,1	14,5	2,1	2,6
12.06.2001	58,2	56,0	5,3	2,1	08.02.2002	18,6	0,0	0,0	18,6
19.06.2001	58,0	57,1	9,0	0,9	12.02.2002	30,6	30,2	5,9	0,4
26.06.2001	75,3	49,9	6,7	25,4	19.02.2002	51,5	43,4	6,2	8,1
03.07.2001	27,5	11,3	0,4	16,3	26.02.2002	43,8	48,4	3,4	-4,6
10.07.2001	29,8	14,0	0,2	15,8	05.03.2002	29,1	54,1	2,5	-25,0
17.07.2001	26,0	16,0	0,5	10,0	12.03.2002	38,1	31,1	1,3	7,0
24.07.2001	8,9	4,4	0,4	4,5	19.03.2002	131,7	91,9	6,4	39,8
31.07.2001	33,4	13,2	1,4	20,2	26.03.2002	18,4	12,3	1,1	6,1
07.08.2001	85,0	53,7	3,5	31,2	02.04.2002	82,0	55,2	3,5	26,9
14.08.2001	0,0	0,0	0,0	0,0	09.04.2002	53,1	47,8	5,8	5,3
21.08.2001	0,0	0,0	0,0	0,0	16.04.2002	34,3	24,4	1,2	9,9
28.08.2001	0,0	0,0	0,0	0,0	23.04.2002	0,0	0,0	0,0	0,0
04.09.2001	4,4	1,6	0,4	2,8	26.04.2002	227,2	104,0	12,3	123,2
11.09.2001	0,0	0,0	0,0	0,0	30.04.2002	34,7	20,9	1,7	13,8
18.09.2001	0,0	0,0	0,0	0,0	07.05.2002	0,0	0,0	0,0	0,0
24.09.2001	0,0	0,0	0,0	0,0	14.05.2002	1,1	1,2	0,2	-0,1
02.10.2001	0,7	0,1	0,0	0,6	21.05.2002	9,3	17,3	1,2	-7,9
09.10.2001	8,4	4,0	0,2	4,3	28.05.2002	9,1	0,0	0,0	9,1
16.10.2001	0,6	0,2	0,1	0,4	04.06.2002	28,6	10,8	0,4	17,8
23.10.2001	3,0	0,3	0,1	2,7	11.06.2002	0,0	45,0	4,4	-45,0
30.10.2001	0,0	0,0	0,0	0,0	18.06.2002	35,0	19,2	0,8	15,8
06.11.2001	107,8	83,8	3,1	24,0	25.06.2002	0,0	0,0	0,0	0,0
17.11.2001	34,5	27,5	1,9	7,0	02.07.2002	0,0	9,5	1,0	-9,5
20.11.2001	27,0	14,3	0,7	12,6	09.07.2002	0,0	11,0	1,1	-11,0
27.11.2001	47,8	29,3	1,5	18,4	16.07.2002	0,0	0,0	0,0	0,0
04.12.2001	6,1	4,5	0,7	1,7	23.07.2002	0,0	9,7	0,6	-9,7
07.12.2001	0,0	0,0	0,0	0,0	30.07.2002	19,5	11,0	0,6	8,5
11.12.2001	37,9	40,7	1,4	-2,8	02.08.2002	1,2			
14.12.2001	0,0	0,0	0,0	0,0	06.08.2002	50,1	17,6	1,3	32,5
18.12.2001	27,5	2,4	0,6	25,2	20.08.2002	23,8	15,4	2,1	8,4
25.12.2001	0,0	0,0	0,0	0,0	27.08.2002	72,4	50,4	4,3	22,0

Cl: Clearings, Sf: Secondary forest, Mf: Mature forest, SE: Standard error

APPENDIX E

Soil Water Suction

Vegetation: **Cl:** Clearings, **Sf:** Secondary forest, **Mf:** Mature forest

Cl_a: Clearings not burned in November 2001

Cl_b: Clearings burned in November 2001

Soil Depth: **1:** 0.10 m, **2:** 0.20 m, **3:** 0.60 m, **4:** 1.10 m

SE: Standard error

Date	C11	SE	C12	SE	C13	SE	C14	SE	Sf1	SE	Sf2	SE
							[hPa]					
24.05.2000	50	5	43	6	25	8	8	10	75	9	63	6
27.05.2000	42	13	51	3	14	17	-7	12	68	11	83	21
31.05.2000	76	5	54	14	38	13	18	8	93	8	94	3
03.06.2000	92	8	69	18	59	9	36	6	100	13	122	3
07.06.2000	36	14	26	8	-12	5	-11	12	34	8	25	9
10.06.2000	27	3	18	3	6	8	-17	6	28	3	33	2
14.06.2000	6	8	-3	5	-11	6	-13	4	-1	4	1	11
17.06.2000	22	1	10	9	8	8	-6	5	27	11	36	6
21.06.2000	31	6	33	4	15	3	-3	3	39	12	33	5
24.06.2000	43	6	46	4	32	8	19	7	43	16	59	1
28.06.2000	3	3	-3	5	-10	5	-18	6	7	2	5	3
01.07.2000	14	4	7	4	-7	5	-22	3	16	5	9	3
05.07.2000	17	7	17	9	10	7	-16	9	43	10	40	5
08.07.2000	71	3	63	1	50	4	28	9	82	8	79	5
12.07.2000	47	8	48	7	34	7	20	3	43	15	58	6
15.07.2000	52	13	51	13	35	9	24	12	73	7	74	5
19.07.2000	42	11	41	9	27	8	21	6	63	17	71	5
22.07.2000	59	8	60	2	54	8	41	5	71	13	91	4
26.07.2000	12	9	5	9	-1	4	-26	7	5	3	10	6
29.07.2000	24	5	17	2	3	5	-16	5	32	10	23	5
02.08.2000	27	3	25	6	20	4	3	9	24	2	36	8
05.08.2000	48	12	46	10	40	8	14	2	34	8	58	10
09.08.2000	60	7	47	6	37	4	27	3	70	6	73	4
12.08.2000	57	15	58	12	41	13	22	11	68	7	74	11
16.08.2000	12	1	37	15	19	9	21	13	39	9	42	2
23.08.2000	85	10	73	9	51	9	41	6	86	17	112	3
25.08.2000	61	10	52	5	27	4	14	6	86	18	99	5
30.08.2000	84	14	78	8	62	18	40	9	96	19	122	8
02.09.2000	86	9	71	8	49	13	36	5	97	21	123	10
06.09.2000	86	6	80	4	61	10	36	2	137	15	149	7
09.09.2000	103	10	95	6	69	16	38	10	145	22	192	26
13.09.2000	132	8	111	9	85	10	63	7	189	37	237	28
16.09.2000	121	21	107	15	80	16	54	7	160	27	247	39
20.09.2000	109	13	99	7	82	2	18	22	113	13	257	46
23.09.2000	95	2	99	20	78	8	48	4	191	16	270	40
27.09.2000	137	15	130	9	108	10	73	5	291	24	320	41
30.09.2000	149	17	142	9	111	9	73	5	315	11	334	40
03.10.2000	72	8	53	8	35	6	20	4	85	3	80	5
06.10.2000	71	8	57	12	42	13	16	4	97	8	94	19
12.10.2000	102	10	85	11	63	8	36	4	168	4	185	38
17.10.2000	124	6	111	7	86	8	55	3	222	15	228	52
20.10.2000	153	6	123	5	94	7	64	4	275	21	288	52
24.10.2000	201	16	156	28	125	9	79	4	327	20	352	51
28.10.2000	257	16	211	19	157	2	95	3	396	30	417	27
31.10.2000	333	30	271	30	193	9	105	10	391	55	498	40
03.11.2000	69	8	85	8	138	22	107	8	89	25	127	36
07.11.2000	138	16	133	21	134	16	115	15	186	38	312	23
10.11.2000	134	17	123	19	124	18	109	14	239	10	303	24
14.11.2000	46	9	39	8	38	5	14	2	82	33	123	38
17.11.2000	48	6	43	6	26	5	16	3	55	6	56	3
21.11.2000	4	2	6	3	8	2	-4	7	14	11	16	8

Date	Sf3	SE	Sf4	SE	Mf1	SE	Mf2	SE	Mf3	SE	Mf4	SE
							[hPa]					
08.12.2000	31	10	25	6	33	6	32	7	9	3	-5	5
12.12.2000	19	3	4	2	9	3	5	5	-6	3	-11	4
15.12.2000	36	14	32	7	45	4	52	11	22	10	5	2
19.12.2000	41	25	36	35	32	6	28	1	17	4	3	8
22.12.2000	20	3	5	2	15	4	15	9	1	4	-7	5
29.12.2000	51	10	24	11	48	5	43	7	22	4	4	1
02.01.2001	23	7	9	8	37	7	42	6	21	8	3	2
05.01.2001	28	3	-3	3	46	7	47	6	37	5	29	9
09.01.2001	27	6	26	15	45	14	51	12	20	11	16	15
12.01.2001	41	5	16	4	34	11	36	12	13	7	-9	16
16.01.2001	7	6	-11	2	6	4	2	4	-13	3	-22	3
19.01.2001												
23.01.2001	11	11	1	11	5	4	-1	7	-6	5	-18	10
26.01.2001	46	3	26	4	23	8	17	4	3	2	-5	2
30.01.2001	12	2	5	3	22	2	20	5	2	7	-2	5
02.02.2001	49	11	13	15	18	2	13	2	-5	5	-6	4
06.02.2001	39	6	30	6	10	6	5	7	-3	6	-5	4
09.02.2001	39	0	21	3	29	3	27	4	12	3	4	5
13.02.2001	47	11	23	7	49	10	49	10	30	9	15	10
16.02.2001	55	5	23	8	42	9	48	1	18	10	8	2
20.02.2001	67	2	34	5	29	4	32	9	23	9	1	4
23.02.2001	55	15	35	14	34	8	37	6	17	6	5	6
27.02.2001	72	7	43	1	38	5	34	7	12	4	3	3
02.03.2001	79	9	44	6	72	7	65	8	33	9	16	5
06.03.2001	74	11	26	11	41	10	44	12	20	6	-12	13
09.03.2001	161	58	369	11								
13.03.2001	115	8	77	7	76	7	80	7	53	10	13	6
16.03.2001	145	9	110	14	40	15	50	14	43	15	21	6
20.03.2001	122	11	101	25	65	13	56	16	45	14	20	8
23.03.2001	99	35	52	38	71	17	73	14	49	7	17	6
27.03.2001	160		169		24	4	26	8	2	11	-21	10
30.03.2001	105	26	110	51	62	5	65	2	41	8	0	3
03.04.2001	22	5	40	45	32	7	29	3	5	4	-18	9
06.04.2001	27	7	19	3	22	3	26	3	14	3	9	5
10.04.2001	31	4	22	1	29	5	26	5	14	2	7	3
17.04.2001	55	8	28	6	37	2	31	2	27	2	17	2
20.04.2001	2	7	-12	10	11	4	8	5	-4	7	-16	7
24.04.2001	15	5	-5	8	17	2	17	2	4	2	-10	4
27.04.2001	15	2	0	2	22	1	21	4	4	8	-4	4
11.05.2001	-2	8	-14	3								
15.05.2001					8	11	12	13	-5	10	-11	12
18.05.2001	3	15	-15	3								
22.05.2001					27	7	29	6	9	9	6	4

Cl: Clearings, Sf: Secondary forest, Mf: Mature forest 1: 0.10 m, 2: 0.20 m, 3: 0.60 m, 4: 1.10 m, SE: Standard error

	Cla 1	SE	Cla 2	SE	Cla3	SE	Cla 4	SE	Cla 1	SE	Cla 2	SE	Cla 3	SE	Cla 4	SE
	[hPa]															
20.11.2001																
23.11.2001	35	8	43	9	32	12	21	21	38	5	60	4	55	7	44	7
27.11.2001																
07.12.2001	83	15	74	19	66	6	32	18	108	20	87	10	53	17	24	31
11.12.2001																
14.12.2001	100	19	108	16	68	2	49	7	124	19	118	29	86	28	57	42
18.12.2001	77	3	82	8	61	5	18	15	72	8	74	7	65	3	20	12
21.12.2001	165	41	115	9	59	6	39	16	130	8	111	5	54	34	47	45
28.12.2001	93	2	116	9	98	10	60	4	135	35	123	31	105	47	97	10 7
04.01.2002	99	20	103	12	64	16	34	17	147	30	124	41	112	51	51	56
08.01.2002	77	13	78	11	61	19	24	15	80	10	74	9	54	8	19	23
11.01.2002	63	20	53	6	66	15	58	11	64	24	34	9	35	15	17	16
15.01.2002	29	2	36	5	18	9	-18	6	37	3	34	2	20	9	6	16
18.01.2002	75	3	65	4	46	7	20	20	74	5	65	1	32	17	29	29
22.01.2002	31	6	30	12	22	10	19	3	20	2	20	3	6	10	6	12
25.01.2002	60	3	52	8	44	7	19	1	53	4	54	2	32	14	17	12
29.01.2002	67	5	65	8	42	5	13	14	70	3	63	4	46	10	29	13
01.02.2002	75	18	53	14	42	9	9	13	64	1	66	3	38	16	6	41
05.02.2002	136	35	96	11	70	4	40	5	104	3	84	7	54	14	21	26
08.02.2002	146	26	113	9	61	9	39	17	141	16	110	5	56	16	50	44
12.02.2002	157	45	127	22	72	6	38	7	115	17	83	2	51	15	29	24
15.02.2002	66	14	66	9	47	7	22	10	77	9	72	5	53	10	27	9
19.02.2002	75	6	73	1	47	5	34	11	55	3	56	7	28	12	13	11
22.02.2002	90	5	74	5	56	3	31	9	94	9	86	12	57	13	29	14
26.02.2002	24	5	49	13	50	7	24	7	30	15	45	9	45	14	34	21
01.03.2002	55	2	55	5	43	1	31	4	57	7	55	9	36	14	23	19
05.03.2002	42	7	48	6	23	6	-7	14	43	9	43	5	32	11	12	15
08.03.2002	56	8	47	8	40	7	12	9	52	7	54	8	29	13	20	19
12.03.2002	47	7	42	4	32	7	4	5	43	3	45	10	33	12	-4	37
15.03.2002	32	8	34	5	26	8	-4	8	38	11	41	12	31	14	4	15
19.03.2002	27	11	33	7	27	4	10	3	26	6	32	5	31	13	26	23
22.03.2002	40	4	43	8	29	9	16	9	41	2	46	5	33	12	15	18
26.03.2002	64	6	53	7	42	1	24	7	76	3	71	4	53	7	33	14
02.04.2002	25	5	34	4	14	11	-15	4	38	4	32	6	20	6	-5	2
05.04.2002	18	4	23	6	14	4	3	5	36	8	32	8	30	8	9	11
09.04.2002	39	5	34	4	23	4	0	11	47	9	49	8	31	11	12	19
12.04.2002	34	1	42	9	25	16	-5	15	28	3	25	1	20	1	-4	2
16.04.2002	21	7	32	3	24	3	7	3	24	11	37	12	33	11	17	12
19.04.2002	22	7	26	7	19	9	-3	17	20	8	36	10	33	14	15	13
23.04.2002																
26.04.2002	32	5	32	7	16	1	5	7	33	4	35	2	19	9	1	21
30.04.2002	35	7	35	3	27	4	9	7	38	3	35	1	22	8	3	18
03.05.2002	33	2	37	9	29	4	8	11	43	4	46	15	35	10	4	10
07.05.2002																
10.05.2002	57	3	56	5	44	4	24	1	56	10	57	14	45	15	26	33
14.05.2002	70	9	63	9	49	4	24	7	76	3	70	2	51	9	34	19
17.05.2002	46	16	70	15	49	12	35	11	59	7	67	4	48	5	37	15
21.05.2002	47	6	44	10	36	9	23	9	47	2	51	4	30	11	17	19
24.05.2002	38	2	38	4	25	4	10	13	40	5	39	3	23	8	6	22

	Cla 1	SE	Cla 2	SE	Cla 3	SE	Cla 4	SE	C1b 1	SE	C1b 2	SE	C1b 3	SE	C1b 4	SE
	[hPa]															
28.05.2002	58	2	66	7	54	2	36	5	61	4	65	5	55	8	38	14
31.05.2002	60	5	59	2	43	8	39	9	60	8	66	12	49	10	37	18
04.06.2002																
07.06.2002	43	6	38	5	35	7	22	6	43	8	59	13	42	16	25	17
11.06.2002	41	5	39	5	30	10	19	8	50	7	49	8	34	10	21	19
14.06.2002	21	2	24	5	20	6	3	9	35	3	43	2	21	10	19	13
18.06.2002	39	3	38	3	32	16	-2	5	42	2	45	2	29	9	22	10
21.06.2002	40	5	51	5	31	5	29	5	44	3	44	5	44	4	21	9
25.06.2002	32	4	37	3	22	5	-1	11	28	5	33	6	20	8	5	19
28.06.2002	46	27	22	27	16	40	-17	54	79	2	77	4	66	2	44	4
02.07.2002	70	10	61	12	55	9	35	16	61	6	58	10	42	10	25	20
05.07.2002	32	2	29	8	26	7	7	10	34	4	35	5	28	12	0	9
09.07.2002	76	11	68	9	46	8	17	10	64	5	70	4	47	11	23	30
12.07.2002	84	4	72	5	56	6	37	11	83	5	83	4	62	5	41	19
16.07.2002	104	6	104	6	81	4	50	14	91	6	91	9	70	14	43	24
19.07.2002	90	16	81	10	64	11	38	12	94	6	72	14	66	8	44	31
23.07.2002	97	7	90	10	65	7	42	1	92	2	66	22	59	3	38	6
26.07.2002	101	6	97	6	81	4	52	12	100	7	97	9	92	2	53	5
30.07.2002	70	13	65	14	63	8	39	11	56	4	59	2	46	8	37	30
02.08.2002	21	5	37	5	38	9	29	11	30	9	21	14	23	12	17	13
06.08.2002	48	4	45	6	40	7	25	12	37	6	31	12	36	7	33	26
09.08.2002																
13.08.2002																
16.08.2002	51	3	46	4	37	3	14	6	48	1	50	6	40	11	23	18
20.08.2002	73	6	67	2	54	1	36	11	76	6	82	5	67	6	39	23
23.08.2002	44	4	58	7	35	10	14	5	49	6	50	9	37	4	35	35
27.08.2002	33	6	36	1	38	5	19	3	30	6	27	7	31	13	23	12

Cla: Clearings plot 1, 3,102; C1b: Clearings plot 2, 101, 103; 1: 0.10 m; 2: 0.20 m; 3: 0.60 m; 4: 1.10 m;
SE: Standard error

	Sf1	SE	Sf2	SE	Sf3	SE	Sf4	SE	Mf1	SE	Mf2	SE	Mf3	SE	Mf4	SE
	[hPa]															
28.05.2002	77	9	78	3	59	2	38	1								
31.05.2002	73	9	73	7	56	2	37	5								
04.06.2002									55	4	59	9	41	7	32	15
07.06.2002	50	2	39	2	33	4	24	12								
11.06.2002	55	2	41	2	39	4	37	3	41	4	36	5	12	8	3	9
14.06.2002	31	5	37	2	29	5	7	12								
18.06.2002	48	5	38	10	28	8	12	6	15	1	22	4	0	4	-25	2
21.06.2002	50	9	45	5	35	2	48	41								
25.06.2002	34	5	39	3	28	6	15	8								
28.06.2002	75	8	76	12	54	7	31	1								
02.07.2002	54	5	65	1	50	1	29	1	44	2	37	2	21	2	-11	3
05.07.2002	37	14	31	15	29	3	34	17								
09.07.2002	76	3	80	1	59	3	36	1	51	3	43	5	29	4	-5	5
12.07.2002	86	1	89	3	67	4	39	1								
16.07.2002	103	9	98	6	73	3	45	2	62	8	71	3	41	4	14	4
19.07.2002	116	7	116	5	77	1	49	6								
23.07.2002	118	3	115	2	85	5	48	7	100	6	92	6	62	4	24	1
26.07.2002	161	7	150	11	121	4	80	4								
30.07.2002	70	7	62	8	62	5	69	2	43	5	47	8	41	10	28	7
02.08.2002	19	5	41	7	55	11	74	9								
06.08.2002	40	1	39	0	32	3	14	7	31	3	31	5	16	9	12	9
09.08.2002																
13.08.2002																
16.08.2002	55	2	52	3	38	3	15	2								
20.08.2002	78	7	75	6	57	3	39	0	52	2	58	3	39	2	24	8
23.08.2002	55	3	62	6	42	6	31	6								
27.08.2002	25	4	41	2	55	1	26	6	27	5	35	4	17	7	-4	8

Sf: Secondary forest; Mf: Mature forest; 1: 0.10 m; 2: 0.20 m; 3: 0.60 m; 4: 1.10 m; SE: Standard error

APPENDIX F**Solution Concentrations**

Vegetation: **Cl:** Clearings, **Sf:** Secondary forest, **Mf:** Mature forest

B Cl: Clearings burned in November 2001

Nutrients: K, Mg, Ca, Na, NO₃-N, NH₄-N, TON, TOC, TOP, PO₄-P, TOS, SO₄-S, pH

Solutions: **R 2100 m:** Rainfall 2100 m

R 2250 m: Rainfall 2250 m

TF: Throughfall

LP: Litter percolate

S1: Soil solution 0.15 m

S2: Soil solution 0.30 m

S3: Soil solution 1.00 m

ST: Stream water

SE: Standard error, **Sd:** Standard deviation

K	R 2100 m	R 2250 m	TF Cl	SE	TF Sf	SE	TF Mf	SE	TF B Cl	SE
29.05.00										
11.06.00	2.61	0.19	2.23	0.96	2.76	0.15	1.61	0.26		
25.06.00	0.25	0.15	2.20	0.80	2.27	0.19	1.38	0.13		
10.07.00	0.33	0.16	2.01	0.73	1.82	0.16	1.22	0.10		
23.07.00	0.47	0.33	2.58	0.90	3.33	0.21	2.26	0.33		
06.08.00		0.29	3.46	0.84	3.46	0.12	2.04	0.50		
21.08.00	2.83	0.44	5.05	0.75	6.14	0.15	3.69	0.53		
04.09.00	3.59		9.00	1.81	10.64	0.88	7.22	1.74		
18.09.00	3.95	1.08	13.02	4.39	13.80	2.46	8.68	1.37		
04.10.00	0.52	0.22	6.69	2.21	5.71	0.75	1.63	0.33		
19.10.00										
02.11.00	1.27	0.89	11.90	1.80	21.13	2.25	5.58	1.20		
16.11.00	0.59	0.18	4.64	0.39	5.20	0.34	1.90	0.49		
30.11.00	0.72	0.22	4.04	0.49	6.86	1.23	2.09	0.29		
14.12.00	1.11	0.24	3.49	0.78	4.65	0.10	2.16	0.28		
28.12.00	0.49	0.67	7.39	0.94	9.62	1.29	1.49	0.09		
12.01.01	1.02	0.16	8.23	0.69	5.56	0.41	1.46	0.19		
25.01.01	1.55	0.47	4.25	0.61	3.49		1.67	0.32		
09.02.01	1.46	1.06	5.13	0.01	4.32	0.03	2.07	0.31		
22.02.01	1.05	0.61	4.57	0.47	5.56	0.30	2.44	0.36		
09.03.01	2.64	1.37	12.73	2.83	15.51	3.60	4.06	0.49		
22.03.01	1.03	0.58	3.96	0.33	7.30	1.77	2.86	0.47		
06.04.01	0.46	0.27	2.56	0.61	3.75	0.50	1.97	0.28		
20.04.01	0.20	0.15	0.92	0.35	1.09	0.13	1.24	0.34		
02.05.01	0.20	0.18	0.84	0.28	1.26	0.08	0.74	0.09		
16.05.01	0.18	0.14	0.88	0.18	1.14	0.21	0.55	0.09	0.75	0.24
30.05.01	0.12	0.11	0.77	0.17	0.95	0.06	0.82	0.13	0.76	0.09
13.06.01	0.22	0.34	2.10	0.59	1.80	0.27	1.61	0.18	1.47	0.37
27.06.01	0.68	0.41	3.11	1.06	2.32	0.08	1.85	0.24	2.36	0.24
11.07.01	0.40	0.62	2.78	0.73	3.69	0.14	2.46	0.46	2.88	0.20
25.07.01	0.70	0.93	6.30	1.91	4.20	0.20	4.46	0.66	4.54	0.68
08.08.01	0.49	0.79	2.57	0.09	2.83	0.09	1.63	0.21	3.01	0.41
22.08.01		1.54	10.13	5.21	8.87	1.40				
05.09.01	1.74	2.61	15.35	2.37	33.21	9.22	9.38	3.16	13.11	3.08
19.09.01										
03.10.01	2.22	4.15	19.33	4.62	40.83	2.70	17.88	2.44	35.19	16.95
17.10.01	1.74	3.71	19.78	8.99	25.58	3.34	17.52	2.93	18.14	3.93
31.10.01	1.85	0.19	13.60	3.19	34.31	6.19	5.03	0.46	20.76	2.00
09.11.01	0.51	0.46	5.92	2.96	8.60	0.84	3.65	0.72	5.38	0.60
24.11.01	0.24	0.40	3.61	1.67	3.74	0.40	3.08	0.20	0.97	0.35
07.12.01	0.78	0.44	15.97	4.33	17.93	2.40	3.52	0.46	1.86	0.72
21.12.01										
04.01.02	0.58	0.38	4.74	0.87	12.37	2.73	3.86	0.30	0.80	0.21
18.01.02	0.39	0.56	3.75	1.08	6.06	0.33	3.68	0.56	1.40	0.75
01.02.02	2.03		15.24	5.15	18.71	8.08	5.87	0.45	3.60	0.79
15.02.02	0.58	1.22	8.47	1.05	9.39	1.36	4.70	0.93	0.79	0.11
07.03.02	0.26	0.19	3.39	0.35	7.37	2.08	2.93	0.40	0.37	0.15
21.03.02	0.28	0.11	1.60	0.74	2.88	0.43	1.39	0.13	0.42	0.32
05.04.02	0.06	0.04	1.30	0.62	2.36	0.40	2.29	0.53	0.37	0.09
18.04.02	0.22	0.11	1.22	0.22	3.65	0.50	2.34	0.46	0.42	0.17
01.05.02	0.09	0.79	0.29	0.08	1.44	0.15	1.78	0.15	0.16	0.05
15.05.02	0.16	0.05	1.05	0.28	2.97	0.20	4.41	0.72	0.28	0.09
29.05.02	0.17	0.45	1.09	0.16	2.99	0.30	2.00	0.28	0.26	0.09
12.06.02	0.54		1.39	0.42	3.14	0.16		0.42	0.58	0.22
26.06.02	0.21	1.65	1.22	0.41	2.11	0.37	0.04	1.15	0.57	0.21
10.07.02	0.55	0.15	4.62	1.42	5.71	1.96	0.04	0.07	1.20	0.43
24.07.02	0.34	0.28	3.69	1.48	5.61	0.22	0.07	0.40	0.96	0.25
07.08.02	0.40		3.51	0.72	3.83	0.19			0.65	0.17
21.08.02		0.21					0.08	0.16		

K	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S1 B Cl	SE
29.05.00									1.19	0.34	0.34	0.10	0.17	0.04		
11.06.00									1.47	0.41	0.43	0.05	0.18	0.05		
25.06.00									2.19	0.15	0.30	0.03	0.24	0.05		
10.07.00									1.36	0.49	0.17	0.01	0.13	0.03		
23.07.00									1.53	0.63	0.17	0.03	0.11	0.03		
06.08.00									1.49	0.60	0.17	0.04	0.19	0.06		
21.08.00									1.59	0.86	0.14	0.03	0.12	0.03		
04.09.00									1.54	0.96	0.20	0.06	0.18	0.03		
18.09.00									2.57	1.30	0.15		0.14	0.04		
04.10.00									1.25	0.82	0.30	0.03	0.12	0.02		
19.10.00									1.18	0.99	0.28	0.06	0.13	0.03		
02.11.00	20.21	5.91	10.73	1.02	5.41	0.44			1.70	1.17	2.10	0.51	0.17	0.06		
16.11.00	10.98	3.07	4.57	0.28	3.38	0.70			2.03	0.83	0.45	0.05	0.18	0.03		
30.11.00	10.86	2.77	4.78	0.51	3.35	0.90			1.42	0.62	0.25	0.07	0.23	0.07		
14.12.00	5.42	0.74	3.09	0.12	1.27	0.52			1.52	0.13	0.23	0.06	0.18	0.07		
28.12.00	3.87	0.42	4.51	0.31	1.14	0.13			2.65	1.84	0.18	0.05	0.13	0.05		
12.01.01	4.25	1.10	4.59	0.61	1.36	0.27			3.56	0.90	0.14	0.02	0.12	0.05		
25.01.01	5.26	1.56	2.74	0.25	0.92	0.25			2.08	0.29	0.14	0.05	0.12	0.03		
09.02.01	8.71	4.10	4.40	0.15	1.34	0.31			4.29	2.66	0.85	0.61	0.24	0.15		
22.02.01	12.46	4.52	4.91	0.20	2.19	0.54			1.64	0.39	0.22	0.06	0.20	0.11		
09.03.01	18.52	5.25	6.04	1.28	1.91	0.52			2.56	0.97	0.24	0.02	0.09	0.03		
22.03.01	13.45	3.94	4.57	0.12	2.63	0.25			0.97		0.19	0.03	0.20	0.12		
06.04.01	6.30	0.95	2.99	0.55	1.31	0.18			2.39	1.03	0.24		0.21	0.05		
20.04.01	2.59	1.17	0.98	0.09	0.96	0.13			1.32	0.85	0.10		0.18	0.07		
02.05.01	1.56	0.68	1.44	0.28	0.85	0.16			1.66	0.98	0.33	0.01	0.24	0.11		
16.05.01	3.10	0.48	1.04	0.14	0.65	2.07	4.41	1.44	1.41	0.69	0.15	0.03	0.21	0.04	1.95	0.56
30.05.01	2.89	0.55	0.88	0.09	0.72	0.36	2.86	0.36	1.36	0.62	0.13	0.03	0.15	0.07	1.88	0.62
13.06.01	4.88	1.22	1.09	0.05	0.36	0.18	5.50	0.05	1.03	0.15	0.06	0.03	0.19	0.09	2.01	1.17
27.06.01	4.71	0.86	1.00	0.13	0.37	0.18	6.24	1.33	1.40	0.27	0.14	0.04	0.19	0.08	3.06	1.86
11.07.01	4.47	0.65	1.95	0.46	0.46	0.13	4.77	0.62	2.89	0.15	0.17	0.02	0.12	0.05	3.20	2.09
25.07.01	3.62		1.53	0.69	0.77	0.34	3.62		0.77	0.40	0.15	0.02	0.14	0.03	3.91	2.36
08.08.01	7.92	3.39	1.42	0.11	0.42	0.24	7.36	2.98	2.98	0.26	0.18	0.02	0.20	0.07	3.16	2.06
22.08.01									2.93	0.32	0.21	0.04	0.20	0.05	3.08	2.08
05.09.01									4.38	0.48	0.28		0.26	0.04	3.08	2.28
19.09.01									5.96				0.29	0.10	0.54	
03.10.01	43.22	10.62	9.73		11.68	3.71	41.08	17.53	4.93				0.28		8.21	
17.10.01	41.24	6.88	9.98	1.02	11.68	6.81	52.89	7.39	3.27				0.43		0.85	
31.10.01	30.41	3.56	21.46	7.17	6.47	0.43	35.81	1.81	2.89				0.24	0.04	7.60	
09.11.01	26.94	12.66	6.46	0.31	3.63	0.90	33.48	12.05	3.13	5.32	0.44	0.12	0.23	0.04	8.81	4.15
24.11.01	12.71	12.98	4.06	0.65	2.37	0.41	25.89	13.27	2.18	13.18	0.43	0.07	0.21	0.04	16.67	12.05
07.12.01	18.91	5.56	11.33	4.74	2.19	0.47	84.10	35.46	2.72	11.79	0.45	0.13	0.44	0.11	38.84	1.36
21.12.01									0.83	11.98	0.36				35.22	5.50
04.01.02	12.18	6.63	6.50	1.84	2.08	0.59	92.65	53.54	3.46	10.80	0.45	0.07	0.20	0.03	39.04	11.27
18.01.02	5.01	3.06	3.99	0.44	1.75	0.60	18.12	8.62	2.48	7.89	0.39	0.09	0.18	0.04	36.60	9.44
01.02.02	25.31	8.98	7.38	1.02	2.20	0.46	44.56	10.87	1.94	9.99	0.42	0.08	0.28	0.07	39.03	8.68
15.02.02	7.59	1.18	5.49	0.12	1.84	0.50	16.86	4.97	2.16	7.60	0.46	0.18	0.20	0.05	39.00	11.67
07.03.02	8.08	2.75	4.57	0.61	1.43	0.48	20.13	2.90	1.93	5.22	0.37	0.09	0.17	0.04	34.38	14.82
21.03.02	5.73	1.25	2.87	0.41	1.89	0.49	11.23	2.12	1.58	3.05	0.30	0.05	0.22	0.05	30.55	16.60
05.04.02	5.22	0.86	2.06	0.21	1.41	0.69	7.24	1.82	1.25	3.02	0.34	0.01	0.16	0.05	24.27	13.29
18.04.02	5.02	3.08	2.66	0.21	1.96	0.87	11.10	2.48	1.27	2.26	0.40	0.07	0.17	0.05	22.91	13.77
01.05.02	2.08	0.76	0.93	0.10	0.92	0.35	3.06	0.85	1.07	1.27	2.67	2.11	0.11	0.04	6.94	2.21
15.05.02	2.07	0.38	1.54	0.74	2.10	0.91	3.15	0.31	0.78	0.93	0.23	0.01	0.13	0.03	8.08	4.50
29.05.02	2.67	0.53	1.09	0.31	1.71	0.66	3.18	0.53	0.50	0.87	0.28	0.04	0.14	0.03	6.77	3.03
12.06.02	4.34	0.73	3.31	0.25	2.18	0.46	5.72	0.85	0.88	0.79	0.35	0.03	0.17	0.04	6.80	2.86
26.06.02	4.09	0.58	1.31	0.48	2.50	0.86	3.18	0.56	0.74	0.69	0.28	0.03	0.17	0.05	10.68	5.79
10.07.02	3.31	0.03	1.75	0.18	0.92	0.31	2.91	0.62	0.46	0.67	0.34	0.06	0.18	0.04	7.22	3.00
24.07.02	6.70	1.58	2.19	1.03	3.43	1.33	3.85	0.93	0.46	0.79	0.27	0.01	0.61	0.32	9.67	5.55
07.08.02	5.32	0.31	2.44	0.72	2.03	0.74	3.81	0.82	0.42	0.73	0.28	0.07	0.18	0.07	7.58	3.22
21.08.02	4.52	0.87	2.34	0.73	1.39	0.50	2.87	0.81	0.29	0.59	0.37	0.17	0.15	0.05	10.24	6.79

K	S2 Cl	SE	S2 Sf	SE	S2 Mf	SE	S2 B Cl	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE	S3 B Cl	SE	ST
29.05.00	0.96	0.47	0.21	0.06	0.30	0.09			1.26	0.82	0.29	0.10	0.25	0.07			
11.06.00	1.64	0.79	0.16	0.04	0.19	0.05			0.60	0.36	0.27	0.08	0.18	0.03			0.49
25.06.00	1.07	0.48	0.18	0.03	0.24	0.08			0.51	0.25	0.31	0.06	0.19	0.04			
10.07.00	0.58	0.24	0.08	0.01	0.16	0.07			0.27	0.13	0.16	0.06	0.12	0.03			0.56
23.07.00	0.45	0.17	0.08	0.01	0.13	0.05			0.28	0.14	0.11	0.05	0.11	0.02			0.50
06.08.00	0.44	0.13	0.10	0.02	0.15	0.04			0.30	0.09	0.13	0.05	0.15	0.03			13.74
21.08.00	0.34	0.10	0.08	0.02	0.14	0.05			0.21	0.07	0.06		0.13	0.03			0.80
04.09.00	0.38	0.12	0.12	0.02	0.19	0.06			0.34	0.14	0.17	0.03	0.16	0.02			0.54
18.09.00	0.25	0.05	0.07		0.15	0.06			0.24	0.01			0.12	0.02			0.60
04.10.00	0.30	0.10	0.17	0.04	0.19	0.07			0.28	0.01			0.15	0.02			0.88
19.10.00	0.21	0.06	0.58		0.18	0.07			0.19	0.03			0.11	0.01			0.75
02.11.00	0.54	0.28	2.57	1.14	0.15	0.05			0.27		1.55	0.98	0.14	0.06			0.72
16.11.00	0.29	0.17	0.31	0.03	0.18	0.05			0.27	0.14			0.16	0.02			0.71
30.11.00	0.24	0.09	0.22	0.06	0.19	0.06			2.81	2.31	0.58		0.37	0.21			0.81
14.12.00	0.64	0.45	0.20	0.03	0.18	0.05			1.53	1.33	0.15	0.03	0.16	0.02			0.68
28.12.00	0.13	0.03	0.16	0.01	0.12	0.01			0.15		1.38	1.20	0.13	0.01			0.67
12.01.01	0.50	0.29	0.16	0.01	0.12	0.01			0.35	0.07	0.21	0.04	0.16	0.02			0.58
25.01.01	0.30	0.06	0.12	0.01	0.14	0.02			0.66	0.42	0.23	0.06	0.14	0.00			0.53
09.02.01	1.06	0.67	0.16	0.02	0.15	0.03			0.86	0.31	0.21	0.04	0.17	0.04			0.62
22.02.01	1.05	0.71	0.17	0.02	0.14	0.03			0.37	0.14	0.19	0.01	0.18	0.04			0.66
09.03.01	0.90	0.67	0.13	0.01	0.15	0.04			0.39	0.11	0.30	0.01	0.12	0.01			0.70
22.03.01	0.87	0.45	0.12	0.02	0.14	0.05			0.28	0.02			0.16	0.03			
06.04.01	0.61	0.37			0.09				0.39		0.19	0.02	0.15	0.03			0.83
20.04.01	0.59	0.44	0.14		0.08	0.02			0.06	0.01	0.18		0.11	0.03			0.70
02.05.01	0.74	0.46	0.33	0.02	0.21	0.07			0.38	0.11	0.39	0.03	0.17	0.03			0.56
16.05.01	0.54	0.34	0.14	0.02	0.16	0.03	1.21		0.23	0.01	0.17	0.01	0.18	0.04	0.35	0.10	0.63
30.05.01	0.48	0.34	0.17	0.03	0.16	0.02	1.17		0.87	0.34	0.16	0.05	0.16	0.04	0.61	0.15	0.65
13.06.01	0.19	0.05	0.12	0.00	0.16	0.00	0.33		0.29	0.12	0.11	0.06	0.22	0.05	0.38		0.66
27.06.01	0.76	0.35	0.18	0.08	0.19	0.03	1.34		0.17		0.27	0.04	0.25	0.07	0.37	0.10	0.95
11.07.01	0.21	0.37	0.15	0.03	0.16	0.02	1.29		0.34	0.08	0.24	0.05	0.17	0.04	0.28	0.06	0.76
25.07.01	3.29	0.28	0.18	0.04	0.15	0.00	0.91		0.88	0.19	0.16		0.13	0.02	0.25	0.02	0.78
08.08.01	0.12	0.35	0.13	0.01	0.16	0.03	1.16		0.22	0.08	0.27	0.06	0.15	0.03	0.24	0.03	0.77
22.08.01	0.17	0.19	0.14	0.04	0.16	0.05	0.73		0.41				0.16	0.05	0.28	0.04	0.80
05.09.01			1.40	1.01	0.21	0.04	0.44		0.50				0.20	0.01	0.21		0.84
19.09.01	0.06				0.22	0.06			0.29		0.15		0.71	0.38	0.24		0.71
03.10.01					0.54	0.11	1.58	0.68	0.37				0.27	0.13	0.34		0.99
17.10.01	2.39						0.46	0.02									0.94
31.10.01	2.31				0.17	0.04							0.18	0.04			1.24
09.11.01	1.69	11.66	0.20	0.04	0.14	0.03	12.67	11.40	1.20	0.37	0.18		0.22	0.05	0.83	0.45	1.16
24.11.01	1.63	3.76	0.18	0.03	0.26	0.06	4.90	3.37	0.44	0.11			0.26	0.11	0.71	0.35	1.28
07.12.01	1.60	3.69	0.36	0.02	0.41	0.23	10.56	0.94	1.24	0.05	0.68		0.35	0.13	0.57	0.12	1.11
21.12.01	0.21	0.07	0.28	0.13			24.88	4.88	0.75	0.07					0.31	0.01	
04.01.02	1.34	5.57	0.18	0.04	0.24	0.06	22.44	5.94	0.17	0.05			0.29	0.10	0.53	0.22	0.85
18.01.02	0.87	4.97	0.13	0.03	0.17	0.07	23.77	5.22	0.82	0.06	0.31		0.22	0.06	0.23	0.01	0.82
01.02.02	0.85	5.79	0.24	0.09	0.23	0.06	29.30	6.60	0.83	0.09	0.48	0.07	0.29	0.06	0.40	0.02	0.95
15.02.02	1.24	4.21	0.35	0.19	0.19	0.03	24.04	5.86	0.32	0.09			0.22	0.06	0.25	0.01	0.90
07.03.02	1.20	1.74	0.17	0.05	0.15	0.05	20.77	10.18	0.66	0.08	0.31		0.22	0.07	2.92	2.67	0.77
21.03.02	1.18	0.62	0.20	0.05	0.19	0.04	21.06	11.31	0.36	1.34	0.37	0.11	0.24	0.06	1.71	1.29	0.70
05.04.02	1.06	0.93	0.19	0.04	0.14	0.04	22.43	12.60	0.41	0.06	0.28	0.10	0.21	0.05	0.24	0.04	0.81
18.04.02	1.04	0.68	0.26	0.06	0.14	0.04	18.44	11.26	0.31	0.05	0.17	0.02	0.25	0.04	0.27	0.05	0.78
01.05.02	0.81	1.28	0.17	0.03	0.15	0.05	7.26	2.37	0.52	0.24	0.14		0.21	0.04	1.43	0.78	0.64
15.05.02	0.20	0.54	0.19	0.02	0.06		3.10	1.05	0.41	0.05	0.19	0.01	0.19	0.04	5.94	5.76	0.48
29.05.02	0.63	0.52	0.24	0.02	0.20	0.09	2.87	0.98	0.91		0.15	0.03	0.21	0.04	5.79	4.56	0.36
12.06.02	1.04	0.72	0.50	0.24	0.29	0.10	5.51	2.63	1.54	0.56	0.20		0.25	0.05	4.97	3.97	0.91
26.06.02	0.61	0.46	0.24	0.08	0.21	0.08	5.24	2.83	0.42	0.07			0.25	0.04	9.80	9.56	0.94
10.07.02	0.54	0.55	0.26	0.13	0.22	0.09	5.36	2.92	0.42	0.03			0.35	0.15	4.60	4.40	0.62
24.07.02	0.53	0.30	0.41	0.14	0.23	0.08	5.37	3.18	1.83	0.05			1.44	1.03	9.51	8.62	0.60
07.08.02	0.57	0.32	0.24	0.10	0.14	0.05	5.90	3.24	0.34	0.09	0.43	0.05	0.20	0.02	8.87	8.69	
21.08.02	1.42	0.50	0.24	0.09	0.13	0.07	6.23	4.14	0.43	0.16	0.38	0.19	0.18	0.06	14.01	10.75	0.92

Ca	R 2100 m	R 2250 m	TF Cl	SE	TF Sf	SE	TF Mf	SE	TF B Cl	SE
29.05.00										
11.06.00	0.11	0.09	0.08	0.00	0.12	0.03	0.13	0.01		
25.06.00	0.15	0.14	0.12	0.02	0.13	0.03	0.16	0.02		
10.07.00	0.12	0.12	0.11	0.01	0.08	0.01	0.18	0.03		
23.07.00	0.19	0.21	0.16	0.00	0.25	0.07	0.23	0.03		
06.08.00	0.10	0.10	0.20	0.12	0.15	0.05	0.16	0.04		
21.08.00	0.20	0.24	0.14	0.04	0.33	0.10	0.37	0.11		
04.09.00	0.25		0.56	0.16	0.64	0.31	0.62	0.11		
18.09.00	0.31	0.73	0.65	0.08	0.97	0.10	0.72	0.11		
04.10.00	0.17	0.11	0.25	0.05	0.46	0.00	0.12	0.01		
19.10.00										
02.11.00	0.11	0.30	0.42	0.10	1.31	0.19	0.38	0.09		
16.11.00	0.06	0.07	0.15	0.01	0.18	0.04	0.13	0.02		
30.11.00	0.07	0.14	0.21	0.04	0.40	0.08	0.30	0.04		
14.12.00	0.08	0.13	0.16	0.02	0.17	0.02	0.15	0.03		
28.12.00	0.05	0.05	0.18	0.02	0.26	0.11	0.09	0.01		
12.01.01	0.02	0.06	0.43	0.11	0.28	0.11	0.09	0.01		
25.01.01	0.06	0.06	0.14	0.04	0.09		0.11	0.01		
09.02.01	0.12	0.24	0.22	0.01	0.11	0.03	0.19	0.05		
22.02.01	0.09	0.15	0.18	0.02	0.15	0.04	0.17	0.03		
09.03.01	0.18	0.10	0.43	0.08	0.39	0.09	0.25	0.04		
22.03.01	0.13	0.15	0.16	0.02	0.14	0.03	0.24	0.03		
06.04.01	0.09	0.05	0.09	0.01	0.15	0.03	0.22	0.06		
20.04.01	0.04	0.04	0.05	0.01	0.05	0.01	0.10	0.02		
02.05.01	0.01	0.01	0.03	0.01	0.09	0.04	0.05	0.01		
16.05.01	0.07	0.09	0.20	0.10	0.18	0.04	0.11	0.02	0.09	0.03
30.05.01	0.08	0.09	0.08	0.01	0.13	0.08	0.10	0.01	0.08	0.00
13.06.01	0.15	0.13	0.08	0.00	0.20	0.04	0.21	0.04	0.09	0.01
27.06.01	0.09	0.13	0.10	0.01	0.14	0.03	0.24	0.04	0.12	0.00
11.07.01	0.17		0.14	0.03	0.34	0.12	0.46	0.15	0.25	0.03
25.07.01	0.22	0.20	0.36	0.06	0.35	0.08	0.85	0.20	0.33	0.06
08.08.01	0.19	0.16	0.27	0.08	0.23	0.06	0.22	0.06	0.17	0.03
22.08.01	0.42		0.94	0.51	0.40	0.11				
05.09.01	0.92	0.52	1.12	0.29	1.84	0.57	0.77	0.15	1.01	0.25
19.09.01										
03.10.01	0.52	0.68	0.94	0.25	3.46	0.60			1.39	0.55
17.10.01	0.59	0.81	0.84	0.24	1.79	0.56	2.16	0.44	0.69	0.15
31.10.01	0.41	0.11	0.86	0.31	2.82	0.25	1.01	0.23	1.20	0.42
09.11.01	0.13	0.21	0.32	0.13	0.35	0.13	0.31	0.06	0.14	0.01
24.11.01	0.10	0.21	0.17	0.07	0.17	0.05	0.24	0.08	0.13	0.01
07.12.01	0.11	0.19	0.28	0.05	0.68	0.19	0.12	0.03	0.22	0.05
21.12.01										
04.01.02	0.16	0.58	0.25	0.08	0.40	0.12	0.66	0.03	0.22	0.07
18.01.02	0.22	0.09	0.21	0.02	0.28	0.10	0.33	0.05	0.30	0.09
01.02.02	0.16	0.11	0.99	0.24	1.77	0.86	0.38	0.08	0.66	0.10
15.02.02	0.23	0.17	0.33	0.03	0.45	0.16	0.34	0.02	0.21	0.02
07.03.02	0.09	0.05	0.18	0.06	0.36	0.11	0.26	0.05	0.07	0.01
21.03.02	0.07	0.04	0.05	0.02	0.12	0.03	0.10	0.03	0.04	0.01
05.04.02	0.02		0.07	0.04	0.06	0.02	0.18	0.06	0.04	0.01
18.04.02	0.03	0.08	0.06	0.02	0.15	0.04	0.33	0.10	0.05	0.01
01.05.02	0.04	0.06	0.03	0.01	0.06	0.01	0.22	0.04	0.07	0.05
15.05.02	0.04	0.04	0.14	0.05	0.17	0.05	0.34	0.08	0.15	0.06
29.05.02	0.15	0.05	0.11	0.04	0.25	0.12	0.23	0.04	0.05	0.02
12.06.02	0.10		0.17	0.05	0.23	0.09	0.37	0.09	0.08	0.02
26.06.02	0.21	0.43	0.15	0.01	0.15	0.08	0.70	0.32	0.06	0.00
10.07.02	0.07	0.06	0.16	0.01	0.51	0.08	0.24	0.04	0.17	0.06
24.07.02	0.34	0.07	0.27	0.13	0.34	0.12	0.39	0.07	0.36	0.05
07.08.02	0.12		0.17	0.05	0.29	0.10			0.16	0.05
21.08.02		0.37					0.39	0.14		

Ca	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S1 B Cl	SE
29.05.00									1.44	0.69	0.31	0.08	0.28	0.07		
11.06.00									1.79	0.81	0.33	0.08	0.38	0.12		
25.06.00									2.41	0.40	0.28	0.05	0.36	0.10		
10.07.00									1.42	0.54	0.16	0.03	0.28	0.09		
23.07.00									1.72	0.75	0.26	0.10	0.31	0.12		
06.08.00									1.67	0.78	0.22	0.09	0.29	0.11		
21.08.00									2.08	1.18	0.27	0.14	0.34	0.10		
04.09.00									1.80	1.23	0.21	0.07	0.30	0.12		
18.09.00									1.45	1.04	0.16		0.24	0.09		
04.10.00									1.47	0.94	0.31	0.06	0.24	0.11		
19.10.00									1.29	0.91	0.28	0.12	0.27	0.13		
02.11.00	1.69	0.47	1.28	0.00	0.85	0.18			1.48	0.87	0.61	0.18	0.30	0.15		
16.11.00	2.63	0.99	0.71	0.07	0.96	0.20			1.81	0.74	0.25	0.07	0.54	0.25		
30.11.00	2.62	0.62	0.91	0.04	0.94	0.25			1.50	0.56	0.13	0.01	0.53	0.05		
14.12.00	0.98	0.14	0.64	0.01	1.19	0.07			1.28	0.43	0.14	0.02	0.25	0.12		
28.12.00	0.46	0.04	0.40	0.06	0.63	0.08			1.64	0.65	0.13	0.02	0.24	0.11		
12.01.01	0.95	0.16	0.47	0.05	0.51	0.14			2.08	0.52	0.11	0.01	0.17	0.09		
25.01.01	1.09	0.30	0.39	0.10	0.38	0.07			1.28	0.16	0.11	0.02	0.18	0.07		
09.02.01	2.53	1.07	0.48	0.18	0.69	0.10			1.77	0.50	0.14	0.02	0.27	0.12		
22.02.01	2.13	0.60	0.54	0.20	1.32	0.48			1.76	0.39	0.14	0.02	0.30	0.14		
09.03.01	2.44	1.29	1.19	0.34	1.03	0.23			1.62	0.05	0.19	0.01	0.23	0.15		
22.03.01	3.33	1.28	1.60	0.13	1.34	0.29			1.31	0.01	0.16	0.04	0.27	0.13		
06.04.01	2.45	0.93	1.09	0.04	0.84	0.10			1.24	0.38	0.17		0.46	0.04		
20.04.01	0.66	0.27	0.26	0.01	0.42	0.05			0.81	0.25	0.17	0.06	0.37	0.14		
02.05.01	0.79	0.50	0.23	0.03	0.51	0.13			0.75	0.24	0.13	0.01	0.31	0.15		
16.05.01	0.68	0.25	0.30	0.03	0.38	0.11	0.91	0.07	0.75	0.31	0.17	0.03	0.26	0.12	0.73	0.32
30.05.01	0.61	0.19	0.26	0.01	0.16	0.15	0.58	0.18	0.68	0.28	0.13	0.02	0.27	0.13	0.44	0.10
13.06.01	1.30	0.37	0.52	0.14	0.97	0.37	1.31	0.31	0.88	0.20	0.14	0.03	0.22	0.11	0.60	0.23
27.06.01	1.51	0.23	0.63	0.11	1.30	0.43	1.50	0.14	1.14	0.36	0.13	0.03	0.20	0.07	0.84	0.43
11.07.01	2.02	0.28	1.09	0.36	1.72	0.75	1.23	0.44	1.73	0.56	0.17	0.04	0.25	0.09	0.81	0.40
25.07.01	1.39		0.87	0.04	3.05	1.09	1.39		1.23	0.51	0.19	0.03	0.23	0.08	0.95	0.41
08.08.01	2.18	0.80	0.91	0.07	0.91	0.26	1.29	0.39	1.75	0.48	0.21	0.02	0.28	0.12	0.74	0.25
22.08.01									1.85	0.49	0.25	0.03	0.29	0.09	0.84	0.32
05.09.01									4.09		0.38		0.36	0.06	0.95	0.38
19.09.01									3.88				0.32	0.08	0.69	
03.10.01	3.09	1.66	2.97		2.86	1.07	3.18	1.47	4.51				0.24		2.17	
17.10.01	6.28	1.78	4.09	0.57	3.53		5.44	0.82	4.71				0.23		0.39	
31.10.01	2.66	0.41	4.06	1.69	0.97	0.13	2.49	0.62	3.48				0.25	0.06	2.26	
09.11.01	4.22	1.74	0.65	0.01	1.28	0.18	4.51	1.40	1.52	0.34	0.35	0.04	0.73	0.53	1.26	0.26
24.11.01	3.25	1.08	0.59	0.07	0.84	0.11	2.09	0.18	1.30	0.45	0.30	0.06	0.25	0.08	1.38	0.25
07.12.01	3.93	0.81	1.51	0.54	0.60	0.07	4.42	2.52	1.47	0.40	0.43	0.11	0.27	0.05	1.68	0.09
21.12.01									1.34	0.71	0.36				3.53	0.89
04.01.02	2.86	0.55	1.80	1.19	1.10	0.20	3.44	1.58	1.93	0.38	0.34	0.03	0.25	0.08	2.87	0.78
18.01.02	2.20	0.11	0.90	0.11	1.23	0.36	1.56	0.28	1.77	0.55	0.25	0.02	0.24	0.07	3.31	0.77
01.02.02	2.17	0.91	1.29	0.15	0.84	0.16	3.95	0.72	1.54	0.72	0.28	0.07	0.24	0.06	3.71	0.50
15.02.02	2.17	0.47	1.00	0.07	0.75	0.11	1.75	0.42	1.81	0.60	0.34	0.06	0.25	0.07	4.01	0.65
07.03.02	2.08	0.43	0.98	0.08	0.71	0.10	2.60	0.28	1.83	0.87	0.33	0.10	0.31	0.08	3.56	0.36
21.03.02	1.19	0.19	1.01	0.38	0.88	0.18	1.10	0.18	1.53	0.71	0.26	0.09	0.23	0.07	2.58	0.44
05.04.02	0.93	0.17	0.57	0.06	0.92	0.20	0.82	0.25	1.23	1.43	0.46	0.15	0.24	0.08	3.27	1.18
18.04.02	1.28	0.62	0.82	0.11	1.05	0.21	1.85	0.53	1.55	1.45	0.29	0.10	0.24	0.07	3.00	1.41
01.05.02	0.27	0.13	0.29	0.09	0.68	0.10	0.48	0.13	0.70	0.32	0.17	0.09	0.17	0.06	0.72	0.35
15.05.02	0.56	0.29	0.77	0.38	0.88	0.13	0.99	0.22	0.80	0.37	0.27	0.10	0.20	0.07	0.88	0.43
29.05.02	0.48	0.31	0.53	0.14	1.18	0.27	0.88	0.22	1.05	0.36	0.34	0.14	0.22	0.07	0.81	0.06
12.06.02	1.56	0.80	0.88	0.00	1.20	0.25	2.05	1.16	1.88	0.84	0.37	0.14	0.20	0.05	0.76	0.14
26.06.02	1.10	0.54	0.99	0.18	1.34	0.26	1.51	0.71	1.06	0.26	0.35	0.15	0.21	0.08	0.79	0.15
10.07.02	1.20	0.52	1.00	0.19	0.66	0.13	1.38	0.62	1.18	0.33	0.45	0.15	0.22	0.07	0.77	0.21
24.07.02	1.74	0.71	1.63	0.14	1.41	0.29	2.30	0.84	0.99	0.33	0.39	0.14	0.26	0.08	0.94	0.29
07.08.02	1.17	0.54	0.82	0.08	1.69	0.49	1.70	0.53	1.17	0.58	0.47	0.21	0.19	0.08	0.74	0.15
21.08.02	1.11	0.25	0.88	0.12	1.99	0.69	1.12	0.31	1.37	0.51	0.46	0.15	0.24	0.06	0.80	0.15

Ca	S2 Cl	SE	S2 Sf	SE	S2 Mf	SE	S2 B Cl	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE	S3 B Cl	SE	ST
29.05.00	1.41	0.89	0.23	0.05	0.37	0.11			1.56	0.93	0.25	0.04	0.29	0.09			
11.06.00	1.80	1.23	0.23	0.06	0.28	0.11			1.11	0.57	0.31	0.03	0.28	0.10			0.12
25.06.00	1.60	1.12	0.19	0.05	0.31	0.11			0.94	0.36	0.21	0.01	0.26	0.09			
10.07.00	1.34	0.93	0.10	0.03	0.26	0.10			0.76	0.35	0.18	0.04	0.25	0.11			0.39
23.07.00	1.22	0.87	0.12	0.03	0.28	0.11			0.75	0.33	0.29	0.15	0.28	0.11			0.13
06.08.00	1.03	0.69	0.08	0.03	0.23	0.09			0.70	0.28	0.17	0.09	0.25	0.10			0.14
21.08.00	0.89	0.59	0.09	0.03	0.27	0.10			0.72	0.30	0.10		0.26	0.10			0.16
04.09.00	0.81	0.52	0.08	0.03	0.28	0.10			0.54	0.20	0.22	0.07	0.26	0.09			0.11
18.09.00	0.83	0.57	0.12		0.20	0.09			0.45	0.08			0.22	0.08			0.11
04.10.00	0.89	0.59	0.17	0.01	0.28	0.10			0.42	0.08			0.24	0.09			0.22
19.10.00	0.73	0.48	0.25	0.07	0.26	0.10			0.37	0.09			0.17	0.07			0.33
02.11.00	1.09	0.68	0.76	0.03	0.26	0.10			0.39		0.92		0.19	0.05			0.14
16.11.00	0.70	0.31	0.16	0.02	0.26	0.08			0.51	0.16			0.25	0.05			0.14
30.11.00	0.63	0.23	0.17	0.08	0.26	0.14			0.35	0.12							0.12
14.12.00	0.90	0.19	0.13	0.03	0.25	0.08			0.53	0.17	0.13	0.02	0.21	0.07			0.13
28.12.00	0.67	0.19	0.15	0.03	0.20	0.09			0.26		0.25	0.09	0.24	0.11			0.14
12.01.01	0.80	0.09	0.14	0.01	0.17	0.09			0.51	0.17	0.20	0.06	0.21	0.05			0.16
25.01.01	1.21	0.24	0.11	0.04	0.24	0.06			0.57	0.21	0.28	0.05	0.24	0.06			0.14
09.02.01	1.14	0.32	0.12	0.04	0.22	0.08			0.68	0.30	0.16	0.02	0.21	0.06			0.16
22.02.01	1.01	0.33	0.13	0.05	0.22	0.08			0.57	0.15	0.21	0.04	0.20	0.06			0.15
09.03.01	0.86	0.38	0.16	0.03	0.22	0.07			0.60	0.12	0.32	0.10	0.15	0.04			0.18
22.03.01	0.97	0.31	0.10	0.04	0.24	0.09			0.41	0.05			0.19	0.05			
06.04.01	1.10	0.37			0.28				0.73		0.24	0.09	0.23	0.00			0.13
20.04.01	1.12	0.25	0.24		0.18	0.10			0.63	0.32	0.22		0.10	0.03			0.19
02.05.01	0.70	0.09	0.12	0.05	0.27	0.11			0.59	0.19	0.26	0.10	0.20	0.05			0.10
16.05.01	0.54	0.19	0.10	0.02	0.25	0.11	0.19		0.35	0.08	0.21	0.07	0.17	0.05	0.74	0.19	0.20
30.05.01	0.55	0.24	0.12	0.02	0.24	0.09	0.16		0.65	0.17	0.15	0.02	0.18	0.05	0.73	0.16	0.20
13.06.01	0.90	0.45	0.11	0.02	0.21	0.07	0.41		0.64	0.29	0.22		0.17	0.04	0.43	0.03	0.18
27.06.01	0.58	0.33	0.11	0.02	0.16	0.05	0.16		0.54		0.25	0.06	0.17	0.03	0.47	0.08	0.14
11.07.01	0.79	0.32	0.08	0.01	0.23	0.10	0.14		0.72	0.17	0.17	0.04	0.25	0.07	0.48	0.07	0.13
25.07.01	1.60	0.44	0.08	0.01	0.28	0.09	0.13		0.93	0.12	0.23		0.17	0.05	0.51	0.05	0.14
08.08.01	1.00	0.40	0.11	0.01	0.27	0.09	0.15		0.99	0.19	0.30	0.05	0.23	0.07	0.45	0.09	0.20
22.08.01	1.05	0.40	0.13	0.03	0.26	0.10	0.18		1.11				0.24	0.11	0.42	0.14	0.16
05.09.01			0.17	0.01	0.28	0.09	0.22		1.08				0.28	0.09	0.33		0.15
19.09.01	1.35				0.37	0.11			1.00		0.15		0.50	0.17	0.17		0.08
03.10.01	2.57				0.64	0.05	0.41	0.05	0.45				0.33	0.15	0.20		0.24
17.10.01	3.03						0.40	0.02	0.56								0.17
31.10.01	2.68				0.31	0.09							0.28	0.11			0.11
09.11.01	1.44	0.35	0.13	0.02	0.25	0.09	0.68	0.11	0.75	0.25	0.15		0.29	0.10	0.67	0.46	0.24
24.11.01	1.55	0.39	0.12	0.02	0.29	0.09	0.71	0.13	0.66	0.23			0.26	0.08	0.50	0.25	0.24
07.12.01	1.29	0.29	0.41	0.09	0.20	0.08	0.87	0.21	1.14	0.10	0.20		0.30	0.12	0.37	0.06	0.08
21.12.01	1.08	0.49	0.17	0.02			1.76	0.58	1.11	0.23					0.33	0.03	
04.01.02	1.47	0.39	0.21	0.05	0.33	0.09	1.11	0.19	0.48	0.07			0.23	0.07	0.37	0.11	0.36
18.01.02	1.36	0.44	0.16	0.03	0.28	0.11	1.37	0.11	0.95	0.12	0.25		0.30	0.12	0.35	0.10	0.14
01.02.02	1.63	0.56	0.15	0.03	0.29	0.10	1.70	0.48	0.99	0.17	0.27	0.05	0.31	0.11	0.33	0.09	
15.02.02	1.77	0.60	0.29	0.09	0.35	0.02	2.41	0.57	0.80	0.17			0.28	0.10	0.38	0.13	
07.03.02	1.76	0.58	0.19	0.01	0.33	0.12	2.11	0.52	0.96	0.22	0.40		0.36	0.10	0.83	0.48	0.14
21.03.02	1.49	0.75	0.25	0.09	0.25	0.10	1.43	0.53	0.81	0.17	0.81	0.54	0.26	0.10	0.56	0.12	0.18
05.04.02	1.34	0.62	0.35	0.23	0.24	0.11	2.23	0.84	0.87	0.17	0.30	0.15	0.29	0.14	0.59	0.18	0.19
18.04.02	1.25	0.67	0.28	0.12	0.27	0.12	2.03	0.74	0.71	0.16	0.29	0.15	0.31	0.13	0.34	0.13	
01.05.02	0.75	0.44	0.25	0.12	0.23	0.07	0.48	0.17	0.70	0.13	0.19	0.07	0.19	0.06	0.18	0.08	0.39
15.05.02	1.01	0.48	0.19	0.06	0.10		0.40	0.16	0.63	0.17	0.13	0.02	0.21	0.07	0.17	0.04	0.24
29.05.02	1.12	0.71	0.21	0.07	0.26	0.10	0.44	0.12	0.46	0.02	0.36	0.11	0.21	0.06	0.17	0.11	0.16
12.06.02	1.20	0.61	0.18	0.02	0.37	0.12	0.49	0.09	0.13	0.00	0.07		0.35	0.15	0.18	0.01	0.16
26.06.02	1.38	0.94	0.24	0.08	0.27	0.10	0.49	0.23	0.49	0.06			0.25	0.09	0.22	0.01	0.12
10.07.02	1.41	1.08	0.35	0.07	0.30	0.10	0.80	0.05	0.62	0.02			0.22	0.07	0.21	0.04	0.10
24.07.02			0.23	0.05	0.27	0.08	0.65	0.31	0.42	0.05			0.27	0.07	0.22	0.10	0.03
07.08.02	1.42	0.92	0.21	0.04	0.34	0.20	0.66	0.28	0.57	0.10	0.04	0.04	0.23	0.06	0.26	0.09	
21.08.02	1.79	1.32	0.25	0.06	0.22	0.13	0.53	0.33	0.45	0.03	0.25	0.08	0.21	0.07	0.27	0.08	0.14

Mg	R 2100 m	R 2250 m	TF Cl	SE	TF Sf	SE	TF Mf	SE	TF B Cl	SE
29.05.00										
11.06.00	0.04	0.03	0.04	0.00	0.06	0.01	0.07	0.01	-	-
25.06.00	0.07	0.07	0.06	0.01	0.05	0.01	0.08	0.01	-	-
10.07.00	0.05	0.04	0.05	0.01	0.04	0.01	0.09	0.01	-	-
23.07.00	0.09	0.07	0.12	0.02	0.15	0.04	0.18	0.03	-	-
06.08.00	0.05	0.06	0.06	0.02	0.08	0.03	0.11	0.03	-	-
21.08.00	0.11	0.15	0.11	0.04	0.22	0.06	0.25	0.05	-	-
04.09.00	0.16		0.39	0.14	0.51	0.22	0.39	0.05	-	-
18.09.00	0.17	0.29	0.47	0.08	0.78	0.17	0.55	0.10	-	-
04.10.00	0.07	0.03	0.13	0.05	0.25	0.02	0.06	0.01	-	-
19.10.00									-	-
02.11.00	0.05	0.13	0.30	0.13	0.99	0.25	0.25	0.07	-	-
16.11.00	0.03	0.02	0.08	0.01	0.09	0.02	0.07	0.02	-	-
30.11.00	0.02	0.04	0.09	0.03	0.30	0.05	0.18	0.02	-	-
14.12.00	0.02	0.07	0.07	0.02	0.14	0.03	0.11	0.02	-	-
28.12.00	0.03	0.03	0.15	0.01	0.31	0.12	0.05	0.01	-	-
12.01.01	0.03	0.03	0.35	0.10	0.22	0.10	0.06	0.00	-	-
25.01.01	0.03	0.04	0.10	0.03	0.04		0.07	0.00	-	-
09.02.01	0.06	0.05	0.13	0.02	0.04	0.01	0.11	0.03	-	-
22.02.01	0.03	0.05	0.13	0.03	0.08	0.02	0.11	0.02	-	-
09.03.01	0.09	0.06	0.35	0.09	0.32	0.10	0.17	0.03	-	-
22.03.01		0.09	0.13	0.02	0.06	0.00	0.17	0.02	-	-
06.04.01	0.03	0.02	0.04	0.01	0.08	0.03	0.14	0.06	-	-
20.04.01	0.02	0.02	0.03	0.01	0.03	0.00	0.06	0.01	-	-
02.05.01	0.01	0.01	0.02	0.01	0.02	0.00	0.02	0.01	-	-
16.05.01	0.02	0.04	0.09	0.05	0.07	0.02	0.11	0.07	0.04	0.01
30.05.01	0.03	0.03	0.03	0.01	0.05	0.02	0.05	0.01	0.03	0.01
13.06.01	0.07	0.05	0.04	0.02	0.08	0.03	0.12	0.02	0.07	0.01
27.06.01	0.04	0.05	0.05	0.03	0.07	0.01	0.13	0.02	0.09	0.02
11.07.01	0.09	0.12	0.08	0.07	0.18	0.06	0.26	0.07	0.19	0.05
25.07.01	0.11	0.11	0.27	0.08	0.20	0.06	0.49	0.10	0.31	0.14
08.08.01	0.09	0.08	0.17	0.03	0.13	0.04	0.11	0.03	0.12	0.03
22.08.01		0.18	0.72		0.27	0.09				
05.09.01	0.41	0.31	0.74	0.09	1.30	0.21	0.46	0.09	0.72	0.17
19.09.01										
03.10.01	0.21	0.42	0.69	0.19	2.60	0.45	1.39	0.28	1.08	0.50
17.10.01	0.30	0.50	0.66	0.16	1.24	0.50	0.65	0.16	0.54	0.17
31.10.01	0.18	0.04	0.68	0.32	1.85	0.14	0.19	0.05	1.08	0.44
09.11.01	0.05	0.09	0.19	0.10	0.25	0.12	0.13	0.04	0.08	0.02
24.11.01	0.04	0.09	0.10	0.05	0.09	0.04	0.13	0.01	0.07	0.01
07.12.01	0.05	0.07	0.18	0.04	0.37	0.04	0.06	0.02	0.08	0.02
21.12.01										
04.01.02	0.08	0.05	0.14	0.03	0.24	0.06	0.20	0.06	0.10	0.04
18.01.02	0.07	0.03	0.12	0.07	0.12	0.04	0.17	0.04	0.16	0.10
01.02.02	0.17		0.66	0.30	0.63	0.61	0.29	0.09	0.12	0.05
15.02.02	0.09	0.07	0.25	0.07	0.25	0.11	0.25	0.01	0.10	0.01
07.03.02	0.04	0.01	0.11	0.05	0.20	0.04	0.18	0.04	0.02	0.00
21.03.02	0.02	0.06	0.03	0.01	0.05	0.00	0.06	0.02	0.02	0.00
05.04.02		0.01	0.04	0.02	0.03	0.01	0.10	0.04	0.02	0.01
18.04.02	0.01	0.03	0.03	0.02	0.10	0.04	0.16	0.05	0.02	0.00
01.05.02	0.04	0.02	0.01	0.00	0.03	0.01	0.11	0.02	0.03	0.02
15.05.02	0.01	0.01	0.06	0.02	0.08	0.03	0.18	0.04	0.06	0.02
29.05.02	0.06	0.02	0.05	0.02	0.10	0.04	0.13	0.03	0.03	0.01
12.06.02	0.05		0.09	0.04	0.10	0.04			0.03	0.01
26.06.02	0.08	0.18	0.09	0.01	0.07	0.03	0.19	0.04	0.03	0.00
10.07.02	0.02	0.01	0.10	0.02	0.25	0.07	0.15	0.04	0.06	0.02
24.07.02	0.12	0.01	0.17	0.08	0.20	0.07	0.22	0.07	0.15	0.03
07.08.02	0.04		0.11	0.04	0.18	0.03			0.07	0.03
21.08.02							0.24	0.08		

Mg	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S1 B Cl	SE
29.05.00									0.50	0.16	0.19	0.06	0.15	0.05		
11.06.00									0.48	0.09	0.27	0.09	0.19	0.06		
25.06.00									0.45	0.04	0.19	0.05	0.20	0.08		
10.07.00									0.35	0.00	0.16	0.05	0.15	0.07		
23.07.00									0.41	0.05	0.17	0.05	0.15	0.06		
06.08.00									0.43	0.08	0.18	0.06	0.15	0.07		
21.08.00									0.49	0.15	0.17	0.06	0.16	0.04		
04.09.00									0.47	0.16	0.16	0.06	0.13	0.03		
18.09.00									0.41	0.16	0.16		0.11	0.03		
04.10.00									0.39	0.14	0.25	0.03	0.10	0.03		
19.10.00									0.34	0.15	0.22	0.05	0.16	0.08		
02.11.00	0.75	0.22	0.66	0.15	0.41	0.12			0.46	0.20	0.45	0.09	0.17	0.09		
16.11.00	0.72	0.12	0.42	0.09	0.54	0.09			0.45	0.11	0.17	0.03	0.19	0.11		
30.11.00	0.83	0.01	0.49	0.06	0.56	0.14			0.40	0.03	0.13	0.03	0.27	0.16		
14.12.00	0.45	0.05	0.31	0.03	0.40	0.03			0.35	0.03	0.12	0.03	0.18	0.13		
28.12.00	0.21	0.02	0.21	0.01	0.21	0.04			0.52	0.11	0.09	0.02	0.13	0.08		
12.01.01	0.31	0.01	0.22	0.02	0.20	0.05			0.60	0.17	0.08	0.01	0.14	0.09		
25.01.01	0.35	0.02	0.21	0.05	0.21	0.04			0.32	0.02	0.09	0.01	0.12	0.07		
09.02.01	0.67	0.13	0.22	0.04	0.37	0.07			0.49	0.11	0.26	0.13	0.15	0.08		
22.02.01	0.99	0.31	0.19	0.06	0.42	0.09			0.49	0.06	0.15	0.05	0.15	0.08		
09.03.01	1.31	0.67	0.67	0.38	0.85	0.18			0.44	0.08	0.22	0.05	0.09	0.04		
22.03.01	1.21	0.35	0.67	0.11	0.63	0.13			0.44	0.06	0.16	0.07	0.15	0.09		
06.04.01	0.77	0.16	0.48	0.04	0.55	0.16			0.34	0.13	0.17		0.25	0.10		
20.04.01	0.24	0.06	0.11	0.01	0.21	0.02			0.20	0.03	0.08		0.21	0.10		
02.05.01	0.32	0.19	0.10	0.01	0.25	0.05			0.21	0.04	0.08	0.02	0.14	0.07		
16.05.01	0.25	0.11	0.14	0.02	0.17	0.01	0.40	0.05	0.24	0.06	0.11	0.02	0.12	0.06	0.36	0.17
30.05.01	0.26	0.08	0.12	0.01	0.18	0.04	0.24	0.08	0.20	0.06	0.09	0.02	0.14	0.07	0.19	0.05
13.06.01	0.54	0.14	0.26	0.11	0.26	0.07	0.50	0.10	0.27	0.06	0.10	0.03	0.13	0.05	0.31	0.12
27.06.01	0.52	0.03	0.22	0.06	0.30	0.09	0.50	0.23	0.42	0.12	0.11	0.03	0.13	0.07	0.48	0.22
11.07.01	1.01	0.14	0.52	0.19	0.55	0.16	0.78	0.35	0.52	0.08	0.13	0.04	0.16	0.07	0.50	0.29
25.07.01	0.55		0.36	0.02	0.93	0.17	0.55		0.34	0.03	0.13	0.04	0.09	0.03	0.63	0.33
08.08.01	1.30	0.56	0.41	0.07	0.26	0.13	0.96	0.61	0.52	0.05	0.17	0.02	0.11	0.03	0.45	0.22
22.08.01									0.52	0.05	0.18	0.04	0.12	0.03	0.48	0.24
05.09.01									0.76	0.08	0.25		0.14	0.02	0.52	0.27
19.09.01									1.05				0.15	0.05	0.40	
03.10.01	1.95	1.23	1.13		1.38	0.43	1.54	0.68	1.12				0.11		1.35	
17.10.01	4.14	0.91	1.35	0.70	2.00		3.42	0.66	0.99				0.13		0.21	
31.10.01	1.31	0.32	1.58	0.52	0.53	0.14	1.39	0.29	0.76				0.12	0.01	1.38	
09.11.01	2.58	0.86	0.41	0.03	0.68	0.03	2.32	0.64	0.54	0.21	0.27	0.02	0.12	0.01	0.77	0.20
24.11.01	1.32	0.40	0.25	0.05	0.35	0.07	0.82	0.07	0.53	0.26	0.19	0.05	0.12	0.03	0.84	0.22
07.12.01	1.88	0.49	0.65	0.31	0.27	0.06	3.34	2.19	0.62	0.30	0.23	0.06	0.12	0.02	1.00	0.11
21.12.01									0.34	0.45	0.26				2.09	0.72
04.01.02	1.38	0.38	0.36	0.13	0.40	0.07	2.90	1.86	0.85	0.28	0.19	0.03	0.11	0.03	1.82	0.68
18.01.02	0.96	0.13	0.32	0.04	0.51	0.19	1.59	0.84	0.71	0.34	0.16	0.03	0.12	0.03	2.07	0.70
01.02.02	2.10	0.65	0.21	0.05	0.37	0.08	4.08	0.82	0.59	0.45	0.17	0.05	0.10	0.03	2.21	0.43
15.02.02	0.99	0.27	0.36	0.13	0.34	0.07	1.84	0.93	0.69	0.39	0.15	0.05	0.09	0.03	2.14	0.40
07.03.02	1.00	0.24	0.35	0.04	0.31	0.07	2.74	0.94	0.62	0.56	0.21	0.06	0.11	0.03	1.81	0.13
21.03.02	0.51	0.14	0.30	0.05	0.27	0.08	0.99	0.34	0.59	0.55	0.21	0.07	0.14	0.04	1.44	0.36
05.04.02	0.49	0.14	0.23	0.03	0.40	0.10	0.72	0.28	0.46	0.77	0.24	0.07	0.11	0.03	1.53	0.62
18.04.02	0.51	0.19	0.29	0.02	0.30	0.11	1.45	0.57	0.53	0.86	0.24	0.08	0.10	0.03	1.61	0.77
01.05.02	0.12	0.08	0.10	0.02	0.29	0.05	0.47	0.21	0.20	0.16	0.11	0.05	0.07	0.02	0.35	0.16
15.05.02	0.30	0.14	0.28	0.11	0.36	0.08	0.83	0.27	0.26	0.10	0.17	0.07	0.08	0.03	0.33	0.13
29.05.02	0.22	0.19	0.16	0.02	0.55	0.13	0.66	0.13	0.30	0.01	0.23	0.10	0.09	0.02	0.24	0.09
12.06.02	0.84	0.19	0.27	0.01	0.58	0.17	1.34	0.49	0.32	0.01	0.19	0.02	0.08	0.02	0.32	0.09
26.06.02	0.62	0.14	0.30	0.02	0.65	0.17	0.93	0.37	0.48	0.10	0.18	0.02	0.05	0.03	0.37	0.11
10.07.02	0.56	0.15	0.34	0.03	0.25	0.07	0.85	0.32	0.35	0.09	0.20	0.03	0.08	0.03	0.32	0.11
24.07.02	1.34	0.14	0.48	0.16	0.66	0.16	1.73	0.33	0.29	0.06	0.25	0.09	0.09	0.03	0.34	0.10
07.08.02	0.66	0.24	0.36	0.03	0.74	0.19	1.34	0.45	0.42	0.04	0.28	0.10	0.08	0.03	0.29	0.02
21.08.02	0.60	0.09	0.31	0.02	1.04	0.47	0.94	0.34	0.33	0.03	0.30	0.13	0.09	0.03	0.25	0.01

Mg	S2 Cl	SE	S2 Sf	SE	S2 Mf	SE	S2 B Cl	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE	S3 B Cl	SE	ST
29.05.00	0.68	0.35	0.23	0.07	0.20	0.07			0.75	0.37	0.24	0.06	0.13	0.02			
11.06.00	0.76	0.40	0.20	0.06	0.14	0.06			0.51	0.18	0.26	0.07	0.13	0.02			0.06
25.06.00	0.66	0.34	0.17	0.06	0.18	0.08			0.42	0.11	0.25	0.06	0.12	0.02			
10.07.00	0.55	0.27	0.12	0.04	0.15	0.07			0.36	0.09	0.19	0.07	0.12	0.02			0.14
23.07.00	0.47	0.23	0.11	0.04	0.15	0.07			0.32	0.07	0.21	0.12	0.12	0.02			0.07
06.08.00	0.40	0.16	0.09	0.04	0.16	0.08			0.33	0.07	0.17	0.10	0.13	0.03			0.08
21.08.00	0.36	0.15	0.08	0.03	0.14	0.06			0.29	0.07	0.06		0.13	0.03			0.08
04.09.00	0.35	0.14	0.09	0.04	0.15	0.07			0.30	0.05	0.20	0.09	0.17	0.06			0.05
18.09.00	0.32	0.15	0.07		0.14	0.06			0.23	0.04			0.16	0.06			0.05
04.10.00	0.30	0.14	0.11	0.03	0.15	0.07			0.21	0.07			0.17	0.07			0.12
19.10.00	0.27	0.15	0.18		0.15	0.07			0.21	0.05			0.12	0.02			0.12
02.11.00	0.39	0.22	0.64	0.20	0.15	0.07			0.27	0.08	0.61	0.03	0.12	0.02			0.07
16.11.00	0.22	0.05	0.14	0.03	0.15	0.07			0.42	0.18			0.13	0.02			0.05
30.11.00	0.33	0.03	0.15	0.05	0.15	0.08			0.44	0.20	0.25		0.16	0.03			0.06
14.12.00	0.41	0.11	0.20	0.06	0.14	0.06			0.37	0.13	0.12	0.03	0.11	0.02			0.03
28.12.00	0.28	0.04	0.17	0.06	0.08	0.02			0.21		0.13	0.04	0.12	0.02			0.02
12.01.01	0.44	0.20	0.14	0.03	0.08	0.01			0.24	0.04	0.18	0.05	0.12	0.01			0.07
25.01.01	0.59	0.27	0.12	0.05	0.13	0.05			0.32	0.10	0.24	0.07	0.12	0.01			0.08
09.02.01	0.43	0.17	0.11	0.03	0.12	0.06			0.42	0.07	0.13	0.03	0.12	0.03			0.06
22.02.01	0.41	0.19	0.11	0.04	0.11	0.05			0.27	0.06	0.15	0.05	0.12	0.03			0.07
09.03.01	0.39	0.18	0.11	0.02	0.12	0.05			0.38	0.11	0.23	0.09	0.09	0.01			0.09
22.03.01	0.42	0.17	0.08	0.03	0.13	0.06			0.18	0.01			0.11	0.02			
06.04.01	0.49	0.23			0.08				0.33		0.21	0.09	0.12	0.04			0.09
20.04.01	0.38	0.12	0.22		0.10	0.04			0.25	0.06	0.28		0.09	0.01			0.08
02.05.01	0.19	0.03	0.07	0.01	0.14	0.06			0.23	0.05	0.20	0.07	0.10	0.03			0.05
16.05.01	0.19	0.07	0.07	0.03	0.10	0.06	0.06		0.13	0.01	0.14	0.04	0.09	0.02	0.29	0.13	0.12
30.05.01	0.20	0.08	0.11	0.02	0.09	0.03	0.05		0.21	0.06	0.10	0.02	0.10	0.02	0.37	0.14	0.09
13.06.01	0.33	0.13	0.10	0.03	0.09	0.04	0.18		0.32	0.05	0.11	0.07	0.10	0.02	0.33	0.11	0.11
27.06.01	0.26	0.10	0.09	0.02	0.08	0.02	0.05		0.20	0.06	0.18	0.05	0.11	0.02	0.27	0.12	0.07
11.07.01	0.31	0.11	0.08	0.02	0.11	0.05	0.05		0.33	0.06	0.13	0.06	0.11	0.01	0.28	0.09	0.07
25.07.01	0.65	0.16	0.09	0.03	0.16	0.08	0.05		0.39	0.06	0.23		0.09	0.02	0.25	0.07	0.08
08.08.01	0.32	0.10	0.09	0.03	0.16	0.08	0.06		0.37	0.07	0.17	0.03	0.12	0.04	0.26	0.09	0.11
22.08.01	0.37	0.11	0.07	0.01	0.15	0.08	0.05		0.48				0.11	0.05	0.26	0.15	0.10
05.09.01			0.09	0.02	0.17	0.10	0.06		0.55				0.14	0.04	0.20		0.09
19.09.01	0.33				0.22	0.12			0.66		0.10		0.23	0.08	0.11		0.03
03.10.01	0.77				0.32	0.06	0.17	0.01	0.22				0.13	0.02	0.13		0.10
17.10.01	0.89						0.13	0.01	0.25								0.08
31.10.01	0.76				0.21	0.10							0.15	0.05			0.05
09.11.01	0.62	0.08	0.11	0.03	0.18	0.09	0.30	0.06	0.56	0.03	0.17		0.15	0.04	0.19	0.06	0.11
24.11.01	0.65	0.10	0.17	0.02	0.20	0.09	0.31	0.09	0.28	0.05			0.14	0.04	0.18	0.04	0.10
07.12.01	0.56	0.10	0.28	0.02	0.18	0.09	0.39	0.11	0.50	0.06	0.08		0.14	0.04	0.22	0.04	0.04
21.12.01	0.31	0.13	0.13	0.04			1.19	0.70	0.34	0.06					0.15	0.04	
04.01.02	0.55	0.15	0.14	0.02	0.23	0.08	0.53	0.11	0.22	0.03			0.15	0.05	0.22	0.11	0.15
18.01.02	0.43	0.14	0.18	0.03	0.18	0.07	0.75	0.20	0.37	0.07	0.20		0.16	0.03	0.23	0.09	0.07
01.02.02	0.41	0.13	0.16	0.03	0.15	0.06	1.05	0.47	0.34	0.05	0.19	0.03	0.16	0.04	0.18	0.04	
15.02.02	0.47	0.18	0.22	0.08	0.18	0.04	1.40	0.57	0.22	0.02			0.14	0.04	0.22	0.08	
07.03.02	0.47	0.14	0.21	0.05	0.15	0.06	1.06	0.36	0.37	0.06	0.19		0.15	0.03	0.44	0.28	0.11
21.03.02	0.46	0.17	0.29	0.11	0.17	0.05	0.88	0.31	0.33	0.03	0.26	0.11	0.18	0.04	0.31	0.06	0.08
05.04.02	0.39	0.15	0.25	0.10	0.13	0.05	1.36	0.60	0.34	0.04	0.20	0.09	0.14	0.03	0.24	0.11	0.09
18.04.02	0.37	0.15	0.24	0.08	0.13	0.05	0.96	0.39	0.33	0.05	0.20	0.11	0.14	0.03	0.21	0.09	0.05
01.05.02	0.18	0.11	0.14	0.08	0.12	0.05	0.19	0.06	0.29	0.05	0.13	0.06	0.11	0.03	0.18	0.07	0.16
15.05.02	0.25	0.12	0.13	0.02	0.03		0.15	0.05	0.26	0.05	0.09	0.02	0.11	0.04	0.28	0.13	0.10
29.05.02	0.30	0.16	0.17	0.04	0.11	0.07	0.19	0.06	0.12	0.01	0.20	0.07	0.11	0.03	0.22	0.12	0.07
12.06.02	0.36	0.15	0.14	0.03	0.18	0.07	0.24	0.08	0.15	0.01	0.03		0.09	0.04	0.25	0.10	0.10
26.06.02	0.43	0.23	0.17	0.07	0.17	0.09	0.26	0.20	0.22				0.13	0.04	0.36	0.05	0.05
10.07.02	0.13		0.20	0.04	0.17	0.08	0.44	0.17	0.24	0.00			0.12	0.04	0.21	0.08	0.05
24.07.02	0.50	0.29	0.12	0.01	0.17	0.08	0.37	0.18	0.11	0.02			0.12	0.06	0.14	0.10	0.01
07.08.02	0.40	0.28	0.13	0.02	0.15	0.09	0.37	0.16	0.16	0.04	0.07	0.01	0.13	0.04	0.24	0.10	
21.08.02	0.38	0.27	0.14	0.02	0.16	0.12	0.27	0.18	0.10	0.01	0.12	0.05	0.14	0.05	0.20	0.11	0.07

Na	R 2100 m	R 2250 m	TF Cl	SE	TF Sf	SE	TF Mf	SE	TF B Cl	SE
29.05.00										
11.06.00	0.38	0.37	0.40	0.05	0.61	0.07	0.53	0.04	-	-
25.06.00	1.44	1.18	0.41	0.05	0.57	0.13	0.70	0.05	-	-
10.07.00	0.46	0.32	0.55	0.05	0.67	0.04	0.96	0.16	-	-
23.07.00	0.80	0.52	0.80	0.11	0.83	0.04	0.93	0.06	-	-
06.08.00	0.45	0.30	0.45	0.04	0.75	0.09	1.02	0.13	-	-
21.08.00	0.94	0.64	0.89	0.03	1.31	0.03	1.33	0.16	-	-
04.09.00	1.25		1.57	0.17	2.73	0.28	2.69		-	-
18.09.00	1.03	1.17	1.54	0.33	2.20	0.42	2.65	0.39	-	-
04.10.00	0.60	0.18	0.64	0.07	1.29	0.36	0.48	0.07	-	-
19.10.00									-	-
02.11.00	0.54	1.80	1.02	0.08	2.35	0.61	1.17	0.16	-	-
16.11.00	0.17	0.16	0.33	0.02	0.53	0.04	0.57	0.13	-	-
30.11.00	0.18	0.25	0.42	0.03	0.78	0.19	0.69	0.13	-	-
14.12.00	0.37	0.25	0.39	0.03	0.39	0.03	0.56	0.05	-	-
28.12.00	0.32	0.28	1.42	0.95	0.57	0.09	0.48	0.12	-	-
12.01.01	0.13	0.17	0.52	0.13	0.53	0.09	0.39	0.06	-	-
25.01.01	0.23	0.24	0.34	0.02	0.46		0.42	0.08	-	-
09.02.01	0.33	0.52	0.60	0.06	0.66	0.12	0.64	0.10	-	-
22.02.01	0.39	0.30	0.37	0.08	0.70	0.07	0.59	0.10	-	-
09.03.01	0.49	0.32	0.71	0.15	1.63	0.28	0.81	0.06	-	-
22.03.01	0.26	0.23	0.32	0.06	0.72	0.11	0.64	0.16	-	-
06.04.01	0.18	0.19	0.19	0.02	0.36	0.05	0.47	0.11	-	-
20.04.01	0.15	0.13	0.16	0.02	0.21	0.02	0.27	0.03	-	-
02.05.01	0.09	0.19	0.13	0.03	0.22	0.01	0.29	0.07	-	-
16.05.01	0.20	0.20	0.27	0.03	0.70	0.27	0.55	0.18	1.03	0.77
30.05.01	0.32	0.20	0.26	0.03	0.36	0.05	0.82	0.47	0.45	0.25
13.06.01	0.58	0.37	0.47	0.05	2.10	0.64	0.59	0.07	0.48	0.10
27.06.01	0.42	0.37	0.69	0.13	1.27	0.52	0.75	0.11	0.53	0.18
11.07.01	0.58	1.06	1.20	0.22	1.18	0.35	1.65	0.46	1.33	0.50
25.07.01	0.83	0.65	1.09	0.21	1.97	0.93	2.12	0.38	0.78	0.05
08.08.01	0.56	0.53	2.15	1.49	1.25	0.56	1.24	0.50	0.73	0.23
22.08.01		1.28	1.15	0.23	4.07	2.01				
05.09.01	2.22	1.58	2.87	0.14	9.12	0.13	3.09	0.30	1.79	0.20
19.09.01										
03.10.01	1.37	1.96	2.20	0.39	5.96	0.92	4.70	0.68	2.80	1.23
17.10.01	2.80	1.79	2.99	0.78	6.98	0.55	4.16	0.84	2.28	0.24
31.10.01	1.27	0.15	1.01	0.06	2.98	0.23	2.18	0.75	1.17	0.22
09.11.01	0.56	0.54	0.45	0.09	1.10	0.14	1.88	0.64	1.20	0.72
24.11.01	0.26	0.57	2.33	1.99	0.51	0.09	0.67	0.10	0.98	0.70
07.12.01	0.35	0.27	0.55	0.03	1.48	0.19	0.56	0.06	0.42	0.03
21.12.01										
04.01.02	0.46	0.24	0.60	0.10	1.04	0.01	0.80	0.11	0.45	0.07
18.01.02	0.80	0.45	0.55	0.05	1.22	0.32	0.97	0.16	0.46	0.05
01.02.02	1.43		2.21	0.79	1.86	0.35	1.02	0.16	1.54	0.20
15.02.02	0.65	0.73	0.84	0.11	1.25	0.08	0.84	0.06	0.66	0.05
07.03.02	0.34	0.42	0.51	0.03	2.01	1.03	0.62	0.11	0.37	0.13
21.03.02	0.22	0.36	0.28	0.01	1.34		0.41	0.04	0.26	0.07
05.04.02	0.06	0.06	0.20	0.09	0.36	0.05	0.58	0.12	0.25	0.07
18.04.02	0.19	0.25	0.21	0.02	0.50	0.04	0.61	0.08	0.17	0.02
01.05.02	0.07	0.15	0.10	0.02	0.23	0.03	0.47	0.05	0.09	0.02
15.05.02	0.23	0.22	0.20	0.02	0.53	0.08	1.09	0.20	0.17	0.02
29.05.02	0.23	0.23	0.24	0.02	0.58	0.07	0.59	0.03	0.23	0.05
12.06.02	0.43		0.39	0.05	0.62	0.07	1.17	0.23	0.41	0.02
26.06.02	0.32	0.85	0.33	0.02	0.43	0.04	1.56	0.47	0.34	0.01
10.07.02	0.40	0.19	0.67	0.24	1.37	0.39	0.94	0.15	0.51	0.05
24.07.02	0.53	0.19	0.58	0.10	1.03	0.11	1.15	0.01	0.44	0.03
07.08.02	0.49		0.68	0.05	0.87	0.06			0.52	0.06
21.08.02		0.38					0.86	0.08		

Na	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S1 B Cl	SE
29.05.00									0.62	0.12	0.69	0.03	0.44			
11.06.00									0.51	0.12	0.58	0.11	0.50	0.09		
25.06.00									0.36	0.03	0.50	0.10	0.61	0.14		
10.07.00									0.44	0.07	0.49	0.11	0.53	0.11		
23.07.00									0.52	0.10	0.50	0.10	0.55	0.07		
06.08.00									0.41	0.10	0.40	0.16	0.46	0.09		
21.08.00									0.61	0.11	0.59	0.11	0.55	0.09		
04.09.00									0.50	0.10	0.47	0.10	0.47	0.06		
18.09.00									0.40	0.08	0.63	0.12	0.48	0.09		
04.10.00									0.35	0.06	0.76	0.17	0.39	0.04		
19.10.00									0.33	0.07	0.63	0.12	0.44	0.11		
02.11.00	1.78	0.46	2.65	0.47	1.31	0.07			0.46	0.08	0.99	0.08	0.52	0.14		
16.11.00	1.05	0.21	1.45	0.21	1.33	0.11			0.58	0.03	0.62	0.08	0.47	0.16		
30.11.00	1.10	0.26	1.63	0.09	1.37	0.20			0.54	0.05	0.50	0.06	0.65	0.23		
14.12.00	0.63	0.05	0.67	0.03	0.52	0.02			0.49	0.01	0.56	0.12	0.46	0.19		
28.12.00	0.74	0.08	0.70	0.03	0.39	0.03			0.51	0.10	0.45	0.07	0.39	0.11		
12.01.01	0.52	0.04	0.67	0.02	0.41	0.04			0.76	0.16	0.41	0.06	0.37	0.09		
25.01.01	0.31	0.05	0.66	0.07	0.35	0.02			0.45	0.08	0.39	0.05	0.36	0.10		
09.02.01	0.53	0.08	0.80	0.06	0.43	0.05			0.51	0.10	1.10	0.46	0.35	0.08		
22.02.01	0.81	0.21	1.21	0.06	0.64	0.07			0.50	0.11	0.58	0.18	0.36	0.08		
09.03.01	2.76	1.45	1.57	0.50	0.75	0.10			0.41	0.11	0.85		0.30	0.07		
22.03.01	1.06	0.14	1.09	0.10	0.76	0.07			0.47	0.01	0.48	0.15	0.36	0.10		
06.04.01	0.48	0.05	1.04	0.31	0.68	0.08			0.29	0.04	0.89		0.51	0.08		
20.04.01	0.42	0.10	0.51	0.07	0.75	0.22			0.29	0.06	0.26		0.50	0.08		
02.05.01	0.20	0.05	0.34	0.02	0.39	0.03			0.20	0.05	0.45	0.12	0.39	0.10		
16.05.01	2.57	1.83	0.44	0.08	0.41	0.80	0.74	0.13	0.25	0.06	0.48	0.09	0.35	0.08	0.47	0.11
30.05.01	0.38	0.04	0.74	0.30	1.08	0.29	0.38	0.03	0.17	0.01	0.37	0.07	0.37	0.07	0.22	0.05
13.06.01	1.52	1.57	0.58	0.17	0.61	0.14	0.81	0.23	0.17	0.01	0.32	0.07	0.33	0.06	0.21	0.01
27.06.01	0.70	0.22	0.69	0.09	0.51	0.44	0.68	0.23	0.22	0.06	0.44	0.06	0.36	0.03	0.42	0.04
11.07.01	0.72	0.22	0.77	0.16	0.79	0.18	0.44	0.11	0.40	0.07	0.49	0.03	1.18	0.64	0.33	0.05
25.07.01	0.86		0.73	0.17	0.98	2.19	0.86		0.32	0.07	0.54	0.02	0.35	0.07	0.41	0.02
08.08.01	1.11	0.46	2.82	2.22	0.43	0.32	0.90	0.29	0.35	0.04	0.49	0.02	0.43	0.07	0.32	0.02
22.08.01									0.35	0.05	0.58	0.09	0.46	0.09	0.36	0.02
05.09.01									0.44	0.09	0.61		0.51	0.07	0.37	0.05
19.09.01									0.67				0.56	0.21	1.24	
03.10.01	3.73	1.61	2.52		3.47	0.41	3.89	1.81	0.66				0.32		0.54	0.07
17.10.01	4.99	0.74	3.96	0.61	4.66	1.40	4.99	1.56	0.65				0.88		0.63	
31.10.01	2.32	0.19	4.87	1.29	1.45	0.21	2.32	0.43	0.46				0.39	0.03	0.42	
09.11.01	1.72	0.80	1.44	0.09	2.78	1.03	2.59	0.84	0.42	0.34	0.97	0.15	0.48	0.08	0.94	0.22
24.11.01	0.92	0.12	0.99	0.16	1.02	0.09	1.22	0.11	0.32	0.53	0.81	0.11	0.44	0.12	1.09	0.39
07.12.01	1.09	0.24	1.33	0.05	0.75	0.01	5.90	4.69	0.45	0.48	0.87	0.14	0.43	0.10	1.89	0.67
21.12.01									0.31	0.46	1.16				2.07	0.24
04.01.02	1.14	0.08	1.11	0.19	0.92	0.12	2.37	1.03	0.48	0.30	0.88	0.09	0.40	0.10	1.90	0.44
18.01.02	1.30	0.32	1.15	0.25	1.25	0.27	1.23	0.40	0.53	0.26	0.82	0.10	0.51	0.14	2.09	0.51
01.02.02	2.08	0.79	1.22	0.08	1.02	0.11	1.42	0.11	0.56	0.36	0.92	0.20	0.42	0.11	2.14	0.48
15.02.02	0.92	0.09	1.18	0.08	0.87	0.08	0.85	0.10	0.46	0.22	0.93	0.20	0.40	0.12	1.91	0.64
07.03.02	0.90	0.16	1.18	0.05	0.83	0.04	0.60	0.03	0.68	0.27	2.08	0.81	0.40	0.12	3.41	1.50
21.03.02	0.82	0.17	0.94	0.04	0.91	0.15	0.48	0.06	0.48	0.39	0.91	0.21	0.37	0.11	1.52	0.55
05.04.02	0.52	0.14	0.80	0.03	0.58	0.06	0.41	0.05	0.34	0.22	0.91	0.16	0.34	0.10	1.04	0.44
18.04.02	0.60	0.11	0.81	0.05	0.75	0.13	0.41	0.05	0.35	0.20	0.93	0.19	0.33	0.08	1.03	0.38
01.05.02	0.29	0.08	0.32	0.02	0.53	0.05	0.15	0.02	0.21	0.05	0.54	0.06	0.38	0.09	0.29	0.02
15.05.02	0.52	0.10	0.79	0.27	0.69	0.10	0.27	0.10	0.19	0.03	0.56	0.11	0.35	0.09	0.34	0.10
29.05.02	0.51	0.05	0.54	0.07	0.80	0.04	0.83	0.42	0.18	0.02	0.55	0.07	0.33	0.09	0.28	0.07
12.06.02	0.63	0.14	0.73	0.00	0.78	0.10	0.35	0.10	0.27	0.05	0.69	0.12	0.42	0.08	0.43	0.14
26.06.02	1.01	0.44	0.89	0.20	0.93	0.10	0.31	0.02								
10.07.02	0.73	0.03	1.40	0.61	0.74	0.17	0.38	0.08	0.28	0.04	0.68	0.10	0.40	0.05	0.41	0.11
24.07.02	1.49	0.65	0.98	0.12	0.76	0.12	0.52	0.05	0.31	0.03	0.75	0.17	0.42	0.09	0.53	0.14
07.08.02	0.80	0.17	1.05	0.07	0.61	0.11	0.43	0.05	0.20	0.03	0.74	0.13	0.40	0.09	0.39	0.14
21.08.02	1.05	0.21	1.02	0.09	1.06	0.29	1.01	0.35	0.25	0.06	0.65	0.10	0.42	0.06	0.36	0.05

Na	S2 Cl	SE	S2 Sf	SE	S2 Mf	SE	S2 B Cl	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE	S3 B Cl	SE	ST
29.05.00	0.56	0.16	0.51	0.07	0.43	0.06			1.08	0.67	0.51	0.11	0.39	0.04			
11.06.00	0.42	0.08	0.46	0.07	0.32	0.04			0.54	0.19	0.47	0.15	0.29	0.03			0.87
25.06.00	0.34	0.06	0.44	0.08	0.44	0.14			0.43	0.09	0.41	0.07	0.27	0.01			
10.07.00	0.33	0.05	0.42	0.06	0.39	0.09			0.36	0.05	0.35	0.06	0.32	0.03			1.09
23.07.00	0.32	0.05	0.43	0.07	0.36	0.15			0.35	0.01	0.34	0.03	0.34	0.02			0.89
06.08.00	0.28	0.10	0.35	0.13	0.25	0.06			0.25	0.02	0.21	0.03	0.25	0.03			1.10
21.08.00	0.38	0.08	0.46	0.11	0.47	0.09			0.40	0.04	0.32		0.41	0.06			2.14
04.09.00	0.29	0.07	0.38	0.10	0.41	0.09			0.34	0.04	0.34	0.02	0.41	0.09			1.28
18.09.00	0.30	0.04	0.32		0.41	0.09			0.30	0.02			0.30	0.01			1.16
04.10.00	0.23	0.04	0.36	0.09	0.25	0.03			0.26	0.04			0.39	0.15			1.45
19.10.00	0.22	0.02	0.22		0.38	0.11			0.30	0.03			0.31	0.04			1.46
02.11.00	0.24	0.06	1.17	0.05	0.39	0.10			0.27		0.68	0.11	0.31	0.01			1.45
16.11.00	0.29	0.05	0.65	0.18	0.34	0.10			0.29	0.04			0.31	0.02			1.08
30.11.00	0.52	0.20	0.72	0.24	0.38	0.09			0.27	0.03	0.40		0.37	0.05			1.21
14.12.00	0.49	0.13	0.69	0.21	0.35	0.07			0.30	0.03	0.30	0.06	0.24	0.02			1.09
28.12.00	0.27	0.02	0.56	0.15	0.28	0.03			0.24		0.47	0.03	0.26	0.03			1.08
12.01.01	0.54	0.16	0.54	0.13	0.29	0.03			0.28	0.03	0.39	0.01	0.33	0.02			1.03
25.01.01	0.40	0.07	0.44	0.14	0.31	0.06			0.28	0.01	0.30	0.03	0.28	0.02			0.89
09.02.01	0.44	0.08	0.42	0.11	0.29	0.05			0.36	0.08	0.46	0.09	0.30	0.05			1.06
22.02.01	0.43	0.09	0.44	0.11	0.27	0.05			0.33	0.06	0.43	0.08	0.30	0.04			1.05
09.03.01	0.47	0.10	0.51	0.12	0.28	0.05			0.49	0.12	0.55		0.30	0.06			1.20
22.03.01	0.40	0.07	0.42	0.14	0.26	0.05			0.38	0.12			0.31	0.03			
06.04.01	0.31	0.15			0.32				0.32		0.28	0.03	0.37	0.04			1.25
20.04.01	0.36	0.04	0.90		0.26	0.04			0.34	0.05	0.40		0.30	0.03			0.98
02.05.01	0.27	0.05	0.40	0.07	0.35	0.08			0.36	0.08	0.43	0.05	0.37	0.08			0.67
16.05.01	0.31	0.02	0.42	0.08	0.28	0.06	0.29		0.23	0.04	0.45	0.06	0.35	0.08	0.44	0.12	
30.05.01	0.19	0.01	0.42	0.08	0.30	0.05	0.20		0.31	0.02	0.44	0.04	0.39	0.11	0.54	0.13	0.99
13.06.01	0.24	0.01	0.40	0.07	0.35	0.07	0.38		0.45	0.04	0.54		0.34	0.10	0.52	0.07	1.14
27.06.01	0.23	0.05	0.33	0.06	0.26	0.07	0.32		0.69	0.29	1.23	0.72	0.33	0.05	0.38	0.11	1.24
11.07.01	0.29	0.06	0.37	0.07	0.59	0.03	0.34		0.58	0.11	0.68	0.07	0.95	0.28	0.43	0.14	1.74
25.07.01	0.51	0.01	0.40	0.07	0.33	0.08	0.23		0.52	0.03	0.52		0.31	0.07	0.44	0.06	1.24
08.08.01	0.23	0.05	0.38	0.10	0.36	0.10	0.28		0.49	0.07	0.69	0.05	0.36	0.06	0.41	0.05	1.30
22.08.01	0.29	0.04	0.44	0.11	0.35	0.10	0.28		0.47				0.32	0.06	0.39	0.08	1.34
05.09.01			0.54	0.08	0.36	0.13	0.36		0.43				0.45	0.08	0.31		1.55
19.09.01	0.24				0.49	0.15	0.82	0.01	0.39		0.37		0.64	0.13	0.43		1.30
03.10.01	0.47				0.74	0.21	0.82	0.01	0.47				0.57	0.26	0.66		1.80
17.10.01	0.68						0.92	0.43	0.39								1.64
31.10.01	0.51				0.39	0.12							0.39	0.07			1.32
09.11.01	0.42	0.42	0.53	0.16	0.43	0.14	0.91	0.30	1.15	0.60	0.32		0.53	0.09	0.67	0.18	1.61
24.11.01	0.38	0.34	0.71	0.13	0.42	0.15	0.81	0.21	0.37	0.07			0.49	0.08	0.52	0.16	1.43
07.12.01	0.48	0.32	0.84	0.11	0.36	0.14	1.06	0.13	0.54	0.05	0.75		0.43	0.08	0.43	0.04	1.56
21.12.01	0.41	0.43	0.81	0.21			1.77	0.09	0.68	0.15					0.37	0.01	
04.01.02	0.37	0.41	0.74	0.26	0.46	0.13	1.56	0.19	0.52	0.08			0.46	0.08	0.45	0.06	1.35
18.01.02	0.45	0.58	0.96	0.20	0.59	0.35	1.84	0.25	0.44	0.05	1.62	0.39	0.41	0.03	0.51	0.09	
01.02.02	0.79	0.47	0.79	0.16	0.37	0.14	1.90	0.44	0.37	0.10	1.72	0.94	0.41	0.07	0.70	0.21	1.24
15.02.02	0.38	0.33	0.79	0.20	0.43	0.11	1.77	0.42	0.51	0.08			0.41	0.06	0.47	0.09	1.20
07.03.02	1.42	0.34	1.01	0.22	0.95	0.62	1.76	0.60	0.61	0.07	1.91		0.77	0.31	0.72	0.13	1.25
21.03.02	0.98	0.68	2.82	2.02	0.33	0.13	1.17	0.45	0.49	0.09	0.51	0.01	0.36	0.05	1.17	0.64	1.15
05.04.02	0.26	0.27	0.92	0.20	0.33	0.13	1.35	0.53	0.45	0.08	0.76	0.13	0.34	0.05	0.50	0.14	1.07
18.04.02	0.24	0.23	0.94	0.22	0.34	0.13	1.12	0.50	0.43	0.07	0.49	0.07	0.36	0.05	0.63	0.26	1.15
01.05.02	0.19	0.15	0.72	0.19	0.39	0.20	0.42	0.13	0.44	0.05	0.48	0.04	0.36	0.02	0.91	0.53	
15.05.02	0.44	0.06	0.52	0.04	0.12		0.27	0.08	0.35	0.02	0.33	0.10	0.42	0.12	1.04	0.51	0.98
29.05.02	0.33	0.02	0.66	0.21	0.37	0.12	0.34	0.05	0.40	0.03	0.42	0.07	0.37	0.06	0.71	0.20	0.65
12.06.02	0.32	0.04	0.51	0.06	0.47	0.16	0.43	0.09	0.44	0.02	0.54		0.48	0.11	0.89	0.25	1.24
26.06.02									0.29								1.09
10.07.02	0.30	0.01	0.68	0.14	0.44	0.20	0.49	0.12	0.55	0.12			0.54	0.09	1.07	0.02	
24.07.02	0.32	0.03	0.66	0.09	0.50	0.17	0.46	0.14	0.50	0.08			0.69	0.31	0.93	0.17	
07.08.02	0.34	0.05	0.70	0.19	0.36	0.10	0.40	0.11	1.76	0.89			0.48	0.11	0.82	0.12	
21.08.02	0.33	0.02	0.62	0.12	0.38	0.19	0.45	0.11	0.46	0.01	0.66	0.04	0.41	0.07	0.78	0.21	1.21

NH₄-N	R 2100 m	R 2250 m	TF Cl	SE	TF Sf	SE	TF Mf	SE	TF B Cl	SE
29.05.00										
11.06.00	0.16	0.24	0.41	0.08	0.28	0.06	0.19	0.04		
25.06.00	0.19	0.27	0.26	0.05	0.35	0.04	0.16	0.04		
10.07.00	0.15	0.15	0.30	0.02	0.14	0.02	0.24	0.04		
23.07.00	0.28	0.30	0.31	0.04	0.28	0.01	0.21	0.06		
06.08.00	0.29	0.06	0.29	0.04	0.25	0.11	0.16	0.02		
21.08.00	0.23	0.33	0.51	0.04	0.67	0.21	0.34	0.06		
04.09.00	0.25		0.55	0.14	1.02	0.20				
18.09.00	0.78	0.31	0.55	0.16	1.10	0.41	0.62	0.09		
04.10.00										
19.10.00										
02.11.00	0.41	0.11	0.10	0.07	0.16	0.06	0.03	0.01		
16.11.00	0.21	0.26	0.16	0.07	0.08	0.03	0.08	0.01		
30.11.00		0.30	0.05		0.05		0.21			
14.12.00	0.18	0.11	0.02	0.00	0.24	0.02	0.38	0.06		
28.12.00	0.14	0.35	0.20	0.07	0.10	0.08	0.26	0.04		
12.01.01	0.18	0.14	0.53		0.21	0.03	0.24	0.04		
25.01.01	0.01	0.18	0.39	0.19	0.16	0.12	0.20	0.05		
09.02.01	0.19	0.17	0.43	0.09	0.17	0.10	0.22	0.04		
22.02.01	0.52	0.14	0.39	0.05	0.17	0.13	0.25	0.03		
09.03.01	0.32	0.25	0.63	0.04	0.04	0.01	0.31	0.04		
22.03.01	0.18	0.16	0.41	0.04	0.51	0.28	0.27	0.05		
06.04.01	0.05	0.12	0.10	0.05	0.19	0.08	0.13	0.04		
20.04.01	0.09	0.11	0.15	0.06	0.15	0.01	0.12	0.02		
02.05.01	0.19	0.05	0.16	0.04	0.31	0.03	0.23	0.10		
16.05.01	0.08	0.13	0.14	0.01	0.18	0.01	0.16	0.02	0.20	0.03
30.05.01	0.08	0.08	0.15	0.02	0.16	0.00	0.15	0.03	0.12	0.01
13.06.01			0.15	0.00	0.19	0.01	0.12	0.01	0.29	0.09
27.06.01			0.18	0.03	0.14		0.06	0.02	0.56	
11.07.01		0.11	0.32	0.08	0.33	0.06	0.19	0.05	0.26	0.10
25.07.01			0.33	0.04	0.38	0.08	0.22	0.07	0.31	0.14
08.08.01	0.31		0.20	0.05	0.15	0.05	0.14	0.03	0.40	0.10
22.08.01			0.46	0.15	1.09	0.38			0.62	
05.09.01	0.52	0.24	0.81	0.11	0.60	0.40	0.35	0.21	0.24	0.01
19.09.01										
03.10.01	0.98	0.99	1.17	0.15	0.37	0.24	0.67	0.20	0.79	0.36
17.10.01	0.72		0.58	0.16	1.36	0.50	0.86	0.28	0.96	0.11
31.10.01	0.14	0.08	0.15	0.06	0.39	0.12	0.28	0.04	0.20	0.09
09.11.01	0.02	0.04	0.14	0.04	0.07	0.03	0.06	0.01	0.17	0.06
24.11.01	0.13		0.13	0.07	0.03	0.00	0.20	0.01	0.09	0.02
07.12.01	0.24	0.34	0.37	0.07	0.13	0.03	0.43	0.04	0.24	0.05
21.12.01										
04.01.02	0.19	0.07	0.26	0.01	0.09	0.03	0.31	0.10	0.23	0.03
18.01.02	0.15	0.04	0.37	0.10	0.17	0.04	0.23	0.04	0.24	0.11
01.02.02	0.46	0.09	0.38	0.18	0.22	0.08	0.12	0.01	0.31	0.19
15.02.02	0.35	0.12	0.19	0.09	0.15	0.05	0.20	0.05	0.22	0.04
07.03.02	0.13	0.08	0.21	0.03	0.98	0.27	0.28	0.06	0.23	0.08
21.03.02	0.24	0.20	0.11	0.01	0.10	0.03	0.06	0.03	0.12	0.08
05.04.02	0.06	0.06	0.05	0.01	0.03	0.00	0.04	0.00	0.04	
18.04.02	0.07	0.03	0.09	0.05	0.04	0.00	0.21	0.09	0.05	0.00
01.05.02	0.04	0.10	0.10	0.02	0.16	0.02	0.17	0.03	0.10	0.00
15.05.02	0.01	0.20	0.21	0.03	0.50	0.14	0.38	0.05	0.12	0.02
29.05.02	0.08	0.05	0.12	0.01	0.27	0.07	0.23	0.07	0.05	0.01
12.06.02	0.12	0.23	0.15	0.04	0.72	0.11	0.18	0.02	0.15	0.01
26.06.02	0.23	0.38	0.15	0.03	0.18	0.05	0.45	0.12	0.14	0.04
10.07.02	0.18	0.27	0.18	0.02	0.20	0.06	0.54	0.11	0.16	0.04
24.07.02	0.21	0.20	0.12	0.04	0.25	0.09	0.38	0.31	0.29	0.08
07.08.02	0.30	0.22	0.58	0.30	0.29	0.08	0.27	0.06	0.25	0.08
21.08.02	0.21	0.04	0.40	0.12	0.29	0.09	0.11	0.03	0.13	0.06

NH₄-N	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S1 B Cl	SE
29.05.00																
11.06.00									0.04	0.02	0.02	0.00	0.02	0.00		
25.06.00									0.10		0.02	0.00	0.02	0.00		
10.07.00									0.03	0.00	0.02	0.00	0.03	0.00		
23.07.00									0.03	0.00	0.02	0.00	0.03	0.00		
06.08.00									0.03	0.00	0.02	0.00	0.02	0.00		
21.08.00									0.05	0.02	0.04	0.02	0.02	0.00		
04.09.00									0.05	0.02	0.03	0.00	0.02	0.00		
18.09.00									0.04	0.02	0.02		0.02	0.00		
04.10.00									0.04	0.01	0.03	0.00	0.02	0.00		
19.10.00									0.04	0.01	0.08	0.01	0.04	0.01		
02.11.00									0.05	0.02	0.15		0.05	0.01		
16.11.00	1.57		1.53		1.10	0.43										
30.11.00	2.96	0.32	1.24	0.33	0.37	0.09				0.00		0.03		0.00		
14.12.00	1.34	0.30	0.68	0.14	0.49	0.07			0.10	0.04	0.04	0.01	0.05	0.00		
28.12.00	0.94	0.21	0.59	0.18	0.81	0.07			0.05	0.01	0.03	0.01	0.03	0.00		
12.01.01	1.11	0.35	1.17	0.43	0.53	0.08			0.28	0.19	0.03	0.01	0.03	0.00		
25.01.01	0.59	0.14	0.42	0.12	0.37	0.06			0.03	0.01	0.02	0.00	0.02	0.00		
09.02.01	0.75	0.12	1.03	0.06	0.37	0.02			0.03	0.01	0.03	0.01	0.02	0.00		
22.02.01	1.57	0.40	2.36	0.20	0.42	0.05			0.03	0.01	0.04	0.01	0.03	0.00		
09.03.01	3.19	0.48	5.19	1.69	0.58	0.06			0.06	0.01	0.10	0.06	0.03	0.00		
22.03.01	1.40	0.37	1.65	0.11	0.40	0.04			0.05	0.01	0.17	0.08	0.03	0.00		
06.04.01	0.65	0.11	0.66	0.20	0.41	0.12			0.03	0.00	0.06	0.02	0.03	0.00		
20.04.01	0.20	0.03	0.27	0.05	0.25	0.08			0.03	0.00	0.03	0.00	0.03	0.00		
02.05.01	0.22	0.12	0.24	0.06	0.25	0.07			0.04	0.00	0.03	0.00	0.04	0.01		
16.05.01	0.34	0.10	0.30	0.06	0.23	0.11	0.59	0.10	0.04	0.01	0.04	0.01	0.06	0.01	0.67	0.48
30.05.01	0.53	0.04	0.20	0.03	0.14	0.03	0.59	0.14	0.07	0.01	0.05	0.00	0.05	0.01	0.16	0.03
13.06.01	0.62	0.06	0.28	0.04	0.15	0.03	0.69	0.12	0.06	0.01	0.06	0.01	0.07	0.03	0.16	0.12
27.06.01	0.70	0.05	0.60	0.09	0.15	0.03	1.07	0.21	0.04	0.01	0.13	0.05	0.10	0.05	0.31	0.18
11.07.01	0.88	0.21	0.98	0.25	0.14	0.02	0.88	0.33	0.07	0.00	0.06	0.01	0.04	0.01	0.15	0.05
25.07.01	0.52		0.50	0.04	0.14	0.05	0.88		0.07	0.01	0.05	0.01	0.04	0.00	0.37	0.14
08.08.01	0.61	0.05	0.55	0.26	0.17	0.04	1.06	0.08	0.05	0.00	0.05	0.01	0.05	0.00	0.16	0.11
22.08.01									0.24	0.01	0.08	0.01	0.09	0.05	0.20	0.10
05.09.01									0.06		0.05		0.08	0.01	0.08	
19.09.01									0.07				0.34	0.18	0.24	0.02
03.10.01	5.04	2.16	8.11		4.67	1.04	7.76	2.43					0.16		14.90	
17.10.01	14.01	8.48	8.53	2.58	2.45	1.34	5.62	0.91	0.07							
31.10.01	4.95	3.67	0.09		0.44	0.09	5.40		0.04				0.10	0.03	17.28	
09.11.01	3.94	2.73	0.73	0.15	0.46	0.15	2.48	0.26	0.06	0.05	0.09	0.01	0.04	0.01	0.70	0.41
24.11.01	1.33	0.27	0.37	0.12	0.52	0.10	2.51	0.90	0.03	0.01	0.06	0.01	0.04	0.00	0.39	0.11
07.12.01	0.73	0.34	0.51	0.21	0.35	0.10	9.65	5.60	0.13	0.08	0.16	0.05		0.02	0.67	0.37
21.12.01									0.03	0.15	0.06	0.02			2.82	1.06
04.01.02	0.97	0.52	0.39	0.13	0.31	0.03	6.23	2.09	0.12	0.02	0.07	0.01	0.04	0.01	4.09	0.67
18.01.02	0.59	0.03	0.22	0.10	0.22	0.07	3.24	1.25	0.03	0.00	0.04	0.01	0.03	0.01	6.24	1.45
01.02.02	6.33	7.93	1.28	0.48	0.21	0.09	2.78	0.78	0.04	0.00	0.08	0.01	0.03	0.01	0.00	
15.02.02	0.79	0.06	0.58	0.23	0.30	0.07	3.55	0.80	0.03	0.00	0.13	0.06	0.02	0.00	3.28	1.90
07.03.02	0.65	0.12	0.75	0.05	0.31	0.07	1.76	0.36	0.03	0.00	0.03	0.00	0.04	0.00	2.08	0.59
21.03.02	0.63	0.03	0.31	0.06	0.36	0.08	0.96	0.15	0.04	0.00	0.05	0.00	0.05	0.00	1.60	1.46
05.04.02	0.41						2.16	0.92	0.02	0.00	0.03	0.00	0.03	0.00	3.05	0.63
18.04.02	0.45				0.33	0.07	1.02	0.14	0.03	0.00	0.03	0.00	0.05	0.01	3.22	0.51
01.05.02	0.21	0.00	0.34	0.02	0.13	0.04	0.46	0.06	0.02	0.00	0.03	0.01	0.03	0.00	0.33	0.08
15.05.02	0.30	0.03	0.32	0.15	0.41	0.16	0.50	0.09	0.02	0.01	0.03	0.01	0.04	0.01	0.33	0.13
29.05.02	0.38	0.16	0.52	0.19	0.32	0.15	0.50	0.14	0.04	0.00	0.02	0.01	0.03	0.00	0.27	0.11
12.06.02	0.29	0.21	1.75	0.19	0.40	0.09	1.02	0.02	0.02	0.00	0.03	0.00	0.04	0.01	0.22	0.02
26.06.02	0.36	0.25	0.33	0.16	0.34	0.11	0.79	0.18	0.03	0.00	0.02	0.00	0.03	0.01	0.39	0.10
10.07.02	0.57	0.44	0.33	0.11	0.36	0.11	0.71	0.13	0.03	0.00	0.04	0.01	0.04	0.00	0.20	0.06
24.07.02	0.56	0.34	0.76	0.18	0.50	0.16	0.95	0.09	0.03	0.01	0.05	0.01	0.05	0.01	0.31	0.17
07.08.02	0.18	0.12	0.40	0.17	0.17	0.03	0.87	0.04	0.04	0.01	0.04	0.00	0.03	0.00	0.22	0.06
21.08.02	0.33	0.12	0.46	0.04	0.22	0.07	0.88	0.06	0.03	0.00	0.05	0.03	0.05	0.01	0.59	0.39

NH ₄ -N	S2 Cl	SE	S2 Sf	SE	S2 Mf	SE	S2 B Cl	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE	S3 B Cl	SE	ST
29.05.00																	
11.06.00	0.26	0.21	0.03	0.01	0.04	0.02			0.08	0.04	0.07	0.00	0.02	0.00			0.26
25.06.00	0.14		0.03	0.00	0.03	0.00			0.08	0.04	0.06	0.01	0.02	0.00			0.14
10.07.00	0.03	0.01	0.03	0.00	0.06	0.04			0.06	0.02	0.05	0.01	0.03	0.00			0.03
23.07.00	0.04	0.01	0.03	0.00	0.03	0.00			0.06	0.02	0.06	0.02	0.02	0.00			0.04
06.08.00	0.02	0.00	0.02	0.00	0.02	0.00			0.07	0.02	0.05	0.01	0.02	0.00			0.02
21.08.00	0.02	0.00	0.02	0.00	0.02	0.00			0.03	0.00	0.05	0.01	0.02	0.00			0.02
04.09.00	0.02	0.00	0.02	0.00	0.02	0.00			0.03	0.01	0.06		0.02	0.00			0.02
18.09.00	0.02	0.00	0.03	0.00	0.02	0.00			0.15	0.06			0.02	0.00			0.02
04.10.00	0.03	0.00	0.03	0.00	0.02	0.00			0.09				0.03	0.00			0.03
19.10.00	0.04	0.00	0.03		0.03	0.01			0.12	0.01			0.03	0.01			0.04
02.11.00	0.08	0.03	0.17		0.04	0.02			0.18		0.17	0.04	0.03	0.00			0.08
16.11.00																	
30.11.00																	
14.12.00	0.05	0.01	0.04	0.00	0.02	0.00			0.53	0.36	0.06	0.03	0.03	0.00			0.05
28.12.00	0.04	0.01	0.06	0.01	0.03	0.01					0.39	0.23	0.03	0.01			0.04
12.01.01	0.02	0.00	0.03	0.01	0.03	0.00			0.93		0.12	0.04	0.03	0.01			0.02
25.01.01	0.03	0.00	0.04	0.01	0.03	0.00			0.06	0.01	0.08	0.01	0.03	0.00			0.03
09.02.01	0.04	0.00	0.03	0.01	0.02	0.00			0.06	0.02	0.02	0.01	0.02	0.00			0.04
22.02.01	0.04	0.01	0.03	0.01	0.02	0.00			0.11	0.03	0.06	0.00	0.02	0.00			0.04
09.03.01	0.06	0.02	0.09	0.04	0.02	0.00			0.18				0.03	0.00			0.06
22.03.01	0.07	0.02	0.14	0.07	0.03	0.01			0.50	0.21			0.03	0.01			0.07
06.04.01			0.05		0.03	0.00							0.03	0.01			
20.04.01	0.03	0.00	0.04	0.00	0.03	0.00			0.06	0.01	0.08	0.01	0.03	0.00			0.03
02.05.01	0.03	0.00	0.03	0.00	0.03	0.00			0.04	0.00	0.06	0.00	0.04	0.00			0.03
16.05.01	0.06	0.01	0.04	0.00	0.06		0.11		0.08	0.03	0.07	0.01	0.05		0.06	0.01	0.06
30.05.01	0.06	0.00	0.05	0.01	0.04	0.00	0.13	0.06	0.05		0.07	0.01	0.05	0.00	0.08	0.00	0.06
13.06.01	0.08		0.04	0.00	0.09	0.04	0.11	0.04	0.09	0.02	0.09	0.03	0.19	0.15	0.08	0.01	0.08
27.06.01	0.07	0.00	0.05	0.01	0.08	0.03	0.04		0.98		0.16	0.02	0.05	0.01	0.09		0.07
11.07.01	0.06	0.01	0.04	0.00	0.04	0.00	0.01		0.12	0.02	0.11	0.05	0.04	0.01	0.18	0.09	0.06
25.07.01			0.03	0.01	0.04	0.00	0.29	0.18	0.19	0.10	0.08		0.04	0.00	0.05	0.02	
08.08.01	0.06	0.01	0.04	0.00	0.04	0.00	0.05		0.34	0.21	0.18	0.07	0.04	0.00	0.06	0.01	0.06
22.08.01	0.06	0.01	0.08	0.01	0.05	0.01	0.06		0.09				0.06	0.01	0.07	0.01	0.06
05.09.01	0.26		0.10	0.04	0.09	0.04	0.11		0.25	0.11			0.05	0.00	0.04		0.26
19.09.01					0.11	0.03					0.28		0.18		0.11		
03.10.01	0.24				0.19		0.52	0.10	0.23				0.21	0.04	0.12		0.24
17.10.01	0.07						0.43	0.16									0.07
31.10.01	0.05				0.13	0.02							0.14	0.04			0.05
09.11.01	0.06	0.01	0.11	0.02	0.03	0.00	0.42	0.05	0.14	0.05			0.05	0.01	0.26	0.18	0.06
24.11.01	0.05	0.01	0.04	0.01	0.04	0.00	0.24	0.31	0.16	0.06	0.42		0.04	0.00	1.02	0.45	0.05
07.12.01	0.06	0.01	0.10	0.01			0.03	0.22	0.14	0.02	0.14				0.06	0.03	0.06
21.12.01	0.07	0.04	0.04	0.01			1.26	0.37	0.06	0.01					0.04	0.01	0.07
04.01.02	0.10	0.02	0.20	0.06	0.03	0.00	1.46	0.49	0.32				0.05	0.01	0.15	0.09	0.10
18.01.02	0.05	0.02	0.03	0.00	0.01	0.00	2.56	1.16	0.05	0.01	0.31		0.03	0.01	0.03	0.02	0.05
01.02.02	0.06	0.01	0.10	0.02	0.05	0.03	0.38		0.07	0.01	0.10	0.05	0.03	0.01	0.19	0.15	0.06
15.02.02	0.33	0.26	0.07	0.02	0.01	0.00	0.56	0.32	0.10	0.03			0.03	0.01	0.02	0.00	0.33
07.03.02	0.03	0.00	0.03	0.00	0.03	0.00	2.01	0.88	0.06	0.01	0.17		0.04	0.01	0.03	0.01	0.03
21.03.02	0.05	0.01	0.05	0.00	0.04	0.00	0.42	0.30	0.06	0.01	0.20		0.05	0.00	0.04	0.00	0.05
05.04.02	0.03	0.00	0.04	0.01	0.03	0.01	2.36	1.85	0.06	0.02	0.22	0.01	0.03	0.00	0.03	0.00	0.03
18.04.02	0.03	0.00	0.03	0.00	0.04	0.01	2.53	1.31	0.07	0.02	0.17	0.02	0.03	0.00	0.03	0.00	0.03
01.05.02	0.03	0.00	0.02	0.00	0.04	0.02	0.26	0.08	0.05	0.03	0.08	0.02	0.03	0.01	0.04	0.00	0.03
15.05.02	0.06	0.02	0.04	0.01	0.02	0.00	0.17	0.04	0.19	0.03	0.13	0.03	0.02	0.00	0.07	0.02	0.06
29.05.02	0.03	0.00	0.04	0.01	0.03	0.00	0.27	0.06	0.12	0.03	0.06	0.00	0.03	0.00	0.08	0.03	0.03
12.06.02	0.04	0.01	0.03	0.00	0.04	0.00	0.09	0.00	0.16	0.07	0.10	0.03	0.03	0.01	0.05	0.01	0.04
26.06.02	0.03	0.01	0.03	0.00	0.03	0.01	0.10	0.05	0.09	0.04			0.04	0.00	0.16		0.03
10.07.02	0.03	0.00	0.03	0.00	0.02	0.00	0.10	0.01	0.09	0.04	0.22		0.04	0.01	0.07	0.03	0.03
24.07.02	0.03	0.01	0.03	0.00	0.04	0.00	0.08	0.05	0.19	0.04	0.33	0.16	0.09	0.03	0.13	0.06	0.03
07.08.02	0.03	0.01	0.04	0.00	0.04	0.00	0.13	0.06	0.08	0.02	0.11		0.05	0.00	0.07	0.03	0.03
21.08.02	0.03	0.01	0.04	0.01	0.04		0.06		0.09	0.01	0.12	0.04	0.05	0.01	0.05	0.00	0.03

NO₃-N	R 2100 m	R 2250 m	TF Cl	SE	TF Sf	SE	TF Mf	SE	TF B Cl	SE
29.05.00										
11.06.00	0.19	0.22	0.23	0.03	0.04	0.01	0.00	0.01		
25.06.00	0.26	0.25	0.36	0.03	0.03	0.11	0.01	0.01		
10.07.00	0.23	0.27	0.44	0.07	0.04	0.17	0.00	0.00		
23.07.00	0.46	0.44	0.41	0.28	0.11	0.09	0.01	0.07		
06.08.00	0.06	0.06	0.30	0.08	0.05	0.05	0.01	0.01		
21.08.00	0.38	0.33	0.57	0.21	0.09	0.05	0.06	0.01		
04.09.00	0.13		0.30	0.44		0.12	0.27			
18.09.00	0.29	0.46	0.15	0.22	0.24	0.07	0.05	0.09		
04.10.00										
19.10.00										
02.11.00	0.14	0.05	0.02	0.18	0.02	0.01	0.08	0.02		
16.11.00	0.07	0.06	0.10	0.01	0.03	0.03	0.01	0.01		
30.11.00	0.09	0.09	0.17	0.02	0.12	0.12	0.01	0.02		
14.12.00	0.03	0.61	0.09	0.07	0.03	0.08	0.03	0.01		
28.12.00	0.08	0.18	0.02	0.02	0.04	0.02	0.02	0.01		
12.01.01	0.02	0.08	0.25	0.02	0.03		0.01	0.01		
25.01.01	0.02	0.08	0.16	0.01	0.03	0.01	0.01	0.01		
09.02.01	0.05	0.08	0.23	0.01	0.07	0.08	0.01	0.02		
22.02.01	0.09	0.06	0.17	0.05	0.10	0.01	0.02	0.08		
09.03.01	0.29	0.08	0.54	0.00	0.16	0.09	0.00	0.05		
22.03.01	0.16	0.19	0.21	0.06	0.17	0.02	0.03	0.05		
06.04.01	0.00	0.00	0.14	0.02	0.08	0.03	0.01	0.06		
20.04.01	0.02	0.02	0.08	0.00	0.03	0.03	0.00	0.01		
02.05.01	0.02	0.05	0.05	0.02	0.01	0.01	0.01	0.01		
16.05.01	0.04	0.02	0.10	0.02	0.05	0.02	0.00	0.02		
30.05.01	0.05	0.15	0.08	0.04	0.03	0.01	0.01	0.02	0.13	0.09
13.06.01	0.20	0.25	0.23	0.06	0.01	0.10	0.01	0.00	0.31	0.15
27.06.01	0.30	0.29	0.24	0.06	0.03	0.04	0.00	0.00	0.24	0.14
11.07.01	0.25	0.46	0.28	0.05	0.14	0.06	0.02	0.06	0.36	0.10
25.07.01	0.99	0.48	0.54	0.04	0.09	0.22	0.00	0.03	0.29	0.14
08.08.01	0.47	0.32	0.35	0.08	0.02	0.05	0.05	0.01	0.75	
22.08.01	0.92		0.73	0.13		0.21	0.07		0.95	0.27
05.09.01	1.15	0.20	0.95	0.48	0.44	0.13	0.38	0.29		
19.09.01									0.54	0.61
03.10.01	1.02	1.13	0.77	0.01	0.50	0.09	0.00	0.12	0.52	0.16
17.10.01	0.53	1.44	0.41	0.19	0.37	0.01	0.10	0.17	0.09	0.14
31.10.01	0.11	0.03	0.13	0.01	0.03	0.11	0.01	0.01	0.15	0.11
09.11.01	0.10	0.36	0.04	0.02	0.03	0.02	0.01	0.02	0.02	0.01
24.11.01	0.29	0.35	0.11	0.00	0.06	0.05	0.00	0.04	0.04	0.03
07.12.01	0.04	0.39	0.07	0.01	0.04	0.05	0.01	0.01		
21.12.01									0.05	0.02
04.01.02	0.06	0.03	0.08	0.00	0.09	0.03	0.00	0.03	0.46	0.71
18.01.02	0.07	0.05	0.10	0.01	0.09	0.04	0.00	0.04	0.46	0.23
01.02.02	0.31	0.21	0.12	0.01	0.14	0.08	0.00	0.05	0.24	0.11
15.02.02	0.36	0.20	0.16	0.03	0.11	0.06	0.03	0.04	0.16	0.07
07.03.02	0.18	0.11	0.57	0.09	0.11	0.15	0.02	0.05	0.16	0.13
21.03.02	0.17	0.17	0.23	0.09	0.11	0.06	0.05	0.08	0.09	0.05
05.04.02	0.09	0.11	0.04	0.03	0.07	0.03	0.02	0.04	0.09	0.07
18.04.02	0.09	0.04	0.06	0.06	0.10	0.04	0.03	0.02	0.04	0.01
01.05.02	0.03	0.01	0.02	0.03	0.08	0.00	0.01	0.02	0.03	0.02
15.05.02	0.07	0.04	0.06	0.15	0.16	0.02	0.05	0.03	0.03	0.02
29.05.02	0.03	0.01	0.07	0.11	0.15	0.02	0.03	0.07	0.03	0.02
12.06.02	0.11		0.09	0.13	0.18	0.04	0.04	0.02	0.05	0.03
26.06.02	0.14	0.14	0.10	0.06	0.38	0.02	0.01	0.22	0.13	0.08
10.07.02	0.09	0.00	0.10	0.08	0.28	0.01	0.04	0.09	0.13	0.07
24.07.02	0.13	0.00	0.16	0.19	0.11	0.10	0.12	0.06	0.16	0.06
07.08.02	0.12	0.01	0.14	0.04	0.03	0.08	0.02	0.01	0.18	0.02
21.08.02	0.12	0.03	0.16	0.03	0.02	0.02	0.02	0.01	0.15	0.13

NO ₃ -N	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S1 B Cl	SE
29.05.00																
11.06.00									3.11	1.28	2.15	0.50	0.27	0.35		
25.06.00									3.95	1.06	2.03		0.22	0.33		
10.07.00									2.30	0.81	1.78	0.44	0.32	0.30		
23.07.00									2.23	0.84	1.75	0.32	0.21	0.26		
06.08.00									2.42	0.76	1.86	0.49	0.27	0.30		
21.08.00									3.35	0.73	1.74	1.41	0.20	0.17		
04.09.00									2.68	0.61	1.52	1.29	0.21	0.30		
18.09.00									2.22	0.82	1.51	1.13		0.27		
04.10.00									2.04	0.85	1.49	0.99	0.06	0.31		
19.10.00									1.81	0.74	1.84	1.10	0.08	0.49		
02.11.00									2.52	1.13	1.91	1.32		0.56		
16.11.00	4.20	1.75	2.25	1.59		0.74										
30.11.00	4.71	1.71	1.65	0.67	0.31	0.83			2.76	0.46	2.21	0.56	0.18	0.85		
14.12.00	1.70	0.82	0.77	0.22	0.05	0.12			1.95	0.33	1.74	0.36	0.19	0.73		
28.12.00	0.39	0.27	0.66	0.03	0.13	0.07			3.19	0.34	1.54	1.14	0.21	0.57		
12.01.01	1.27	0.63	0.33	0.34	0.21	0.13			3.60	0.36	1.21	0.67	0.24	0.45		
25.01.01	1.51	0.41	0.50	0.53	0.08	0.07			2.46	0.39	1.03	0.39	0.24	0.45		
09.02.01	3.45	0.92	0.88	1.96	0.00	0.16			3.64	0.60	1.12	1.22	0.35	0.46		
22.02.01	3.47	1.33	1.21	0.86	0.13	0.30			3.40	0.79	1.22	1.05	0.41	0.50		
09.03.01	1.83	3.15	2.42	1.07	1.19	0.54			3.07	0.83	1.27	0.55	0.50	0.54		
22.03.01	4.71	3.43	1.92	1.04	0.06	0.55			2.91	0.86	1.39	0.20	0.53	0.59		
06.04.01	2.65	2.20	1.24	0.72	0.35	0.18			2.30	1.06	1.67	0.45	0.60	0.58		
20.04.01	0.88	0.43	0.67	0.42	0.11	0.13			1.14	0.66	0.96	0.13	0.34	0.16		
02.05.01	0.83	0.40	0.77	0.58	0.15	0.21			0.97	0.43	1.16	0.08	0.17	0.43		
16.05.01	1.95	0.48	0.51	0.81	0.07	0.18	2.66	0.85	1.16	0.60	0.94	0.13	0.23	0.26	2.19	0.86
30.05.01	1.03	0.45	0.61	0.31	0.05	0.32	1.38	0.31	0.77	0.44	1.04	0.07	0.15	0.28	1.57	0.48
13.06.01	3.02	0.89	1.01	1.30	0.22	0.15	3.07	0.38	1.24	0.63	1.14	0.03	0.24	0.16	2.86	1.14
27.06.01	3.73	0.62	1.32	1.60	0.11	0.15	4.15	1.22	1.73	0.76	1.21	0.06	0.23	0.25	2.63	2.07
11.07.01	4.95	1.60	1.27	2.97	0.40	0.50	3.81	1.78	4.96	0.91	1.80	2.63	0.39	0.32	4.05	2.38
25.07.01	2.71	1.29	3.23		0.13	0.23	2.71		1.67	0.89	1.10	0.58	0.37	0.30	5.04	2.85
08.08.01	5.69	1.19	1.09	2.76	0.26	0.23	4.01	2.48	5.17	1.18	1.54	3.57	0.30	0.50	3.39	1.79
22.08.01									5.91	1.03	1.42	4.27	0.29	0.34	4.08	2.50
05.09.01									8.96	1.59	1.37	4.81		0.60	3.46	
19.09.01									14.84		1.73			0.78	1.35	0.99
03.10.01	7.56	12.76	6.82	7.16		0.96	9.19	2.45	7.80		0.70				10.10	
17.10.01	12.25	7.68	4.25	15.37	3.00	1.07	19.73	3.46	14.61		0.70					
31.10.01	6.15	0.07	1.31	5.49		0.24	1.23		10.38		1.35			0.47	10.63	
09.11.01	12.23	1.10	1.39	10.52	0.30	0.26	10.82	2.79	3.75	0.88	1.72	2.25	0.29	0.60	4.08	0.75
24.11.01	4.06	0.76	1.07	3.92	0.08	0.17	6.81	1.31	3.56	0.88	1.81	1.99	0.25	0.80	6.63	1.02
07.12.01	6.58	0.08	0.74	7.92	0.06	0.05	7.66	1.91	3.95	1.37	2.11	2.26	0.48	0.88	9.93	1.33
21.12.01									4.34	1.03		2.16	0.12		20.17	2.44
04.01.02	4.39	0.25	0.86	4.33	0.10	0.27	8.84	1.16	4.77	1.07	2.00	2.41	0.23	0.91	19.15	1.45
18.01.02	2.77	0.33	0.77	3.24	0.18	0.19	6.68	1.13	4.59	0.99	1.94	2.39	0.11	0.96	22.90	4.43
01.02.02	1.23	0.42	0.79	0.90	0.29	0.22	7.84	2.15	4.15	0.87	1.73	2.33	0.13	0.90	24.88	3.23
15.02.02	4.40	0.64	0.63	2.65	0.25	0.14	5.31	0.41	4.26	1.21	1.85	1.69	0.22	0.88	19.58	4.81
07.03.02	4.46	0.77	0.45	3.13	0.15	0.10	8.07	1.53	4.06	1.34	1.90	2.18	0.27	0.82	15.19	2.89
21.03.02	1.95	0.72	0.48	1.47	0.12	0.13	3.71	0.43	3.40	1.39	1.74	1.97	0.38	0.73	18.28	7.09
05.04.02	1.27						3.63		3.19	1.80	1.60	1.82	0.52	0.57	17.49	5.27
18.04.02	3.53		0.74			0.24	5.05	1.60	3.04	1.86	0.91	1.37	0.50	0.25	17.69	5.61
01.05.02	0.63	0.16	0.42	0.56	0.03	0.12	1.25	0.59	1.14	1.12	1.27	0.35	0.28	0.40	5.14	1.58
15.05.02	0.63	0.54	0.98	0.24	0.06	0.23	2.28	0.65	1.43	1.65	1.28	0.51	0.44	0.62	4.82	1.60
29.05.02	0.83	0.43	0.78	0.40	0.10	0.31	2.11	0.71	1.85	2.04	1.35	0.51	0.70	0.51	3.72	1.32
12.06.02	1.31	0.61	1.08	0.44	0.12	0.28	3.78	1.89	2.73	2.05	1.32	0.76	0.55	0.49	4.25	1.28
26.06.02	0.83	0.62	1.32	0.66	0.23	0.35	2.03	1.26	2.74	2.21	1.67	1.02	0.52	0.71	5.75	2.57
10.07.02	1.12	0.71	0.87	0.81	0.25	0.36	2.01	1.30	2.50	2.82	1.67	0.75	0.83	0.70	5.19	2.40
24.07.02	2.13	1.35	1.53	1.72	0.35	0.39	3.46	0.93	1.97	2.20	1.47	1.02	0.59	0.64	5.74	2.33
07.08.02	1.27	0.77	1.28	1.59	0.31	0.37	1.79	0.48	2.50	2.42	1.67	0.61	0.59	0.85	5.21	1.83
21.08.02	1.04	0.52	0.77	0.85	0.18	0.16	1.94	0.54	2.06	2.67	1.82	0.51	0.71	0.92	3.84	1.91

NO ₃ -N	S2 Cl	SE	S2 Sf	SE	S2 Mf	SE	S2 B Cl	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE	S3 B Cl	SE	ST
29.05.00																	
11.06.00	1.96	0.44	1.55	1.04	0.13	0.24			0.44	0.50	0.97	0.13	0.35	0.10			0.66
25.06.00	3.63	0.31	1.52		0.11	0.12			0.41	0.18	0.83	0.12	0.10	0.09			
10.07.00	1.17	0.30	1.63	0.64	0.13	0.13			0.42	0.17	1.04	0.12	0.11	0.11			0.66
23.07.00	0.91	0.23	1.68	0.53	0.10	0.16			0.40	0.03	1.05	0.14	0.01	0.11			
06.08.00	0.81	0.16	1.49	0.48	0.08	0.26			0.33	0.04	1.15	0.17	0.02	0.14			0.54
21.08.00	0.65	0.13	1.60	0.35	0.08	0.16			0.56	0.01	1.07	0.03	0.00	0.20			0.50
04.09.00	0.57	0.10	1.61	0.35	0.07	0.18			0.59	0.03	1.30	0.01		0.33			0.39
18.09.00	0.63	0.01	1.62	0.34	0.01	0.19			0.36		1.36	0.07		0.31			0.03
04.10.00	0.66	0.11	1.61	0.31	0.04	0.16			0.43		1.37			0.37			
19.10.00	0.58	0.16	1.65	0.30		0.19			0.55		1.03	0.07		0.13			
02.11.00	0.57	0.75	1.63	0.12		0.20			0.21	0.45	1.18		0.19	0.08			0.42
16.11.00																	0.51
30.11.00	0.66	0.16	1.53	0.23	0.12	0.23			0.34	0.95	1.06	0.03	0.59	0.09			0.55
14.12.00	1.82	0.31	1.55	0.13	0.18	0.11			0.41	0.18	0.91	0.06	0.12	0.10			0.59
28.12.00	0.40	0.25	1.37	0.31	0.14	0.10			0.64	0.58	1.14		0.25	0.15			0.61
12.01.01	1.39	0.24	1.20	0.86	0.14	0.10			0.23	0.27	1.04	0.06	0.16	0.11			0.65
25.01.01	2.22	0.25	1.08	1.10	0.18	0.14			0.32	0.15	1.07	0.09	0.08	0.14			0.64
09.02.01	2.16	0.36	1.07	1.46	0.27	0.14			1.49	0.54	1.14	0.73	0.41	0.13			0.65
22.02.01	2.32	0.19	1.09	1.66	0.14	0.13			0.39	0.22	1.12	0.06	0.13	0.12			0.60
09.03.01	2.20	0.18	1.15	1.64	0.14	0.13			0.38	0.31	1.24	0.18		0.15			
22.03.01	2.31	0.19	1.20	1.42	0.13	0.13			0.59		1.27	0.22		0.10			0.59
06.04.01	2.63	0.32	1.26	1.72	0.15	0.13			0.19	0.06	1.26	0.05	0.01	0.18			0.60
20.04.01	2.69	0.71	1.48	1.68	0.22	0.16			0.33	0.24	1.26	0.04	0.09	0.19			0.81
02.05.01	2.17	0.44	1.48	1.54	0.20	0.30			0.27	0.24	1.06	0.10	0.09	0.14			0.62
16.05.01	1.74	0.44	1.13	1.20	0.15	0.31	0.20		0.24	0.32	0.88	0.07	0.10	0.10	0.38	0.13	
30.05.01	1.39	0.35	1.09	0.94	0.15	0.25	1.48	2.14	0.36	0.38	1.02	0.07	0.13	0.19	0.55	0.21	0.77
13.06.01	1.28	0.39	1.03	0.43	0.05	0.19	0.91		0.38	0.28	0.94	0.23	0.15	0.17	0.57	0.31	0.70
27.06.01	1.30	0.23	0.98	0.28	0.05	0.21	0.06		0.86	0.40	0.98		0.15	0.11	0.73	0.50	0.69
11.07.01	1.34	0.22	1.14	0.23	0.08	0.16	0.06		0.79	0.43	1.07	0.37	0.16	0.15	0.31	0.07	1.13
25.07.01	1.19	0.20	1.48		0.12	0.29	6.11	8.57	1.94	1.49	1.00	1.08		0.15	0.29	0.04	1.36
08.08.01	1.46	0.29	1.63	0.37	0.09	0.32	0.07		3.09	0.26	1.29	1.60	0.10	0.24	0.33	0.09	0.63
22.08.01	1.65	0.13	1.74	0.34	0.07	0.37	0.05		1.67		1.11			0.17	0.20	0.06	0.57
05.09.01	1.09	0.18	1.86		0.05	0.44	0.01		1.36		1.30	0.31		0.18	0.24		0.53
19.09.01			2.11			0.50				0.08	1.36				0.31		0.44
03.10.01	7.79		0.97				1.29	0.52	1.49		1.06			0.16	0.30		0.47
17.10.01	7.82						1.13	0.50									0.40
31.10.01	8.12		1.63			0.47					1.12			0.19			0.52
09.11.01	2.87	0.29	1.59	1.83	0.12	0.52	1.47	0.76	3.60		1.10	2.72		0.19	0.26	0.04	0.53
24.11.01	3.72	0.31	1.51	2.80	0.14	0.43	2.01	0.54	0.93	0.29	1.12	0.52		0.17	0.26	0.12	0.40
07.12.01	2.55	0.48	1.66	1.95	0.25	0.58	2.64	0.80	1.79	0.07	1.15	1.20		0.18	0.22	0.11	0.44
21.12.01	0.91	0.39		0.34	0.13		10.96	5.88	2.53			1.93			0.22	0.05	
04.01.02	3.33	0.22	1.49	2.65	0.10	0.53	7.31	2.48	0.87		0.93	0.17		0.22	0.34	0.17	0.44
18.01.02	2.31	0.33	1.40	1.67	0.09	0.45	12.46	7.42	1.92	0.12	0.98	1.44		0.15	0.25	0.11	0.51
01.02.02	3.62	0.32	1.34	2.62	0.07	0.39	9.94	7.01	3.53	0.77	1.06	2.78	0.41	0.18	1.11	0.45	0.55
15.02.02	4.16	0.38	1.71	3.08	0.20	0.13	11.86	5.18	0.76		1.03	0.32		0.20	0.64	0.26	0.62
07.03.02	5.06	0.40	1.23	3.68	0.13	0.37	9.15	6.09	1.45	0.16	1.09	1.01	0.03	0.20	2.41	2.23	0.65
21.03.02	4.10	0.73	1.19	2.64	0.24	0.41	12.87	11.51	0.80	0.05	1.06	0.45		0.19	0.93	0.11	0.62
05.04.02	3.84	1.12	1.13	2.35	0.36	0.40	11.98	12.09	1.07	0.73	1.00	0.65	0.44	0.19	0.42	0.17	0.85
18.04.02	3.26	1.13	1.21	1.77	0.27	0.46	15.82	14.72	0.80	0.20	1.01	0.44	0.07	0.21	0.47	0.18	0.72
01.05.02	1.91	1.37	1.13	0.99	0.26	0.40	6.99	7.69	1.00	0.33	1.01	0.55	0.18	0.19	1.05	0.64	
15.05.02	1.62	1.11	1.12	0.41	0.11	0.55	3.04	3.28	0.90	0.25	1.09	0.50	0.12	0.24	2.83	2.46	
29.05.02	2.05	1.21	1.42	0.50	0.17	0.45	2.99	3.13	0.92	1.48	0.95	0.62	0.99	0.23	2.22	1.66	
12.06.02	3.15	1.00	1.40	1.12	0.00	0.46	3.01	2.67	1.19	0.36	0.96	0.76	0.20	0.23	3.43	3.01	
26.06.02	2.63	1.32	1.60	0.40	0.12	0.57	4.08	5.23	1.12		1.11	0.62		0.32	5.63	3.64	0.51
10.07.02	2.52	1.51	1.60	0.31	0.08	0.57	3.85	3.73	1.13	0.55	1.13	0.68		0.33	2.66	1.97	
24.07.02	2.73	1.31	1.94	0.74	0.22	0.65	2.93	2.90	0.79	0.69	1.33	0.44	0.38	0.29	3.42	2.64	
07.08.02	3.06	1.86	1.70	0.59	0.49	0.86	3.58	3.59	0.82	0.17	1.28	0.46	0.06	0.30	3.49	2.80	
21.08.02	2.89	1.38	0.57	0.64	0.18		3.48	4.84	0.33	0.48	1.37	0.12	0.30	0.39	3.75	2.79	0.64

TON	R 2100 m	R 2250 m	TF Cl	SE	TF Sf	SE	TF Mf	SE	TF B Cl	SE
29.05.00										
11.06.00	0.07	0.10	0.32	0.08	0.50	0.03	0.40	0.08	-	-
25.06.00	0.18	0.15	0.26	0.08	0.51	0.07	0.51	0.12	-	-
10.07.00	0.33	0.18	0.19	0.04	0.27	0.02	0.30	0.08	-	-
23.07.00	0.15	0.13	0.26	0.05	0.17	0.02	0.41	0.09	-	-
06.08.00	0.41	0.12	0.48	0.23	0.44	0.04	0.46	0.06	-	-
21.08.00	0.31	0.21	0.30	0.13	0.73	0.06	0.61	0.02	-	-
04.09.00	0.54	0.00	0.60	0.12	1.15	0.07			-	-
18.09.00	0.92	0.15	0.81	0.22	1.18	0.39	1.05	0.27	-	-
04.10.00									-	-
19.10.00									-	-
02.11.00	0.78	0.47	0.88	0.17	0.59	0.41	0.79	0.09	-	-
16.11.00	0.13	0.68	0.44	0.19	0.57	0.07	0.40	0.05	-	-
30.11.00	0.45	0.16	0.92	0.23	1.17	0.26	0.58	0.05	-	-
14.12.00	0.35	0.03	0.65	0.07	0.57	0.02	0.54	0.03	-	-
28.12.00	0.18		0.82	0.07	0.62	0.07	0.30	0.04	-	-
12.01.01	0.45	0.04	0.87		1.29	0.50	0.34	0.06	-	-
25.01.01	0.30	0.06	0.72	0.05	0.58	0.12	0.37	0.04	-	-
09.02.01	0.40	0.12	0.61	0.08	0.63	0.05	0.38	0.04	-	-
22.02.01	0.59	0.22	0.52	0.04	0.71	0.09	0.52	0.11	-	-
09.03.01	1.08	0.64	1.25	0.11	1.55	0.27	0.98	0.11	-	-
22.03.01	0.60	0.24	0.77	0.08	1.01	0.26	0.60	0.09	-	-
06.04.01	0.53	0.32	0.45	0.04	0.52	0.05	0.51	0.07	-	-
20.04.01	0.03	0.01	0.12	0.06	0.13	0.02	0.28	0.03	-	-
02.05.01	0.13	0.05	0.11	0.02	0.34	0.05	0.55	0.32	-	-
16.05.01	0.11	0.14	0.11	0.01	0.60	0.14	0.35	0.07	0.19	0.04
30.05.01	0.05	0.03	0.13	0.04	0.33	0.11	0.24	0.06	0.10	0.02
13.06.01	0.31	0.47	0.30	0.08	0.29	0.02	0.34	0.04	0.21	0.01
27.06.01	0.50	0.44	0.31	0.03	1.06	0.25	0.44	0.09	0.88	0.25
11.07.01	0.70	0.11	0.35	0.04	0.47	0.03	0.53	0.07	0.31	0.01
25.07.01	1.43	0.78	0.66	0.15	0.59	0.04	0.75	0.04	0.47	0.06
08.08.01	0.23	0.65	0.41	0.04	0.44	0.01	0.37	0.04	0.40	0.05
22.08.01	1.78		0.82	0.35	1.44	0.07			0.43	0.35
05.09.01	0.92	0.83	2.37	0.13	2.54	0.34	2.58	0.60	2.40	0.27
19.09.01										
03.10.01	0.89	0.82	1.30	0.33	2.34	0.73	2.11	0.21	2.08	0.48
17.10.01	1.17		1.69	0.39	1.75	0.49	2.31	0.35	1.83	0.18
31.10.01	1.37	0.15	1.24	0.07	1.22	0.53	0.72	0.10	1.24	0.53
09.11.01	0.54	0.37	0.60	0.09	0.76	0.06	0.78	0.19	0.96	0.32
24.11.01	0.37	0.43	0.71	0.26	0.61	0.05	0.40	0.09	0.42	0.04
07.12.01	0.40	0.31	0.53	0.18	0.68	0.31	0.49	0.09	0.53	0.04
21.12.01										
04.01.02	0.64	0.18	0.70	0.11	1.04	0.38	0.58	0.05	0.59	0.07
18.01.02	0.35	0.20	0.49	0.07	0.74	0.11	0.57	0.07	0.41	0.09
01.02.02	1.60	0.27	1.14	0.04	0.93	0.17	0.57	0.11	2.76	1.13
15.02.02	0.71	0.27	0.69	0.04	0.94	0.17	0.59	0.10	0.49	0.10
07.03.02	0.19	0.11	3.22	0.41	1.06	0.27	0.47	0.07	0.19	0.10
21.03.02	0.19	0.12	0.30	0.09	0.46	0.07	0.36	0.03	0.19	0.03
05.04.02	0.09	0.04	0.14	0.01	0.32	0.07	0.33	0.06	0.16	0.04
18.04.02	0.17	0.16	0.20	0.04	0.33	0.17	0.45	0.15	0.13	0.02
01.05.02	0.04	0.06	0.09	0.01	0.27	0.03	0.43	0.06	0.13	0.06
15.05.02	0.24	0.00	0.21	0.02	0.63	0.01	0.65	0.09	0.20	0.03
29.05.02	0.17	0.09	0.16	0.01	0.76	0.29	0.39	0.05	0.16	0.02
12.06.02	0.24	0.13	0.38	0.03	0.52	0.23	0.61	0.06	0.21	0.02
26.06.02	0.21	0.74	0.18	0.03	0.35	0.02	0.82	0.24	0.15	0.02
10.07.02	0.18	0.20	0.19	0.02	0.30	0.01	1.06	0.38	0.19	0.01
24.07.02	0.35	0.25	0.40	0.03	0.46	0.21	0.86	0.20	0.42	0.04
07.08.02	0.17	0.21	0.54	0.15	0.55	0.07	0.58	0.04	0.21	0.01
21.08.02	0.29	0.11	0.44	0.09	0.43	0.03	0.39	0.03	0.18	0.03

TON	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S1 B Cl	SE
29.05.00																
11.06.00									0.12	0.06	0.09	0.02	0.14	0.02		
25.06.00									0.13		0.07	0.01	0.11	0.01		
10.07.00									0.15	0.02	0.03	0.01	0.07	0.01		
23.07.00									0.10	0.00	0.01	0.01	0.06	0.01		
06.08.00									0.12	0.02	0.05	0.01	0.12	0.01		
21.08.00									0.17	0.00	0.06	0.01	0.10	0.02		
04.09.00									0.14	0.01	0.06	0.01	0.07	0.03		
18.09.00									0.13	0.02	0.03		0.07	0.02		
04.10.00									0.11	0.01	0.04	0.00	0.07	0.02		
19.10.00									0.11	0.02	0.08	0.01	0.09	0.01		
02.11.00									0.13	0.01	0.22		0.11	0.03		
16.11.00	2.55	0.36	0.70		1.41	0.38										
30.11.00	2.42	0.34	1.13	0.03	0.65	0.07				0.03		0.03		0.01		
14.12.00	1.02	0.06	1.03	0.04	0.93	0.04			0.20	0.05	0.06	0.03	0.12	0.03		
28.12.00	1.38	0.04	1.23	0.03	0.69	0.03			0.45	0.22	0.04	0.03	0.11	0.02		
12.01.01	1.06	0.11	1.15	0.18	0.68	0.07			0.47	0.21	0.06	0.02	0.12	0.03		
25.01.01	1.41	0.33	0.84	0.07	0.48	0.06			0.64	0.45	0.04	0.00	0.08	0.01		
09.02.01	1.61	0.19	0.66	0.33	0.62	0.04			0.26	0.02	0.05	0.02	0.06	0.02		
22.02.01	1.68	0.20	1.58	0.35	0.68	0.07			0.24	0.07	0.04	0.02	0.07	0.02		
09.03.01	9.80	7.20	2.64	0.27	0.85	0.07			0.27	0.08	0.28	0.05	0.13	0.08		
22.03.01	2.66	0.86	1.81	0.48	0.88	0.15			0.12	0.01	0.07	0.03	0.06	0.01		
06.04.01	1.88	0.36	0.96	0.13	0.63	0.23			0.30	0.03	0.04	0.03	0.20	0.09		
20.04.01	0.86	0.09	0.71	0.05	0.59	0.11			0.19	0.02	0.04	0.02	0.93	0.83		
02.05.01	0.66	0.18	0.47	0.06	0.51	0.07			0.30	0.02	0.10	0.04	0.29	0.11		
16.05.01	0.47	0.15	0.41	0.01	0.45	0.13	0.59	0.10	0.22	0.04	0.12	0.09	0.72	0.37	0.67	0.48
30.05.01	0.55	0.12	0.43	0.00	0.27	0.04	0.59	0.14	0.14	0.03	0.05	0.02	0.04	0.01	0.16	0.03
13.06.01	0.70	0.04	0.54	0.08	0.49	0.06	0.69	0.12	0.16	0.05	0.03	0.02	0.06	0.02	0.16	0.12
27.06.01	0.95	0.05	0.49	0.07	0.56	0.08	1.07	0.21	0.15	0.02	0.07	0.04	0.69	0.62	0.31	0.18
11.07.01	0.99	0.29	0.74	0.20	0.72	0.10	0.88	0.33	0.19	0.15	0.14	0.11	0.16	0.04	0.15	0.05
25.07.01	0.88		0.50	0.06	0.67	0.11	0.88		0.22	0.05	0.06	0.02	0.17	0.08	0.37	0.14
08.08.01	1.10	0.12	0.58	0.12	0.65	0.10	1.06	0.08	0.30	0.07	0.04	0.01	0.15	0.06	0.16	0.11
22.08.01									0.23	0.07	0.09	0.02	0.21	0.09	0.20	0.10
05.09.01									0.46		0.15		0.26	0.08	0.08	
19.09.01									0.63				0.28	0.05	0.24	0.02
03.10.01	3.29	2.90	1.50		2.23	0.58	7.76	2.43							14.90	
17.10.01	5.65	1.42	2.85	0.34	0.70	0.14	5.62	0.91	0.88							
31.10.01	2.43	0.09	2.18		0.92	0.11	5.40		0.52				0.17	0.03	17.28	
09.11.01	2.49	0.15	1.00	0.04	1.15	0.13	2.48	0.26	0.63	0.42	0.10	0.02	0.15	0.03	0.70	0.41
24.11.01	1.85	0.75	0.79	0.12	0.85	0.04	2.51	0.90	0.26	0.07	0.10	0.04	0.11	0.05	0.39	0.11
07.12.01	2.41	0.66	2.28	0.16	0.71	0.09	9.65	5.60	0.19	0.39	0.18	0.07	0.63	0.25	0.67	0.37
21.12.01									0.94	0.58	0.08	0.03			2.82	1.06
04.01.02	1.95	0.45	1.26	0.36	0.69	0.03	6.23	2.09	1.09	0.88	0.11	0.02	0.39	0.17	4.09	0.67
18.01.02	1.56	0.32	0.98	0.09	0.87	0.09	3.24	1.25	0.77	1.01	0.19	0.06	0.56	0.26	6.24	1.45
01.02.02	3.77	1.58	1.50	0.88	0.66	0.06	2.78	0.78	0.38	0.11	1.33	1.18	0.45	0.21	0.00	
15.02.02	1.97	0.09	1.20	0.32	0.68	0.04	3.55	0.80	0.19	2.16	0.49	0.27	0.53	0.22	3.28	1.90
07.03.02	2.31	0.82	1.12	0.10	0.77	0.10	1.76	0.36	0.97	0.58	0.31	0.08	0.43	0.17	2.08	0.59
21.03.02	1.30	0.20	0.92	0.10	0.83	0.11	0.96	0.15	0.19	0.02	0.03	0.02	0.14	0.02	1.60	1.46
05.04.02	2.32	0.34		0.10		0.31	2.16	0.92	0.23	1.20	0.08	0.03	0.25	0.16	3.05	0.63
18.04.02	1.94	0.36		0.21	1.09	0.09	1.02	0.14	0.78	1.09	0.07	0.02	0.05	0.02	3.22	0.51
01.05.02	0.76	0.06	0.57	0.03	0.74	0.06	0.46	0.06	0.20	0.07	0.05	0.02	0.13	0.02	0.33	0.08
15.05.02	0.97	0.07	0.55	0.07	0.81	0.06	0.50	0.09	0.21	0.06	0.11	0.04	0.15	0.01	0.33	0.13
29.05.02	0.97	0.06	0.67	0.07	0.96	0.16	0.50	0.14	0.15	0.01	0.15	0.07	0.12	0.03	0.27	0.11
12.06.02	1.55	0.22	1.42	0.89	0.93	0.11	1.02	0.02	0.23	0.02	0.10	0.02	0.09	0.01	0.22	0.02
26.06.02	1.94	0.59	0.69	0.10	0.61	0.22	0.79	0.18	0.18	0.01	0.13	0.05	0.17	0.03	0.39	0.10
10.07.02	0.91	0.37	0.68	0.13	0.71	0.10	0.71	0.13	0.19	0.02	0.09	0.02	0.12	0.02	0.20	0.06
24.07.02	1.50	0.18	0.76	0.04	0.87	0.06	0.95	0.09	0.15	0.01	0.10	0.06	0.14	0.02	0.31	0.17
07.08.02	1.30	0.15	0.72	0.06	0.92	0.16	0.87	0.04	0.26	0.06	0.09	0.02	0.13	0.02	0.22	0.06
21.08.02	1.34	0.22	0.87	0.04	0.83	0.07	0.88	0.06	0.18	0.02	0.05	0.00	0.10	0.00	0.59	0.39

TON	S2 Cl	SE	S2 Sf	SE	S2 Mf	SE	S2 B Cl	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE	S3 B Cl	SE	ST
29.05.00																	
11.06.00	0.11	0.04	0.03	0.01	0.10	0.03			0.11	0.07	0.08	0.03	0.06	0.02			0.07
25.06.00	0.10		0.04	0.00	0.08	0.01			0.07	0.04	0.08	0.03	0.04	0.00			
10.07.00	0.06	0.02	0.00	0.00	0.05	0.01			0.02	0.02	0.02	0.01	0.02	0.01			0.00
23.07.00	0.04	0.01	0.00	0.00	0.05	0.02			0.03	0.02	0.02	0.02	0.02	0.01			
06.08.00	0.05	0.01	0.01	0.00	0.08	0.02			0.04	0.02	0.03	0.02	0.05	0.01			0.04
21.08.00	0.09	0.03	0.01	0.01	0.07	0.01			0.02	0.00	0.03	0.02	0.02	0.01			0.22
04.09.00	0.08	0.03	0.02	0.00	0.04	0.01			0.01	0.00	0.01		0.04	0.02			0.09
18.09.00	0.06	0.02	0.03	0.01	0.04	0.01			0.04	0.01			0.03	0.02			0.21
04.10.00	0.07	0.02	0.03	0.01	0.05	0.01			0.00				0.03	0.01			0.10
19.10.00	0.08	0.03	0.07		0.06	0.01			0.05	0.02			0.03	0.01			0.04
02.11.00	0.09	0.02	0.43		0.08	0.03			0.05		0.17	0.05	0.04	0.01			0.05
16.11.00																	0.28
30.11.00																	0.08
14.12.00	0.07	0.03	0.04	0.02	0.05	0.03			0.08	0.06	0.02	0.02	0.02	0.01			0.07
28.12.00	0.14	0.02	0.03	0.01	0.05	0.02			0.19		0.10	0.02	0.03	0.01			0.03
12.01.01	0.31	0.08	0.03	0.01	0.04	0.01			0.26		0.06	0.01	0.02	0.01			0.10
25.01.01	0.18	0.04	0.03	0.02	0.05	0.03			0.02	0.01	0.06	0.01	0.01	0.00			0.05
09.02.01	0.10	0.01	0.01	0.01	0.04	0.02			0.12	0.08	0.01	0.01	0.02	0.01			0.19
22.02.01	0.19	0.08	0.04	0.03	0.05	0.01			0.04	0.01	0.02	0.00	0.02	0.02			0.05
09.03.01	0.61	0.26	0.08	0.06	0.02	0.01			0.22	0.05	0.21		0.44	0.28			
22.03.01	0.18	0.09	0.02	0.01	0.05	0.00			0.08	0.03			0.04	0.01			0.14
06.04.01			0.00		0.04	0.01							0.05	0.03			
20.04.01	0.26	0.14	0.01	0.01	0.07	0.01			0.05	0.03	0.01	0.01	0.02	0.01			0.24
02.05.01	0.59	0.41	0.09	0.05	0.37	0.07			0.04	0.02	0.01	0.01	0.26	0.04			
16.05.01	0.23	0.07	0.10	0.05	0.40		0.11		0.03	0.02	0.04	0.02	0.31	0.29	1.26	1.00	0.36
30.05.01	0.10	0.01	0.04	0.00	0.07	0.02	0.13	0.06	0.20	0.11	0.06	0.03	0.04	0.01	0.08	0.01	0.14
13.06.01	0.06	0.03	0.02	0.00	0.06	0.01	0.11	0.04	0.04	0.03	0.06	0.01	0.02	0.00	0.06	0.03	0.09
27.06.01	0.02	0.02	0.03	0.02	0.09	0.03	0.04		0.84		0.10	0.02	0.03	0.01	0.21	0.09	1.12
11.07.01	0.07	0.03	0.01	0.01	0.09	0.04	0.01		0.26	0.11	0.32	0.22	0.05	0.02	0.17	0.06	0.37
25.07.01	0.36		0.03	0.00	0.12	0.06	0.29	0.18	0.30	0.06	0.15		0.02	0.01	0.06	0.03	1.49
08.08.01	0.03	0.01	0.10	0.06	0.13	0.06	0.05		0.10	0.01	0.17	0.08	0.13	0.07	0.07	0.03	0.09
22.08.01	0.07	0.01	0.11	0.04	0.13	0.04	0.06		0.08				0.04	0.02	0.06	0.05	0.32
05.09.01	0.12		0.13	0.02	0.14	0.04	0.11		0.24	0.13			0.13	0.10	0.03		0.03
19.09.01					0.15	0.04					0.11		0.06	0.04	0.04		0.05
03.10.01					0.52		0.52	0.10	0.32				0.12	0.05	0.17		0.11
17.10.01	0.57						0.43	0.16					0.28				0.19
31.10.01	0.37				0.09	0.04							0.21	0.16			0.07
09.11.01	1.08	0.79	0.17	0.05	0.05	0.01	0.42	0.05	0.39	0.12			0.05	0.02	0.39	0.04	0.05
24.11.01	0.19	0.07	0.05	0.00	0.04	0.01	0.24	0.31	0.15	0.06	0.18		0.02	0.01	1.16	0.62	0.07
07.12.01	0.71	0.53	0.14	0.04	0.30	0.08	0.03	0.22	0.64	0.34	0.10		0.23	0.04	0.12	0.03	0.07
21.12.01	0.15	0.07	0.05	0.01			1.26	0.37	0.58	0.44					0.08	0.02	0.00
04.01.02	0.39	0.26	0.05	0.00	0.15	0.03	1.46	0.49	0.18	0.08			0.05	0.03	0.14	0.02	0.09
18.01.02	0.30	0.16	0.05	0.01	0.22	0.07	2.56	1.16	1.29	1.05	0.10		0.21	0.04	0.12	0.05	0.03
01.02.02	0.60	0.23	0.04	0.02	0.25	0.09	0.38		0.04	0.00	0.07	0.03	0.20	0.05	0.37	0.20	0.08
15.02.02	0.10	0.07	0.10	0.03	0.35	0.04	0.56	0.32	0.20	0.07			0.19	0.06	0.15	0.08	0.11
07.03.02	1.15	0.82	0.06	0.03	0.20	0.07	2.01	0.88	0.26	0.20	0.00		0.17	0.06	0.57	0.54	0.09
21.03.02	0.21	0.11	0.04	0.02	0.07	0.01	0.42	0.30	0.07	0.03	0.18		0.02	0.01	0.12	0.05	0.07
05.04.02	1.06	0.70	0.02	0.01	0.20	0.11	2.36	1.85	0.08	0.03	0.06	0.03	0.19	0.06	0.05	0.01	0.10
18.04.02	0.89	0.69	0.03	0.01	0.05	0.01	2.53	1.31	0.06	0.03	0.04	0.00	0.01	0.01	0.10	0.04	0.13
01.05.02	0.16	0.05	0.06	0.02	0.09	0.00	0.26	0.08	0.10	0.03	0.06	0.02	0.04	0.02	0.09	0.02	0.00
15.05.02	0.13	0.00	0.05	0.00	0.09	0.01	0.17	0.04	0.11	0.02	0.09	0.01	0.04	0.00	0.17	0.10	
29.05.02	0.10	0.02	0.05	0.01	0.10	0.02	0.27	0.06	0.06	0.03	0.11	0.03	0.04	0.01	0.14	0.03	0.00
12.06.02	0.12	0.05	0.03	0.01	0.10	0.02	0.09	0.00	0.09	0.03	0.11	0.02	0.04	0.01	0.06	0.02	
26.06.02	0.17	0.05	0.05	0.02	0.08	0.01	0.10	0.05	0.13	0.03			0.05	0.01	1.55	0.98	0.02
10.07.02	0.13	0.03	0.03	0.01	0.10	0.03	0.10	0.01	0.67	0.42	0.14		0.08	0.05	0.27	0.20	0.00
24.07.02	0.36	0.25	0.04	0.02	0.15	0.04	0.08	0.05	0.17	0.01	0.13	0.01	0.19	0.13	0.17	0.08	0.00
07.08.02	0.18	0.03	0.09	0.03	0.12	0.03	0.13	0.06	0.07	0.05	0.22	0.04	0.05	0.01	0.40	0.42	
21.08.02	0.09	0.00	0.05	0.01	0.12	0.03	0.06		0.11	0.04	0.07	0.00	0.05	0.01	0.92		0.02

TOC	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S1 B Cl	SE
29.05.00																
11.06.00																
25.06.00									3.5	2.1	2.2	0.7	0.3	0.2		
10.07.00									3.3	2.0	2.2	0.4	0.5	0.2		
23.07.00									3.6	2.4	2.0	0.3	0.6	0.2		
06.08.00									3.1	2.0	2.2	0.3	0.4	0.2		
21.08.00									3.5	2.2	2.1	0.1	0.5	0.1		
04.09.00									3.2	2.1	2.1	0.2	0.4	0.2		
18.09.00									2.8	2.4	1.7	0.3	0.4	0.3		
04.10.00									3.4	2.0	2.5	0.9		0.8		
19.10.00									3.6	2.0		0.5				
02.11.00	43.0	0.5	56.3	8.7	29.3	2.4			3.9	3.3	2.4	0.6	0.3	0.3		
16.11.00	40.9	6.2	37.0	2.4	25.6	3.1			4.1	12.2	2.6	0.5	0.7	0.1		
30.11.00	41.1	3.9	43.3	5.8	23.7	3.0						0.7	0.9			
14.12.00	28.9	2.3	33.0	2.2	27.4	1.3			6.6	4.3	3.1	0.2	1.5	1.0		
28.12.00	30.4	3.1	33.2	3.5	17.4	1.4			6.9	5.0	4.4	0.9	1.3	0.4		
12.01.01	30.7	3.4	26.9	1.9	18.0	2.4			6.8	5.2	6.2	0.3	1.0	0.9		
25.01.01	24.9	2.5	25.5	2.4	14.0	2.3			8.6	3.4	4.8	2.0	0.8	0.8		
09.02.01	35.6	2.3	31.3	7.2	16.5	1.2			7.0	5.7	5.0	1.8	0.5	0.7		
22.02.01	34.4	3.1	24.9	3.0	16.4	2.1			5.7	4.9	5.0	0.5	0.4	0.6		
09.03.01	39.1	10.0	34.9	7.8	21.4	1.8			6.0	5.4	5.0	0.1	0.3	0.5		
22.03.01	32.4	3.5	28.3	1.5	22.4	3.6			4.9	3.9	3.4	2.3	0.9	1.2		
06.04.01	38.9	4.0	30.2	1.7	21.7	3.8			4.2	6.1	4.1	0.6	1.3	0.3		
20.04.01	22.5	2.3	20.1	2.1	17.2	3.0			4.8	3.4	2.1	1.2	1.4	0.6		
02.05.01	14.0	3.6	12.5	2.1	11.4	1.8			9.0	4.4	3.4	0.8	1.2	0.9		
16.05.01	11.3	0.9	17.9	1.2	15.2	1.2			4.2	2.8	2.6	0.6	0.6	0.7		
30.05.01	13.5	1.9	22.5	10.4	9.1	2.2	13.6	1.2	6.3	2.5	2.4	1.4	0.3	0.8	6.0	0.9
13.06.01	27.2	4.9	17.6	1.9	17.8	2.1	14.4	2.1	4.9	2.3	2.3	0.2	0.5	0.6	5.9	0.9
27.06.01	23.2	3.1	18.7	1.9	20.7	2.7	21.4	2.9	4.9	1.8	3.0	0.3	0.4	0.3	3.6	0.3
11.07.01	26.8	14.6	22.9	1.4	22.5	4.2	24.5	1.8	5.2	1.9	2.8	0.5	0.4	0.5	5.8	1.2
25.07.01	48.0		15.8		31.5	3.5	20.5	5.4	4.6	1.9	2.7	0.2	0.4	0.6	3.8	0.5
08.08.01	27.6	3.1	17.3	2.1	19.4	2.6	48.0		3.2	2.1	2.4	0.7	0.4	0.7	3.5	0.4
22.08.01							24.7	4.3	5.3	1.9	2.8	0.9	0.3	0.7	4.3	0.5
05.09.01									4.6	6.4	3.2	2.0	1.6	0.4	4.3	0.3
19.09.01									6.4		5.9			1.4	3.6	0.3
03.10.01	55.4	10.5	18.6		32.2	4.7										
17.10.01	71.6	14.8	38.0	3.4	21.5	3.4	60.0	8.3	2.7							
31.10.01	71.2	2.7	183.8	61.2	21.5	2.6	52.8	2.5	4.0					4.0		
09.11.01	45.6	6.4	25.8	3.2	41.0	9.1	149.6	86.6	4.3		3.0			0.7	5.7	
24.11.01	47.3	13.5	22.4	3.0	22.0	2.5	53.9	4.0	5.5	2.4	2.9	1.8	0.4	0.5	6.3	3.4
07.12.01	43.8	16.4	41.1	4.4	18.3	1.7	39.7	4.1	2.9	2.0	2.2		0.3	0.2	5.5	
21.12.01							143.0	70.5	4.2		2.9	0.8		0.6	2.6	0.4
04.01.02	47.0	10.8	75.2	26.0	22.7	1.1			4.4	2.7		0.5		4.0	0.9	
18.01.02							58.5	14.3	4.1	2.5	1.9	0.5	0.5		3.8	0.2
01.02.02	35.0	8.6	46.3	1.8	15.3	1.3	32.3	3.3	4.4	2.0	2.4	0.4	0.3	0.2	3.7	0.6
15.02.02	25.5	5.7	26.4	2.8	20.2	1.5	60.8	1.1	3.9	3.9	2.5	0.5	1.7	0.3	4.4	0.9
07.03.02	32.4	7.7	31.5	3.8	25.0	1.8	43.3	7.8	3.7	2.1	2.6	0.3	0.4	0.2	3.4	0.6
21.03.02	28.7	4.7	26.5	2.1	22.8	2.6	28.0	2.7	5.2	2.3	2.6	1.0	0.5	0.3	4.8	0.3
05.04.02	25.5	4.5	20.2	1.4	26.8	3.5	17.8	1.2	5.2	3.1	2.6	0.9	1.1	0.4	3.2	0.5
18.04.02	37.7	7.2	27.7	1.8	30.3	3.3	12.6	0.4	5.0	1.9	2.9	1.1	0.1	0.5	3.0	0.4
01.05.02	16.7	1.9	16.0	1.4	23.4	2.2	20.7	2.5	4.7	1.9	2.9	0.6	0.2	0.3	3.7	0.2
15.05.02	19.5	1.0	15.1	1.9	21.3	2.2	8.7	1.4	5.5	2.8	3.6	1.7	0.6	0.6	3.2	0.2
29.05.02	17.3	1.3	17.0	1.5	34.5	5.1	8.7	2.0	4.0	1.8	3.1	1.6	0.2	0.7	4.0	3.0
12.06.02	33.0	6.1	35.9	5.4	29.7	4.4	8.4	2.2	3.6	1.9	3.3	0.3	0.3	0.5	3.5	0.2
26.06.02	34.8	5.0	21.9	1.6	24.7	2.1	19.6	2.9	4.5	0.6	2.6	0.1	4.0	0.3	3.7	1.0
10.07.02	32.4	2.9	20.9	2.7	21.4	3.3	15.6	2.5	4.9	0.8	2.2	0.3	4.3	0.7	3.9	1.0
24.07.02	32.1	6.8	22.1	2.6	22.2	2.0	14.4	4.0	4.5	0.9	2.1	0.2	3.6	0.5	4.6	1.6
07.08.02	48.9	9.3	34.1	6.8	38.8	7.9	14.9	1.3	4.4	0.6	2.3	0.3	4.5	0.2	3.5	0.7
21.08.02	35.8	5.5	29.7	1.5	28.8	4.1			4.4	0.3	2.0	0.4	3.7	0.4	6.9	2.0

TOC	S2 Cl	SE	S2 Sf	SE	S2 Mf	SE	S2 B Cl	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE	S3 B Cl	SE	ST
11.06.00																	
25.06.00									6.0	3.0	1.8	4.1	0.5	0.2			6.0
10.07.00									4.0	3.3	1.5	2.2	0.7	0.1			4.0
23.07.00									4.2	3.0	1.2	1.6	0.8	0.1			4.2
06.08.00									3.1	4.1	1.4	1.4	1.7	0.2			3.1
21.08.00									3.3	2.7	1.3	1.2	0.8	0.1			3.3
04.09.00									3.0	1.8	1.2	1.0		0.1			3.0
18.09.00									1.9		1.2	0.1		0.1			1.9
04.10.00									3.0		1.3			0.1			3.0
19.10.00									2.2		1.2			0.1			2.2
02.11.00									2.5		1.5			0.1			2.5
16.11.00									2.8	16.1	1.3		2.8	0.2			2.8
30.11.00												2.7		0.1			
14.12.00									6.7	4.4	3.6	0.9	1.5	0.6			6.7
28.12.00									5.6	3.6	3.3	1.5	1.2	0.8			5.6
12.01.01										11.4	3.4		2.5	0.8			
25.01.01									4.1	2.7	1.9		1.1	0.4			4.1
09.02.01									2.8	6.2	1.6	1.8	1.8	0.3			2.8
22.02.01									5.3	5.7	2.4	0.4	0.6	0.8			5.3
09.03.01									5.0	7.1	3.6	0.3	2.2	0.6			5.0
22.03.01									1.5		1.2			0.2			1.5
06.04.01									4.7		4.6			1.3			4.7
20.04.01									3.8	6.7	2.7	2.1		0.6			3.8
02.05.01									4.3	1.8	3.3	1.6	0.2	1.0			4.3
16.05.01									1.3	1.7	1.3	0.2	0.3	0.3			1.3
30.05.01									2.0	1.7	1.1	0.1	0.3	0.3	1.8		2.0
13.06.01									2.7	2.0	3.0	0.8	0.5	0.5	2.8	1.3	2.7
27.06.01									1.7	1.2	1.9	0.6		0.5	10.8		1.7
11.07.01									5.0	1.3	2.9	1.6		0.2	4.2	2.2	5.0
25.07.01									5.4	1.5	2.3	0.1		0.7	2.3	1.0	5.4
08.08.01									3.7	1.4	3.2	0.4		1.0	4.0	1.3	3.7
22.08.01									2.7	2.5	1.7	1.0	0.4	0.3	1.8	0.1	2.7
05.09.01									3.4		2.5			0.5	3.1	1.2	3.4
19.09.01									2.9		3.9			1.2	1.9		2.9
03.10.01											0.9			0.7	1.3		
17.10.01											1.4			0.3	1.5		
31.10.01																	
09.11.01											2.5			0.5			
24.11.01									5.5		1.0			0.1	1.3		5.5
07.12.01									3.8		1.4	1.2		0.2	6.1	1.4	3.8
21.12.01									4.4		0.8			0.3	3.4	1.3	4.4
04.01.02									1.6			0.5		0.3	1.2		1.6
18.01.02									2.8		0.8	1.7			4.0	2.1	2.8
01.02.02									1.7	1.3	0.9	0.5		0.1	1.5	0.6	1.7
15.02.02									4.6	2.7	0.6	0.8	1.0	0.2	2.4	0.6	4.6
07.03.02									2.7		0.8			0.3	1.2	0.5	2.7
21.03.02									1.6	1.6	1.1	0.2		0.2	2.0	0.5	1.6
05.04.02									1.3	1.0	0.2	0.2		0.2	1.4	0.3	1.3
18.04.02									1.0	4.1	0.5	0.4	1.5	0.3	1.2	0.4	1.0
01.05.02									1.5	1.2	0.6	0.1	0.2	0.4	1.3	0.3	1.5
15.05.02									1.3	1.1	2.4	0.2	0.9	0.5	1.6	0.3	1.3
29.05.02									0.9	2.8	1.9	0.7	0.6	0.4	1.8	0.4	0.9
12.06.02									3.9	3.3	2.2	0.8	1.1	0.9	3.0	0.1	3.9
26.06.02									2.4	0.3			2.5	0.4	0.0		2.4
10.07.02									3.8	1.6	4.5		3.1	0.3	3.7	1.8	3.8
24.07.02									4.5	0.2	10.9		2.5	0.7	2.3	0.5	4.5
07.08.02									3.3	1.0			3.4	0.3	2.6	1.1	3.3
21.08.02									2.4	0.8	2.0	0.0	2.5	0.2	1.4	0.1	2.4

TOP	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE	PO ₄ P	LP Cl	SE	LP Sf	SE	LP Mf	SE	LP B Cl	SE
30.11.00	0.36	0.13	0.06	0.01	0.02	0.01				0.85	0.11	0.13	0.02	0.07	0.01		
14.12.00	0.08	0.01	0.05	0.00	0.03	0.01				0.19	0.02	0.12	0.00	0.09	0.03		
28.12.00	0.08	0.01	0.06	0.01	0.04	0.00				0.09	0.01	0.08	0.02	0.09	0.00		
12.01.01	0.07	0.02	0.05	0.02	0.01	0.01				0.16	0.05	0.11	0.02	0.05	0.00		
25.01.01	0.08	0.02	0.05	0.00	0.02	0.01				0.19	0.07	0.07	0.02	0.05	0.00		
09.02.01	0.08	0.02	0.07	0.01	0.00					0.25	0.14	0.11	0.00	0.04	0.00		
22.02.01	0.13	0.02	0.12	0.01	0.02					0.39	0.09	0.24	0.05	0.06	0.02		
09.03.01																	
22.03.01	0.39	0.18	0.08	0.00	0.01	0.00				1.00	0.22	0.15	0.02	0.04	0.00		
06.04.01			0.05	0.00	0.02	0.01						0.13	0.00	0.05	0.01		
20.04.01					0.05							0.05		0.05	0.01		
02.05.01	0.04	0.02	0.02	0.00	0.01	0.01				0.09	0.03	0.06	0.01	0.04	0.01		
16.05.01	0.15	0.10	0.03	0.01	0.23	0.14	0.04	0.00		0.21	0.09	0.04	0.00	0.12	0.09	0.11	0.01
30.05.01	0.05	0.01	0.04	0.01	0.04	0.01	0.06	0.01		0.07	0.04	0.06	0.02	0.05	0.02	0.05	0.03
13.06.01	0.07	0.03	0.05	0.01	0.02	0.00	0.05	0.02		0.28	0.08	0.06	0.01	0.04	0.01	0.26	0.00
27.06.01	0.09	0.02	0.05	0.01	0.06	0.02	0.10	0.02		0.17	0.07	0.08	0.01	0.04	0.02	0.13	0.01
11.07.01	0.07	0.02	0.06	0.01	0.09	0.01	0.07	0.02		0.27	0.16	0.10	0.01	0.06	0.01	0.13	0.04
25.07.01	0.05				0.15	0.13	0.05			0.13		0.15		0.18	0.12	0.13	
08.08.01	0.21	0.17	0.27	0.17	0.05	0.03	0.04	0.01		0.19	0.05	0.16	0.06	0.08	0.04	0.20	0.06
22.08.01																	
05.09.01																	
19.09.01																	
03.10.01	1.90	0.42	0.30	0.17	0.04	0.02	1.85	0.51		1.63	0.16	0.48	0.18	0.26	0.08	3.84	2.11
17.10.01	2.11	0.37	0.21	0.08			1.31	0.99		1.81	0.08	1.21	0.65	0.19		1.84	0.20
31.10.01	1.28	0.48	0.15	0.07	0.04	0.01	1.10	0.50		0.92	0.47	0.17	0.06	0.12	0.03	0.56	0.05
09.11.01	0.49	0.27	0.08	0.01	0.12	0.04	0.82	0.24		1.38	0.10	0.16	0.02	0.13	0.02	2.28	0.88
24.11.01	0.08	0.01	0.07	0.01	0.13	0.03	0.23	0.11		0.64	0.00	0.24	0.10	0.38		1.12	0.51
07.12.01	0.11		0.07	0.02	0.02	0.01	0.56	0.34		0.85	0.18	0.15	0.04	0.08	0.01	5.46	2.12
21.12.01																	
04.01.02	0.14	0.03	0.11	0.04	0.03	0.00	1.08	0.67		0.50	0.06	0.19	0.06	0.07	0.02	6.15	3.32
18.01.02	0.08	0.01	0.08	0.01	0.06	0.02	0.16	0.12		0.50	0.11	0.19	0.04	0.09	0.01	3.66	2.20
01.02.02	0.12		0.61	0.14	0.03	0.00	0.81			0.69		0.91		0.07	0.00	2.81	1.81
15.02.02	0.04	0.00	0.04	0.02	0.03	0.00	0.23	0.13		0.52	0.04	0.35	0.21	0.07	0.00	3.18	2.21
07.03.02	0.07	0.02	0.06	0.00	0.04	0.01	0.18	0.14		0.32	0.02	0.27	0.10	0.08	0.01	2.40	1.44
21.03.02	0.09	0.02	0.04	0.01	0.03	0.01	0.52	0.46		0.26	0.07	0.24	0.14	0.07	0.01	0.88	0.25
05.04.02	0.05	0.00	0.03	0.01	0.02	0.01	0.25	0.22		0.22	0.05	0.20	0.10	0.05	0.01	0.71	0.25
18.04.02	0.05	0.00	0.05	0.01	0.02	0.01	0.41	0.37		0.15	0.03	0.23	0.09	0.08	0.02	0.88	0.30
01.05.02	0.08	0.00	0.09	0.03	0.03		0.48	0.25		0.11	0.01			0.05	0.00	0.22	
15.05.02	0.05	0.02	0.05	0.03	0.03	0.02	0.07	0.03		0.07	0.01	0.14	0.06	0.07	0.01	0.32	0.17
29.05.02	0.05	0.02	0.04	0.02	0.06	0.02	0.07	0.02		0.07	0.01	0.08	0.01	0.06	0.02	0.30	0.14
12.06.02	0.06	0.02	0.09	0.00	0.08	0.02	0.09	0.01		0.08	0.01	0.12	0.00	0.06	0.01	0.41	0.18
26.06.02	0.29	0.16	0.03	0.00	0.04	0.02	0.06	0.01		0.10	0.02	0.06	0.01	0.05	0.01	0.43	0.16
10.07.02	0.03	0.01	0.02	0.01	0.05	0.01	0.07	0.02		0.05	0.00	0.07	0.02	0.06	0.01	0.41	0.14
24.07.02	0.10	0.02	0.04	0.01	0.03	0.00	0.06	0.01		0.15	0.05	0.07	0.01	0.05	0.01	0.32	0.17
07.08.02	0.05	0.01	0.04	0.01	0.03	0.01	0.06	0.00		0.07	0.01	0.06	0.03	0.02	0.00	0.32	0.17
21.08.02	0.06	0.00	0.06	0.01	0.03	0.00	0.08	0.03		0.09	0.01	0.09	0.01	0.04	0.00	0.30	0.11

SO4-S	R 2100	R 2250	TF Cl	SE	TF Sf	SE	TF Mf	SE	LP Cl	SE	LP Sf	SE	LP Mf	SE
14.12.00	0.10	0.10	0.05	0.05	0.05	0.05	0.00	0.00	0.42	0.08	0.31	0.06	0.23	0.01
28.12.00	0.10	0.15	0.14	0.02	0.04	0.04	0.22	0.03	0.34	0.07	0.18	0.10	0.25	0.03
12.01.01	0.10	0.10	0.22	0.07	0.11	0.06	0.15	0.06	0.40	0.11	0.37	0.13	0.14	0.05
25.01.01	0.12	0.16	0.23	0.02	0.22	0.01	0.20	0.02	0.31	0.07	0.25	0.03	0.19	0.02
09.02.01	0.10	0.26	0.33	0.02	0.27	0.01	0.28	0.01	0.45	0.19	0.37	0.01	0.22	0.02
22.02.01	0.16	0.19	0.24	0.01	0.26	0.00	0.28	0.03	0.40	0.06	0.49	0.06	0.28	0.02
09.03.01	0.41	0.28	0.52	0.04	0.35	0.02	0.35	0.03	2.30	1.26	0.88	0.34	0.35	0.03
22.03.01	0.10	0.10	0.29	0.07	0.28	0.05	0.14	0.05	1.43	0.56	0.52	0.02	0.23	0.03
06.04.01	0.10	0.10	0.08	0.04	0.12	0.12	0.03	0.03	0.30	0.09	0.27	0.02	0.21	0.04
20.04.01	0.10	0.10	0.05	0.05	0.00	0.00	0.05	0.05	0.17	0.09	0.19	0.01	0.24	0.05
02.05.01	0.10	0.10	0.00	0.00	0.08	0.04	0.06	0.05					0.16	0.02
16.05.01	0.10	0.10	0.07	0.06	0.22	0.07	0.09	0.05	1.33		0.17	0.01	0.11	
30.05.01	0.10	0.10	0.12	0.01	0.09	0.04	0.15	0.11	0.13	0.08	0.20	0.02	0.19	0.07
13.06.01	0.21	0.18	0.21	0.01	0.49	0.09	0.17	0.03	0.52	0.23	0.14	0.07	0.19	0.04
27.06.01	0.24	0.27	0.29	0.03	0.34	0.08	0.15	0.01	0.27	0.05	0.25	0.04	0.23	0.08
11.07.01	0.38	0.56	0.59	0.10	0.47	0.09	0.52	0.10	0.30	0.06	0.39	0.10	0.20	0.01
25.07.01	0.56	0.40	0.61	0.02	0.70	0.14	0.63	0.08			0.27	0.01	0.84	0.41
08.08.01	0.36	0.32	0.71	0.30	0.43	0.12	0.28	0.07	0.37				0.48	
22.08.01	0.47		0.62	0.02	1.12	0.46								
05.09.01	0.97		1.20		1.98	0.38	0.69	0.13						
19.09.01														
03.10.01	0.90	1.52	1.27	0.08	1.69	0.25	1.30	0.13	2.12		1.99		0.72	0.06
17.10.01	1.17	0.96	1.04	0.22	1.68	0.10	0.86	0.02	1.87	0.94			1.05	
31.10.01	0.63		0.62	0.09	1.19	0.20	0.36	0.06	1.30	0.27			0.29	0.01
09.11.01	0.23	0.25	0.27	0.09	0.23	0.03	0.38	0.13	0.39	0.04	0.42	0.06	0.38	0.09
24.11.01	0.18	0.78	0.78	0.49	0.27	0.08	0.17	0.03	0.35	0.12	0.51	0.07	0.25	0.02
07.12.01	0.13	0.20	0.13	0.01	0.11	0.00	0.23	0.02	0.27	0.01	0.58	0.13	0.23	0.02
21.12.01					0.14		0.00						0.16	0.02

TOS	R 2100	R 2250	TF Cl	SE	TF Sf	SE	TF Mf	SE	LP Cl	SE	LP Sf	SE	LP Mf	SE
14.12.00	0.00	0.00	0.07	0.07	0.00	0.00	0.00	0.00	0.29	0.05	0.21	0.02	0.14	0.01
28.12.00	0.00	0.00	0.15	0.13	0.10	0.10	0.09	0.04	0.23	0.01	0.16	0.08	0.04	0.03
12.01.01	0.00	0.00	0.16	0.08	0.09	0.09	0.04	0.03	0.30	0.04	0.32	0.07	0.23	0.05
25.01.01	0.00	0.00	0.20	0.02	0.08	0.06	0.00	0.00	0.20	0.06	0.14	0.03	0.02	0.02
09.02.01		0.23	0.17	0.04	0.13	0.02	0.10	0.01	0.28	0.09	0.24	0.02	0.09	0.03
22.02.01	0.00	0.00	0.10	0.01	0.27	0.00	0.09	0.03	0.40	0.04	0.27	0.04	0.20	0.12
09.03.01	0.23	0.15	0.34	0.04	0.57	0.09	0.17	0.05	0.92	0.19	0.73	0.12	0.24	0.04
22.03.01	0.00	0.00	0.20	0.12	0.04	0.04	0.14	0.10	0.34	0.22	0.26	0.01	0.20	0.07
06.04.01	0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.00	0.46	0.11	0.26	0.06	0.18	0.08
20.04.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.06	0.10	0.05	0.12	0.04
02.05.01	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.04					0.15	0.07
16.05.01	0.00	0.00	0.00	0.00	0.02	0.02	0.05	0.05	0.30		0.17	0.01	0.00	
30.05.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.05	0.05	0.00	0.00	0.02	0.02
13.06.01	0.16	0.00	0.05	0.04	0.20	0.02	0.03	0.02	0.15	0.08	0.07	0.04	0.08	0.05
27.06.01	0.17	0.16	0.09	0.07	0.15	0.01	0.00	0.00	0.26	0.03	0.02	0.10	0.01	0.01
11.07.01	0.21	0.12	0.18	0.04	0.22	0.04	0.21	0.03	0.24	0.01	0.18	0.05	0.16	0.04
25.07.01	0.18	0.26	0.32	0.03	0.34	0.07	0.47	0.23			0.20	0.02	0.33	0.03
08.08.01	0.03	0.11	0.23	0.06	0.12	0.00	0.04	0.03	0.26				0.21	
22.08.01	0.22		0.42	0.04	0.64	0.13								
05.09.01	0.41		0.93		1.42	0.18	0.68	0.08						
19.09.01														
03.10.01	0.18	0.48	0.61	0.06	1.77	0.29	0.79	0.19	1.41		0.68		0.56	0.03
17.10.01	0.50	0.38	0.43	0.10	1.22	0.09	0.67	0.29	1.91	0.11			0.48	
31.10.01	0.25		0.34	0.10	0.46	0.12	0.27	0.04	0.71	0.04			0.31	0.03
09.11.01	0.21	0.14	0.14	0.11	0.30	0.04	0.17	0.07	0.75	0.08	0.35	0.02	0.39	0.05
24.11.01	0.16	0.43	0.29	0.23	0.11	0.09	0.16	0.02	0.79	0.17	0.36	0.05	0.22	0.01
07.12.01	0.19	0.00	0.10	0.08	0.43	0.01	0.18	0.03	0.68	0.24	0.57	0.13	0.26	0.01
21.12.01					0.28		0.00							

SO4-S	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE
14.12.00	0.30	0.06	0.21	0.05	0.30	0.12					0.08	0.09
28.12.00	0.25	0.16	0.20	0.06	0.28	0.14			0.37		0.14	0.19
12.01.01	0.13	0.03	0.04	0.08	0.13	0.01	0.00		0.00		0.00	0.00
25.01.01	0.43	0.08	0.22	0.08	0.28	0.08					0.00	0.00
09.02.01	0.49	0.12	0.26	0.10	0.30	0.11					0.11	0.13
22.02.01	0.37	0.13	0.22	0.06	0.31	0.09					0.04	0.07
09.03.01	0.33	0.10	0.99		0.47	0.60					0.11	
22.03.01	0.09	0.09	0.05	0.08	0.05	0.08	0.00				0.12	0.17
06.04.01	0.51	0.30	0.19	0.06	0.18	0.05	0.18	0.06			0.08	0.15
20.04.01	0.46	0.07	0.23	0.09	0.23	0.04	0.22		0.31	0.04	0.11	0.13
02.05.01	0.55	0.26	0.21	0.07	0.20	0.08	0.17	0.04	0.13	0.18	0.00	0.00
16.05.01	0.33	0.04	0.19	0.04	0.22	0.10	0.14	0.02	0.10	0.17	0.00	0.00
30.05.01	0.48	0.27	0.10	0.08	0.17	0.14	0.36	0.24	0.18	0.01	0.03	0.05
13.06.01	0.24	0.02	0.00		0.16	0.05	0.40	0.36	0.33		0.03	0.06
27.06.01	0.31	0.14	0.24	0.14	0.18	0.07	0.21	0.01	0.00		0.03	0.06
11.07.01	0.31	0.09	0.16	0.03	0.45	0.39	0.32	0.18	0.27	0.04	0.28	0.21
25.07.01	0.32	0.20	0.10	0.15	0.07	0.08	0.24	0.06	0.00		0.13	0.10
08.08.01	0.35	0.07	0.04	0.06	0.06	0.07	0.32	0.24	0.13	0.18	0.18	0.12
22.08.01	0.33	0.07	0.77	0.56	0.07	0.08	0.29				0.12	0.12
05.09.01	0.36	0.08	1.11		0.14	0.05					0.21	0.10
19.09.01					0.22						0.00	
03.10.01					0.00						0.12	
17.10.01												
31.10.01					0.18	0.06					0.14	0.11
09.11.01	0.19	0.02	0.09	0.09	0.12	0.10	0.62	0.09	0.17		0.10	0.14
24.11.01	0.23		0.09	0.08	0.12	0.09	0.34	0.27			0.16	0.06
07.12.01	0.21	0.02	0.00	0.00	0.12	0.09			0.65		0.05	0.10
21.12.01	0.21	0.02	0.13		0.06	0.08	0.46	0.09	0.36			

TOS	S1 Cl	SE	S1 Sf	SE	S1 Mf	SE	S3 Cl	SE	S3 Sf	SE	S3 Mf	SE
14.12.00	0.01	0.02	0.02	0.03	0.09	0.10					0.04	0.08
28.12.00	0.00	0.00	0.00	0.00	0.01	0.01			0.15		0.02	0.03
12.01.01	0.69	0.12	0.58	0.16	0.34	0.45	0.46		1.53		0.34	0.40
25.01.01	0.01	0.01	0.02	0.04	0.07	0.13					0.00	0.00
09.02.01	0.00	0.00	0.01	0.02	0.02	0.04					0.00	0.00
22.02.01	0.02	0.02	0.02	0.04	0.03	0.04					0.00	0.00
09.03.01	0.03	0.02	0.00		0.01	0.02					0.00	
22.03.01	0.70	0.06	0.61	0.19	1.34	1.04	0.83				0.18	0.35
06.04.01	0.03	0.05	0.03	0.06	0.02	0.04	0.05	0.07			0.02	0.04
20.04.01	0.12	0.10	0.08	0.14	0.00	0.00	0.00		0.07	0.01	0.00	0.00
02.05.01	0.21	0.16	0.03	0.05	0.05	0.08	0.00	0.00	0.04	0.06	0.08	0.17
16.05.01	0.14	0.05	0.04	0.07	0.05	0.07	0.00	0.00	0.04	0.07	0.08	0.16
30.05.01	0.03	0.05	0.00	0.00	0.02	0.05	0.07	0.10	0.00	0.00	0.09	0.19
13.06.01	0.06	0.08	0.00		0.00	0.00	0.05	0.07	0.03		0.09	0.17
27.06.01	0.02	0.03	0.10	0.10	0.02	0.04	0.19	0.12	0.00		0.09	0.17
11.07.01	0.09	0.07	0.13	0.22	0.08	0.07	0.06	0.06	0.11	0.05	0.19	0.15
25.07.01	0.03	0.06	0.20	0.29	0.00	0.00	0.04	0.06	0.00		0.06	0.07
08.08.01	0.17	0.02	0.00	0.00	0.00	0.00	0.09	0.08	0.06	0.09	0.04	0.05
22.08.01	0.14	0.03	0.16	0.15	0.00	0.00	0.04				0.00	0.00
05.09.01	0.11	0.02	0.26		0.00	0.00					0.04	0.05
19.09.01					0.15						0.00	
03.10.01					0.00						0.00	
17.10.01												
31.10.01					0.04	0.07					0.04	0.09
09.11.01	0.14	0.02	0.00	0.00	0.00	0.00	0.36	0.25	0.00		0.00	0.00
24.11.01	0.14		0.00	0.00	0.00	0.00	0.18	0.03			0.03	0.06
07.12.01	0.06	0.09	0.00	0.00	0.00	0.00			0.07		0.02	0.05
21.12.01	0.14	0.00	0.00		0.00	0.00	0.24	0.07	0.06			

pH	R 2100	R 2300	TF Cl	Sd	TF Sf	Sd	TF Mf	Sd	LP Cl	Sd	LP Sf	Sd	LP Mf
29.05.00													
11.06.00	5.2	5.0	5.8	0.6	5.7	0.4	5.7	0.5					
25.06.00	6.4	6.5	5.6	0.9	5.8	0.2	5.7	0.5					
10.07.00	4.8	4.7	5.7	1.3	6.4	2.2	5.9	0.9					
23.07.00	4.6	4.5	5.0	0.4	5.1	0.1	5.4	0.5					
06.08.00	5.1	4.9	5.7	0.5	5.9	0.1	6.1	0.5					
21.08.00	4.7	5.4	6.0	0.7	5.8	0.2	5.8	0.9					
04.09.00	5.1		6.2	0.1	6.2	0.1	5.5	0.4					
18.09.00	5.8	4.9	6.4	0.5	6.1	1.0	6.5	0.2					
04.10.00	5.3	5.2	6.4	0.2	5.7	0.6	5.5	0.2					
19.10.00	6.0	5.5	6.3	0.5	6.0	0.4	5.9	0.3					
02.11.00	5.4	6.4	6.5	0.1	5.5	1.1	6.0	0.3	4.5	0.2	4.0	0.2	4.7
10.11.00		5.1	5.9	0.1	5.7	0.0	5.8	0.3	3.9		4.4	0.3	4.3
14.11.00													
17.11.00	5.5	4.9	6.2	0.2	5.7	0.2	6.0	0.2	4.2	0.4	4.1	0.1	4.5
22.11.00	5.0	5.2	6.2	0.2	5.6	0.3	5.8	0.5	4.2	0.5	4.3	0.4	4.3
30.11.00													
14.12.00	6.0	5.1	6.4	0.0	6.4	0.2	6.6	0.1	4.8	0.6	4.8	0.4	4.7
28.12.00	6.1	6.3	6.5	0.2	6.5	0.3	6.5	0.1	5.0	1.0	4.8	0.2	5.1
12.01.01	6.5	5.6	6.5	0.1	6.3	0.4	6.5	0.1	4.5	0.2	5.0	0.4	4.7
25.01.01		6.3	6.6	0.1	6.1	0.4	6.4	0.2	4.6	0.8	4.4	0.2	4.7
09.02.01	6.4	6.3	6.6	0.0	6.4	0.2	6.4	0.2	4.6	0.9	4.6	0.3	4.5
22.02.01	6.0	6.3	6.5	0.1	6.3	0.2	6.5	0.1	5.0	1.2	5.5	0.4	4.6
09.03.01													
22.03.01	5.9	6.0	6.5	0.1	6.5	0.3	6.5	0.1	5.2	1.2	4.4	0.4	4.3
06.04.01	5.9	6.0	6.4	0.1	6.1	0.3	6.3	0.1	4.3	0.6	4.1	0.1	4.2
20.04.01	5.8	5.4	6.4	0.2	6.1	0.2	6.3	0.2	4.5	0.5	4.5	0.3	4.3
28.04.01			6.4	0.3	6.0	0.2	5.9	0.1	4.7	0.3	4.6	0.4	4.5
07.03.02	6.7	6.0	6.3	0.4	6.5	0.1	6.4	0.0	4.7	0.6	4.8	0.7	4.3
21.03.02	5.6	6.0	5.7	0.7	6.4	0.2	6.2	0.6	4.8	0.8	4.6	0.7	4.5
05.04.02	5.3	5.3	5.7	0.6	6.0	0.3	5.8	0.7	4.5	0.5	4.5	0.4	4.2
18.04.02	5.3		6.1	0.3	6.1	0.4			4.0		4.0		
01.05.02	5.5	5.9	6.0	0.1	5.7	0.7	6.3	0.1	4.6	0.5	4.4	0.4	4.3
15.05.02	5.8		6.1	0.2	6.2	0.0	6.4	0.1	5.1	0.6	4.7	0.4	4.4
29.05.02	5.9	5.7	6.0	0.3	6.3	0.2			4.9	0.5	4.5	0.2	
12.06.02	5.4		6.3	0.3	6.2	0.0			4.5	0.4	4.7	0.5	
26.06.02	5.6		6.3	0.2	6.3	0.2			4.5	0.7	4.5	0.3	3.9
10.07.02	5.9	6.1	6.4	0.2	6.2	0.0	6.5	0.1	4.5	0.7	4.3	0.2	4.3
24.07.02	6.1	6.2	6.4	0.2	6.3	0.2	6.5	0.1	4.4	0.8	4.5	0.5	4.2
07.08.02	4.4		5.6	0.9	6.2	0.3			4.5	0.5	4.2	0.3	4.2
21.08.02	6.0	6.0	6.0	0.5	6.1	0.2	20.0	27.4	4.5	0.6	4.4	0.3	4.3

pH	Cl S1	Sd	Cl S2	Sd	Cl S3	Sd	Sf S1	Sd	Sf S2	Sd	Sf S3	Sd
29.05.00	5.2	0.5	5.6	0.1	5.8	0.3	4.7	0.3	5.4	0.4	5.7	0.4
11.06.00	4.4	0.2	4.8	0.2	5.2		4.7	0.5	5.8		4.6	
25.06.00	4.4	0.2	6.4	0.7	6.3	1.1	5.1	0.9	5.5	0.5	6.3	0.2
10.07.00	4.3	0.1					5.0	0.9				
23.07.00	4.4	0.2					4.5	0.2				
06.08.00	4.5	0.1	6.0	0.9			4.6	0.2	5.8	0.5		
21.08.00	4.4	0.1					4.5	0.1				
04.09.00	4.7	0.3	5.9	0.9	5.2		4.7	0.1	5.9	0.4		
18.09.00	4.7	0.2					4.8					
04.10.00	4.5	0.1	6.0	0.4			5.2	1.2	5.6			
19.10.00	4.7	0.1	5.5	0.6	6.4		4.8	0.0	6.1			
02.11.00	4.4	0.1	6.0		6.5		4.5	0.0	4.7		4.9	0.6
10.11.00	4.5	0.1	5.7	1.3			4.5		5.3			
14.11.00	4.5	0.0	5.5	0.9	6.3		4.8	0.2	5.8	0.6		
17.11.00	4.4	0.1	5.1	0.8	5.8	0.6	4.8	0.2	5.4	0.2		
22.11.00	4.3	0.1	5.5	0.6	5.8	0.7	4.6	0.1	5.6	0.5		
30.11.00	4.3	0.1	5.0	0.4	6.3	1.2	4.6	0.0	5.2	0.2	5.0	0.9
14.12.00	4.4	0.1	4.9	0.8	5.9	0.8	4.7	0.2	4.9	0.3	5.0	0.3
28.12.00	4.5	0.0	5.8				4.7	0.1	5.1	0.3	4.7	0.2
12.01.01	4.4	0.1	4.9	0.8	6.1		4.8	0.2	5.1	0.3	5.6	
25.01.01	4.4	0.2	4.9	0.9	5.6	0.4	4.7	0.2	5.2	0.4	5.6	0.2
09.02.01	4.2	0.2	5.4	0.5	5.2	1.0	4.5	0.2	5.0	0.5	4.8	0.5
22.02.01	4.3	0.2	5.1	0.9	5.5	0.1	4.6	0.2	5.1	0.3	5.5	0.0
09.03.01	4.3	0.2	5.3	1.0			4.7	0.6	5.1	1.1		
22.03.01	4.3	0.2	5.1	0.9			4.3		5.1			
06.04.01	4.4	0.1	5.1	0.8	5.9	0.4	4.5	0.2	5.1	0.5	4.2	
20.04.01	4.5	0.1	5.0	0.7	5.7	0.4	4.6	0.2	4.9	0.3	5.2	0.1
28.04.01	4.8	0.1	5.3	0.9	5.9	0.2	4.7	0.2	5.2	0.5	5.6	0.3
07.03.02	4.3	0.3	5.2	0.4	5.9	0.5	4.7	0.7	4.8	0.1	6.3	
21.03.02	4.3	0.5	5.5	0.9	5.8	0.6	4.4	0.2	5.4	1.1	6.2	0.7
05.04.02	4.3	0.4	5.3	0.5	5.8	0.0	4.5	0.1	4.9	0.2	5.2	
18.04.02	4.4	0.5	5.0	0.7	5.8		4.2	0.4	4.6	0.1	5.9	
01.05.02	4.6	0.3	5.5	0.8	5.8	0.4	4.5	0.2	4.5	0.1	5.1	0.0
15.05.02	4.6	0.3	5.5	1.0	5.5	0.7	4.4	0.3	4.5	0.1	5.6	0.1
29.05.02	4.5	0.3	5.3	0.8	5.6	0.6	4.3	0.2	4.5	0.1	4.8	0.8
12.06.02	4.4	0.2	5.0	0.6	5.4	0.6	4.3	0.2	4.5	0.0	4.7	
26.06.02	4.5	0.2	5.3	0.8	5.6		4.4	0.2	4.6	0.1		
10.07.02	4.6	0.3	4.8	0.4	5.6	0.4	4.3	0.1	4.4	0.1		
24.07.02	4.6	0.4	5.3	0.9	6.3		4.4	0.1	4.5	0.1		
07.08.02	4.4	0.3	5.2	0.9	5.9	0.4	4.4	0.2	4.6	0.0		
21.08.02	4.4	0.1	4.9	0.8	5.7	0.1	4.3	0.1	4.4	0.1	5.5	

pH	Mf S1	Sd	Mf S2	Sd	Mf S3	Sd	ST
29.05.00	4.5	0.3	4.4	0.2	5.0	0.3	6.4
11.06.00	4.6	0.6	4.6	0.5	5.0	0.2	5.2
25.06.00	4.4	0.1	4.6	0.1	4.9	0.2	5.7
10.07.00	4.4	0.3					6.3
23.07.00	4.2	0.1					5.7
06.08.00	4.4	0.1	4.6	0.1	5.1		5.7
21.08.00	4.9	1.3					7.0
04.09.00	4.4	0.2	4.9	0.9	4.8	0.1	6.9
18.09.00	4.3	0.1	4.6				6.5
04.10.00	4.3	0.1	4.5	0.1			6.6
19.10.00	4.4	0.0	4.6	0.2	4.7	0.1	6.3
02.11.00	4.3	0.1	4.6	0.2	4.7	0.1	6.4
10.11.00	4.4	0.0	4.4	0.0	4.7	0.1	6.0
14.11.00	4.4	0.0	4.5	0.1	4.9	0.2	6.4
17.11.00	4.4	0.1	4.5	0.1	4.8	0.2	5.3
22.11.00	5.0	1.0	5.3	1.9	4.9	0.4	5.8
30.11.00	4.2	0.1	4.3	0.1	4.5	0.1	6.3
14.12.00	4.2	0.1	4.3	0.1	4.6	0.1	6.0
28.12.00	4.3	0.0	4.4	0.1	4.6	0.2	6.3
12.01.01	4.4	0.1	4.4	0.1	4.6	0.3	5.9
25.01.01	4.4	0.1	4.4	0.1	4.6	0.1	6.1
09.02.01	4.4	0.3	4.3	0.1	4.4	0.2	6.0
22.02.01	4.4	0.3	4.4	0.0	4.5	0.1	6.3
09.03.01	4.3	0.1	4.4	0.1	4.4	0.1	6.3
22.03.01	4.4	0.2	4.4	0.1	4.4	0.1	6.5
06.04.01	4.4	0.2	4.4	0.0	4.5	0.1	
20.04.01	4.4	0.4	4.4	0.0	4.5	0.1	
28.04.01	4.5	0.2	4.5	0.0	4.7	0.1	5.9
07.03.02	4.3	0.2	4.5	0.5	4.5	0.0	6.1
21.03.02	4.4	0.3	4.4	0.1	4.6	0.1	6.3
05.04.02	4.3	0.3	4.4	0.2	4.6	0.2	5.8
18.04.02							
01.05.02	4.5	0.2	4.5	0.2	4.7	0.2	5.9
15.05.02	4.5	0.3	4.4	0.2	4.5	0.1	
29.05.02	4.4	0.2	4.4	0.1	4.8	0.7	
12.06.02	4.5	0.3	4.4	0.2	4.9	0.7	
26.06.02	4.5	0.3	4.4	0.3	4.9	0.6	6.4
10.07.02	4.4	0.3	4.3	0.2	5.0	0.9	6.6
24.07.02	4.4	0.3	4.4	0.2	4.6	0.2	6.6
07.08.02	4.5	0.3	4.6	0.3	4.6	0.1	
21.08.02	4.3	0.3	4.2	0.2	4.4	0.1	6.3