Humus Dynamics
along Forest Conversion Sequences
in the Lowland and Ore Mountain Region
of Saxony, Germany.

Dissertation

Attainment of the academic title

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Preface

This thesis consists of an introduction chapter that presents the main current problems related to humus dynamics and C storage in soil and the overall objectives of this study. A profound literature review follows with chapter two and study sites are introduced in a clearly arranged overview to the reader in chapter three. Chapters four, five, six, seven and eight present the main aspects that I have dealt with in my scientific work during my PhD. Finally, a concluding discussion chapter and a summary sum up the main results and perspectives of this work.

The work of chapters four, five, seven and eight I have carried out myself in cooperation with technical staff and student helpers at the Institute of Soil Science and Site Ecology of Dresden University of Technology (TUD). Applying the special method of pyrolysis, that forms part of chapter six, I was grateful to find support by Dr. Falk Liebner, Institute of Plant and Wood Chemistry at TUD. The outcome of this very constructive cooperation is a joined publication combining structural-chemical data of soil organic horizons with data and information on microbial properties, litter decay rates and organic matter turnover. The litter decay study has been part of the master thesis of Christian Stuhlmann who was supervised and participated in the humus dynamics project.

Due to the collaborations and fruitful discussions with my supervisor and colleagues from the Institute of Soil Science and Site Ecology at TUD, Institute of Plant and Wood Chemistry at TUD, University of California in Davis and during my time in Jena also from the Max-Planck-Institute for Biogeochemistry, I have chosen the plural form in the discussion of this thesis.

Each of the chapters four, five, six, seven and eight are submitted or will be submitted as manuscripts in slightly modified versions to the international peer reviewed research journals: *European Journal of Forests Research, Journal for Plant Nutrition and Soil Science, European Journal of Soil Science, Plant and Soil and Forest Ecology and Management*, respectively.

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List of Abbreviations

C	carbon
CFE	chloroform fumigation extraction
C_{cwe}	cold water-extractable C
C_{hwe}	hot water-extractable C
C_{mic}	microbial biomass C
CWE	Cold Water Extract
DOC	dissolved organic carbon
DOM	dissolved organic matter
GC-C-IRMS	gas chromatography-combustion-isotope ratio mass spectrometry
GC-MS	gas chromatography- mass spectrometry
HWE	Hot Water Extract
k_{EC}	extraction efficiency coefficient for carbon
k_{EN}	extraction efficiency coefficient for nitrogen
N	nitrogen
NcPP	nitrogen-containing pyrolysis products
N_{cwe}	cold water-extractable N
N_{hwe}	hot water-extractable N
N_{mic}	microbial biomass N
TOC	total soil organic carbon
TN	total soil nitrogen
POC	particulate organic carbon
POM	particulate organic matter
ppm	parts per million
rpm	rotations per minute
RSOM	refractory organic matter
SD	Standard deviation
SE	Standard error
SOC	soil organic carbon
SOM	soil organic matter
WSOC	water-soluble organic C

1 Introduction

1.1 Problem

Soils as a dynamic, living compartment play a central role for functioning of terrestrial ecosystems. During the past decades they gained increased attention as soil protection, changing land use systems and thus, the C sequestration function of soils became more and more important. Due to the establishment of sustainable land use systems it is hoped to counteract to the rising CO_2 concentration in the atmosphere (Houghton et al., 2001, Paustian, 2001). Litter decomposition is a key component for nutrient dynamics and C storage and has been central subject of a number of investigations already since the early phases of soil science, i.e. in the studies of Waksman and Tenney (1928) and Wittich (1943a,b,c,d) or later e.g. by Swift et al. (1979) and von Zezschwitz (1980, 1985). During the last two decades, an extensive amount of experimental research has been published on plant litter decomposition and the mechanisms of C sequestration in soil - headed by the papers emerging from the groups around Dr. Björn Berg, Dr. Marie-Madelaine Couteaux, Prof. Charles Mc Claugherty, Prof. Vernon Meentenmeyer, Dr. Jerry Melillo, and many others.

The results of the mentioned work groups enter studies on the impact of land use systems and management by model projections. On a general scale, in European forests resource supply was reported to exceed resource use and thus, C and N cycles are not balanced (Schulze et al., 2000b). The German carbon sink in forest ecosystems was reported to suffer a gradual decrease due to ageing of forest stands (Karjalainen et al., 2002). For Europe, a carbon sink of 0.7 Gt C $year^{-1}$ and a possible further addition of 0.2-0.3 Gt C $year^{-1}$ by implementation of improved management methods (“C forestry”) has been predicted from model calculations (Schulze et al., 2001).

In Saxony, current forest conversion policies aim to convert the wide spread coniferous stands into semi-natural deciduous forests dominated by European beech and Common oak (Sächsische Landesanstalt für Forsten, 1999). These forests are recorded of being ecologically stable and to fulfil the demands for a multi-functional forestry. However, very few investigations have been undertaken to explain the effects of forest conversion on stocks and especially on dynamics of carbon and nitrogen in soil. The amount and type of carbon stored in a forest soil reflects the past balance between C accumulation and C loss (Entry and Emminham, 1998). Total stocks and organic layer morphology reflect rather long-term dynamics while recent influences of vegetation cover and climate on turnover processes are characterized by amounts of medium-term and readily decomposable C and N fractions. The latter approach offers an opportunity to assess dynamics of organic matter turnover in relation to microbial activity and thus, to evaluate influences on the C sequestration potential of soils.

Studying organic matter decomposition in soil, two basic targets should be distinguished: (i) to understand mechanisms of the degradation process and (ii) to search for indices for prediction of long-term decomposition rates (Berg and Mc Claugherty, 2003). Separating these effects is not always easy and when it comes to practical approaches the latter may not be answered without knowledge about the first. Thus, as it is known that about 80% of soil organic matter are formed by microorganisms (Andres, 1984) we focused on soil microbial biomass as driving force for organic matter decomposition in our study. Microbial biomass plays a very important role in organic matter turnover and humus dynamics – dominantly driven by substrate quality, the climatic and physico-chemical environment and the decomposer community (Berg and McClaugherty, 2003; Lal, 2002; Swift et al., 1979). These factors can be influenced to some extent by forest management.

In fact, forest conversion rules all mentioned factors as it includes the change of canopy vegetation as well as the increase in stand structure and results in most cases in older forests. Thus, in order to investigate the impact of forest conversion on the humus build-up rate the effects of canopy vegetation and thus, litter quality, of stand structure and density and thus, radiation at the forest ground, as well as the humus accumulation during ageing of stand vegetation have to be taken into consideration.

1.2 Objectives of this Study

Forest conversion aims to result in a great portion of European beech (*Fagus sylvatica* L.) and Common oak (*Quercus petreae* Liebl.) in our forests. In comparison to Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) deciduous stands grow older and shall develop a characteristic continuous forest structure due to management [i.e., selective felling] and natural regeneration (*Dauerwald*). Thus, investigations on the effect of forest conversion include and combine studying effects of stand species and litter quality, stand age and the structure of forest stands. Furthermore, climate [i.e., temperature and moisture] and the abundance and composition of the microbial decomposer communities are main influencing factors and are thus, responsible for the decomposition dynamics and accumulation of humus (Berg and McClaugherty, 2003; Prescott et al., 2000). Hence, various factors have to be considered in order to explain the processes and mechanisms involved into decomposition dynamics leading to a stand-specific accumulation rate of humus.

Subsequently, the main objectives of this work can be summarised beneath the following points which at times cannot be entirely separated:

1) *To determine the impact of forest conversion on humus accumulation.*

(Chapter 4)

→ In May 2001 a soil inventory was performed along three forest conversion sequences in order to determine mass and morphology of the organic layers.

2) *To evaluate the impact of litter quality on humus dynamics.*

(Chapter 6)

→ In order to receive further information on the impact of litter quality on turnover dynamics humus chemistry was characterized by pyrolysis-GC-MS after litter shed and after four months exposition. In addition, turnover during winter-term was mirrored by microbial biomass and activity as well as water-extractable and water-soluble C fractions.

3) *To evaluate the role of microbial biomass for the turnover of different C and N fractions in coniferous and deciduous stands as well as in advanced plantings.*

(Chapter 5 and 8)

→ Contents of microbial biomass and activity were evaluated in relation to the different C fractions and in the different forest stands involved in the soil inventory. A tree clustering analysis shows the relationship between microbial biomass and the different C and N fractions in soils of two forest stands studied during one year from fall 2001 to fall 2002.

4) *To define indicators for the influence of forest conversion on carbon and nitrogen cycling in soils.*

(Chapter 4)

→ The discriminant analysis was applied to evaluate the parameters involved into the soil inventory and to define indicators for the impact of forest conversion on organic matter turnover.

5) *To describe the stand-specific decomposition dynamics of organic matter and humus formation.*

(Chapters 6, 7 and 8)

→ The amount of organic matter accumulated, different C fractions, microbial biomass and its activity as well as the amount of litter shed were determined during one year from fall 2001 to fall 2002 and discussed in order to explain the mechanisms of humus formation. In addition, litter decomposition was observed applying the litter bag method.

6) *To assess the C balance of the top soils, to compare organic matter turnover rates and thus, to investigate the contribution of different forest stands to the C sequestration in soil.*

(Chapter 8)

→ The litter input, different C pools and the C-output by mineralisation and contents of soluble organic C were compared in a Scots pine and European beech/Common oak stand revealing a C balance. Thus, the function of both sites as possible source or sink of C was discussed.

2 Literature Review

2.1 Background of this Investigation: Soils and the Global C Cycle

Soils play an elucidating role in the global carbon cycle since they store worldwide up to estimated 2,000 Gt (10^{15}g) C (Dixon and Turner, 1991; Dixon et al., 1994; Houghton et al., 2001; Rice, 2002). Thus, the C storage function of soils exceeds C stocks of atmosphere and vegetation together (Brady and Weil, 2002). In contrast, Schlesinger (1991a,b) estimated the total C stored in soil and vegetation together as 1,000 Gt, which accounts to 1.5 fold of the atmospheric 700 Gt (Townsend et al., 1996). These values vary as they are either based on soil (Buringh, 1984) or vegetation groups (Schlesinger, 1984), life-zone classes (Post et al., 1982), or on model projections (Meentenmeyer et al., 1981). In order to prevent the impact of global change on world ecosystems, sequestration of the increased atmospheric CO_2 in components of terrestrial ecosystems is thought to be a promising alternative (Houghton et al., 2001).

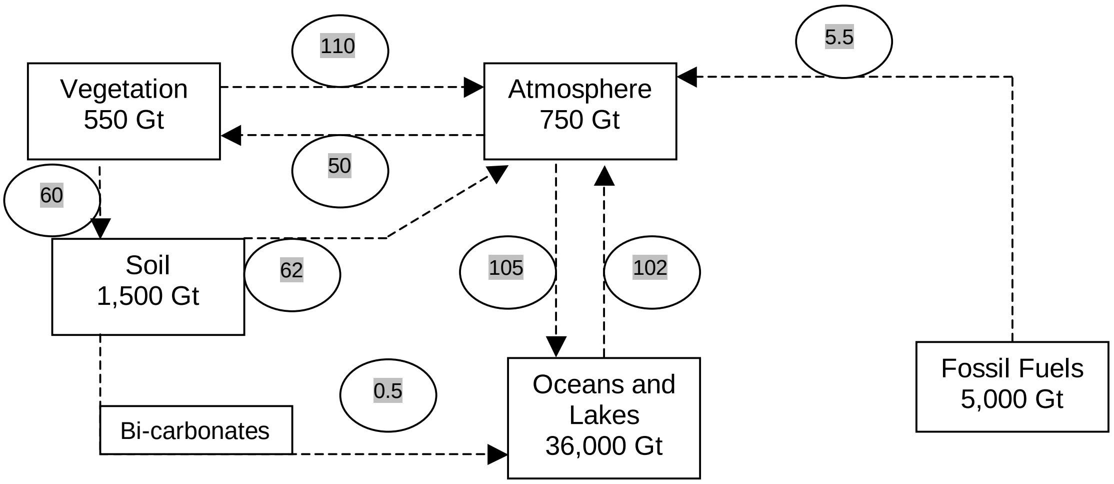

Fig. 2.1: Global C cycle (Gt = 10^{15} g) (according to Brady and Weil, 2002).

For Europe, a carbon sink of 0.7 Gt C year^{-1} and a possible further addition of 0.2 - 0.3 Gt C year^{-1} by implementation of improved management methods has been predicted from model calculations (Schulze et al., 2001a). There is both, concern that climate, land use change and changing management systems will result in an increasing CO_2 release from soils and hope that suitable management methods ("C forestry", Schulze et al., 2001a) will enhance soils in their C storage function (Paustian, 2001). Thus, the function of soils as C sink or source and understanding of C sequestration mechanisms will gain future attention.

Considering the amount of C yearly bound by oceans, lakes and forest systems, a worldwide unknown terrestrial sink of 1.3 (± 1.5) (Houghton et al., 2001) to 2 Gt C year^{-1} (Paustian, 2001) has been estimated. A fundamental reason for the increasing CO_2 concentrations lays in changing land use systems. Hereby, transformations from forest into agricultural land are an evident factor. Every year 1.6 (± 1.0) Gt C and 5.5 (± 0.5) Gt C enter the atmosphere due to land use change and the burning of fossil fuels, respectively (Lal et al., 1997). The conversion of native systems [i.e., forests, grasslands and wetlands] has resulted worldwide in a significant loss of about 120 - 170 Gt C in the past 150 - 300 years (Paustian, 2001).

Fearnside and Barbosa (1998) gave an estimate of 11.7 10^6 t C emitted from the 1.38 10^6 ha land cleared in the Brazilian Amazon in 1990. This accounts to 20 % of the all over C emissions from fossil fuel. Even higher amounts of C are released due to shifting cultivation. Proceeding on the assumption that shifting cultivation would be practised on 25 million ha, a total of 6.25 10^6 t C year^{-1} would be lost from the ecosystem (Lal, 2002). In boreal forests, the number of fire events increases: Yearly 4 - 6 10^9 t C enter the atmosphere due to vegetation fires; 1.2 - 1.8 % originate from circumpolar boreal wood lands (Crutzen and Andreae, 1990). Also in temperate forest tree species and management systems have an important role in the terrestrial C cycle. Formerly common clear cutting practices lead to an increase in mineralisation processes and a C loss of about 40 % in organic and upper soil layers (Rehfuess, 1990), while semi-natural, continuous forest structures (*Dauerwald*) are believed to represent an equilibrium between vegetation and soil (Entry and Emmingham, 1998). Considering the increasing demand for renewable energy sources the impact of forest management on C accumulation in soil has to be further investigated in order to gain a possible great sink effect. Consequently, the influences of vegetation cover, stand structure, and management practices on litter decomposition are of main interest when C sequestration in forest soils shall be enhanced.

Burschel et al. (1993) published an overall study for Germany on the role of forests and forestry on the C cycle. According to these authors, 35 % (888 Mio t) of the total of 2.5 10^3 Mio t C stored in German forests are in living tree biomass. The greater share, 16 % (392 Mio t) and 47 % (1,174 Mio t) is stored in the organic layers and mineral soil, respectively. Carbon storage was shown to be strongly related to climatic factors. Thus, giving an overview on C stored in forest soils all over Germany Baritz (1998) classified by climatic regions and humus forms. Depending on the natural region, about 10 to 55 t C ha^{-1} are stored in the organic layer of forests in Germany. Mineral soils hold about 40 up to 200 t C ha^{-1} (0-90 cm). Yet, the highest values were found in the Alps and on moor land. In sum, this author estimates a German carbon budget in forests soils of 1.17 10^9 t and an average of 108 t ha^{-1}.

In comparison, amounts of the global soil N are estimated to be 133 to 140 Pg for the upper 100 cm (Batjes, 1996). Soil C and N stocks and dynamics are mainly influenced by elevated atmospheric CO_2 concentrations, depositions or losses of NH_4 and NO_x and the limitation of available N on microbial activity as well as on land use systems (Batjes, 1996; Dixon and Turner, 1991; Dise and Wright, 1995; Harrison et al., 2000; Persson et al., 2000; Townsend et al., 1996).

2.2 Possible Impacts of Global Change on Soil C sequestration

Schlesinger and Andrews (2000) gave an overview on the impact of global change on soil respiration and C storage. They predicted an increase of the CO_2 flux from soils and a higher sequestration of carbon in vegetation and soil due to the increasing atmospheric nitrogen deposition. Generally, metabolic processes such as photosynthesis, respiration and thus C mineralisation are enhanced by a raise in temperature (Townsend and Rastetter, 1996). Additionally, increasing CO_2 concentrations in the atmosphere result in a higher C fixation within plant material and thus, in wide C/N ratios (Townsend and Rastetter, 1996). The wide C/N ratios in litter lead to a higher immobilisation of inorganic N by soil microbial biomass. Finally, this chain of reactions results in a negative impact on site productivity as consequently less N is plant available. At the same time leaching and denitrification is restricted and the rate of total N sequestration in the soil raised. Both effects, wide C/N ratios in the plant material and the elevated N contents enhance C sequestration (Townsend and Rastetter, 1996). According to Dixon and Turner (1991) the described decline of site productivity is mainly observed on sites short in water supply. In northern forests the opposite effect of raised site productivity is predicted due to the elevated N mineralisation rates within the organic layer (Pastor and Post, 1988). Additionally, there is evidence that at high N inputs the humus stock may increase due to the increased formation of nitrogen-polyphenol-complexes (Berg and Matzner, 1997).

Temperature was shown to affect 80 % of data variance in a study on CO_2 emission within a spruce stand in the *Fichtelgebirge* mountains (Buchmann, 2000). In comparison of primary production and decomposition (mineralisation) the hypothesis has been stated, that the latter is stronger affected in the case of an increase in temperature (Kätterer and Reichstein, 1998). Furthermore, positive correlations between temperature, annual actual evapotranspiration and litter fall were observed for various European, mainly Fennoscandian forests (Berg and Meentenmeyer, 2001). Leirós et al. (1999) estimated twice the current CO_2 emission in the rather strong case of a 5℃ rise in temperature and a 10 % increase in soil moisture. Optimal decomposition occurred at 22℃ in a study comparing organic matter incubation at 5℃, 12℃, 22℃ and 32℃ (Pöhhacker, 1995). In addition, there is evidence for a greater use of older carbon for microbial respiration at rising temperatures (Waldrop and Firestone, 2004). Investigations on the impact of global warming revealed that decomposition rates would show a larger increase in boreal and in acid soils than in warmer temperate regions and calcareous sites (Coûteaux et al., 2001). At the same time, other authors predict an increase in carbon sequestration in northern forests with global warming caused by the synthesis of total ecosystem carbon, decomposition rates and litterfall amounts (Vucetich et al. 2000). There is also evidence that organic matter decomposition in mineral soil is not affected by temperature (Giardina and Ryan, 2000). Thus, the organic layer of forest soils will play an important role in future C sequestration, as temperature changes may effect the turnover of organic matter in different ways. These mechanisms need to be subjec of further investigations.

2.3 Turnover of Organic Matter and Model Approaches

According to the widely held opinion soil organic matter consists of three different pools: (a) one rather active fraction, which is turned over within a few months or years basically comprised of microbial biomass and labile organic compounds, (b) one slowly decomposing pool with residence times of 20-100 years and (c) one recalcitrant, more or less inert pool, taking hundreds to 1,000 years to turn over (Fig. 2) (Parton et al., 1987; Rice, 2002).

The recalcitrant pool is said to make up to 60-70 % of soil C, while the slow pool amounts to 20-40 % and active organic matter usually not exceeds 5 % of total soil-C (Rice, 2002). As natural systems are thought to represent an equilibrium, the rate of formation of so-called stable humus equals here the rate of decomposition. In general, 10-20 % of plant-C enter humus formation (Rice, 2002). However, these mechanisms depend on different factors such as climate, litter quality and land use and may differ in a wide range between sites.

According to Smith (2002) altogether 33 SOM models are currently represented within the international Soil Organic Matter Network. Paustian et al. (1997) and Powlson et al. (1996) gave an overview on SOM models by classifying them according to the number of pools and litter components considered. The most popular models are the Rothamsted model (Jenkinson et al., 1987), the Century model (Parton et al., 1987) and the Q model (Ågren and Bosatta, 1987). The Rothamsted model (RothC) includes two litter components “decomposable” and “resistant”, two microbial biomass pools “opportunistic” and “basal”, and a humus pool, representing the secondary decomposition products (Paustian et al., 1997).

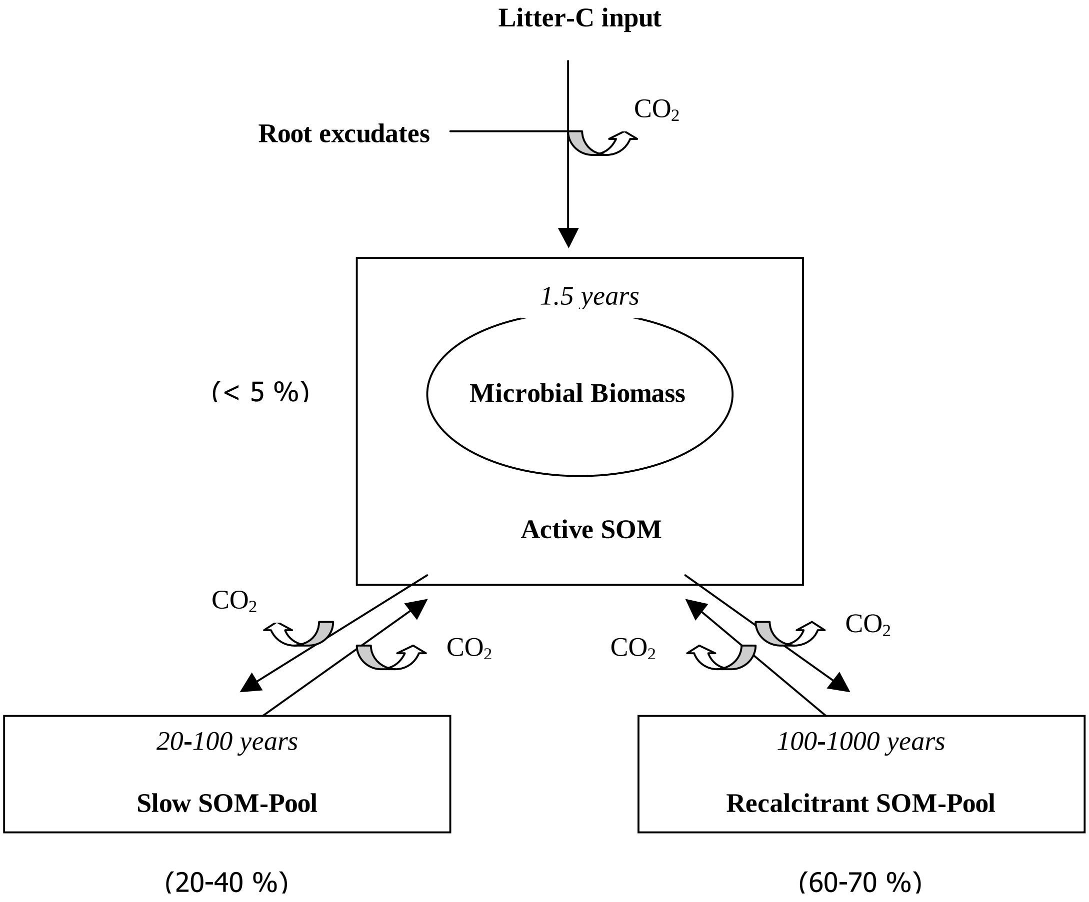

Fig. 2.2: Model of soil organic matter turnover (according to Parton et al., 1987; Rice, 2002).

The Century model also consists of two litter pools, described as an easily decomposable “metabolic” and a more resistant “structural” component, but includes three SOM pools [i.e., active, slow and recalcitrant]. The Q model defines the C fraction assimilated at quality q´ that is returned to the substrate at qualitity q (Paustian et al., 1997). Emerged from these theories, various models of organic matter turnover have been published. However, mechanisms that are responsible for the accumulation of organic matter remain little understood and are currently subject of various studies. One major control of decomposition dynamics is the litter nitrogen and lignin content (Berg, 2000; Lorenz et al., 2000; Melillo et al., 1982).

Four basic techniques are commonly applied to estimate SOM turnover: (i) Simple first order modelling, (ii) ^{13}C natural abundance technique, (iii) ^{14}C dating technique, and (iv) “bomb” ^{14}C technique (Six and Jastrow, 2002). Yet, the most simple methods still are the Two-Component-Model, calculating the saldo of C input [e.g., aboveground and belowground litter, root exsudates] and C output [e.g., microbial C mineralisation, root respiration, dissolved organic matter] and calculation of the turnover rate as long as one of these two parameters is known (Scheffer and Schachtschabel, 2001). Both methods can be applied so far in- and/or outflow of the system as well as SOM are determined. Yet, the major disadvantage of these approaches is that soil organic matter turnover is treated as a linear functioning process, that it is not. Based on the observation of a sequential pattern of decomposition with different classes of compounds, turnover of organic material is thought to follow simple negative exponential kinetics (Berg and McClaugherty, 2003; Brady and Weil, 2002; Scheffer and Schachtschabel, 2001).

2.4 Litter Compounds and Humus Chemistry

Generally, soil organic compounds are grouped into macromolecular substances [i.e., polysaccharides and lignin] and low-molecular weight substances [i.e., aromatic, phenolic compounds, terpenes, aliphatic acids such as fats and waxes and alcohols] (Fengel and Wegener, 1989). Generally, soluble and low-molecular weight compounds are the first to dominate litter decomposition, followed by hemicelluloses and somewhat later also cellulose and fats, waxes and lignin (Berg and McClaugherty, 2003; Brady and Weil, 2002). Thus, turnover rates are generally believed to slow down the more the easily decomposable compounds are used up. Yet, most recent studies reveal indications for a rather fast structural transformation due to microbial decomposition of certain lignins (Gleixner et al., 2002).

Haider (1999), Kögel-Knabner (1996) and Berg and McClaugherty (2003) gave an overview on humus formation explaining the mechanisms on destruction of celluloses and other polysaccharides by hydrolyzing enzymes as well as oxidative lignin decomposition processes. During the latter, carboxyl- and hydroxyl-groups are formed allowing the formation of chelates, a complex of lignin-derivates, and metal ions. These substances are important for the long-term stability of humus.

2.5 Basic Parameters influencing Humus Dynamics

The factors (i) amount, quality and distribution of litter, (ii) site-, stand-specific and climatic characteristics, (iii) mass, activity and composition of the decomposing microbial biomass, and (iv) anthropogenic influences like depositions and amelioration have been widespread investigated in the context of humus dynamics. The interaction of these factors leads to specific biochemical processes of organic matter cycling which have been estimated in various turnover models (Fig. 2.3).

2.5.1 Litter: Mass, Quality and Distribution

The mass of fallen annual organic litter in temperate forest ecosystems accounts to 3.1-6.5 t ha^{-1} (Vogt et al., 1986). In stands of European beech and Scots pine amounts of annual litter of 2.0 to 5.5 t ha^{-1} and 2.0 to 4.1 t ha^{-1} were reported, respectively (Ganter, 1927; Thomasius and Schmidt, 1996). Heller and Göttsche (1986) investigated long-term litter fall in beech and spruce between 1967 – 76, fine litter (< 2 cm) fallen in beech revealed a mean of 3.7 t dry mass ha^{-1} a^{-1} and varied between 3.1 – 4.5 t. In contrast, annual variation of litter fall in spruce exceeded these values (2.0 – 4.6 t dry mass ha^{-1} a^{-1}); the mean accounted here to 3.2 t dry mass ha^{-1} a^{-1} (Ellenberg, 1986).

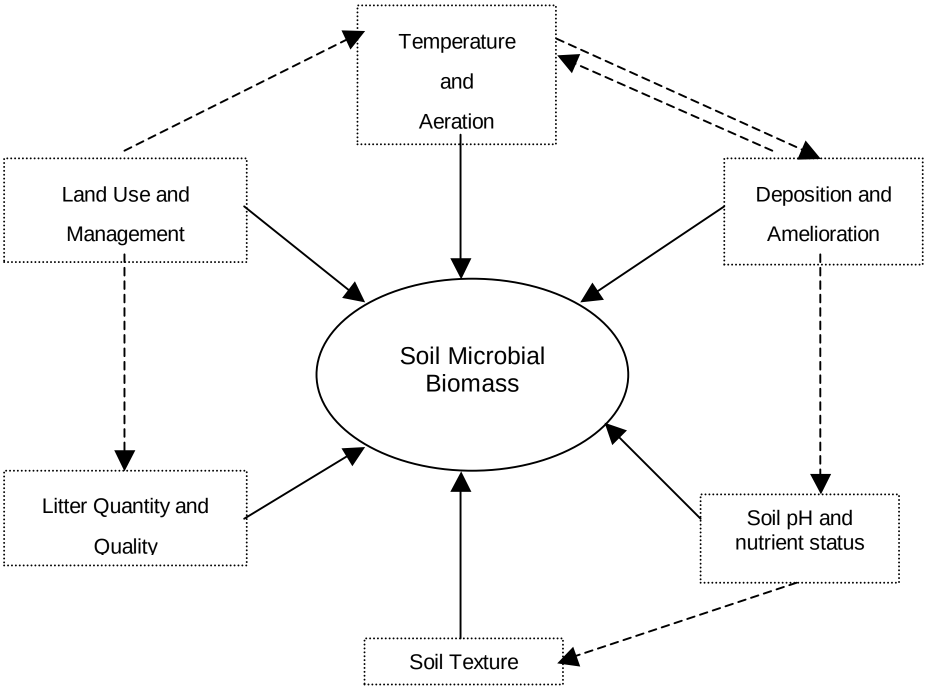

Fig. 2.3: Interaction between natural and anthropogenic factors and microbial biomass in OM turnover in soils.

Litter fall data can vary in a wide range according to climatic conditions. On a global scale, the amount of above-ground litter input increases as the latitude decreases from boreal to tropical forests (Kögel-Knabner, 2002). Berg et al. (1999a) found a highly significant regression between litter fall and annual average temperature, plus annual precipitation, plus latitude in an investigation along a North European spruce forest transect. Pine forests revealed only significant relations of litter fall amounts in respect to latitude, stand age and basal area (Berg et al., 1999b). Furthermore, the effects of beech mast and wind throw have to be taken into consideration. Litter fall in coniferous forests is not bound to a defined season, but usually reveals a peak in fall/winter. The portion of leaves and needle litter of the total above ground litter is estimated ca. 80 % for deciduous (Jensen, 1974) and 60 – 80 % for coniferous stands (Millar, 1974). However, as litter fall may vary between single years related to the weather long-term studies are very important in order to receive reliable information and to discuss results of short-term observations.

Although the determination of root biomass and fine root turnover rate is a very work-intensive procedure and can thus often not be included in studies on humus dynamics, some important aspects about these parameters shall be mentioned in order to predict their role in relation to the data obtained as far as possible. Root biomass varies site- and vegetation-specific. Especially the physiologically important fine roots (< 2mm) show high temporal dynamics and are a key factor for subterranean litter production. Generally, the portion of root-derived litter on the total annual litter mass is estimated to account for 20-50 % (Vogt et al., 1986). The annual fine root turnover in temperate forests was estimated to be between 2.3-9 t ha^{-1} (Picollo, 1996). Yet, these numbers vary with climatic conditions, stand and site characteristics. The comparison of beech and spruce stand revealed nearly twice as much fine root biomass beneath beech than in a spruce stand (Rothe, 1997). George and Marschner (1996) reported that between 2 months and 2 years are necessary for the complete turnover of fine roots in forest ecosystems. According to an investigation conducted by Edwards and Harris (1977) in a poplar stand in *Tennessee* (U.S.A.) root respiration accounts for ca. 35 % of total soil respiration, while root mineralisation accounts for 42.2 %. The remaining part divides into 20,6 % litter mineralisation in the organic layer and 2,2 % turnover of humic substances. Bottner et al. (1999) found a daily root derived input of 5.4 and 3.2 % of plant biomass-C. The same authors as well as Helal and Sauerbeck (1986) reported on the importance of roots for microbial biomass - especially during the second phase of organic matter turnover, when rather slowly decomposable compounds are mineralised. In respect to site quality, Leuschner et al. (1998) found a comparatively high fine root biomass accompanied with a high mortality and thus high necromass in beech stands of rather unfavorable acid soils. According to Raich and Nadelhoffer (1989) aboveground as well as belowground production are controlled by the same factors. Therefore, we can evaluate total soil respiration and total carbon allocation to roots in forest ecosystems from litter fall measurements in forests under steady state conditions.

With regard to the nutrient supply [i.e., N, P, K, and Mg], there is no clear advantage of beech, but of oak litter as compared to pine needles (Thomasius and Schmidt, 1996). Up to 98 % of soil-N and up to 60 % of P within a soil are bound in organic material (Kuntze et al., 1994). Yet, with 58 % carbon is the main element of litter (Ellenberg et al., 1986). Generally, the C:N:P:S ratio in soil is 100:10:1:1 (Rice, 2002). Rothe (1997) observed a faster turnover of Ca, K and Mg under beech than in spruce. Generally, decomposition of beech leaves revealed a slow initial mass loss with only ca. 30 % within one year (Jörgensen, 1991; Wise and Schäfer, 1994). In comparison, oak litter has shown a loss of ca. 10 % during the first 6 weaks (Tietema and Wessel, 1994). The advantage of deciduous trees in litter decomposition has been often stated and explained by lower lignin and higher nutrient (especially N-containing protein) portion. Yet, recent studies revealed little difference in nutrient concentrations and condensed C compounds such as lignin between spruce and beech litter (Vesterdal, 1999).

2.5.2 Microbial Biomass: Mass, Activity and Composition

The microbial biomass (C_{mic}) is a source and sink of biologically mediated nutrients and responsible for transforming OM and nutrients within soils (Gregorich et al., 2000). Thus, microbial biomass can be regarded to as the engine of organic matter decomposition as it rules mineralisation and humification. A major task in humus studies was the development of methods for microbial biomass determination, e.g. by Vance et al. (1987), Sparling and West (1988), Heinemeyer et al. (1989). Martens (1995) evaluated the most current methods. In the 1980s, systematic organization of so-far knowledge and new methodological approaches allowed the definition of indicators for ecosystem stress/restoration capability and organic matter turnover. Anderson and Domsch (1986a,b, 1993) characterized the term “microbial activity” and developed the metabolic quotient (qCO_2) as specific activity parameter in soil.

Generally, microbial biomass represents only 2 to 5 % of organic carbon in soil (Jenkinson and Ladd, 1981; Haider, 1996). If temperature and soil moisture are rather high and constant, microbial biomass is comparatively high and active. In our climate most favorable conditions are found in spring and fall, when soil microbial biomass peaks (Berg et al., 1998). Furthermore, soil microbial biomass is affected by management impacts such as liming, amelioration and depositions (Chapter 2.5). Table 2.1 gives an overview in microbial biomass in different soils as related to climate and management.

In soils of different forest stands, higher microbial biomass was detected in deciduous stands as compared to conifers (Bauhus et al., 1998; Saetre et al., 1999; Smolander and Kitunen, 2002). Furthermore, the ratio between fungi:bacteria was observed to be lower under deciduous trees (Paul and Clark, 1996) and to decrease with depth within the organic layer (Berg et al., 1998). These findings are confirmed and can be studied in detail by new approaches using PLFA analyses. Fierer et al. (2003) observed highest occurrence of Gram-negative bacteria, fungi, and protozoa at the surface, while Gram-positive bacteria and actinomycetes tended to increase with soil depth. Thus, nitrogen-containing polyphenol complexes are presumably broken down by specialized microbial communities at the subsurface, when N is released into easier available fractions. Microbial biomass living in deeper soil horizons might not be able to fulfill this. Furthermore, it was shown that amelioration [i.e., liming or N-fertilisation] and management influence microbial community composition (Bardgett et al., 1996; Frostegård et al., 1993; Marschner et al., 2003).

Tab. 2.1: Estimates of soil microbial biomass C (C_{mic}) in various land use systems and soils (literature review).

Location	Land use	sampling depth	C_{mic} contents [µg g^{-1} dw]	stock [kg ha^{-1}]	Reference
Germany	Beech forest	L	24,945		Maraun & Scheu (1995)
		F	20,900		
		H	18,870		
Germany	Beech forest	litter	3,200		Pöhhacker (1995)
Germany	Spruce forest	L	4,140 - 4,315		Zhong & Makeschin (2004)
		F	3,010 - 3,222		
		H	1,780 - 1,772		
	Spruce mixed with beech	L	9,092		
		F	3,683		
		H	2,540		
Germany	Forest	L	ca. 5,000 - 11,000		Raubuch & Beese (1995)
		F	ca. 200 - 600		
		H	ca. 100 - 300		
		L - Bv		148.8 - 618.10	
	Forest	L	20,780 - 25,080		Ross & Tate (1993)
		F+H	9,120 - 10,260		
Sibiria	Forest	litter	7,840 - 11,000		Ross et al. (1999)

Location	Land use	sampling depth	C_{mic} contents [µg g^{-1} dw]	 stock [kg ha^{-1}]	Reference
Canada	Forest				Scheu & Parkinson (1995)
	Populus tremuloides	L	35,387		
		F	22,415		
		H	9,268		
	Pinus contorta	L	16,865		
		F+H	5,549		
Finland	Forest (Norway spruce)	topsoil	2,450 - 6,520		Smolander & Mälkönen (1994)
Germany	Beech forest	litter	ca. 6,000 - 12,000		Stork & Dilly (1998)
European transect	coniferous forest	topsoil	2,100 - 2,800		Tietema (1998)
Germany	Spruce and beech forest	litter	10,900 - 12,500		Albers et al. (2004)
Canada	Aspen forest	organic layer	10,756 - 12,344		Bauhus et al. (1998)
	Birch forest		9,285 - 10,588		
	Conifer forest		8,873 - 11,347		
Finland	Birch forest	organic layer	14,800		Smolander & Kitunen (2002)
	Spruce forest	organic layer	11,900		
	Pine forest	organic layer	10,300		
Sweden	Norway spruce forest	H horizon	6,000		Saetre et al. (1999)
	Birch forest	H horizon	5,800		
Spain	Pine forest	0-15 cm	282 - 1,275		Diaz-Ravina et al. (1995)
	Oak forest	0-15 cm	387 - 555		

			C_{mic}		
Location	**Land use**	**sampling depth**	**contents** [µg g^{-1} dw]	**stock** [kg ha^{-1}]	**Reference**
Germany	Black alder forest	litter	<10,000 - 46,000		Dilly & Munch (1996)
U.K.	Forest	topsoil	177 - 1,285		Grisi et al. (1998)
Brazil	Mata	topsoil	599		
	Cerrado		366		
	Jaiba		161		
Germany	Beech forest	0-10 cm	268 - 21,116		Joergensen et al. (1995)
Germany	Pine/ beech forest	L	2,906 - 3,717		Klose et al. (2003)
		F	3,575 - 4,870		
		H	1,783 - 2,241		
Germany	fallow	0-10 cm	69.7 - 270.9		Landgraf (2001a)
U.S.A., Oregon	agriculture	0-20 cm	150.6		Burket & Dick (1998)
	fallow	0-20 cm	64.5 - 142.7		
	forest	0-20 cm	1, 352.0		
Nigeria	tropical Rainforest	0-15 cm		760	Haider (1996)
England	fallow	0-23 cm		2240	
England	agriculture	0-23 cm		660	
Australia	grassland	0-10 cm		1170	
Germany	agriculture	0-15 cm		910	
Germany	agriculture		ca. 200 - 1,000		Martens (1995)
Germany	agriculture	topsoil	1,280 - 16,330		Martens (1986)

Litter decomposition is an important link in the global C cycle, as well as for nutrient dynamics and ecosystem stability. According to Kuntze et al. (1994) up to 98 % of soil-N and up to 60 % of P within a soil are bound in organic material. Yet, with 58 % carbon is the main element of litter (Ellenberg et al., 1986). Generally, the C:N:P:S ratio in soil is 100:10:1:1 (Rice, 2002). According to Jensen (1974) soil fauna metabolizes max. 20 % of organic matter, while 80 % are decomposed by soil microbial biomass (Andres, 1984). Therefore, soil microbial biomass plays an elucidating role in soil organic matter turnover and humus dynamics.

2.5.3 Site- and Stand-specific Effects on Humus

The activity of the decomposing biomass (soil organic matter) is strongly affected by forest stand-, site-specific as well as climatic factors. Entry and Emmingham (1998) reported an increase in soil C accumulation with stand age in an investigation in Douglas fir, while other authors could not find such effects (Bauer, 1989; Ulrich and Puhe, 1994). According to the influence of stand age and tree species on soil organic matter quality, Bauhus et al. (1998) found a decrease in C assimilation efficiency with stand age as well as less microbial biomass beneath conifers compared to deciduous species. The effect of higher microbial biomass under deciduous stands was reported in various studies (Albers et al 2004; Fischer et al., 2002; Zhong and Makeschin, 2003a). Mahendrappa et al. (2000) observed a higher C fixation in mixed stands compared to pure stands in Canadian maritime provinces. A decline in humus mass along with a shift from moder towards mull humus forms was reported from a sequence from pine via under-canopy plantings to deciduous sites by Fischer et al. (2002).

Recent investigations of Albers et al. (2004) and Persson et al. (2000) report on the major importance of the different environmental and site-specific conditions in spruce and beech stands rather than the impact of litter quality. Comparing spruce and a mixed spruce-beech stand, lower C/N ratios and qCO_2 were reported along with an increase in base saturation, thus providing a precondition for a future improvement of the site quality (Zhong and Makeschin, 2003a).

Along with soil chemical properties, the soil type is a further influencing factor, probably revealing a higher impact on organic matter decomposition under species that produce a higher litter quality (Vesterdal, 1999). Depending on bedrock material Berger et al. (2002) found significantly higher C and N accumulated under pure spruce than under mixed stands on rather less acidic material, while on acidic sites no species dependant effect was observed. Soil chemical properties [i.e., pH, base saturation] influence dominantly the composition of soil microbial biomass [i.e., fungi/bacteria-ratio]. Berg et al. (1998) reported a positive relation between fungi and bacteria with soil moisture and reported a decline of microorganisms with soil depth. Important for the soil water and air content is the soil texture. Zech and Guggenberger (1996) investigated the impact of soil texture on the soil organic matter (SOM) content and found a faster turnover rate of organic matter in sandy soils, followed by clay and slowest turnover rates in silt. Furthermore, the C/N ratio is commonly known to effect microbial activity. This has been explained with the competition of microbes for nitrogen in the case of a wide C/N ratio; nitrogen, on the other hand, is a limiting factor for litter decomposition as soils generally tend to show rather stable C/N (Brady and Weil, 2002). However, litter-N and lignin content control the mechanisms for litter decomposition due to the capability of low-molecular N to form rather recalcitrant aromatic compounds with lignin, and the possibility that low-molecular N may repress the synthesis of lignin-degrading enzymes in white-rot fungi (Berg 2000). Thus, in stands with N-rich litter humus accumulation may be accelerated.

2.5.4 Dissolved Organic Matter (DOM)

Dissolved (or also soluble) organic matter is of special interest for the C sequestration in soil as these compounds can be transferred to deeper, mineral soil horizons and thus, can potentially be stored for long-term. Organic compounds dissolved in the percolation water are displaced vertically within the soil profile and therefore contribute largely to element cycling and transport of natural compounds as well as pollutants. They are predominantly fixed to Fe- and Al-oxides and -hydroxides as well as attached to minerals of mica and clay (Jardine et al., 1989). However, experiments showed that the pool of potentially soluble organic compounds in both mineral as well as organic horizons is much larger than the amount actually dissolved during any leaching event (Qualls, 2000). Studying a watershed, Qualls et al. (2002) found that most labile DOC was decomposed before being leached into the mineral soil and determined a dominance of refractory organic matter within DOC transported through the system.

The soil pH is a determinant factor of DOM loss within a soil profile due to precipitation of dissolved organic macro-molecules. An increase of 0.5 in pH value already leads to a 50 % higher DOM mobilisation (Zech and Guggenberger, 1994). According to Cronan and Aiken (1985) there is no influence of tree species on DOM composition, but on its concentration within the soil solution. In accordance with this result, Michalzik et al. (2001) found no general difference in DOC and DON concentration and fluxes between coniferous and hardwood forest floor leachates. Contrary to these findings, David and Driscoll (1984) determined 50-100 % more DOM under conifers as compared to deciduous stands. In a study on the influence of droughts on DOC leaching Borken et al. (1999) found no significant effect depending on the drought period or subsequent a rainfall period. Amelioration with nitrogen seems to clearly decrease the amount of water-soluble C due to microbial growth

(Chantigny et al., 1999). Furthermore, the impact of various depositions was investigated along a European transect (NITREX data). The results revealed the highest correlation between N input and N output, followed by a input-SO_4 to N-output and a negative correlation between pH and N output (Dise and Wright, 1995). Guggenberger and Zech (1993) reported on different mobility of DOM fractions, divided into hydrophilic acids, hydrophobic or hydrophilic neutrals, and hydrophilic bases and presumed implications for the transport of organic pollutants and heavy metals within a soil profile. The hydrophilic fractions of DOM were found in larger proportions in winter and spring, whereas in summer and fall the hydrophobic fraction dominated (Kaiser et al., 2001). Michel and Matzner (1999) found a two- to threefold higher DOC and DON release from the F as compared to the H horizon. While DOM release from the F layer was correlated to N mineralisation, the loss of dissolved organic compounds from the H horizon was positively related to pH and soil respiration. In contrast, Solinger et al. (2001) reported on highest DOC and DON concentrations and fluxes in H horizon leachates in a deciduous forest. These results may indicate different patterns in decomposition dynamics and DOC contents in organic horizons between coniferous and deciduous stands.

Concluding, Kalbitz (1996) defined the following characteristics for a high DOM release: early decomposition degree and a high proportion of easily degradable organic compounds, long and intensive droughts, high microbial activity, high sand content, low contents of Fe-oxides with a high content of crystal oxides, low cation exchange capacity (especially Ca^{2+} within the soil solution), and high pH. Kalbitz et al. (2000) gave a further detailed overview on DOM controls in forest soils. They pointed out that hydrological conditions are generally more important than biotic factors for DOM fluxes and presented indications that the microbial degradation of DOM is underestimated in subsoil horizons and has not yet been quantified.

2.6 Liming and Deposition Impacts on Litter Decomposition

During the 20th century the intensification in land use lead to diverse impacts on ecosystems. Thus, factors such as deposition and amelioration practices gained importance. At this time, various studies focused on the compensation of atmogenic depositions and amelioration practices. In this context, the impact of N(PK) addition (Fog, 1988; Bergmann and Flöhr, 1989; Rehfuess et al., 1991; Tietema, 1998; Berg, 2000) and liming vs. acidification (Ammer and Makeschin, 1994; Bååth et al., 1980; Eruz et al., 1985; Fiedler, 1988; Fiedler et al., 1988; Kreutzer, 1995; Kreutzer et al., 1998; Olsson, 1986; Rosenberg, 1999; Ulrich et al., 1994) were main points of interest.

Due to heterotrophic and/or autotrophic nitrification subsequent liming the NO_3^- production is enhanced and thus, the increased availability of these mobile anions may result in a loss of base cations in the top soil (Papen et al., 1991; Makeschin and Rodenkirchen, 1994; Kreutzer, 1995). Karlik (1995) reported on a significantly higher loss of DOM in limed soils, which was observed in pot, lysimeter and field experiments. Additionally, subsequent liming, the pH rises and microbial biomass gains activity. Thus, SOM is rapidly decomposed and a general re-distribution of C down the profile towards upper mineral soil takes place (Rehfuess, 1990).

Many forest ecosystems in northeastern Germany are heavily influenced by atmospheric depositions of acidic (SO_2, NO_x) and alkaline compounds (fly ash from coal-fired power plants) (Herpel et al., 1995*;* Klose et al., 2001; Koch, 2000; Rumpel et al. 1998a,b). This type of deposition was described as the “sulphur-lime-fly-ash-type” (Hofmann and Heinsdorf, 1990). Together with these compounds, other constituents such as “black carbon”, nutrient salts, and heavy metals were accumulated in soils near these urban-industrial areas (Klose et al., 2001). Various effects of these atmospheric depositions on forest soils in the *Dübener Heide* region have been described, such as untypical high pH values, high base saturation and wide TOC:TN-ratios, high magnetic susceptibility values and total ash contents (Baronius, 1992; Herpel*,* 1991; Hofmann and Heinsdorf, 1990; Hüttl and Bellmann, 1998; Klose et al., 2001; Köhler and Lieber*,* 1972; Konopatzky, 1995; Lux, 1974; Nebe et al., 2001; Rumpel et al., 1998 a,b). Morphology and chemical properties of humic horizons in forest soils of immission areas have been studied in detail by Kopp and Schwanecke (1994). These authors as well as Konopatzky (1995) described a process called „Shift in topsoil characteristics“ („*Oberbodenzustandswandel*“) as changes in morphological properties of formerly inactive humus forms [i.e., raw humus-type moder] towards active forms [i.e., moder] occurred on a widespread scale within the northeast German lowland.

2.7 Forest Conversion and its Possible Effects on Humus

Historically, the major part of the Saxonian woodland was covered with deciduous tree [i.e., European beech] dominated forests. This changed, when forests were devastated by the increasing demand for charcoal and fuelwood during the 16th to 18th century and land use intensification lead to a multi-purpose use of forests, i.e. by forest pasture. The so overexploited forests were restored during the 19th century, when vast areas were replanted and management regulations were implemented. During the second half of the 20th century various industrial and traffic emissions lead to forest damage and decline (Lux, 1974; Hofmann and Heinsdorf, 1990; Heinsdorf et al., 1992; Hüttl and Bellmann, 1998; Ulrich et al, 1989; Ulrich et al., 1994). Various studies were conducted in order to gain information on the mechanism of forest damages. A major outcome of these investigations was that forests that correspond to the potential natural vegetation are more resistant and stable and can therefore better fulfill the demands of future forest management. Thus, the major goal of the current forest conversion policies is to convert the wide spread coniferous stands - dominantly Norway spruce (*Picea abies* L.) in the Ore Mountain region and Scots pine (*Pinus sylvestris* L.) in the lowland - to multi-storey, mixed semi-natural forests. The fundamental concept of current silvicultural policies is the principle of “close to nature” production forest („*naturgemäßer Wirtschaftswald*“). It was defined as mixed and uneven-aged forest of site-adapted species that represents a qualitative climax and optimal growing stock (Krutzsch, 1940). All management procedures that support these principles are summarized as forestry based on natural conditions. The respective basics of current silvicultural management strategies can be traced back to the work of Krutzsch (1926) in *Bärenthoren*, Saxony.

Forest conversion has been defined as the planned conversion of forests, which do not meet the ecological and social-economic demands, following natural models such as the potential natural vegetation scheme (PNV) allowing for a functional modification (Thomasius, 1996). There are three basic targets of current forest conversion:

i) Ecological stabilization of forest ecosystems to enhance resistance and stability against non-biotic and biotic interference as well as the elasticity, resilence, and ecosystem functionality.
ii) Reduction of production risks by balanced matter cycles and a balanced ratio between primary and secondary production.
iii) Development of a base for biological rationalization of forest conversion and the enhancement of long-term economic productivity (Irrgang, 1999).

One major goal of forest conversion is the increased accumulation of C (Thomasius, 1996). This author calculated that an increase in C stock by only 10 % would give a total outcome of 3 Mio. t C bound to Saxons forests, which could possibly be reached within a 100 years.

Wickel (2000) reported on the necessity of and possible ways to create mixed, multi-storied forests. He stressed the impact of forest conversion on ecosystem stability and elasticity especially in the Ore mountain region, that was heavily affected by air pollution. Irrgang (1999) pointed at the limiting factor of the water-budget for the lowland region. Thus, regarding to current management policies, a decline in forest transpiration has to be reached by reducing stand density on such sites. However, the ability of humus to store nutrients as well as water is well known (Kuntze et al., 1994; Rehfuess, 1990; Scheffer and Schachtschabel, 2001). Meyer-Heisig (1996) pronounces the necessity to re-create closely linked matter turnover cycles in forest soils, which were dominantly damaged by atmospheric depositions. Replacement of beech by spruce is associated with changes in soil acidity, soil structure and humus form (Ellenberg et al., 1986). Further knowledge about organic matter turnover along forest conversion sequences may help to improve future forest management strategies.

3 Material and Methods

3.1 Location of Study Sites

The study was carried out in two typical regions of Saxony, the Ore Mountain region (*Erzgebirge,* forest district of *Heinzebank*) and in the Saxonian lowland (*Dübener Heide* region, forest district of *Falkenberg*) (Fig. 3.1). The following chapter gives a detailed overview on site characteristics.

Site	Forest location	Stocking
study area in the Ore mountains		
A1	23 a^3	spruce
B1	35 a^3	spruce underplanted with beech
C1	24 a^2	beech
study area in the Saxonian lowlands		
A2	502 b^4	pine
B2	585 a^3/a^4	pine underplanted with beech
C2	624 a^6	beech
B3	752 a^3	pine underplanted with beech/oak
C3	593 a^1	beech/oak

Fig. 3.1: Location of the study sites in the Ore Mountain region and in the Saxonian Lowland.

3.1.1 Study Sites in the Ore Mountain Region

Tab. 3.1: Growth region, ecological classification, climatic and geomorphic characteristics of study sites in the Ore Mountains.

Study Site	**A1**	**B1**	**C1**
Growth region	Ore mountains (Growth region 45)		
Forest district	Heinzebank		
Quarter	Zöblitz		
Ecological Site Classification	Mf TM2		
	medium, humid altitude - terrestrial, medium nutrient and water supply		
Macro climate zone	*Bärenfels*		
Average temperature	5.5 - 7.2 °C		
Average precipitation	850 - 950 mm		
Elevation (m above sea level)	580	550	580
Relief	even to smoothly inclined	even	even to smoothly inclined

Stand Characteristics of the Study Sites in the Ore Mountain Region

Fig. 3.2: Spruce stand.

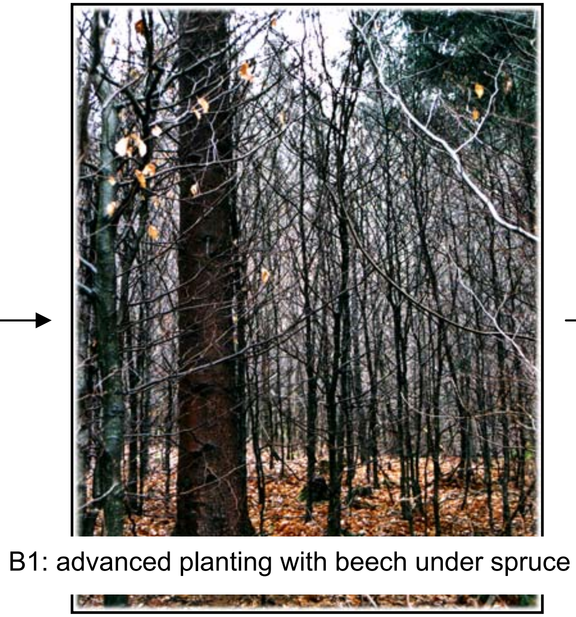

Fig. 3.3: Spruce stand with beech.

Fig. 3.4: Beech stand.

Tab. 3.2: Description of the investigated forest stands in the Ore Mountain region.

Study Site	**A1**	**B1**	**C1**
Stand Description	*Picea abies* (119 yrs.), old timber, closed;	*Picea abies* (51 yrs.), medium timber, open structure; 2nd storey: *Fagus sylvatica* (22 yrs.), under-canopy planting, thicket stage, interrupted,	*Fagus sylvatica* (156 yrs.), old timber, closed; *Fagus sylvatica* (1-ca. 10 yrs.), in small groups, covering ca. 10% of the area
Stand Density	0.9	1st storey 0.3 2nd storey 0.8	0.8
Understorey Vegetation	*Vaccinium myrtillus, Dryopteris carthusiana, Oxalis acetosella, Luzula luzuloides, Hordelymus europeus*	*Agrostis capillaris, Oxalis acetosella*	*Hordelymus europeus Melica uniflora, Prenathes purpurea, Dryopteris carthusiana, Oxalis acetosella, Luzula luzuloides*

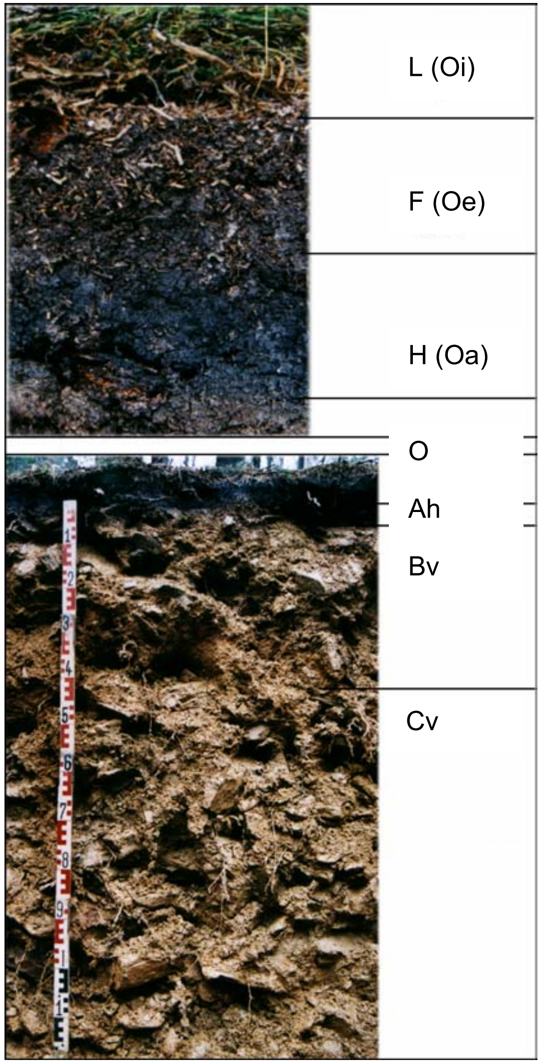

Fig. 3.5: Humus and soil profile at site A1.

Characterisation of the Soil Profile under Spruce (Site A1)

Date:	23.11.2002
Soil type (WRB-System):	Dystric Cambisol
Soil type (DBG-System):	Braunerde
Ecological Site Classification[1]:	Og.GN-5 Mf TM2
Local Soil Type[1]:	*Oelsengrunder Gneis-Braunerde*
Humusform:	Raw humus-type moder

Tab. 3.3: Characterization of the soil horizons under spruce (site A1).

Horizon	Depth [cm]	Description
L (Oi) F (Oe) H (Oa)	+9 +8 +4	Leaf litter, grass and moss weakly felt up, partly arranged in layers, diffuse change to coherent, unsharply breakable, medium formation of roots, diffuse change to
Ah	5	10YR 3/4, very silty sand, sub-polyhedral structure, medium compact, medium humus content, medium formation of roots, ca. 15 Vol.-% stone content, diffuse change to
Bv	40	10YR 5/8, poorly sandy loam, sub-polyhedral structure, medium compact, low humus content, medium formation of roots, ca. 30 Vol.-% stone content, diffuse change to
Cv	+40	10YR 6/4, poorly sandy loam, sub-polyhedral structure, contains partly rubble, very compact, very low humus content, low formation of roots, >50 Vol.-% stone content, parent rocks

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[1] according to the site map (1980)

[1] Standortkarte (1980)

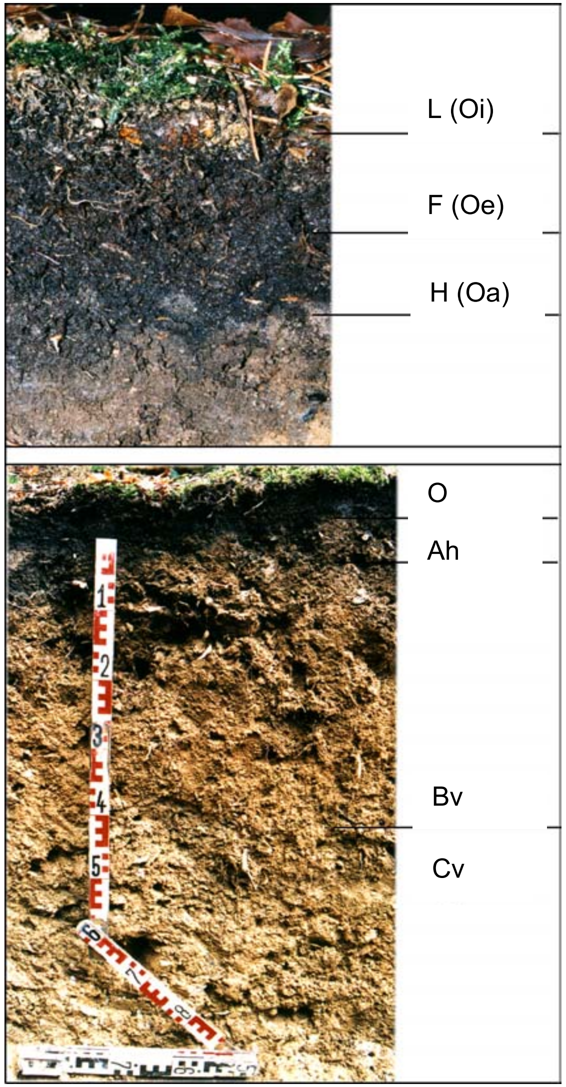

Fig. 3.6: Humus and soil profile at site B1.

Characterisation of the Soil Profile of the Advanced Planting with Beech (Site B1)

Date:	23.11.2002
Soil type (WRB-System):	Dystric Cambisol
Soil type (DBG-System):	Braunerde
Ecological Site Classification[1]:	Og.GN-5 Mf TM2
Local Soil Type[1]:	*Oelsengrunder Gneis-Braunerde*
Humusform:	Raw humus-type moder

Tab. 3.4: Characterization of the soil horizons of the advanced planting with beech (site B1).

Horizon	Depth [cm]	Description
L (Oi) F (Oe) H (Oa)	+1 +3 +3	Leaf litter weakly felt up, partly arranged in layers, diffuse change to medium compact, undulating change to
Ah	7	10YR 3/4, poorly sandy loam, sub-polyhedral structure, medium compact, low humus content, medium root formation, ca. 5 Vol.-% stone content, diffuse change to
Bv	40	10YR 5/8, poorly sandy loam, sub-polyhedral structure, medium compact, low humus content, low root formation, ca. 10 Vol.-% stone content, diffuse change to
Cv	+40	10YR 4/6, poorly sandy loam, sub-polyhedral structure, very compact, very low humus content, very little root formation, ca. 30 Vol.-% stone content

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[1] according to the site map (1980)

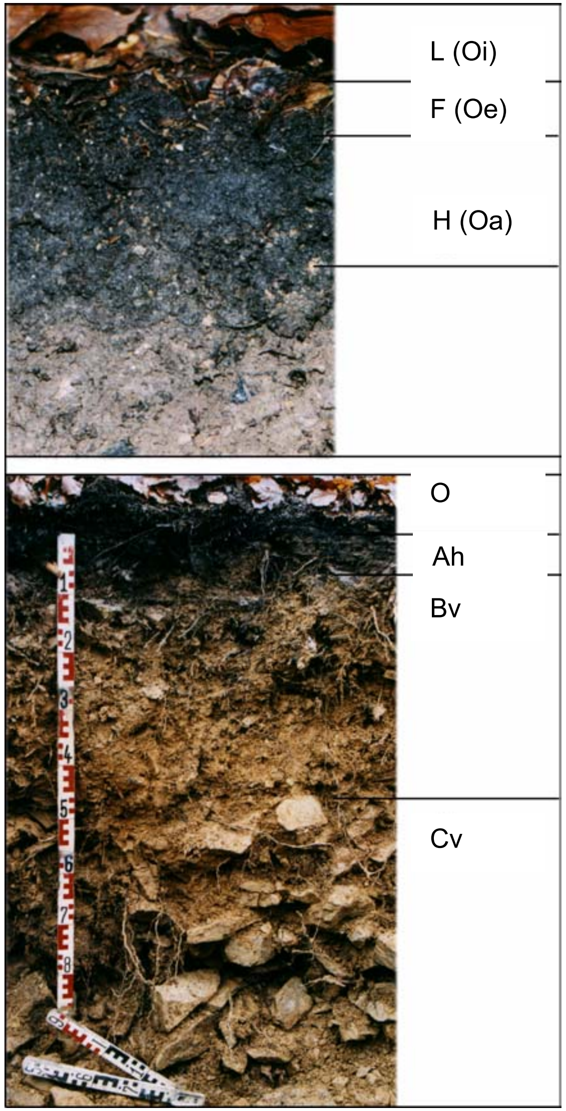

Fig. 3.7: Humus and soil profile at site C1.

Characterisation of the Soil Profile under Beech (Site C1)

Date:	23.11.2002
Soil type (WRB-System):	Dystric Cambisol
Soil type (DBG-System):	Braunerde
Ecological Site Classification[1]:	Wo.GN5 Mf TM2
Local Soil Type[1]:	*Wolkensteiner Gneis-Braunerde*
Humusform:	Moder

Tab. 3.5: Characterization of the soil horizons under beech (site C1).

Horizon	depth [cm]	Description
L (Oi) F (Oe) H (Oa)	+6 +5 +4	Leaf litter Litter fragments Compact, complex organic substances without a certain structure
Ah	7	10YR 3/4, poorly sandy loam, sub-polyhedral structure, medium compact, medium humous, medium formation of roots, ca. 10 Vol.-% stone content, diffuse change to
Bv	45	10YR 5/8, poorly sandy loam, sub-polyhedral structure, medium compact, low humus content, medium development of roots, ca. 15 Vol.-% stone content, diffuse change to
Cv	+45	10YR 4/6, poorly sandy loam, sub-polyhedral structure, very compact, very low humus content, poor developments of roots, >50 Vol.-% stone content, parent rocks

---

[1] according to the site map (1980)

3.1.2 Study Sites in the Saxonian Lowland

Tab. 3.6: Growth region, ecological classification, climatic and geomorphic characteristics of study sites in the Saxonian lowland.

Study Site	**A2**	**B2**	**C2**	**B3**	**C3**
Growth region	Düben-Niederlausitzer Altmoränenland (Growth region 15)				
Forest district	Falkenberg				
Quarter	Jagdhaus	Jagdhaus	Roitzsch	Spitze	Jagdhaus
Ecological Site Classification	Tm TM2				
	medium dry, lowland region - terrestrial, medium nutrient and water supply				
Macro climate zone	*pseudomaritim*				
Average temperature	8.0-8.5 °C				
Average precipitation	580 630 mm (per year)				
Elevation (m above sea level)	120 m	130 m	130 m	120 m	130 m
Relief	even				

Stand Characteristics of Study Sites in the Saxonian Lowland (Forest Conversion Sequence 2)

Fig. 3.8: Pine stand.

Fig. 3.9: Pine with beech.

Fig. 3.10: Beech stand.

Tab. 3.7: Description of the investigated forest stands in the Saxonian lowland (sequence 2: from pine to beech).

Study Site	**A2**	**B2**	**C2**
Stand Description	*Pinus sylvestris* (74 years), medium timber, closed structure	*Pinus sylvestris* (79 yrs.) medium timber, closed stand *Fagus sylvatica* (34-44 years), under-canopy planting	*Fagus sylvatica* (175 years), old timber, closed stand
Stand Density	0.8	1st storey 0.4 2nd storey 0.7	0.9
Understorey Vegetation	*Calamagrostis epigeios, Vaccinium myrtillus,*	*Luzula luzuloides, Avenella flexuosa, Carex pilulifera, Dryopteris carthusiana,*	*Dryopteris carthusiana, Oxalis acetosella, Prenanthes purpurea, Luzula luzuloides*

Forest Conversion Sequence 3

Fig. 3.8(2): Pine stand.

Fig. 3.11: Pine with beech/oak.

Fig. 3.12: Beech/Oak stand.

Tab. 3.8: Description of the investigated forest stands in the Saxonian lowland (sequence 3: from pine to beech/oak).

Study Site	**A2**	**B3**	**C3**
Stand Description	*Pinus sylvestris* (74 years), medium timber, closed structure	*Pinus sylvestris* (82 yrs.) medium timber, closed stand *Fagus sylvatica* (34-44 years), *Quercus petreae* (34-44 years) under-canopy planting	*Fagus sylvatica* (168 years), *Quercus petreae* (211 years) old timber, closed stand
Stand Density	0.8	1st storey 0.4 2nd storey 0.7	0.9
Understorey Vegetation	*Calamagrostis epigeios, Vaccinium myrtillus,*	*Avenella flexuosa, Prenanthes purpurea, Agrsotis capillaris, Dryopteris carthusiana,*	*Dryopteris carthusiana, Oxalis acetosella, Luzula luzuloides*

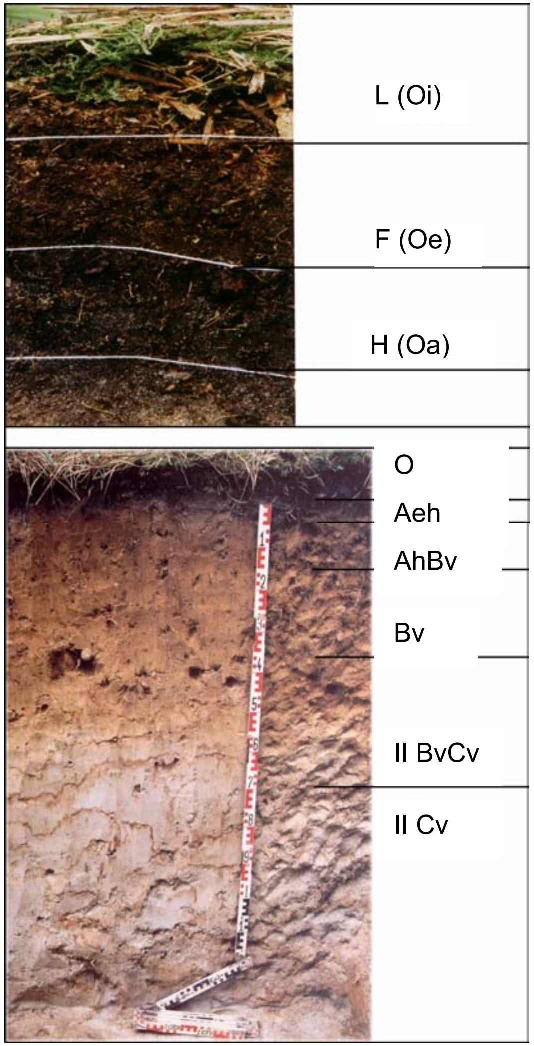

Fig. 3.13: Humus and soil profile at site A2.

Characterization of the Soil Profile under Scots Pine (site A2)

Date:	29.10.2002
Soil type (WRB-System):	Dystric Cambisol with weak albic properties
Soil type (DBG-System):	schwach podsolige Braunerde
Ecological Site Classification[1]:	NeS M2 msRo
Local Soil Type[1]:	*Nedlitzer Sandbraunerde*
Humusform:	Raw humus-type moder

Tab. 3.9: Characterization of the soil horizons under pine (site A2).

Horizon	Depth [cm]	Desription
L (Oi) F (Oe) H (Oa)	+6 +5 +1	Leaf litter and moss (*Scleropodium purum*) Little clotted, partly arranged in layers, diffuse change to coherent, unsharply breakable, strong formation of roots, diffuse change to
Aeh	5	10YR 5/2, poorly silty sand, coherent structure, little compact, weak albic properties, low humus content, medium root formation, diffuse change to
AhBv	15	10YR 4/5, poorly silty sand, coherent structure, little compact, low humus content, medium root formation, diffuse change to
Bv	35	10YR 5/5, poorly silty sand, coherent structure, single stones, little compact, very low humus content, medium root formation, diffuse change from stones to
II BvCv	65	10YR 7/4, poorly silty sand, coherent to single corn structure, single stones, little compact, very low humus content, even change to
II Cv	+65	10 YR 7/2, poorly silty sand, single corn structure, single stones, little compact, very low humus content, very few roots, clay lines from 2 to 10 cm width, single clay lenses, here smooth hydromorphical properties

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[1] Site map (1980)

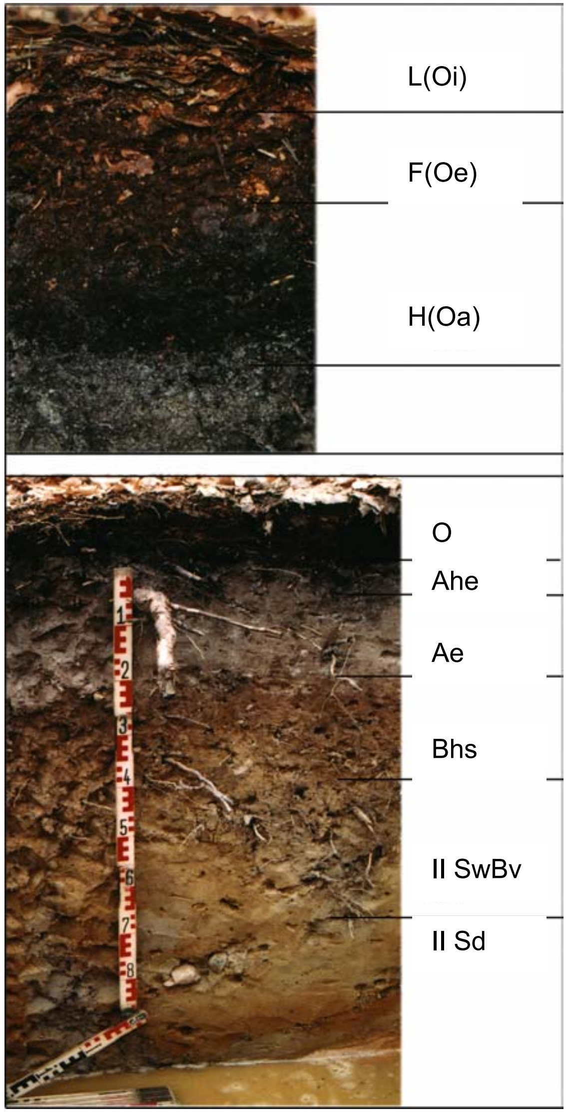

Fig. 3.14: Humus and soil profile at site B2.

Profile of the Advanced Planting with European Beech (Site B2)

Date:	29.10.2002
Soil type (WRB-System):	Podzol with stagnic properties
Soil type (DBG-System):	Pseudogley Podsol
Ecological Site Classification[1]:	NeS M2 isRo
Local Soil Type[1]:	*Nedlitzer Sandbraunerde*
Humusform:	Raw humus-type moder

Tab. 3.10: Characterization of the soil horizons of the advance planting with beech (site B2).

Horizon	Depth [cm]	Description
L (Oi) F (Oe) H (Oa)	+7 +6 +4	Leaf litter weakly felted, partly arranged in layers loose, undulating change to
Ahe	5	10YR 3/1, middle sand, coherent structure, little compact, albic properties, low humus content, medium root formation, undulating change to
Ae	20	10YR 5/2, poorly silty sand, coherent to single corn structure, little compact, strong albic properties, very low humus content, medium root formation, undulating change to
Bhs	40	10YR 4/5, poorly silty sand, coherent structure, medium compact, strong humus formation, undulating, stony change to
II SwBv	65	10YR 7/3, poorly silty sand, coherent to putty structure, medium compact, very low humus content, few roots, some hydromorphical properties, diffuse change to
II Sd	+65	From 10YR 6/6 to 10YR 7/2, poorly silty sand, coherent to putty structure, medium compact, single stones, very low humus content, very few roots, strong hydromorphical properties

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[1] Site map (1980)

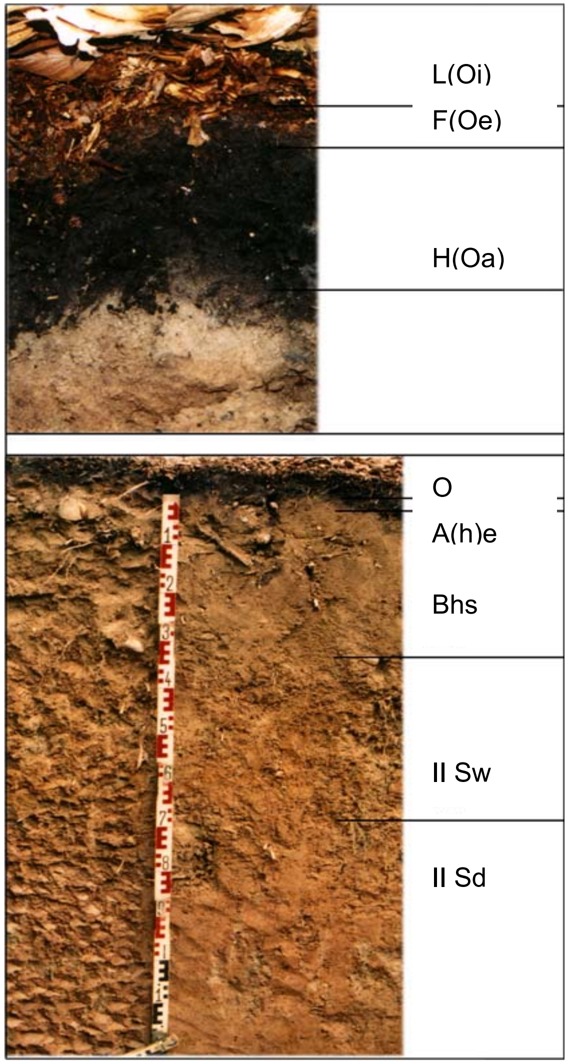

Fig. 3.15: Humus and soil profile at site C2.

Characterization of the soil profile under European beech (Site C2)

Date:	29.10.2002
Soil type (WRB-System):	Dystric Cambisol with albic properties
Soil type (DBG-System):	Podsol Pseudogley
Ecological Site Classification[1]:	SmSu M1 msRo
Local Soil Type[1]:	*Schmeckendorfer Sand-Graugley*
Humusform:	Raw humus-type moder

Tab. 3.11: Characterization of the soil horizons under European beech (Site C2).

Horizon	Depth [cm]	Description
L (Oi) F (Oe) H (Oa)	+9 +8 +4	Leaf litter Weakly felted, partly arranged in layers, diffuse change to loose, undulating change to
A(h)e	15	10YR 3/4, silty-loamy sand, coherent structure, little compact, albic properties, low humus content, medium root formation, undulating to sharp change to
Bhs	30	10YR 4/5, silty-loamy sand, coherent structure, medium compact, very low humus content, medium root formation, stony layer change to
II Sw	65	10YR 7/2, silty-loamy sand, putty structure, medium compact, very low humus content, some hydromorphological properties, few roots, horizontal change to
II Sd	+65	10YR 6/1 bis 7,5YR 6/5, silty-loamy sand, putty structure, very compact, very low humus content, very few roots, hydromorphic properties

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[1] Site map (1980)

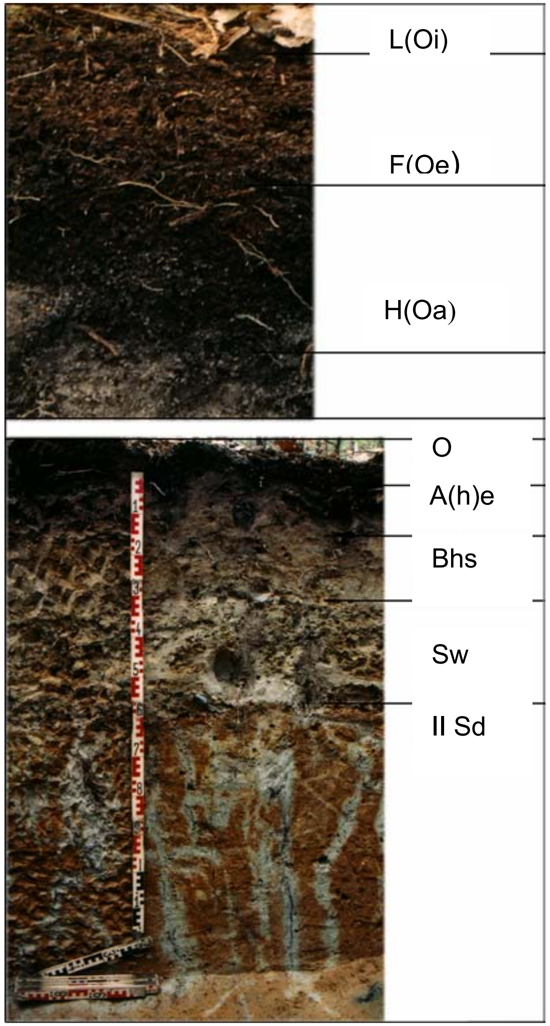

Fig. 3.16: Humus and soil profile at site B3.

Characterization of the Advanced Planting with Beech/Oak (Site B3)

Date:	29.10.2002
Soil type (WBR-System):	Podzol with strong stagnic properties
Soil type (DBG-System):	Podsol-Pseudogley
Ecological Site Classification[1]:	PoLB M2 msRo
Local Soil Type[1]:	*Ponikauer Tieflehm-Braunstaugley*
Humusform:	Raw humus-type moder

Tab. 3.12: Characterization of the soil of the advance planting with beech/oak (Site B3).

Horizon	Depth [cm]	Description
L(Oi) F(Oe) H(Oa)	+6 +4 +3	Leaf litter Weakly felted, partly arranged in layers, diffuse change to loose, undulating change to
A(h)e	3	10YR 3/4, middle silty rich sand, coherent structure, little compact, albic properties, low humus content, medium root formation, unsharp change to
Bhs	35	10YR 4/5, middle silty rich sand, coherent structure, medium compact, low humus content, medium root formation, undulating change to
Sw	70	10YR 3/2, middle silty rich sand, putty structure, medium compact, very low humus content, hydromorphological properties, few roots, horizontal change to
II Sd	+70	10YR 6/2bis 7,5YR 6/5, middle silty rich sand, putty structure, very compact, very low humus content,very few roots, very strong hydromorphic properties

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[1] Site map (1980)

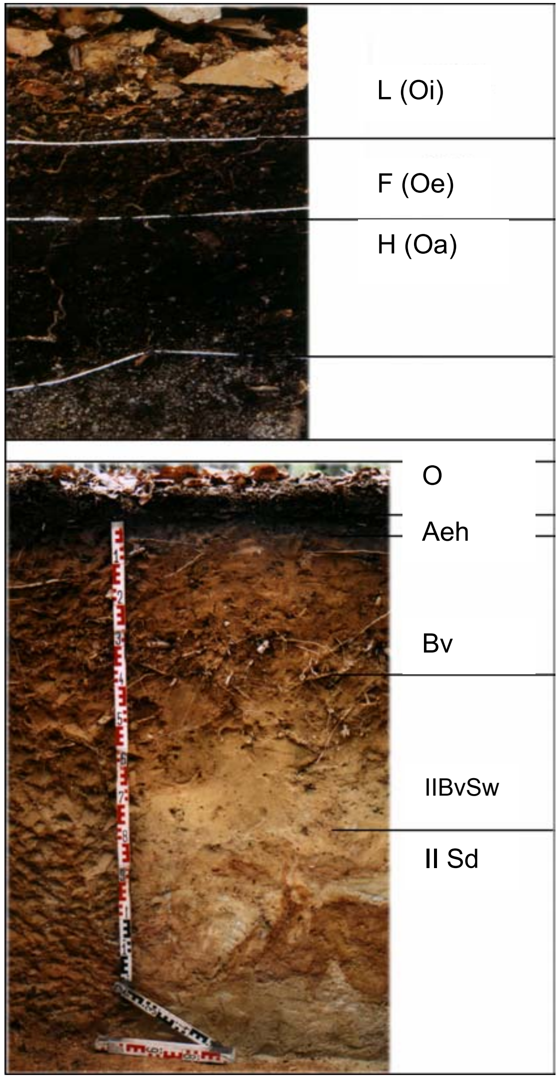

Fig. 3.17: Humus and soil profile at site C3.

Characterization of the Soil Profile under European Beech/Common Oak (Site C3)

Date:	29.10.2002
Soil type (WRB-System):	Dystic Cambisol with weak stagnic properties
Soil type (DBG-System):	Pseudogley Braunerde
Ecological Site Classification[1]:	NeS M2 msRo
Local Soil Type[1]:	*Nedlitzer Sandbraunerde*
Humusform:	Raw humus-type moder

Tab. 3.13: Characterization of the soil horizons under beech/oak (site C3).

Horizon	Depth [cm]	Description
L (Oi) F (Oe) H (Oa)	+7 +6 +4	Leaf litter clotted compact, complex organic substances without a certain structure
Aeh	3	10YR 3/2, poorly silty sand, coherence structure, little compact, low humus content, intensive root formation, undulating change to
II BvSw	40	10YR 4/5, poorly silty sand, coherence structure, medium compact, low humus content, intensive root formation, diffuse change to
II Bwg	80	10YR 6/5, poorly silty sand, single corn structure, medium compact, few hydromorphical characteristics, low humus content, medium to low root formation, diffuse change to
II Sd	+80	from 10YR 7/1 to 7,5YR 4/2, poorly silty sand, putty structure, very compact, very low humus content, nearly no roots

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[1] Site map (1980)

3.2 Soil Sampling and Sample Preparation

3.2.1 Soil Inventory

Soil sampling was performed in spring 2001 when six composite samples were collected from the L, F and H horizons, and the uppermost mineral soil (0–10 cm) [classification according to Soil Survey Staff (1996)]. Samples were taken by spade by pooling at least three to five sub-samples from an area of 400 cm^2 at each of the sampling points within 10 m around the key soil profile of each investigation site. After the removal of green plant materials, roots and wood particles, the samples were sieved (mesh size 5 mm for the organic horizons, 2 mm for the mineral soils).

For analyses of TOC and TN samples were dried at 60 °C for 120 h prior to grinding to a mesh size < 180 µm. For determination of microbial biomass (C_{mic} and N_{mic}), potential C mineralisation and of hot and cold water-extractable C and N fresh soil samples were stored at 4 °C.

3.2.2 One Year Study

Samples of the L, F and H horizons as well as the uppermost 10 cm of mineral soil were collected in November 2001 and in January, March, May, July, September, October and November 2002. During each sampling procedure, six composite samples were collected from the L, F and H horizons, and the uppermost mineral soil (0–10 cm) [classification according to Soil Survey Staff (1996)]. Samples were taken by spade by pooling at least three to five sub-samples from an area of 400 cm^2 at each of the sampling points within 10 m around the key soil profile of each investigation site. Sample preparation for analyses was carried out by sieving using a mesh size of 5 mm for organic layers (L was cut into pieces before) and a mesh size of 2 mm for mineral soil samples.

For determination of microbial biomass (C_{mic} and N_{mic}), potential C mineralisation and of hot and cold water-extractable C and N fresh soil samples were stored at 4 °C. For pyrolysis the pre-dried (60°C, air circulation) and ground samples of L, F and H horizons were homogenized and freeze-dried for seven days under reduced pressure (10^{-3} Torr). For the litter decomposition experiment generally fresh samples were used.

3.3 Analyses

Soil pH was determined by a combination glass electrode in H_2O and in 0.01 M $CaCl_2$ solution after 4 h [soil-to-solution ratio 1:10 for organic horizons and 1:2.5 for mineral soils].

NH_4Cl-extractable cations were determined after extraction with 0.5 M NH_4Cl solution [soil-to-solution ratio 1:80 for L, F and H horizons, for mineral soils 1:40]. Samples were shaken at 180 rpm for 2 h on the evening before and for another 30 min on the morning of filtration [membrane filters, 0.45-µm pore size]. H^+ concentration was determined by means of a pH electrode; concentrations of Ca^{2+}, Mg^{2+}, Na^+, Mn^{2+}, Fe^{3+}, Al^{3+} by ICP-OES; and K^+ by AAS.

Total organic C and total N contents were measured on ground soils (mesh size 180 µm) by a flame-photmetrical CNS analyser [model Foss Heraeus]. The medium-term decomposable C and N fractions [i.e., hot-water-extractable organic C (C_{hwe}) and TN (N_{hwe})] were determined according to the method of Bronner and Bachler (1979). This method involves boiling a soil/water solution [ratio 1:5 for mineral soils and 1:20 for L, F and H horizons] for 1 h. Samples were centrifuged at 4,000 rpm for 10 min afterwards. Concentrations of C_{hwe} and N_{hwe} were determined using a multi CN analyser (Jena Analytics). In order to determine the readily decomposable C and N [i.e., cold-water-extractable organic C (C_{cwe}) and TN (N_{cwe})], the soil/water solution was shaken for 24 h at 180 rpm. The same procedure, with regard to the soil-to-water solution ratio, centrifuging and measurement of cold-water-extractable C and N, was followed as for the hot-water-extractable fraction. According to the SOM classification model in three different pools (Parton et al., 1987, Rice, 2002) we defined the hot- and cold-water organic matter fraction as being medium-term and readily decomposable within the soils active (and probably also slow) C pool, respectively. The water-soluble organic carbon content is the non-particular fraction of the cold-water extract (Scheuner, 2004). Thus, in order to obtain the WSOC fraction Ccwe samples were filtered through 0.45 µm membrane filter. Concentrations WSOC were determined by a multi CN-Analyser (Jena Analytics).

Potential C mineralisation was determined using 5 g (L, F and H samples) or 20 g (mineral soil) of field-moist soil samples incubated in closed 200-ml jars according to the method of Isermeyer (1952) as described by Alef (1991). Conditioning of soil samples was carried out at 15 °C for 24 h according to the average temperature of the summer months in the study region („realistic potential C mineralisation“). The CO_2 production after incubation was estimated by titration with 0.05 M HCl after adding 0.5 M $BaCl_2$ and phenolphthalein indicator.

Determination of microbial biomass (C_{mic}) was carried out by the fumigation–extraction method as described by Vance et al. (1987) including a 24-h chloroform fumigation of one equivalent of two duplicate field-moist sample sets. After evacuation of the desiccator, both samples were treated with 75 ml of 0.5 M K_2SO_4 (soil-to-K_2SO_4 ratio 1:5), shaken for 30 min on an end-to-end shaker, centrifuged and filtered (Whatman No. 42). In order to remove any dissolved carbonate, one drop of 2 M HCL was added before determination of organic C and

N concentration using a CN analyser (Jena Analytics). For calculation of results a k_{EC} factor of 0.30 (Sparling et al., 1990) and a k_{EN} factor of 0.45 (Jenkinson, 1988) were applied.

Structure analysis of organic matter was performed by thermal degradation of the humus samples (2 replicates each) at 600°C using Curiepoint Pyrolysis-GC/MS (Fischer / Agilent Technologies). The multitude of single peaks in the obtained total ion pyrogrames were evaluated using the mass spectral library and the search program of NIST 98 (National Institute of Standards and Technology, USA). As pyrolysis temperature has a central influence on the intensity of pyrolytic degradation, we have chosen a temperature which allows a possibly high determination of low molecular substances on the one hand, and on the other hand also a maximum of structural information that may be obtained by a careful pyrolysis process. In addition, a similar compromise was chosen in determination of pyrolysis duration. A short process inhibits secondary reactions, that would complicate a detailed interpretation of chromatogrames seriously. Otherwise, substances with a short thermal conductivity need a longer pyrolysis duration to ensure representative analytical results. Furthermore, higher portions of mineral components can influence the pyrolysis result. But as the samples of this study were obtained from the organic layer, total ash content is comparatively low and a sample treatment with concentrated HCl or HF was not carried out in order to preserve organic substances.

In order to determine the quantity of aboveground-litter shed during one year a set of six litter collectors were installed diagonal across the study site in constant distances of 5 m between at each study site. Samples were collected, dried at 40 °C and determined by weight separating leaves/needles from twigs and seeds.

For the litterbag study newly shed litter was collected in November 2001, stored at 4°C and shredded into ca. 2 cm pieces in order to ensure the comparability of decomposition dynamics and lab analytical methods (Schinner and Sonnleitner, 1996; Weaver, 1999). The homogenization of material is an essential precondition for soil chemical and (micro-) biological analyses using standardized methods (Dunger, 1997). Additionally, we reduced the negative effects of low aeration within the litter bags and the risk of agglutination of leaves, which may result in a higher colonization with fungi and thus, have an impact on litter decay (Hüttl et al., 1995; Pöhhacker, 1995). Considering a mean annual litter fall of ca. 4 t dry matter ha^{-1} a^{-1} (Ellenberg et al. , 1986), newly shed litter according to 16 g air dry mass was filled into 20 cm x 20 cm litter bags with a mesh size of 1 mm (Bockock and Gilbert, 1957; Schinner and Sonnleitner, 1996). As litter decomposition in moder humus forms was reported of being dominated by the functioning of micro- and mesofauna (Beck, 1984; Beck, 2000), soil macrofauna was widely excluded in our study. A set of 12 repeated litter bags with site-specific litter was placed on the surface of the organic layer of the pine and beech/oak stand. Additionally, a set of reference litter bags of beech/oak litter was placed into the pine stand (Schinner and Sonnleitner, 1996).

3.4 Data Processing and Statistics

All results reported are mean values of six replicates, averages of duplicated analyses and are expressed on a moisture free-basis. Moisture was determined after drying of a sample aliquot at 65℃ for 96 h.

Box-whisker-plot graphics represent an overview on statistical values including the median, the 25 % and 75 % percentile and the extrem values. The median was chosen as it is a more stable measure towards extrem values and thus, more suitable than the mean – especially for comparatively small data sets. The percentile is reflected by the box. The length of the box indicates the variability of data and the position of the median within the box specifies the distribution of data [i.e., towards left or right]. T-bars show data extremes. Box-Whisker test was calculated with the program Statsoft Statistica © 1999 edition.

Data were not normal distributed. During the soil inventory when mean values of three sites along each forest conversion sequence were compared, **analyses of variance** was performed by the Kruskal-Wallis-Test and further separation of means by the χ^2-test. During the one-year-study the Mann-Whitney U-test ($p \leq 0.01$) was used to test the difference between the two contrasting stands studied during the one year [i.e. Scots pine and European beech/Common oak stand]. Significant differences between the different sets of litter bags exposed were calculated applying the Games-Howell-Test (La France, 2002; Stuhlmann, 2005). Analyses of variance [i.e., the Kruskal-Wallis test and further separation of means by the χ^2-test, the Mann-Whitney U-Test, the Games-Howel-Test] was performed using the program SPSS for Windows, 2002 edition, version 11.5.1. Critical values were obtained in Sachs (2002).

In order to reflect relations between parameters correlation analyses were performed. **Correlation coefficients** by Pearson and regression analyses were calculated with the program Statsoft Statistica © 1999 edition.

Discriminant function analysis is used to determine which parameters discriminate between the three stands involved in each forest conversion sequence. A canonical correlation analysis was applied, that determined the successive functions discriminating every two out of the three data sets [i.e., stands] involved. Standardized coefficients for each variable [i.e., parameter] indicate the respective parameter´s contribution to the discrimination specified by the respective discriminant function. The analysis was performed using the program SPSS for Windows, 2002 edition, Version 11.5.1.

4 Carbon and Nitrogen Dynamics in a Mountain and a Lowland Region of Saxony

4.1 Objectives

The objectives of our study are

(i) to quantify carbon and nitrogen stocks and microbial activity in top soils in relation to forest tree cover and

(ii) to find soil indicators that describe the influence of forest conversion on C and N turnover.

4.2 Results and Discussion

4.2.1 Morphology and Mass of the Organic Layer

Total organic matter thickness and mass revealed an increasing trend from coniferous to deciduous stands, dominated by the characteristics of the H layer. Also the investigated B sites in the lowland representing conifers with deciduous trees in advanced plantings showed evidently higher organic layer thickness as compared with pure coniferous or deciduous stands (Table 4.1). They represent comparatively dense forest stands characterised by a higher litter production and lower radiation at the forest floor.

Differentiation of thickness and mass within the single organic horizons was most pronounced in deciduous stands in the lowland. There, L and F layer thickness and mass revealed a declining trend along the sequences, and the H horizons showed an increasing tendency (Table 4.1, Fig. 4.1). Organic layer mass differed significantly between pine and the advanced plantings in the L horizon, and in F and H horizons between the advanced plantings and the pure deciduous stands ($p \leq 0.01$). In the Ore Mountain region, differences were proved significant between spruce and the mixed spruce/beech site in F and H layers, and between the mixed stand and beech in L ($p \leq 0.01$). The comparatively high H horizon mass of deciduous stands might also be explained by higher boar activity during leaf litter fall within the pine-dominated forest district. Yet, as the TOC content determined was within the range or even higher as compared to the H layer of the other study sites, we predict that the comparatively high mass and TOC stock is presumably a result of an increased (micro-

)biological activity in the upper layer of the forest ground, which is composed predominantly of leaf litter and leading to an accumulation of secondary decomposition products in deeper organic horizons of deciduous stands.

Tab. 4.1: Forest stands, thickness and mass as well as soil chemical characteristics (pH, base saturation, C/N ratios) of the organic layer (L, F and H) and upper mineral soil (0-10 cm) of the study sites in the Ore Mountains (Heinzebank) and Saxonian lowland (region Falkenberg) (sites “type A”: mature conifer stands; “type B”: advanced plantings of deciduous trees under conifers; “type C”: mature deciduous forests).

Site	**Horizon**	**Stocking (age in yrs.)**	**Stand density**	**Thickness cm**	**Mass (t ha^{-1})**	**pH (CaCl$_2$)**	**NH$_4$Cl-extr. basic cations (%)**	**TOC/TN**	**(C/N)$_{hwe}$**	**(C/N)$_{cwe}$**
A1	L			2.0	23.9	4.3	96.7	23.6	16.7	13.2
	F	*P. abies* (70)	0.9	1.7	37.8	3.5	86.5	23.2	17.6	15.7
	H			2.0	40.6	3.2	61.6	24.1	19.1	18.6
	sum/mean			**5.7**	**102.3**	**3.7**	**81.3**	**23.6**	**17.8**	**15.8**
	0-10cm				432.2	3.2	28.4	22.0	22.0	17.5
B1	L			2.3	33.6	5.5	97.8	27.1	17.9	12.1
	F	*P. abies* (50)	1.1	2.8	36.5	4.8	94.2	19.6	15.8	11.3
	H	*F. sylvatica* (18)		1.4	36.7	3.4	66.4	20.8	20.5	16.1
	sum/mean			**6.5**	**106.8**	**4.6**	**86.1**	**22.5**	**18.1**	**13.2**
	0-10cm				601.3	3.3	12.7	19.9	28.2	19.3
C1	L			2.3	20.8	5.1	91.9	30.9	18.6	13.2
	F	*F. sylvatica* (103-153)	0.8	2.7	45.5	4.8	98.4	19.4	13.8	7.5
	H			2.2	54.1	3.8	93.7	20.1	16.4	10.9
	sum/mean			**7.2**	**120.4**	**4.6**	**94.7**	**23.5**	**16.3**	**10.5**
	0-10cm				309.0	4.4	85.8	17.2	15.7	11.4
A2	L			2.7	41.3	3.8	81.5	27.5	18.3	10.3
	F	*P. sylvestris* (74)	0.8	2.3	55.1	3.4	48.1	22.4	18.8	9.3
	H			1.7	83.6	3.4	25.2	23.2	20.3	12.2
	sum/mean			**6.7**	**180.0**	**3.5**	**51.6**	**24.4**	**19.1**	**10.6**
	0-10cm				1067.0	3.8	13.9	24.7	26.5	17.1
B2	L			3.0	32.3	4.8	90.0	26.4	17.4	10.2
	F	*P. sylvestris* (79)	1.1	2.0	58.3	3.8	74.0	20.1	15.0	7.5
	H	*F. sylvatica* (34-44)		2.3	92.8	3.7	33.6	21.2	19.2	12.0
	sum/mean			**7.3**	**183.4**	**4.1**	**65.9**	**22.6**	**17.2**	**9.0**
	0-10cm				1386.8	3.5	10.6	21.7	22.4	17.7
C2	L			2.0	16.8	4.2	89.3	28.0	21.4	12.3
	F	*F. sylvatica* (175)	0.9	2.0	43.2	3.5	66.4	19.4	18.8	8.9
	H			3.0	171.5	3.2	21.0	22.1	21.7	13.3
	sum/mean			**7.0**	**231.5**	**3.6**	**58.9**	**23.2**	**20.6**	**11.5**
	0-10cm				1573.4	3.3	14.8	24.2	24.7	16.0
B3	L			2.3	35.1	4.0	92.5	28.7	13.5	8.0
	F	*P. sylvestris* (82)	1.1	3.0	70.1	3.2	52.9	23.5	13.3	6.7
	H	*F. sylvatica* (34-44)		4.0	135.6	3.1	34.9	25.3	18.5	11.0
	sum/mean	*Q. petreae* (34-44)		**9.3**	**240.8**	**3.4**	**60.1**	**25.8**	**15.1**	**8.6**
	0-10cm				1154.5	3.3	24.2	23.9	18.9	16.5
C3	L			2.3	26.1	4.0	83.3	26.5	15.2	8.7
	F	*F. sylvatica* (168)	0.9	2.0	72.1	3.3	60.1	22.8	17.2	9.7
	H	*Q. petreae* (211)		3.2	97.8	3.2	36.4	23.0	20.9	16.4
	sum/mean			**7.5**	**196.0**	**3.5**	**59.9**	**24.1**	**17.8**	**11.6**
	0-10cm				1346.8	3.4	14.5	24.3	23.2	16.1

Total organic layer thickness was 5.7 (site A1) to 7.2 cm (site C1) in the Ore Mountain study region and 6.7 (site A2) to 9.3 cm (site B3) in the lowland. The increase in total organic layer mass revealed a very similar pattern with values between 102.3 and 120.4 t ha^{-1} in the Ore Mountains and between 180.0 and 240.8 t ha^{-1} in the lowland (Table 4.1). The H layer, which is most important for C sequestration according to Persson et al. (2000), accounted for 22–43% of total organic layer thickness (Table 4.1).

Differences in organic layer morphology between coniferous- and deciduous-tree-dominated sites have been explained in the past by the deceleration of needle-litter decay caused by the wax layer and lower litter resource quality (Berg and Staaf, 1980; Berg and Ekbohm, 1993; Flanagan and van Cleve, 1983) or by the low nutrient concentration and high content of polyphenolic substances in coniferous litter which lead to a slow decomposition rate (Millar 1974). The comparatively fast initial turnover of leaf litter as compared to coniferous litter was described by Beck (1989) and Heal et al. (1997). Yet recent investigations by Persson et al. (2000) and Albers et al. (2004) reveal the major impact of the different environmental and site-specific conditions in spruce and beech stands rather than the influence of litter quality. Furthermore, similar lignin contents of deciduous and coniferous litter (Vesterdal 1999) leading to rather small differences in decomposition between broadleaf and needle litter (Prescott et al., 2000) have been observed. Vedrova (1995) reported on the impact of litter quality on soil C sequestration comparing coniferous and deciduous stands in middle Siberia and found that 8% of the total C loss from spruce litter but as much as 25% from pine and aspen litter enter humus formation (H horizon). Reinhardt and Makeschin (2003) compared organic layer mass of beech-dominated stands („green eyes“) with adjacent spruce sites in Thuringia and found an increased mass in L and F horizons under spruce, whereas H-horizon mass declined; the forest floor of beech stands revealed an opposite tendency. These results are in principal accordance with our findings. The influence of roots on the formation and composition of, especially, the F and H horizons plays a role in the spruce stand and especially in the *Calamagrostis epigejos* (L.)-covered pine stand. This groundcover is characteristic for the comparatively open pine stands in the lowland with moderate nutrient and water budgets (site quality index “M2”).

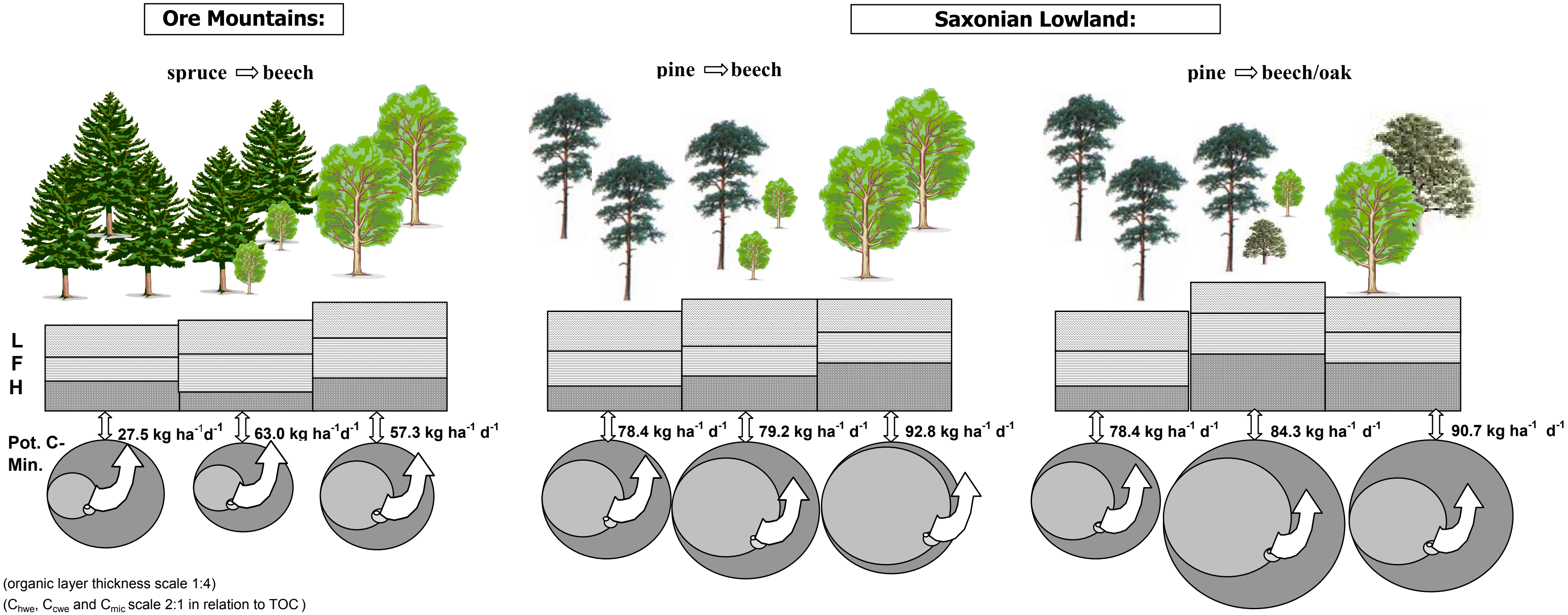
In the Ore Mountain region, the described differentiation of thickness and mass within the individual organic horizons has been evened-out due to liming activities during the 1990s. Top soils continue to show a very high base saturation of 81–95% (Table 4.1). Increases in forest-floor decay rates due to a higher (micro-)biological activity following liming and subsequently raised pH and base saturation, have been described by Kreutzer (1995). Ammer and Makeschin (1994) reported on a lime-induced shift of organic matter morphology towards moder following increased earthworm activity in an organic layer formed by spruce litter. Liming also resulted in a changed composition of ground vegetation and hence may have led to a higher proportion of more easily decomposable compounds. Concomitantly, characteristic species that indicate rather rich sites [e.g. *Hordelymus europaeus* (L.) Harz] were observed on our study sites in the Ore Mountain region. We assume that similar stand-specific effects as described for the lowland region existed in the Ore Mountain region before the liming activities occurred and will therefore be relevant again once the amelioration effect loses its influence.

4.3.2 Microbial Biomass and Potential C Mineralisation

Generally, in the lowland region microbial biomass and potential C mineralisation increased with influence of deciduous litter. Significant differences were found between sites B2 and C2 in the F horizon (and for C mineralisation also in the H horizon) and B3 and C3 as well as B2 and C2, B3 and C3 in the H horizon at $p \leq 0.01$. Values of microbial biomass in the organic layers ranged from 496.6 to 899.6 kg ha^{-1} (sequence pine to beech) and to 683.6 kg ha^{-1} (pine to beech/oak), while total organic layer C_{mic} mass at sites in the Ore Mountain regions revealed no distinct trend [values between 443.3 (B1) and 546.2 kg ha^{-1} (C1)] (Fig. 4.1). Yet, individual horizons revealed significantly different C_{mic} values for the L horizon between site B1 and C1 and for the underlying organic horizons between spruce and the mixed stand ($p \leq 0.01$). In the L horizon microbial respiration was significantly different between sites ($p \leq 0.01$). The upper mineral soil held between 11.1 (site B3) and 492.1 kg C_{mic} ha^{-1}(site C2), but revealed no distinct trend along the investigated sequences (data not shown, see Annex 18). In the lowland the increasing trend of total microbial biomass in the organic layer is mainly driven by elevated C_{mic} in F and H horizons of deciduous stands along with higher potential C mineralisation rates (Fig. 4.2). In contrast, L horizons revealed no clear differences along the conversion sequences.

In the Ore Mountain region, microbial biomass decreased within organic horizons in deciduous litter-influenced sites indicating currently relatively inactive F and H horizons following atypically intensive decomposition rates after liming in 1996. In the L horizon of the advanced planting (B1) and beech stand (C1) microbial biomass and activity were comparatively high, demonstrating the rather fast initial turnover dynamics of deciduous litter today as compared to spruce litter (Beck 1989; Heal et al. 1997). In contrast, the investigated spruce stand revealed no clear differentiation between single organic horizons.

Comparing coniferous and deciduous stands, we detected increasing organic layer mass and thickness and a simultaneous increase in microbial biomass and activity. This result may partly be explained by the higher litter production in deciduous forest stands. As the described effect occurred along with a higher C mineralisation, a higher C sequestration potential in deciduous stands may possibly be indicated. Thomasius and Schmidt (1996) reported on litter production of 1–4 t ha^{-1} a^{-1} in pine and of 2–5 t ha^{-1} a^{-1} in beech forests. In our study, leaf litter production accounted for 3.1 t ha^{-1} in the pine stand and for 3.3 t ha^{-1} in the beech/oak stand. Thomasius and Schmidt (1996) also evaluated litter quality of different tree species using N, P, K, Ca and Mg concentrations and found a clear advantage of oak, but not of beech, compared to pine. Thus, higher litter production combined with accelerated microbial activity leads to an active turnover rate but also provides the basis for a possibly higher C sequestration. In accordance with our results, Krumrei et al. (2004) and Lorenz et



(organic layer thickness scale 1:4)

(C_{hwe}, C_{cwe} and C_{mic} scale 2:1 in relation to TOC)

TOC	42.2 t ha^{-1}	37.1 t ha^{-1}	36.7 t ha^{-1}	47.2 t ha^{-1}	55.0 t ha^{-1}	51.8 t ha^{-1}	47.2 t ha^{-1}	69.2 t ha^{-1}	60.4 t ha^{-1}
C_{hwe}	2 010 kg ha^{-1}	2000 kg ha^{-1}	2 208 kg ha^{-1}	3 026 kg ha^{-1}	3 520 kg ha^{-1}	4 893 kg ha^{-1}	3 026 kg ha^{-1}	3 807 kg ha^{-1}	2 927 kg ha^{-1}
C_{cwe}	380 kg ha^{-1}	491 kg ha^{-1}	600 kg ha^{-1}	537 kg ha^{-1}	665 kg ha^{-1}	717 kg ha^{-1}	537 kg ha^{-1}	643 kg ha^{-1}	695 kg ha^{-1}
C_{mic}	489 kg ha^{-1}	443 kg ha^{-1}	546 kg ha^{-1}	497 kg ha^{-1}	549 kg ha^{-1}	900 kg ha^{-1}	497 kg ha^{-1}	578 kg ha^{-1}	684 kg ha^{-1}

Fig. 4.1: Model on humus morphology, C pools and potential C mineralisation along the investigated forest conversion sequences in the Ore Mountain region and in the Saxonian lowland in May 2001.

al. (2004) found a lower decomposition rate under beech than under pine; Albers et al. (2004) under beech than under spruce. Furthermore, Krumrei et al. (2004) stated no clear relation between initial C/N ratio and litter decay, but assumed a strong relation between polyphenol content and litter decay. In addition, Lorenz et al. (2000) reported on a greater mass loss for black-spruce litter as compared to Norway spruce, despite lower litter resource quality in terms of a lower N and higher alkyl-C content. Albers et al. (2004) found a higher N loss under spruce, while soil under beech seemed to immobilise nitrogen [i.e., by polyphenol–protein complexes].

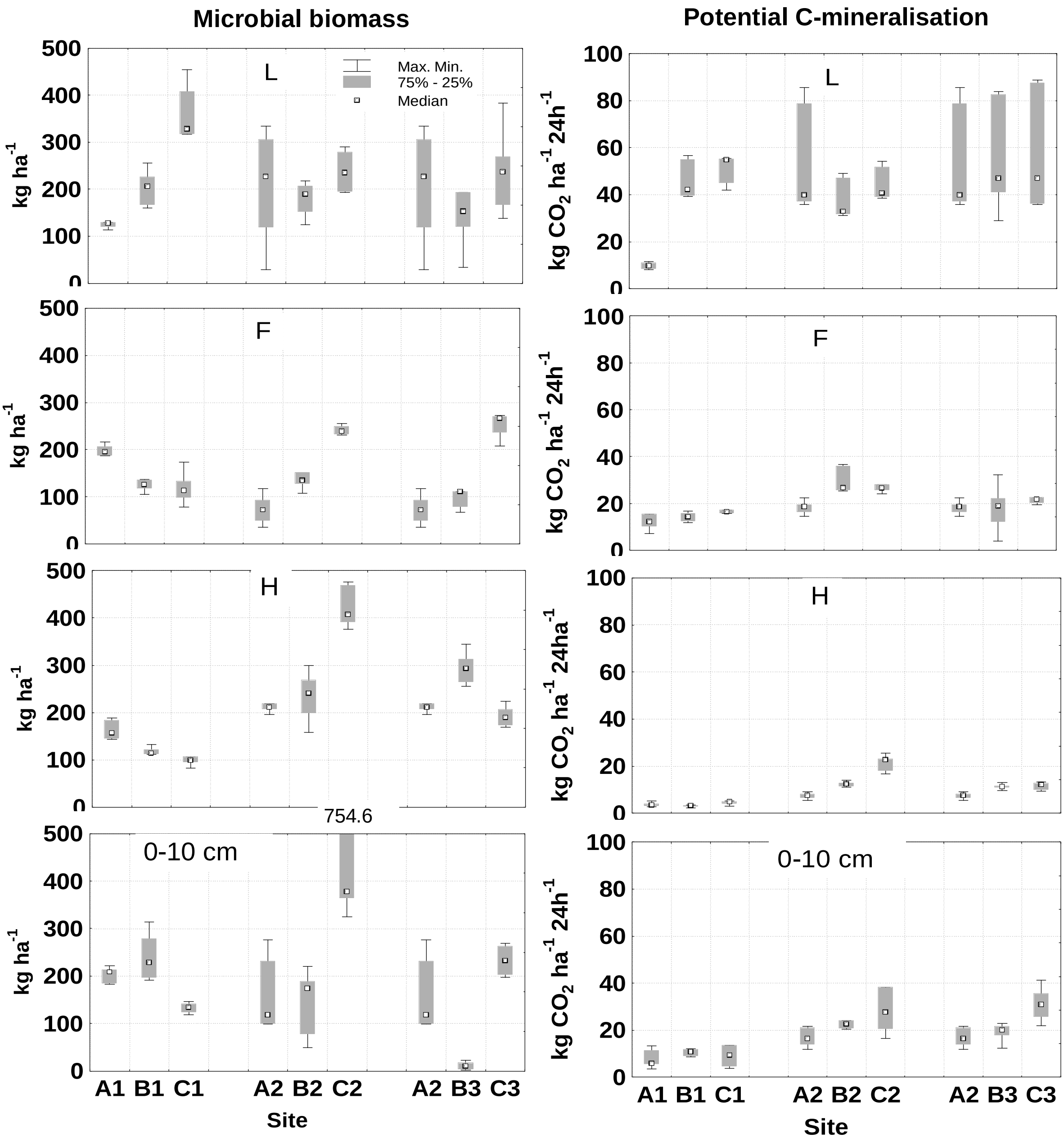


Fig. 4.2: Microbial biomass and potential C mineralisation in organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated sequences in May 2001 (sites “type A”: mature conifer stands; “type B”: advanced plantings of deciduous trees under conifers; “type C”: mature deciduous forests).

Along forest conversion sequences in the lowland, Fischer et al. (2002) described a decreasing trend in organic layer thickness. Their result is in accordance with our findings concerning the higher microbial activity in deciduous forests compared to the pine stand. Yet, we assume that the opposite tendency in organic layer thickness revealed in our study was caused by the typical open stand structure of the pine site combined with the influence on humus degradation of ground vegetation and its roots. These are stand-specific differences - typical for the widespread sites of medium nutrient and water supply (M2) in the lowland.

Besides its ecological importance as a decomposer, soil microbial biomass also acts as a C and N source or sink (Marumozo et al., 1982; Brady and Weil, 2002). This fact provides the basis for the discussion of microbial activity with regard to C and N dynamics in soil. We detected potential C mineralisation between 27.5 (A1) and 63.0 kg CO_2 ha^{-1} 24 h^{-1} (B1) in the Ore Mountain region; in the lowland, microbial activity increased from 78.4 (A2) to 92.8 kg CO_2 ha^{-1} 24 h^{-1} (C2) and to 90.7 kg CO_2 ha^{-1} 24 h^{-1} (C3) (Fig. 4.1 and 4.2).

The corresponding values for the upper mineral soil (0–10 cm) ranged from 7.6–33.0 kg CO_2 ha^{-1} 24 h^{-1}, but revealed no stand-specific trend (Fig. 4.2). Saetre et al. (1999) stated that within the organic layer of mixed stands microbial biomass and C mineralisation were approximately 15% higher under birch than under spruce trees. Smolander and Kitunen (2002) detected a much higher C mineralisation rate in soils from birch and spruce stands than in soil under a pine stand. These results are in principal accordance our results in respect to the higher microbial activity observed under deciduous trees.

Thus, canopy vegetation influence on horizon-specific development in the topsoil was evident from coniferous to deciduous stands: In the Ore Mountains, a clear stand-specific impact was found in the L horizon as microbial biomass increased, but the impact decreased in the limed F and H horizons. Lowland sites showed a higher microbial activity especially in H (and F) horizons of deciduous forests, indicating specific turnover dynamics also in deeper horizons under these stands (Fig. 4.2). For evaluation of the C mineralisation potential, this result has to be considered in relation to the distribution of total and especially available C and N pools.

4.2.3 Stocks of TOC and TN

Based on the observation of stand-specific humus morphology and microbial activity, we hypothesised a specific differentiation in C and N stocks within the organic layer of forest conversion sites. Increasing stocks of TOC and TN were detected along the investigated sequences in the lowland, while the sequence in the Ore Mountain region revealed a declining trend (Table 4.1). These differences were significant in the L layer between sites A2 and B2 and in the underlying organic horizons between advanced plantings and pure deciduous stands in the lowland. In the Ore Mountains, differences proved to be significant for sites B1 and C1 in the L horizon and between spruce and the advanced stand for F and H horizons ($p \leq 0.01$). Yet, the declining trend of organic layer TOC along forest conversion sequences has also been stated by Heinsdorf (2002). Stand structure has a strong effect on litter production, influencing organic matter accumulation, and therefore reveals a relation to the site quality. Higher litter production in beech compared to pine has been stated by Thomasius and Schmidt (1996). Also Anders et al. (1997) reported on lower litter decay rates in semi-natural beech forests as compared to planted pine stands in the lowland region. The combination of higher litter production and higher microbial activity in the F (and H horizon) leading to organic matter accumulation in deeper horizons [i.e., H horizon and upper mineral soil] explains the increase in C and N stocks along the forest conversion sequences found in our investigation. Hence, profound differences in decomposition dynamics between conifers and deciduous trees are presumed. In the lowland, TOC and TN ranged from 47.2–69.2 and 1.9–2.9 t ha^{-1} respectively. Advanced plantings and pure deciduous forests held 10–47% (TOC) and 21–47% (TN) higher stocks than pure conifer stands (Table 4.1, Fig. 4.1). Higher TOC and TN stocks were detected on rather intensively stocked sites (B2, B3 and C3). This result proves the sensitivity of total organic layer C to stand structure and climatic conditions on the forest floor.

Thus, the effect of forest structure seems to be of no less importance than litter quality and water budget for evaluation of litter decay rates. Gerighausen (2002) found a carbon loss of 14% within the total organic layer and mineral soil (0–70 cm) within 22 years after opening the canopy in a shelterwood system of beech, and emphasised the positive effect of canopy opening on C turnover. In accordance with this result, we found an inverse effect with elevated TOC and TN stocks in the investigated dense, advanced planted sites. Yet, processes of C turnover need to be studied in detail in order to obtain information about the specific mineralisation to humification rate and thus, the potential C sequestration. Heinsdorf (2002) reported the same stand-density-depending effect when comparing pure pine stands with advanced plantings of European beech into Scots pine stands in Sauen in the northeastern German lowland. Thus, the creation of more-structured forest sites along with forest conversion will most certainly lead to higher C sequestration in intermediate phases of forest conversion and presumably also (to a lesser extent) in deciduous stands - as long as they have a dense stand structure. The total C stock of the organic layer investigated by Gerighausen (2002) was 52.6–61.2 t ha^{-1} and thus comparable to our findings.

However, in the Ore Mountain region no significant differences were found between the limed study sites. Stocks of TOC and TN there ranged between 36.7–42.2 and 1.7–1.8 t ha^{-1} respectively, once again indicating elevated (micro-)bio-logical activities after liming (Tab. 4.2, Fig. 4.1).

An increase in stocks of hot- and cold-water-extractable C and N was observed in the organic layers along all investigated sequences with the exception of site C3 which revealed comparatively low C_{hwe} and N_{hwe} values (Fig. 4.2).

Tab. 4.2: Stocks of TOC, TN, C_{hwe}, N_{hwe}, C_{cwe} and N_{cwe} in the organic layer (L, F and H) and upper mineral soil (0-10cm) of the study sites in the Ore Mountains and Saxonian lowland in May 2001 (sites "type A": mature conifer stands; "type B": advanced plantings of deciduous trees under conifers; "type C": mature deciduous forests).

Site	**Horizon**	**Stocks of TOC and TN** $t\ ha^{-1}$		**Stocks of C_{hwe} and N_{hwe}** $kg\ ha^{-1}$		**Stocks of C_{cwe} and N_{cwe}** $kg\ ha^{-1}$	
		C	**N**	**C**	**N**	**C**	**N**
Heinzebank:							
A1	L	11.12	0.46	480.67	28.76	100.02	7.56
	F	16.58	0.72	775.09	44.14	150.93	9.74
	H	14.52	0.60	754.20	39.38	129.00	6.88
	sum	**42.22**	**1.78**	**2 009.96**	**112.28**	**379.95**	**24.18**
	0-10 cm	40.75	1.85	2 575.76	117.11	495.34	28.36
B1	L	15.06	0.57	690.95	38.83	181.38	15.04
	F	11.67	0.60	662.59	42.02	177.25	15.76
	H	10.39	0.50	646.72	31.76	132.45	8.27
	sum	**37.12**	**1.67**	**2 000.26**	**112.61**	**491.08**	**39.07**
	0-10 cm	26.05	1.31	2 326.86	82.48	269.23	13.95
C1	L	9.84	0.32	621.77	32.94	245.63	18.53
	F	14.91	0.77	815.15	58.96	163.78	21.93
	H	11.99	0.60	771.07	46.03	190.34	17.27
	sum	**36.74**	**1.69**	**2 207.99**	**137.93**	**599.75**	**57.73**
	0-10 cm	15.00	0.87	800.50	50.85	197.11	17.35
Falkenberg:							
A2	L	17.22	0.63	1 050.79	57.39	239.96	23.22
	F	17.97	0.79	1 138.21	60.52	180.31	19.43
	H	12.01	0.52	837.23	41.35	116.42	9.56
	sum	**47.20**	**1.94**	**3 026.23**	**159.26**	**536.69**	**52.21**
	0-10 cm	17.40	0.72	1 130.54	42.66	217.31	12.69
B2	L	13.41	0.51	994.08	57.07	292.78	28.70
	F	20.07	0.99	1 287.59	85.63	208.82	27.85
	H	21.55	1.02	1 238.11	64.42	162.91	13.61
	sum	**55.66**	**2.52**	**3 519.78**	**207.12**	**664.51**	**70.16**
	0-10 cm	21.52	0.95	2 592.60	137.05	720.91	43.76
C2	L	7.50	0.27	448.58	21.04	156.85	12.63
	F	12.69	0.65	968.58	51.42	153.50	17.28
	H	31.63	1.43	3 476.01	160.59	406.87	30.57
	sum	**51.82**	**2.35**	**4 893.17**	**233.05**	**717.22**	**60.48**
	0-10 cm	55.00	2.29	2 761.88	123.04	539.48	30.54
B3	L	17.05	0.60	699.77	51.76	143.75	18.11
	F	26.35	1.12	1 258.80	94.52	226.10	33.95
	H	25.76	1.13	1 848.10	99.76	272.91	24.88
	sum	**69.16**	**2.85**	**3 806.67**	**246.04**	**642.76**	**76.94**
	0-10 cm	16.18	0.77	1 372.09	59.07	461.05	28.64
C3	L	10.88	0.41	558.51	36.75	227.78	26.17
	F	25.57	1.12	1 195.44	69.46	235.26	24.17
	H	23.97	1.04	1 173.15	56.28	232.39	14.18
	sum	**60.42**	**2.57**	**2 927.10**	**162.49**	**695.43**	**64.52**
	0-10 cm	29.81	1.21	1 748.29	70.88	573.77	35.83

For water-extractable C, significant differences were shown between sites B1 and C1 in L and F horizons, for B2 and C2 in F and H horizons and for sites A2 and B3 in the L layer and B3 and C3 in the H horizon ($p \leq 0.01$). The HWE and CWE fractions reached proportions of 4.8–6% and 0.9–2.0% (C_{hwe} and C_{cwe}) on TOC and 6.3–9.0% and 1.4–4.3% (N_{hwe} and N_{cwe}) on TN (Tab. 4.2). Water-extractable N differed significantly between sites B1 and C1 in the L layer and in F and H horizons between sites B2 and C2 and B3 and C3 ($p \leq 0.01$).

The upper mineral soil (0–10 cm) held 15.0–55.0 t TOC ha^{-1}. C_{hwe} and C_{cwe} stocks ranged in upper mineral soil from 800.5–2,761.9 and 197.1–720.9 kg ha^{-1} respectively (Tab. 4.2). As these results reveal no stand-specific trends, C and N stocks in mineral soil seem to be mainly site-specific parameters as stated by Hofmann and Anders (2002), who defined the local water budget as the most important site-specific regulating factor for TOC sequestration.

TOC/TN ratios of the organic layer ranged from 23–26, C/N_{hwe} from 15–21 and C/N_{cwe} from 9–16 (Table 4.1). There was a general tendency towards lower C/N ratios in deeper organic horizons (F and H horizons) on study sites in the Ore Mountains indicating the impact of liming. The L layer had not been influenced and revealed no distinct trend. Yet, sites B2, C2 and B3 revealed lower C/N ratios in the F horizon compared to L and H horizons indicating a higher N concentration in that horizon. This might be an impact of earthworm activity [i.e., bioturbation] leading to a greater amount of fresh litter material in the F horizon. On the other hand, N might be immobilised due to a high polyphenol content (Berg and Meentenmeyer, 2002; Couteaux et al., 2001; Kögel-Knabner, 1996; Melillo et al., 1982). In the present study, ratios of C to N of total and extractable fractions cannot be recommended as a measure of the impact of forest conversion on C and N dynamics as no clear site-specific differences were observed for the investigated sequences. Yet, cold-water-extractable C/N ratios are generally lower than hot-water-extractable C/N, and both are lower than TOC/TN (Tab. 4.1). Therefore, it can be assumed that the organic matter described as medium-term decomposable (HWE) and even more readily decomposable (CWE) holds higher proportions of N-containing compounds such as proteins, showing a close relationship to microbially fixed C (Leinweber et al., 1995).

4.3.4 Horizon-specific Distribution of C and N Stocks

With regard to stand- and management-specific effects on soil C accumulation, increasing as well as decreasing tendencies have been described (Bauer, 1989; Entry and Emmingham, 1998; Gerighausen, 2002; Ulrich and Puhe, 1994). Hence, in order to understand soil C-sequestration mechanisms, the distribution and dynamics of active C and N pools need to be explained. In the present study, we found a horizon-specific increase in soil C and N with depth along the investigated forest conversion sequences, while TOC (and TN) in L horizons declined (Tab. 4.2, Fig. 4.3). The increase in the TOC proportion in the H layer was most obvious along the sequence A2 to C2 showing values from 25.4% (A2) to 38.7% (B2) and 61.0% (C2) (Fig. 4.3).

Also the hot-water-extractable C and N revealed higher proportions accumulated in F and H horizons of deciduous as compared to coniferous stands, indicating the accumulation of fairly easily decomposable C and N fractions following initial turnover dynamics in L (and F horizons). The horizontal distribution was most pronounced at site C2 (beech), where stocks of C_{hwe} increased with depth from 448.6 (L) to 968.6 (F) and to 3,476.0 kg ha^{-1} (H). Along sequence 3, site C3 (beech/oak) revealed lower proportions of medium-term and readily decomposable C and N compared to the advanced planting, but held lower proportions in the L layer and higher proportions accumulated in the H horizon; C3 was therefore in accordance with the general trend (Fig. 4.3; Tab. 4.2). Along the conversion sequences, the cold-water extract revealed a trend similar to the hot-water extract, but showed a less clear differentiation between single horizons for coniferous and deciduous stands (Fig. 4.3; Tab. 4.2).

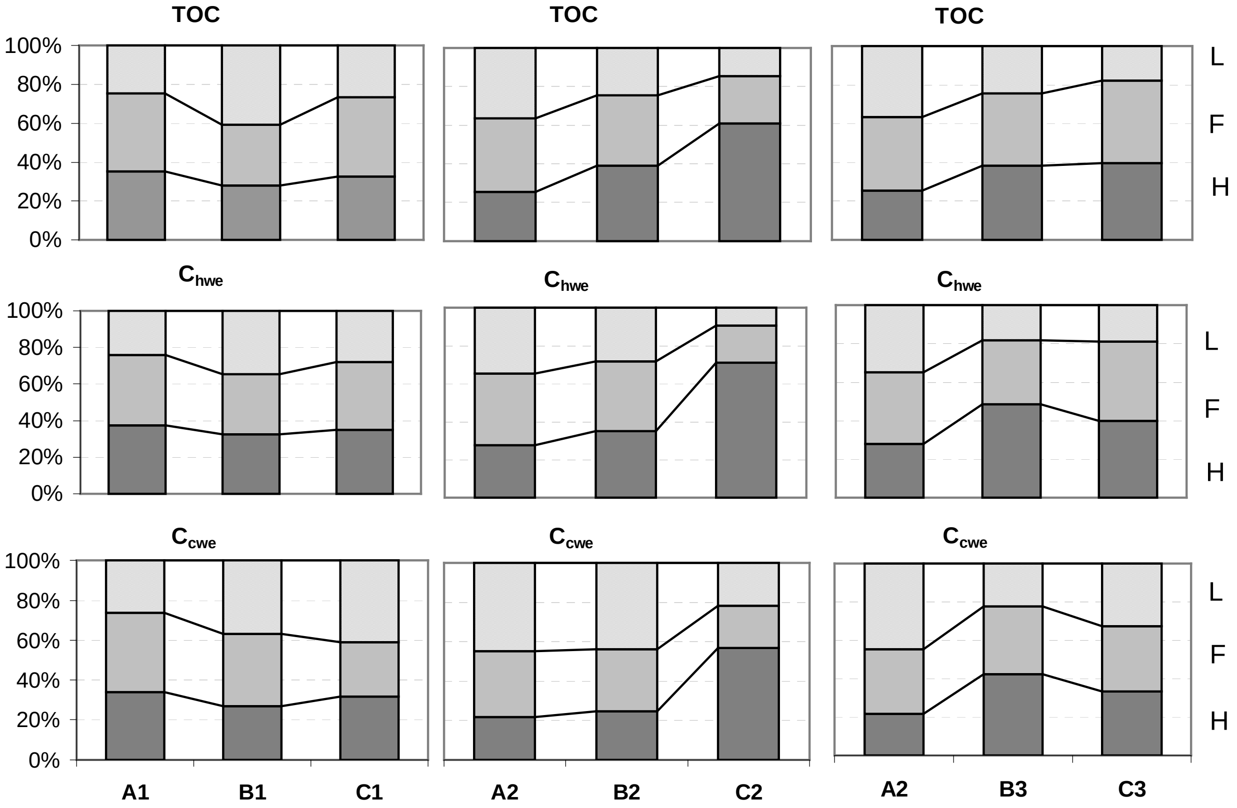


Fig. 4.3: Distribution of TOC, C_{hwe} and C_{cwe} stocks in the organic layers (L, F and H) along the investigated sequences in May 2001 (sites “type A”: mature conifer stands; “type B”: advanced plantings of deciduous trees under conifers; “type C”: mature deciduous forests).

Persson et al. (2000) found 3–44% of total soil C accumulated within the organic layer and drew special attention to the importance of H layers in C sequestration. In their study, organic layers without an H horizon held only 3–7% of total soil C, while at sites with H horizons 12–44% of total soil C were accumulated in the organic layers (NIPHYS/CANIF Project). Thus, the H layer seems to play a significant role in soil C sequestration. Very few studies have been undertaken on hot-and cold-water-extractable C and N dynamics, and most of them have been investigating agricultural soils (Körschens et al., 1990, 1998; Jandl and Sollins, 1997; Landgraf and Klose, 2002; Landgraf et al., 2003). Up to now, hot- and cold-water extracts have been defined as „medium-term“ and „readily decomposable“ C and N pools respectively, but no clear differences in chemical composition have been described. As far as we know, the origin of hot-water-extractable organic matter is soil microbial biomass, root exudates and lysates as well as soil solution and organic particles adsorbed to soil minerals or within the humified SOM (Leinweber et al., 1995). In the present study, the proportion of this medium-term-degradable organic matter fraction was shown to be an index of soil C and N dynamics.

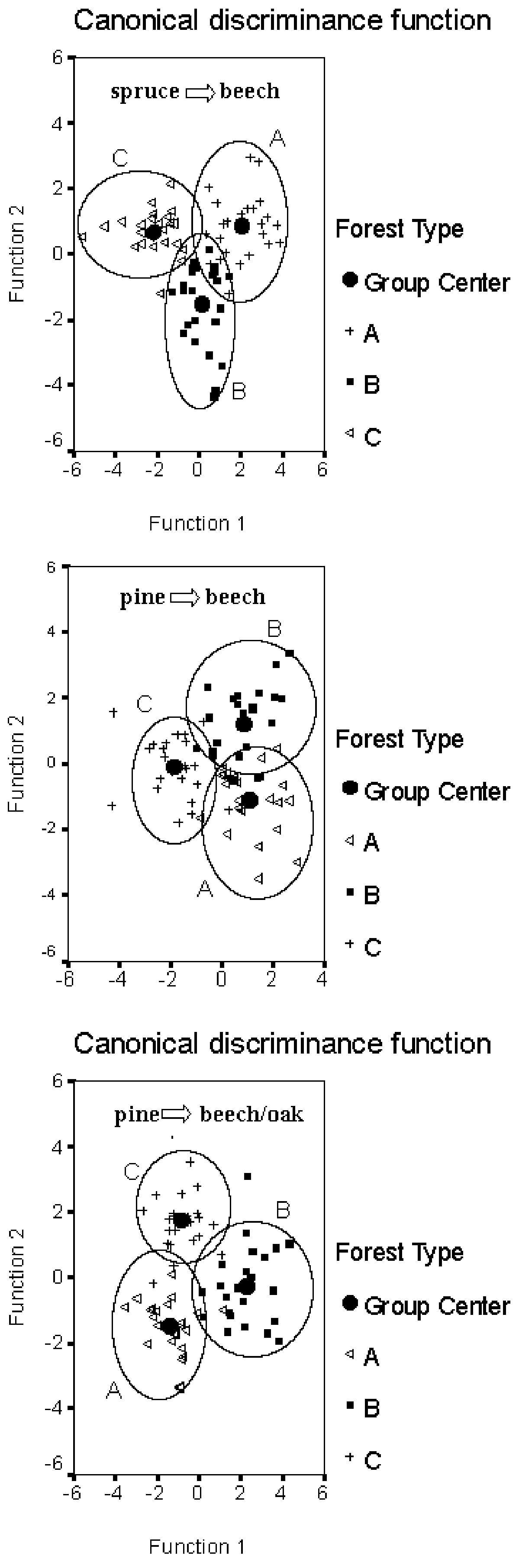


Fig. 4.4: Separation of „forest types“ by the Discriminant function including the analyzed parameters [as listed in Tab. 4.3].

Along with higher stocks of TOC, C_{hwe} and C_{cwe}, we found high microbial biomass and activity especially in H horizons of advanced and deciduous stands. Preliminary experiments in fall 2000 revealed a clear increase in potential C mineralisation especially in L horizons along the investigated sequences from coniferous to deciduous stands in the lowland. This increasing trend was then, in spring 2001, detected in F and H horizons. Thus, our findings indicate high initial turnover rates of beech and beech/oak compared to pine in fall, assumedly followed by a second turnover phase in deeper soil organic horizons in spring. Therefore, we predict that deciduous forests in the lowland can store C over a longer period within deeper soil horizons compared to coniferous forest soils. As a result of liming activities, these cycles have been de-coupled in the Ore Mountain region to a greater degree.

4.3.5 Indicators for Key C and N Dynamics in Organic Layers

For parameter evaluation and definition of indicators for key differences in organic layer C and N dynamics, the canonical discriminant analyse was performed along each investigated sequence. Results revealed a clear differentiation in top soils [organic layer and upper mineral soil (0–10 cm)] along the forest conversion sequences from conifers to deciduous forests (Fig. 4.4).

Tab. 4.3: Standardised canonical coefficient of discriminant function for topsoils (L, F, H and 0-10 cm) between forest types A, B and C.

Site 1 (spruce → beech)			**Site 2 (pine → beech)**		**Site 3 (pine → beech/oak)**	
functions	**Wilks-Lambda**	**% of variance**	**Wilks-Lambda**	**% of variance**	**Wilks-Lambda**	**% of variance**
1 to 2	0.11	75.9	0.18	66.6	0.10	58.4
2	0.48	24.1	0.52	33.4	0.35	41.6
Standardised canonical coefficient of discriminance function						
	Function		Function		Function	
	1	**2**	**1**	**2**	**1**	**2**
mass	-0.03	-0.13	1.12	0.46	0.47	-0.74
TOC	-0.22	0.03	-24.78	-6.44	-2.62	2.16
TN	-0.16	0.02	24.52	6.22	2.26	-3.18
TOC/TN	-0.10	0.10	2.81	0.84	1.28	-0.46
C_{hwe}	-0.14	-0.10	4.44	2.50	-7.49	-2.68
N_{hwe}	-0.09	0.05	-5.17	-2.95	7.68	2.71
$(C/N)_{hwe}$	-0.16	-0.37	-1.94	-1.30	2.72	3.46
C_{cwe}	-0.04	0.64	0.68	0.58	5.11	0.83
N_{cwe}	0.65	0.17	0.22	0.32	-4.38	-1.00
$(C/N)_{cwe}$	-0.46	-0.21	0.13	0.54	-2.01	-1.35
C_{mic}	-0.01	0.00	1.15	-1.25	0.16	-1.06
N_{mic}	-0.03	-0.18	-0.58	0.90	-0.84	1.38
$(C/N)_{mic}$	-0.00	0.21	-0.33	0.77	-0.30	0.65
C mineralisation	0.15	-0.19	0.19	-0.45	0.47	-0.36

Between 58.4–75.9% of variance and 82–90% of data variance were explained by grouping into forest types (Tab. 4.3). The combination of relevant parameters (limit of canonical coefficient of discriminance function ± 2.0) demonstrated differences between the three forest conversion sequences. The comparatively low coefficients of the discriminance

function in the Ore mountains do not allow a specific evaluation of the parameters as indicators and underline once more the impact of liming on decomposition processes. In the lowland region, TOC and TN as well as their hot-water-extractable fractions were proved relevant for discriminance along both sequences (Tab. 4.3).

4.4 Conclusion

Thus, the presented results define TOC and TN and medium-term decomposable C and N, but not their ratios, as indicators of turnover dynamics along not limed forest conversion sites. Our results indicate that deciduous forests in the lowland store a greater amount of C within deeper soil (organic) horizons compared to coniferous forest soils. As a result of liming activities, these cycles have been de-coupled in the Ore Mountain region to a greater degree. Stand structure age and soil properties have further major impacts – besides stand vegetation - on turnover dynamics and humus accumulation. Thus, canopy opening has to occur carefully in order to preserve the comparatively high carbon stocks under advanced plantings.

5 Total and water-extractable Fractions of Carbon and Nitrogen as related to Microbial Biomass along Forest Conversion Sequences

5.1 Objectives

The objectives of the here presented part of the study were

(i) to assess the amounts and distribution of microbial biomass and total as well as fairly easily available C and N fractions in organic layers of two main forest growth regions in Saxony, Germany,

(ii) to relate microbial biomass to TOC and TN as well as to the water-extractable C and N fractions and thus,

(iii) to evaluate the different C fractions as indicators for C and N turnover.

5.2 Saxonian Lowland

5.2.1 Results and Discussion

5.2.1.1 Contents of TOC and TN

Forest management can influence microbial activity, C and N turnover and thus, C sequestration. In our study, data of TOC and TN varied in a range between 143.7 (H at site A2) to 485.9 mg TOC g^{-1} (L at site B3) and between 6.2 (H at site A2) and 17.0 mg TN g^{-1} (F at site B2) (Tab. 5.2). The contents of TOC and TN revealed a decline from the L to the H horizons and even stronger between organic layer and upper mineral soil (Tab. 5.1). In upper mineral soil (0-10 cm) under pure deciduous stands contents of TOC and TN were higher than under advanced plantings and under Scots pine. TOC reached 35.0 mg g^{-1} and TN 1.5 mg g^{-1} in 0-10 cm mineral soil at site C2 (Tab. 5.2). These contents correspond to stocks between 47.2 t TOC ha^{-1} in the organic layer under Scots pine and 69.2 t TOC ha^{-1} in the organic layer under the advanced planting with beech/oak (Tab. 5.1) and are thus, in the common order of magnitude for C and N in organic layers of forest soils (Baritz, 1998; Vesterdal,1999; Andersson and Nilsson, 2001). In average a C stock of about 30-40 t C ha^{-1} has been calculated to be stored in the organic layer at sites of medium nutrient budget in the NE-German lowland (Baritz, 1998). In general, an amount of 100-200 t dw ha^{-1} [corresponding to ca. 50-100 t C ha^{-1}] is usually found to be stored in the organic layer of sustainable managed forests (Podrazsky and Remeš, 2005).

Table 5.1: Basic stand characteristics [i.e., tree species, stand age and density, ground vegetation], thickness, mass and chemical characteristics [i.e., TOC stocks, pH, base saturation and TOC/TN] of the organic horizons (L, F and H) and upper mineral soil (0-10 cm) of the Ore Mountains and Saxonian lowland in May 2001.

			Topsoil					
Site	**Horizon**	**Stand Species**	**Thickness [cm]**	**Mass [t ha^{-1}]**	**TOC Stock [t ha^{-1}]**	**pH [$CaCl_2$]**	**NH_4Cl-extr. basic cations [%]**	**TOC/TN**
A2	L	*P. sylvestris*	2.7	41.3	17.22	3.8	81.5	27.5
	F		2.3	55.1	17.97	3.4	48.1	22.4
	H		1.7	83.6	12.01	3.4	25.2	23.2
	sum/mean		**6.7**	**180.0**	**47.20**	**3.5**	**51.6**	**24.4**
	0-10cm			1067.0	17.40	3.8	13.9	24.7
B2	L	*P. sylvestris*	3.0	32.3	13.41	4.8	90.0	26.4
	F	*F. sylvatica*	2.0	58.3	20.07	3.8	74.0	20.1
	H		2.3	92.8	21.55	3.7	33.6	21.2
	sum/mean		**7.3**	**183.4**	**55.66**	**4.1**	**65.9**	**22.6**
	0-10cm			1386.8	21.52	3.5	10.6	21.7
C2	L	*F. sylvatica*	2.0	16.8	7.50	4.2	89.3	28.0
	F		2.0	43.2	12.69	3.5	66.4	19.4
	H		3.0	171.5	31.63	3.2	21.0	22.1
	sum/mean		**7.0**	**231.5**	**51.82**	**3.6**	**58.9**	**23.2**
	0-10cm			1573.4	55.00	3.3	14.8	24.2
B3	L	*P. sylvestris*	2.3	35.1	17.05	4.0	92.5	28.7
	F	*F. sylvatica*	3.0	70.1	26.35	3.2	52.9	23.5
	H	*Q. petreae*	4.0	135.6	25.76	3.1	34.9	25.3
	sum/mean		**9.3**	**240.8**	**69.16**	**3.4**	**60.1**	**25.8**
	0-10cm			1154.5	16.18	3.3	24.2	23.9
C3	L	*F. sylvatica*	2.3	26.1	10.88	4.0	83.3	26.5
	F	*Q. petreae*	2.0	72.1	25.57	3.3	60.1	22.8
	H		3.2	97.8	23.97	3.2	36.4	23.0
	sum/mean		**7.5**	**196.0**	**60.42**	**3.5**	**59.9**	**24.1**
	0-10cm			1346.8	29.81	3.4	14.5	24.3

Generally, in the lowland no specific trend in TOC and TN contents along the forest conversion sequences was observed. While the L layer revealed no differences, in the F horizon highest TOC and TN contents were found under the comparatively dense and litter-rich advanced plantings and H horizons revealed an increase only along sequence 3. Also Heinsdorf (2002) found no differences in the soil C and N content in the organic layers under pine, beech and oak stands and concluded that site characteristics may have a stronger impact than organic matter quality. Concomitantly, Berger et al. (2002) determined different TOC and TN stocks in organic layers in relation to different types of canopy vegetation and bedrock material. Yet, Fischer et al. (2002) reported a decline in organic layer thickness and humus stocks along a forest conversion sequence from Scots pine to European beech in the Northeastern lowland. However, this finding was not in accordance with our results (Koch and Makeschin, 2004a,b). The contrasting results may possibly be explained by different climatic influences such as the soils water budget and temperature that have been found to dominate litter decay (Berg et al., 1993; Buchmann, 2000; Dalias et al., 2003; Hofmann and Anders, 1996; Matteucci et al., 2000; Swift et al., 1979) and are regulated by management [i.e., different stand structures]. These site-specific climatic influences were found to play a very important role also in our investigation as open stands [i.e., site A2] revealed less soil C than dense, two-stored advanced plantings [i.e., sites B1 and B3] (Koch and Makeschin, 2004a,b). Thus, we arrive at the conclusion that climate and precipitation may have a stronger impact on litter decay processes – besides and controlled by stand density – than litter quality and canopy species.

Table 5.2: Contents of TOC and TN in the organic horizons (L, F and H) and upper mineral soil (0-10 cm) along the forest conversion sequences in the Saxonian lowland in May 2001.

	Pine to Beech			Pine to Beech/Oak		
Site	**A2**	**B2**	**C2**	**A2**	**B3**	**C3**
		TOC [mg g^{-1}]			**TOC** [mg g^{-1}]	
L	416.9	415.6	446.4	416.9	485.9	416.6
F	326.0	344.2	293.6	326.0	375.8	354.8
H	143.7	232.1	184.5	143.7	190.0	245.2
mean	**262.19**	**300.05**	**223.87**	**262.19**	**287.22**	**308.34**
0-10 cm	14.8	15.6	35.0	14.8	14.0	22.1
		TN [mg g^{-1}]			**TN** [mg g^{-1}]	
L	15.2	15.7	15.9	15.2	16.8	15.5
F	14.3	17.0	15.1	14.3	16.0	15.6
H	6.2	11.0	8.4	6.2	7.4	10.7
mean	**10.74**	**13.74**	**10.19**	**10.74**	**11.27**	**13.14**
0-10 cm	0.7	0.7	1.5	0.7	0.6	0.9

However, an active organic matter turnover under deciduous trees resulted in generally higher TOC and TN contents in upper mineral soil than under coniferous stands. This effect was also reported by Rehfuess (1990) and by Prietzel (2004) who observed an increase of 9 % TOC in upper mineral soil subsequent introduction of European beech into Scots pine monocultures. Furthermore, our finding of a comparatively active C turnover in the L and F layer, resulting in an accumulation of decomposition (side-)products within the still active H horizon and finally leading to higher contents of organic matter in (upper) mineral soil under deciduous trees (Koch and Makeschin, 2004a,b), is thus backed-up. The higher carbon contents within upper mineral soil may – additionally to the described turnover dynamics within the organic layer – also be related to bioturbation [i.e., by earthworms] and wild boar activity. But this is presumably not the major cause as the organic layers under the deciduous stands involved in our study showed a clear stratification in single organic horizons. However, the observed effect of higher TOC and TN contents may additionally be related to stand age as forest stands were observed to accumulate more organic matter with time (Entry and Emmingham, 1998).

5.2.1.2 Contents of C_{mic} and N_{mic}

C_{mic} and N_{mic} as well as C_{mic}/TOC and N_{mic}/TN were confirmed as measures of organic matter quality by Bauhus et al. (1998). Smolander and Kitunen (2002) compared stands of pine, fir and birch and detected higher C_{mic} and N_{mic} in birch and fir stands accompanied by higher DOC production and higher C mineralisation rates. In contrast, the pine stand showed comparatively wide TOC/TN ratios and thus, a microbially rather inactive organic layer.

In our study, between 0.9 – 1.6 % of TOC and 1.8 - 3.2 % of TN were bound in soil microbial biomass in the organic layer; in upper mineral soil C_{mic} and N_{mic} reached up to 1.0 % and 2.0 % of the total C and N contents, respectively (Tab. 5.3). C_{mic} varied between 1.3 (F at A2) and 14.1 mg g^{-1} (L at C2) (Fig. 5.1). Our data are basically within the reported range of 1 – 5 % of TOC and 2 - 7 % of TN bound in soil microbial biomass (Bauhus et al., 1998; Friedel and Scheller, 2002; Scheuner, 2004; Zhong and Makeschin, 200_). Within the organic layers, microbial biomass C and N generally declined with increasing depth (except F layer at sites A2, B2 and B3).

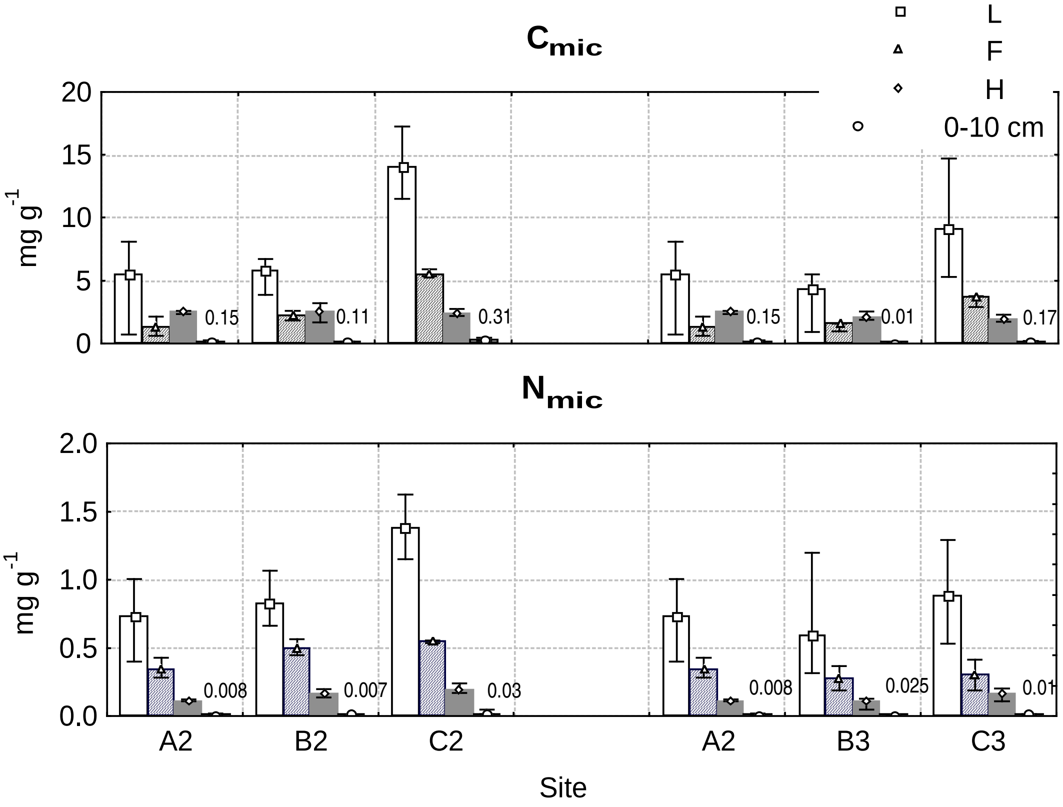


Fig. 5.1: Contents of C_{mic} and N_{mic} within the organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated sequences in the Saxonian Lowland in May 2001 (sites “type A”: mature pine stand; “type B”: advanced plantings of beech and beech/oak trees under pine; “type C”: mature beech and beech/oak forests) [Data shown in the graphic represent values for upper mineral soil].

N_{mic} accounted to 4.4 % to 26.5 % in relation to microbial C, and followed principally the same trend as C_{mic}. In upper mineral soil (0-10 cm), microbial biomass reached values only up to 0.31 mg g^{-1} C_{mic} and 0.03 mg g^{-1} N_{mic} and thus, are comparable with the findings by Bauhus et al. (1998), Zhong and Makeschin (200_), and Scheuner and Makeschin (2004).

A trend of increasing microbial C and N along the investigated forest conversion sequences was observed and found significant ($p \leq 0.05$) in the L horizon from Scots pine to European beech (sequence 2) (Fig. 5.1). Within the F horizons microbial C and N revealed an increasing trend from pine towards deciduous forests (except N_{mic} along sequence 3). The H horizons did not show a distinct trend in the lowland. Studying microbial biomass under deciduous and coniferous forest stands Saetre et al. (1999) compared spruce and mixed birch-spruce stands and reported no significant differences between these stands. Yet, within the mixed stand this author determined 15 % higher microbial biomass under birch trees than under spruce. Consistent with these findings, Smolander and Kitunen (2002) as well as Bauhus et al. (1998) reported a higher C_{mic} under deciduous trees (2.2-2.5 % of TOC) than under conifers (1.9-2.0 % of TOC). Concomitantly, our results revealed - especially in L and F horizons - higher microbial biomass under deciduous than under pure coniferous stands.

5.2.1.3 Contents of Hot- and Cold-water-extractable C and N

Microbial biomass as well as turnover-derived fractions of C and N are subject to fluctuation and therefore major influencing factors on medium- and short-term dynamics of the soil C and N pool. The soil inventory performed in May 2001 revealed hot-water-extractable C (C_{hwe}) contents from 10.0 mg g^{-1} (H at A2) to 30.8 mg g^{-1} (L at B2) in the organic layer (Fig. 5.2). Thus 4.0 % to 11.0 % of the TOC are considered as medium-term decomposable and are therefore involved in the active C pool of the soil, that is available to microbial decomposition (Behm, 1988; Franko, 1997; Gregorich et al., 2000; Körschens et al., 1998; Körschens et al. 1990; Lal et al., 2001; Leinweber et al., 1995; Manzke, 1995; Mazzarino et al., 1993; Sparling et al., 1998).

The contents found in our study are comparable to the C_{hwe} portion of 4 % on TOC determined in an agricultural soil of the lowland (Landgraf, 2001) and to the results by Scheuner (2004), who determined a maximum of 10 % C_{hwe} of TOC in soils under pine forests in the German lowland. Both organic C fractions declined within the organic layers from the L towards the H horizons and to the top mineral soil (except at site A1) as rather easily available organic compounds are involved into the decomposition process.

As a difference to the hot-water extract, cold water extraction was shown to deliver low humified material (Wu et al., 2003). C_{cwe} contents ranged from 1.4 mg g^{-1} (H at A2) to 9.3 mg g^{-1} (L at C2) in the organic layers (Fig. 5.2). Thus, cold-water-extractable C accounted for 0.8 % to 3.3 % of TOC. In upper mineral soil, C_{hwe} accounted for 1.1 to 6.0 mg g^{-1} and C_{cwe} for 0.2 to 0.6 mg g^{-1} (Fig. 5.2). Scheuner (2004) determined 2- to 3-fold lower C_{cwe} as compared to C_{hwe}. In comparison, this relation was higher in our study with a respective average factor of 4-6.

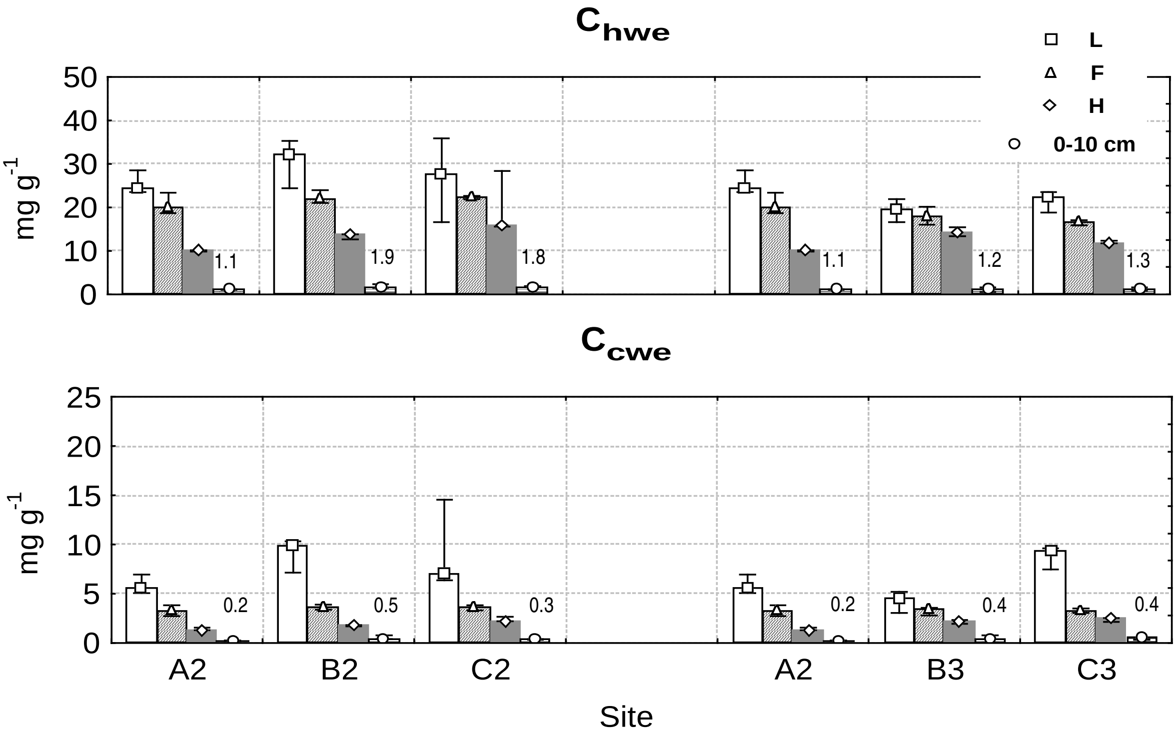


Fig. 5.2: Contents of C_{hwe} and of C_{cwe} within the organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated sequences in the Saxonian Lowland in May 2001 (sites “type A”: mature pine stand; “type B”: advanced plantings of beech and beech/oak trees under pine; “type C”: mature beech and beech/oak forests) [Data shown in the graphic represent values for upper mineral soil].

Along the forest conversion sequences in the lowland region a significant decrease ($p \leq 0.05$) in C_{hwe} and C_{cwe} was proved for the F layers along sites A2 to C3. However, the H horizons of sequence A2 to C2 showed a significant increase in C_{hwe} and C_{cwe} ($p \leq 0.05$).

Values of N_{hwe} on total N accounted for 5.4 % to 11.4 %; for N_{cwe} on TN for 1.1 % to 6.6 % (Fig. 5.3). Sites in the Saxonian lowland revealed only within the H along the sequence from pine to beech (A2 to C2) a significant increase in N_{hwe} ($p \leq 0.05$) (Fig. 5.3).

In order to evaluate the soils C turnover dynamics, active organic matter fractions need to be focused on in detail. Leinweber et al. (1995) characterized hot-water-extractable organic matter of agricultural soils using a combined method of ^{13}CNMR and pyrolysis-field ionization mass spectrometry and revealed its composition as large parts of it being carbohydrates and N-containing compounds, such as amino-N species and amides. Thus, these authors defined the origin of hot-water-extractable organic matter as microbial biomass, root exsudates and lysates as well as soil solution, and organic particles adsorbed to soil minerals or within humified SOM (Leinweber et al., 1995).

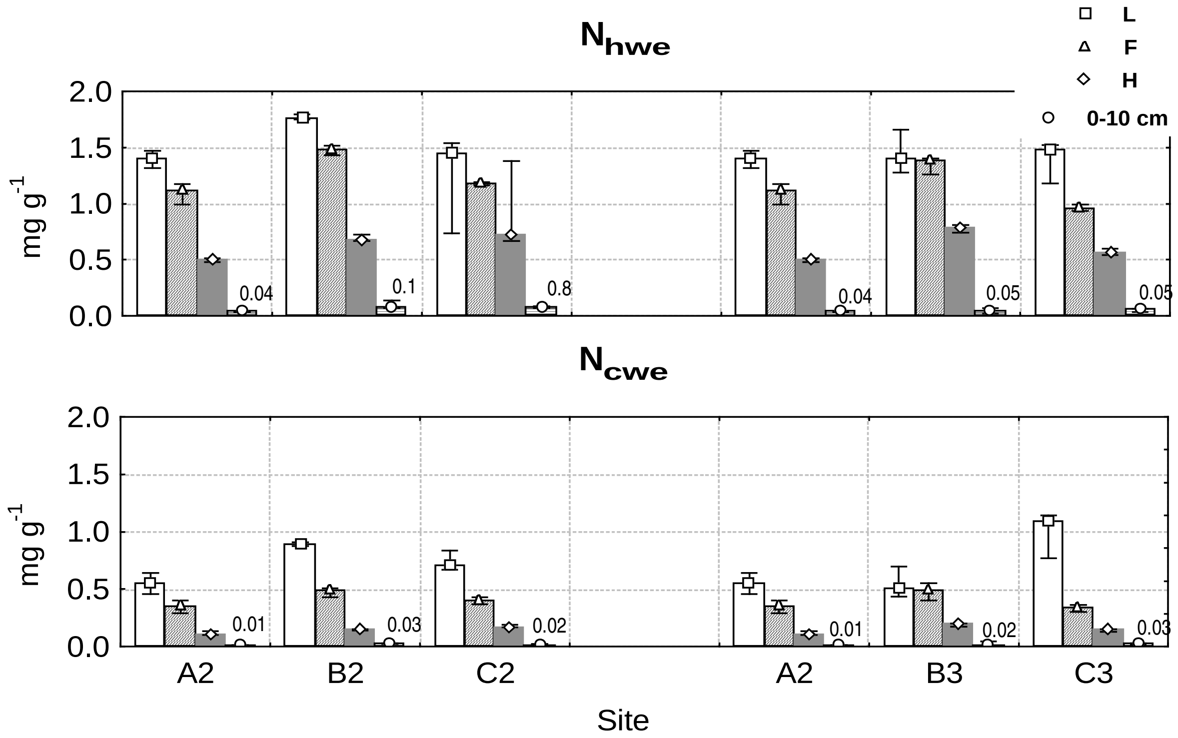


Fig. 5.3: Contents of N_{hwe} and of N_{cwe} within the organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated sequences in the Saxonian Lowland in May 2001 (sites “type A”: mature pine stand; “type B”: advanced plantings of beech and beech/oak trees under pine; “type C”: mature beech and beech/oak forests) [Data shown in the graphic represent values for upper mineral soil].

As the method for cold-water extraction includes a weaker sample treatment, the portion of this fraction among the organic carbon and nitrogen is much lower than the hot-water fraction. Recently Landgraf et al. (200_) proved that the hot water-extractable fraction of C and N contained more easily available substances such as carbohydrates, phenols and lignin monomers and organic N-compounds than the cold water-extractable fraction, and therefore, serves as a better predictor of easily decomposable organic matter than the cold water extract. In contrast, the composition of the cold-water extract revealed similar or even higher portions of rather stable compounds such as lipids, fatty acids and aromatic compounds. Thus, the characterization of cold-water-extractable C and N as being “readily available” might need to be questioned.

5.2.1.4 C/N Ratios

Study sites in the Saxonian lowland revealed a decreasing tendency along the conversion sequence from pine to beech. Generally, values of the organic layers ranged here between 22.6 at site B2 and 26.1 at site B3 (Fig. 5.4). The observed lower TOC/TN ratios in later stages of forest conversion [i.e., deciduous forests] may indicate higher turnover dynamics in these soils (Koch and Makeschin, 2004a,b).

N dynamics were observed to differ according to the stand vegetation (Lovett et al., 2004; Verchot et al., 2001) and thus, may explain the differences found in TOC/TN ratios along the forest conversion sequences studied. Yet, no clear differences were observed comparing the old-growth stands along sequence 3 (pine and beech/oak). Therefore, we assume that the similar TOC/TN ratios of these two stands may be related to the very similar soil chemical properties of both sites (Koch and Makeschin, 2004a,b).

Ratios of $(C/N)_{hwe}$ and $(C/N)_{cwe}$ were higher in the H than in F und L horizons. This result may reflect the changes in N availability down the humus profile (Landgraf et al., 200_). The ratios ranged in average of organic layer between 15.1 (B3) and 20.8 (C2) and of $(C/N)_{cwe}$ between 8.5 (B3) and 16.0 (A1) (Fig. 5.4).

In the lowland advanced plantings with a higher variety of C and N compounds showed lower ratios of hot- and cold-water-extractable C and N than pure coniferous or deciduous stands. Within the studied humus profiles, cold water-extractable C/N ratios were lowest in F horizons (Fig. 5.4).

$(C/N)_{mic}$ ratios varied in a range between 8.9 (site B2) and 11.9 (site C1) for the organic layers and in upper mineral soil (0-10 cm) between 10.5 (site B1) and 17.5 (site A2) (Fig. 5.4). Along the forest conversion sequences in the lowland an increase in $(C/N)_{mic}$ ratios was observed in L and F horizons, while H layers and the upper mineral soils revealed a rather declining trend along sequence 2 (Fig. 5.4). Right after litter shed decomposition of deciduous litter has started (see Chapter 7). Thus, the N supply for microbial biomass is now, in May, lower in these stands than e.g. under pine where decomposition begins later, in spring (Fig. 7.2). Thus, the reasons for the change in $(C/N)_{mic}$ observed might be (i) a higher N availability in fresh litter and therefore, better N supply for the maintenance of microbial biomass, which than in later phases of decomposition might even become stressed caused by a lack of available nitrogen, or (ii) a qualitative shift or adaptation of the microbial community to the changed organic matter quality. Unfortunately, we were not able to separate one of these reasons, so we assume that both have to be taken into consideration. Yet, the first reason is supported by our finding of lower N contents in rather easily available fractions in the H horizons as shown by wider $(C/N)_{hwe}$ and $(C/N)_{cwe}$ ratios.

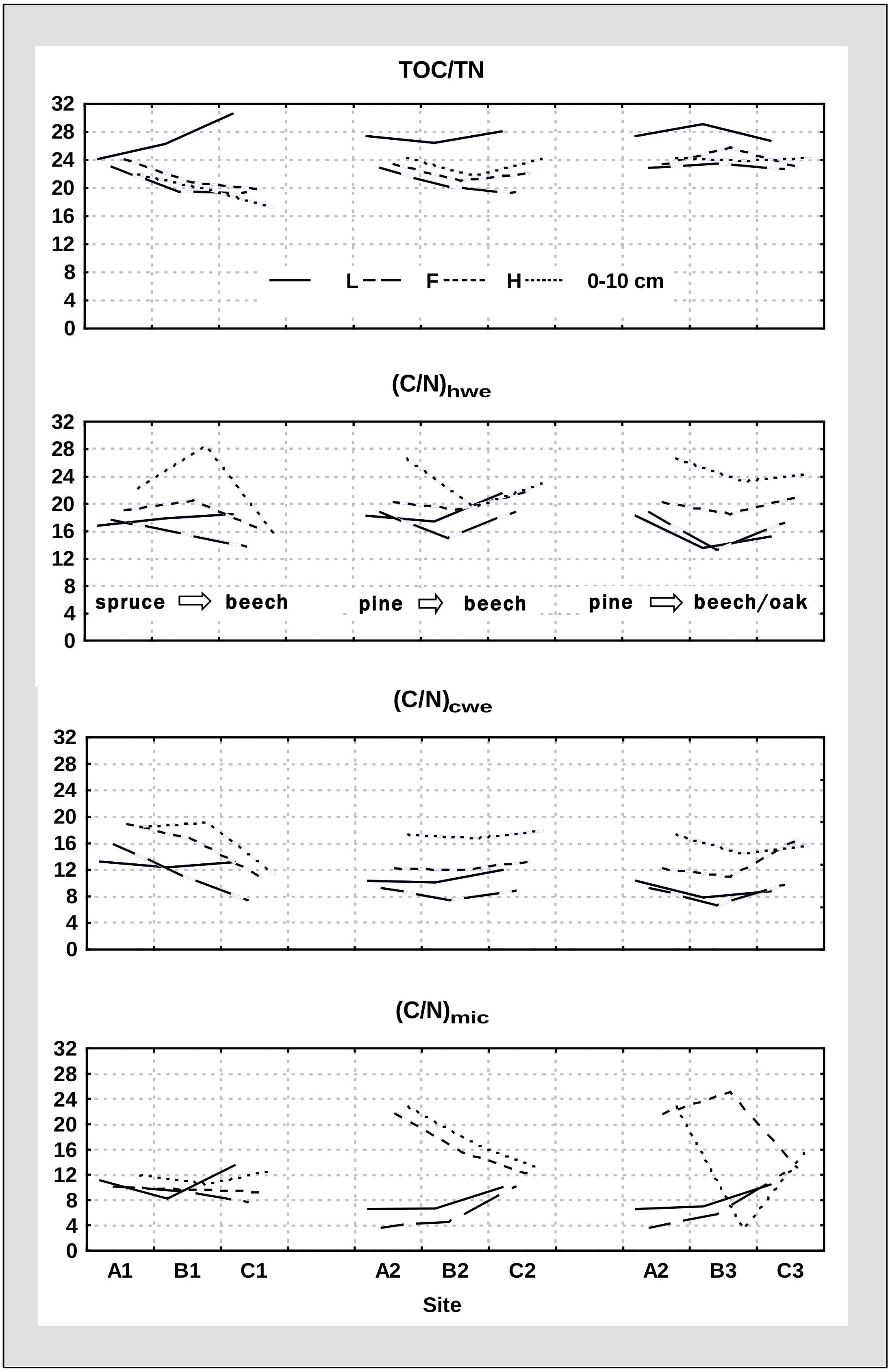


Fig. 5.4: Ratios of TOC/TN, $(C/N)_{hwe}$, $(C/N)_{cwe}$ and $(C/N)_{mic}$ in the organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated sequences in the Ore Mountains and Saxonian lowland in May 2001 (sites “type A”: mature coniferous stands; “type B”: advanced plantings of deciduous trees under conifers; “type C”: mature deciduous forests).

In sum, a decline of C/N with rising availability of the extracted carbon and nitrogen was observed (Fig. 5.4). This reflects the preferential use of N compounds as primary resource for microbial biomass. Our assumption is confirmed by the results of Fierer et al. (2003) who observed indices of a subsurface break-down of nitrogen-containing polyphenol complexes by specialized microbial communities, where N is released into easier available fractions. Microbial biomass living in deeper soil horizons might not be able to fulfill this.

5.2.1.5 Relationship between Microbial Biomass and C and N

The relationship between microbial biomass and TOC and TN [i.e., C_{mic}/TOC and N_{mic}/TN] was shown to be a sensitive indicator of factors such as stand age, tree species, and soil type (Bauhus et al., 1998; Insam and Domsch, 1988; Ross et al., 1999; Scheu and Parkinson, 1995). Generally, as total soil organic matter is a comparatively stable parameter, the C_{mic}/TOC ratio is mainly influenced by the growth and mortality of microbial biomass (Bosatta and Ågren, 1994).

Tab. 5.3: Relationship of microbial C and N to TOC and TN and their specific water-extractable fractions in organic layers (L, F and H) and upper mineral soil (0-10 cm) if the Saxonian lowland in May 2001.

Site	**Horizon**	**TOC**	**C_{mic}/ C_{hwe}**	**C_{cwe}**	**TN**	**N_{mic}/ N_{hwe}**	**N_{cwe}**
			%			%	
Saxonian Lowland:							
A2	L	1.21	19.66	86.10	4.62	50.54	124.93
	F	0.42	6.45	40.71	2.48	32.19	100.27
	H	1.79	25.87	186.03	1.97	24.82	107.29
	mean	**1.14**	**17.33**	**104.28**	**3.03**	**35.85**	**110.83**
	0-10cm	0.99	13.89	72.27	1.38	21.00	70.62
B2	L	1.34	18.08	61.39	5.39	47.39	94.21
	F	0.66	10.46	64.51	2.94	34.67	106.61
	H	1.09	18.93	143.87	1.48	23.36	110.59
	mean	**1.04**	**15.82**	**89.92**	**3.27**	**35.14**	**103.81**
	0-10cm	0.68	5.69	20.46	1.02	7.19	22.53
C2	L	3.17	52.98	151.51	8.81	112.14	186.81
	F	1.91	24.87	156.94	3.66	46.39	138.03
	H	1.33	12.11	103.48	2.46	21.98	115.49
	mean	**2.14**	**29.99**	**137.31**	**4.98**	**60.17**	**146.78**
	0-10cm	0.98	17.82	91.21	1.97	33.33	134.25
B3	L	1.01	24.83	120.88	3.90	45.25	129.30
	F	0.42	8.77	48.83	1.73	20.56	57.23
	H	1.13	15.90	107.69	1.26	13.00	52.13
	mean	**0.85**	**16.50**	**92.47**	**2.30**	**26.27**	**79.55**
	0-10cm	0.06	0.81	2.40	0.71	9.28	19.13
C3	L	2.26	42.68	104.65	5.65	61.29	86.09
	F	0.99	21.19	107.70	1.91	30.96	88.98
	H	0.80	16.35	82.54	1.47	27.20	107.93
	mean	**1.35**	**26.74**	**98.30**	**3.01**	**39.82**	**94.33**
	0-10cm	0.85	13.31	40.54	1.24	19.73	39.02

In our study, the portion of C_{mic} on total organic carbon and of N_{mic} on total nitrogen increased within the L horizons along all investigated sequences (except site B3) (Tab. 5.3, Tab. 5.4).

These results reflect the influence of microbial biomass on initial turnover dynamics when a high N availability can be assumed.

In the lowland soils, an increasing trend was determined in the F layer, while H horizons showed a decline (Tab. 5.2). This result is also seen in relation to the comparatively high C_{mic} values in the H layer at the mature pine stand (site A2), a relatively high C_{mic}/TOC ratio was found within that horizon. A similar effect down the soil profile was observed by Scheu and Parkinson (1995) who compared C_{mic}/TOC in an aspen (*Populus tremuloides*) and a pine (*Pinus contorta*) forest in Canada and found a decline with soil depth in the aspen forest, while soil of the pine forest held maximum values in the mineral soil layer. Bauhus et al. (1998) compared stands of aspen, birch and mixed conifers, spruce and balsam fir and determined lower C_{mic}/TOC and N_{mic}/TN ratios beneath conifers than beneath deciduous species. Landgraf and Klose (2002) compared different management systems near Riesa (Saxony, Germany) and found highest C_{mic}/TOC ratios under the forest stand of locust while agricultural systems revealed lower C turnover indices.

As the ratios of C_{mic} and N_{mic} to total C and N have been proved to be suitable indicators for decomposition dynamics in different soils, the relationships between microbial C and N to active pools of carbon and nitrogen are assumed to be even more sensitive indicators of the influence of forest management on soil organic matter quality. However, Wagai and Sollins (2002) questioned the function of water-extractable organic matter as primary substrate for microbial biomass as so far no regeneration time of this fraction has be defined.

Microbial biomass (C_{mic}) accounted for 16 % to 30 % of the hot water-extractable C and was about 90 % to 140 % of cold water-extractable C in total of the organic layer (Tab. 5.2). Therefore, C_{mic}/C_{hwe} and N_{mic}/N_{hwe} seem to be more reliable factors for organic matter turnover dynamics than C_{mic}/C_{cwe} and N_{mic}/N_{cwe} already due to the relation of the pool sizes. Additionally C_{mic} was rather correlated to the hot than to the cold water extract (Fig. 5.5; Fig. 5.6).

As the ratio of C_{mic} to the hot water extract increased along the forest conversion sequences in L (and F), but revealed a declining trend in H horizons, the supply of fairly easily available organic compounds for microbial decomposition was found to be higher in early phases of litter decomposition under conifers as compared to deciduous stands at the sampling time [i.e., in May 2001]. This effect may be explained with an active decomposition of the newly shed litter under deciduous stands in fall; subsequently easily available substances have already been mineralized by spring. Under pine, in contrast, we assume that microbial activity increased only after the wax layer of pine needles had undergone a physical decay during the winter season and thus, rather active C fractions are then available for microbial decomposition in May (see Chapter 7). During later decomposition phases (H horizon) microbial biomass is still comparatively active under deciduous trees (Fig. 5.1) using-up available organic fractions. These findings are reflected by the humus morphology of the study sites (Koch and Makeschin, 2004a,b).

Correlation analysis between C_{mic}, C_{hwe} and C_{cwe} as well as between N_{mic}, N_{hwe} and N_{cwe} revealed no general trend in relation to horizon/depth or along the conversion gradients (Fig. 5.5, Fig. 5.6). However, on a general scale microbial biomass C in forest soils tended to be rather related to C_{hwe} than to C_{cwe}. This contradicts the widely held opinion that C_{cwe} acts as measure of easily available resources of microbial activity rather than the hot water extract. Yet, in our study most common within the organic horizons or upper mineral soil were relationships between the cold water and hot water extract (Fig. 5.5; Fig. 5.6). Chodak et al. (2003) determined correlations between TOC or TN with microbial biomass as well as with base saturation but found not such a clear relation with the hot water extract. On the other hand, Schulz (1990) found a strong relation between C_{hwe} and a soils CO_2 release and Franzluebbers et al. (2001) confirmed the elevated occurrence of active, decomposable organic fractions in soils of higher microbial activity – resulting in lower humus stocks. Indications found in our study are in accordance to both authors in respect to the finding of the hot water-extractable fraction as being a rather active organic matter fraction.

5.2.2 Summary and Conclusion

In the lowland, contents of TOC and TN revealed no general trend, except higher values under advanced plantings, which are most probably related to the dense stand structure and higher litter production. Thus, we predict that TOC and TN as well as the TOC/TN ratio reflect primarily climatic and soil properties as well as the impact of stand density. However, generally higher TOC and TN contents were observed in upper mineral soil under deciduous stands indicating a positive effect of forest conversion on C sequestration.

Microbial biomass as well as contents of water-extractable C and N revealed an evident influence of tree species and stand structure. Especially regarding to L (and F) horizons a distinct increase along the conversion sequences was shown for microbial biomass. Contents of water-extractable C and N fractions revealed an inverse trend to C_{mic} in the L and F layers. In the H horizon no specific trend with forest conversion was observed for microbial biomass and cold water-extractable organic compounds; hot water-extractable organic compounds increased.

Generally, a decrease of C/N with raising availability of the C and N extracted was observed in this study. Within the soil profile, ratios between water-extractable C/N were highest in the

H horizons and upper mineral soil, reflecting the lower portion of available N fractions involved into late decomposition phases.

Correlation analyses revealed no distinct trend with regard to soil depth and along the conversion sequences. Yet, on a general scale, microbial biomass was rather related to the hot than to the cold water extract. Thus, from our data hot water-extractable C and N are rather recommended as a suitable measure for decomposition dynamics than the cold water extract. Although this outcome derived from a quantitative approach, it backs up the results of Landgraf et al. (200_), who determined the hot water-extractable organic fraction as being more easily decomposable than the cold water extract by a qualitative approach. In order to continue the work with water-extractable C fractions, further research should be performed on the structure-chemical characterization of the C pools obtained.

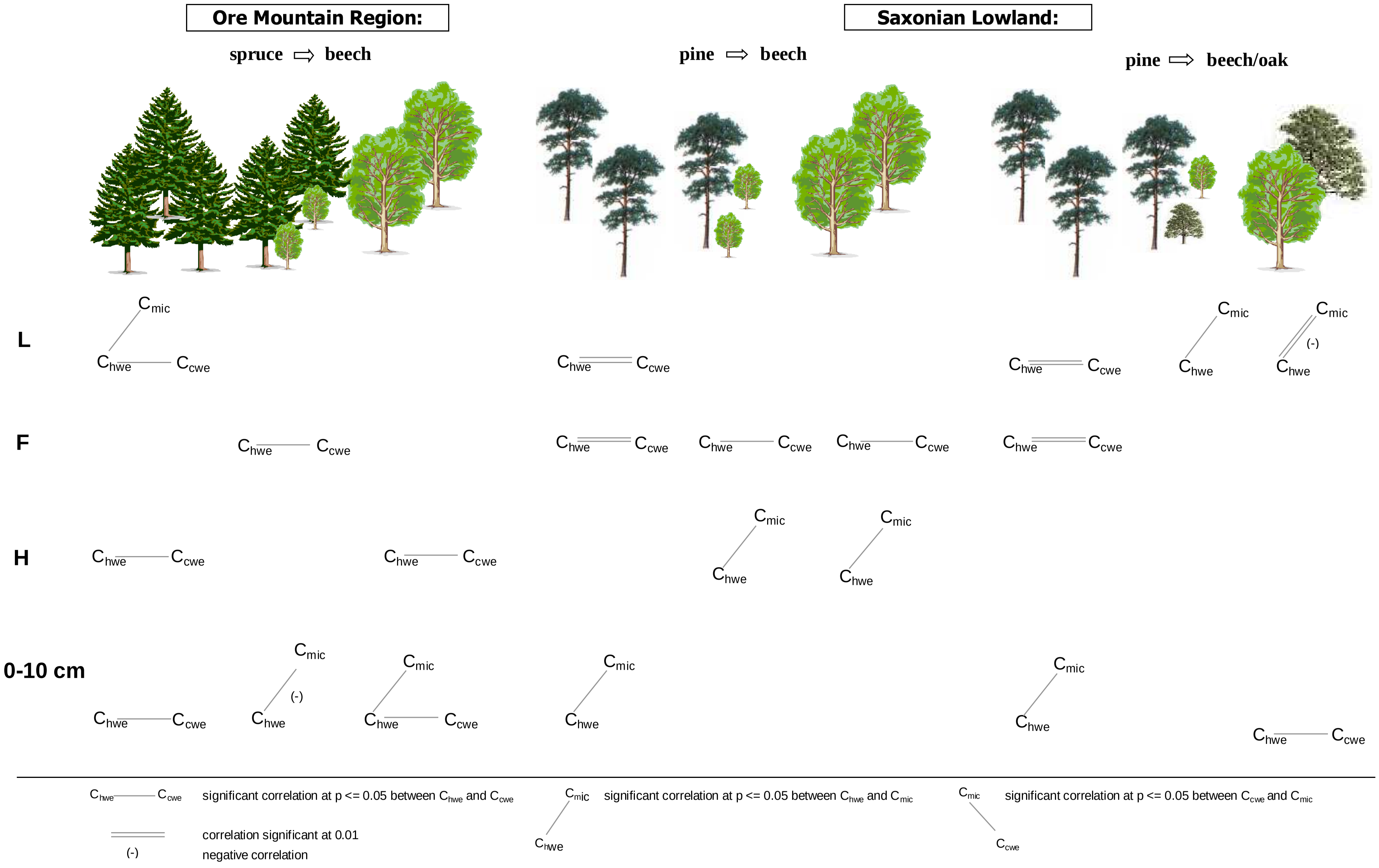


Fig. 5.5: Correlations between C_{mic}, C_{hwe} and C_{cwe} within the organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated forest conversion sequences in May 2001.

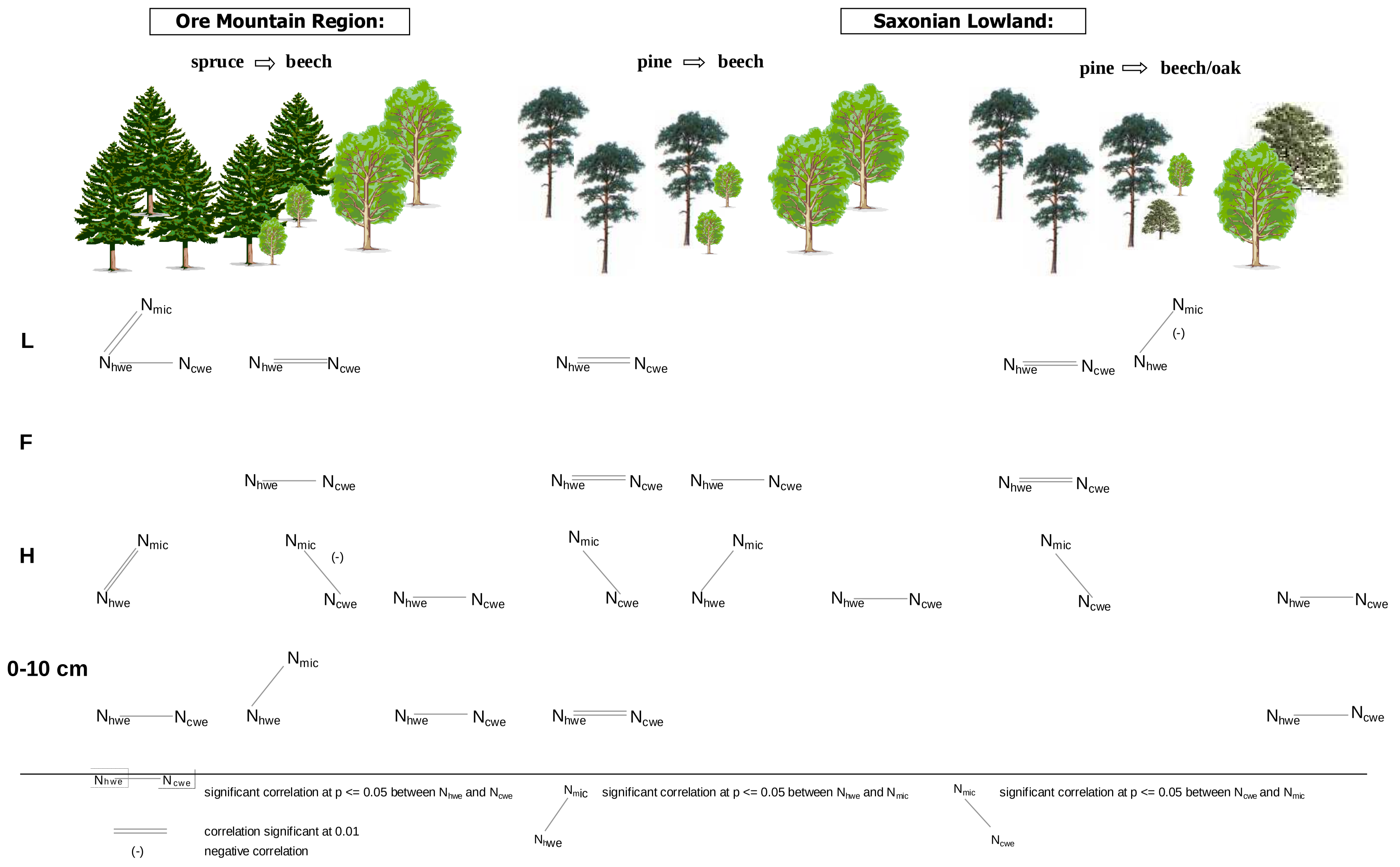


Fig. 5.6: Correlations between N_{mic}, N_{hwe} and N_{cwe} within the organic layers (L, F and H horizons) and uppermost mineral soil (0-10 cm) along the investigated forest conversion sequences in May 2001.

5.3 Ore Mountain Region

5.3.1 Results and Discussion

5.3.1.1 Contents of TOC and TN

In the Ore Mountain region, the relatively high C and N contents as compared to the lowland are most probably related to the cooler and wetter climate as compared to the lowland as this decelerates organic matter turnover. During the top soil inventory performed in May 2001, TOC contents ranged from 221.8 (H at site C1) to 473.4 mg TOC g^{-1} (L at site C1) and from 11.1 (H at site C1) and 19.2 mg TN g^{-1} (L at site A1). These values account for TOC and TN stocks between 36.7 – 42.2 and 1.7 – 1.8 t ha^{-1} in the organic layer under beech and spruce, respectively (Tab. 5.4).

While the TOC content in the L layer under the lime-influenced soils of the Ore Mountains did not show any canopy vegetation specific effect, the underlying organic horizons revealed a decreasing trend along the conversion sequence, which was most pronounced in the H horizon (by 38 %). The lower TOC contents in deciduous litter-influenced F and H horizons (sites B1 and C1) may indicate a faster C turnover subsequent liming in these stands. Also TN revealed a declining trend along the conversion sequence in the Ore Mountains [from 17.4 to 14.0 mg g^{-1} in the organic layer (Tab. 5.5)], indicating the effect of higher N mineralisation in deciduous litter influenced soils (Persson et al., 2000).

Table 5.4: Basic stand characteristics [i.e. tree species, stand age and density, ground vegetation], thickness, mass and chemical characteristics [i.e. TOC stocks, pH, base saturation and TOC/TN] of the organic horizons (L, F and H) and upper mineral soil (0-10 cm) of the Ore Mountains and Saxonian lowland in May 2001.

			Topsoil					
Site	**Horizon**	**Stand Species**	**Thickness [cm]**	**Mass [t ha^{-1}]**	**TOC Stocks [t ha^{-1}]**	**pH [$CaCl_2$]**	**NH_4Cl-extr. basic cations [%]**	**TOC/TN**
A1	L		2.0	23.9	11.1	4.3	96.7	23.6
	F	*P. abies*	1.7	37.8	16.6	3.5	86.5	23.2
	H		2.0	40.6	14.5	3.2	61.6	24.1
	sum/mean		**5.7**	**102.3**	**42.2**	**3.7**	**81.3**	**23.6**
	0-10cm			432.2	40.8	3.2	28.4	22.0
B1	L		2.3	33.6	15.1	5.5	97.8	27.1
	F	*P. abies*	2.8	36.5	11.7	4.8	94.2	19.6
	H	*F. sylvatica*	1.4	36.7	10.4	3.4	66.4	20.8
	sum/mean		**6.5**	**106.8**	**37.1**	**4.6**	**86.1**	**22.5**
	0-10cm			601.3	26.1	3.3	12.7	19.9
C1	L		2.3	20.8	9.8	5.1	91.9	30.9
	F	*F. sylvatica*	2.7	45.5	14.9	4.8	98.4	19.4
	H		2.2	54.1	12.0	3.8	93.7	20.1
	sum/mean		**7.2**	**120.4**	**36.7**	**4.6**	**94.7**	**23.5**
	0-10cm			309.0	15.0	4.4	85.8	17.2

In our study, the differentiation of TOC and TN contents between organic layer and mineral soil was generally greater in the lowland than in the Ore Mountain region. In the Ore Mountains, upper mineral soils (0-10 cm) held between 12.5 % to 22.9 % of the TOC and 14.0 % to 24.7 % of TN of the total of C and N stored in the organic layers. In contrast, mineral soils in the lowland revealed lower TOC and TN in relation to the organic layer above of only 4.9 % to 7.2 % and 5.1 % to 6.8 % for TOC and TN, respectively [except site C2] (Tab. 5.2). From our data this result may indicate an elevated bioturbation. A comparable effect subsequently liming was reported from Ammer and Makeschin (1994) and Makeschin and Rodenkirchen (1994). Additionally, Rehfuess (1990) reported a general redistribution of organic substances from the organic layer towards mineral soil subsequent liming as a consequence of the microbial decomposition enhancement. In his studies, most of the organic material lost from the organic layer was found in the top 10 cm of mineral soil. This result is in accordance with our findings and may support the assumption of an un-even lime distribution leading to a higher TOC content in the upper mineral soil under the spruce stand than under beech and the advanced planting, which is contrary to the trend observed in the lowland.

Table 5.5: Contents of TOC and TN the organic horizons (L, F and H) and upper mineral soil (0-10 cm) along the forest conversion sequence in the Ore Mountain region in May 2001.

	Spruce to Beech			Spruce to Beech		
Site	**A1**	**B1**	**C1**	**A1**	**B1**	**C1**
	TOC [mg g^{-1}]			**TN** [mg g^{-1}]		
L	464.2	448.2	473.4	19.2	17.1	15.5
F	438.9	319.6	327.3	19.1	16.4	16.8
H	357.9	282.9	221.8	14.8	13.6	11.1
mean	**412.66**	**347.45**	**305.13**	**17.42**	**15.66**	**14.01**
0-10 cm	94.3	43.3	48.5	4.3	2.2	2.8

Additionally, in the Ore Mountain soils generally much higher TN contents were observed than in the lowland. A possible explanation is that nitrogen, mineralized in concomitance with the lime-induced higher decomposition rates of humus, was incorporated in the newly formed SOM (Soil Organic Matter). This effect may occur on rather poor sites if liming is not combined with N fertilisation (Czerny and Mai, 1970; Derome et al., 1986; Kreutzer, 1995; Zöttl, 1963). The described effects are concentrated on H (and F) horizons, reflecting the lime-induced shift in soil chemical and (micro-)biological properties, but much less pronounced in the newly formed and thus, less influenced L horizons.

5.3.1.2 Contents of C_{mic} and N_{mic}

In the Ore Mountain region between 0.9 – 1.6 % of TOC and 1.8 - 3.2 % of TN were bound in soil microbial biomass in the organic layer; in upper mineral soil C_{mic} and N_{mic} reached up to 1.0 % and 2.0 % of the total C and N contents, respectively (Tab. 5.6). Thus, the data are within the range of 1 - 5 % of TOC and 2 - 7 % of TN bound in soil microbial biomass (Bauhus et al., 1998; Friedel and Scheller, 2002; Scheuner, 2004; Zhong and Makeschin, 200_). Within the organic layers, microbial biomass C and N generally declined with increasing depth (except F layer at sites A2, B2 and B3). In the organic layers of the Ore Mountains microbial biomass carbon (C_{mic}) varied between 2.2 and 14.9 mg g^{-1}.

Along the investigated forest conversion sequence from Norway spruce to European beech a trend of increasing C_{mic} and N_{mic} was found significant ($p \leq 0.05$) in the L horizon, but both parameters declined in the F and H horizon along the conversion sequence (significant at $p \leq 0.05$ in the H horizon) (Fig. 5.5).

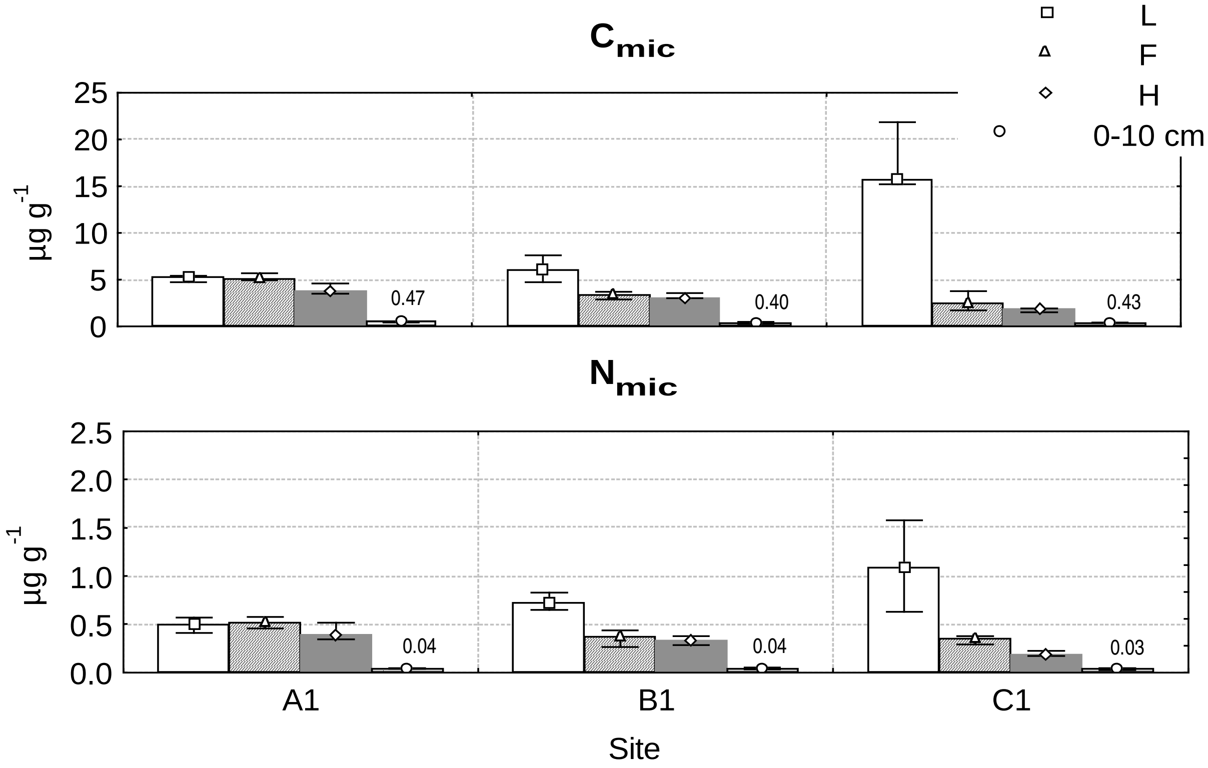


Fig. 5.7: Contents of C_{mic} and N_{mic} within the organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated sequences in the Ore Mountains in May 2001 (site A1: mature spruce; B1: advanced plantings of beech trees under spruce; C1: mature beech forest) [Data shown in the graphic represent values for upper mineral soil].

There is evidence from the literature on higher microbial biomass under deciduous trees than under conifers (Bauhus et al., 1998; Berger et al. 2002, Saetre et al., 1999; Smolander and Kitunen, 2002). Concomitantly, the not lime-affected L and F horizons involved in our study revealed higher microbial biomass under deciduous than under pure coniferous stands. Additionally, these horizons were less/not influenced by the liming.

Upper mineral soil generally revealed a higher content of microbial biomass than the soils in the lowland – related to the mentioned redistribution of SOM subsequent liming (Rehfuess, 1990). While in the L layers only little differences in C_{mic} were observed between the Ore Mountains and lowland soils, F and H horizons revealed ca. 2- to 1.3-fold higher microbial biomass in the mountain region reflecting the lasting effect of liming (Rehfuess, 1990; Kreutzer, 1995). In addition, liming may have had a greater influence on the comparatively dense spruce stand enhancing needle litter production (Rehfuess, 1990). Currently, the C_{mic} and N_{mic} contents increased in L (not lime-influenced), but decreased in F and H horizons (influenced) along the Ore Mountain sequence revealing the impact of canopy vegetation and litter quality.

5.3.1.3 Contents of Hot- and Cold-water-extractable C and N

In the studied organic layer, hot water-extractable C (C_{hwe}) ranged from 14.3 (H at C1) to 29.9 mg g^{-1} (L at C1) (Fig. 5.6). Contents of the readily decomposable fraction [i.e., cold-water-extractable C (C_{cwe})] varied between 3.2 (H at A1) and 11.8 mg g^{-1} (L at C1) in the organic layer (Fig. 5.6). Generally, cold-water-extractable C accounted for 0.8 % to 3.3 % of TOC. In upper mineral soil, C_{hwe} accounted for 1.1 to 6.0 mg g^{-1} and C_{cwe} for 0.2 to 0.6 mg g^{-1} (Fig. 5.6).Both organic C fractions [i.e., C_{hwe} and C_{cwe}) declined within the organic layers from the L towards the H horizons and to the top mineral soil (except at site A1) as rather easily available organic compounds are involved into the decomposition process.

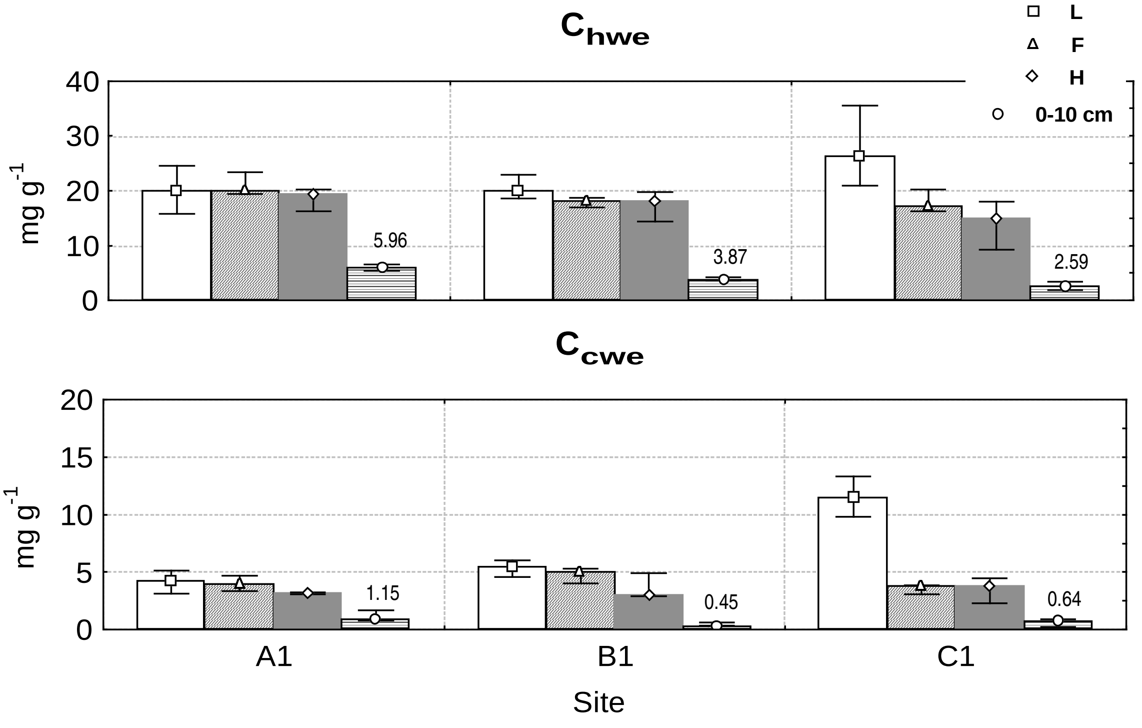


Fig. 5.8: Contents of C_{hwe} and C_{cwe} within the organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated sequences in the Ore Mountains in May 2001 (sites A1: mature spruce stand; B1: advanced plantings of beech trees under spruce; C1: mature beech forest) [Data shown in the graphic represent values for upper mineral soil].

A significant increase ($p \le 0.05$) was proved for C_{cwe} in the L horizon along the forest conversion sequence from spruce to beech. This young horizon was not affected by the lime applied in 1996. Hot water-extractable C declined in the F and H horizons ($p \le 0.05$), while the C_{cwe} content revealed no clear trend.

Values of N_{hwe} on total N accounted for 5.4 % to 11.4 %; for N_{cwe} on TN for 1.1 % to 6.6 % (Fig. 5.7). In the Ore Mountains, a significant decline in N_{hwe} in the H, but an increase in N_{cwe} in all three organic horizons was proved to be significant ($p \le 0.05$).

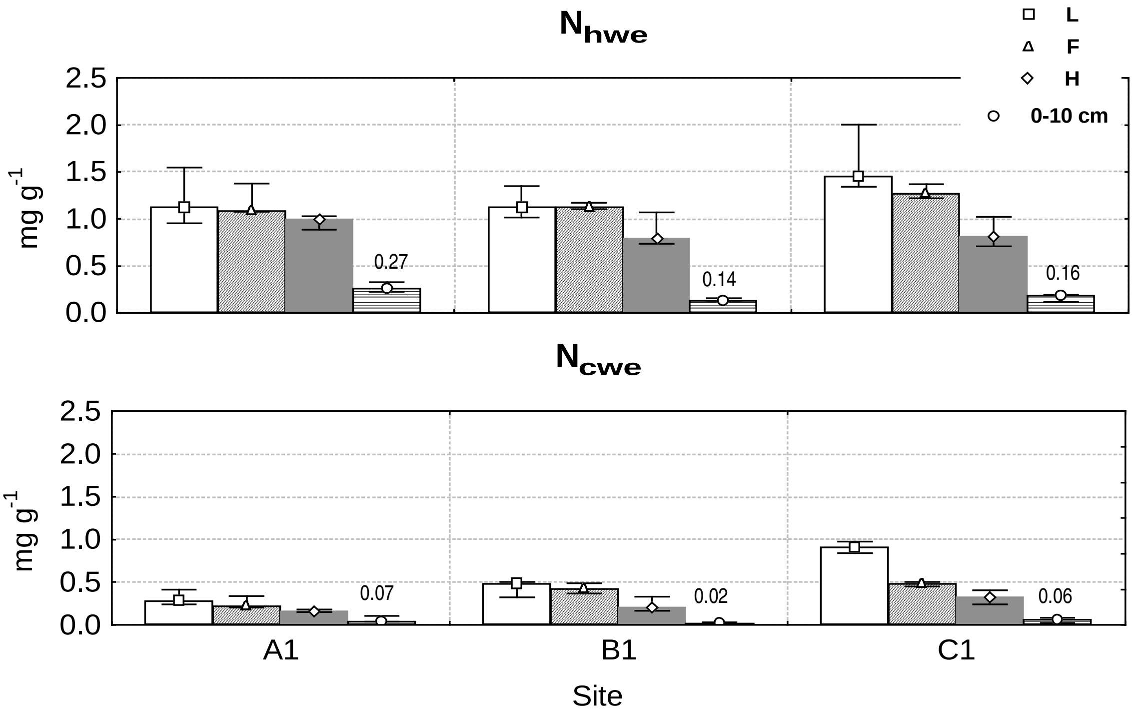


Fig. 5.9: Contents of N_{hwe} and N_{cwe} within the organic layers (L, F and H) and upper mineral soil (0-10 cm) along the investigated sequences in May 2001 (sites “type A”: mature conifer stands; “type B”: advanced plantings of deciduous trees under conifers; “type C”: mature deciduous forests) [Data shown in the graphic represent values for upper mineral soil].

5.3.1.4 C/N Ratios

Along the forest conversion sequences no significant differences were observed in C/N ratios for the total organic layers. Yet, respective to single organic horizons an increasing trend in L from 24.1 to 30.5 and a decline in the F and H horizons – ruled by the TOC contents - along the conversion sequence was determined [data range from 24.1 (A1) to 17.3 (C1)] (Fig. 5.4). The clear decline of TOC/TN in the lime-influenced humus horizons indicates the limiting factor N in late decomposition phases, possibly due to the stronger re-fixation in the humus after the easily decomposable organic matter has been mineralized (Kreutzer, 1995). Along the conversion sequences studied, hot and cold water-extractable C/N revealed a decreasing trend in soils of the Ore mountain region. Within the studied humus profiles, cold water-extractable C/N ratios were lowest in F horizons (Fig. 5.4).

Generally, a decline of C/N with rising availability of the extracted carbon and nitrogen was observed (Fig. 5.4). This reflects the preferential use of N compounds as primary resource for microbial biomass. Our assumption is confirmed by a subsurface breakdown of nitrogen-containing polyphenol complexes by specialized microbial communities, where N is released into easier available fractions (Fierer et al., 2003). Microbial biomass living in deeper soil horizons might not be able to fulfill this. Furthermore, lime-influenced sites in the Ore mountain region probably contain altered (adapted) microbial communities (Bardgett et al., 1996; Frostegård et al., 1993; Marschner et al., 2003).

5.3.1.5 Relationship between Microbial Biomass and C and N

The C_{mic}/TOC ratio is dominantly influenced by the growth and mortality of microbial biomass (Bosatta and Ågren, 1994). In our study, the portion of C_{mic} on total organic carbon and of N_{mic} on total nitrogen increased within the L horizons along all three investigated sequences (Tab. 5.6). These results reflect the influence of microbial biomass on initial turnover dynamics when a high N availability can be assumed. In contrast, the respective ratios revealed a slight decrease in the F and H horizons (Tab. 5.6).

Table 5.6: Relationship of microbial C and N to TOC and TN and their specific water-extractable fractions in organic layers (L, F and H) and upper mineral soil (0-10 cm) in the Ore Mountains in May 2001.

			C_{mic}/			N_{mic}/	
Site	**Horizon**	**TOC**	**C_{hwe}**	**C_{cwe}**	**TN**	**N_{hwe}**	**N_{cwe}**
			%			**%**	
Ore mountains:							
A1	L	1.16	27.41	134.90	2.50	40.50	154.00
	F	1.20	25.90	133.77	2.72	44.56	202.00
	H	1.14	21.73	125.86	2.75	42.11	241.20
	mean	**1.15**	**24.61**	**128.60**	**2.66**	**42.39**	**199.06**
	0-10cm	0.52	8.00	46.63	0.93	14.65	60.50
B1	L	1.35	30.05	114.60	4.34	63.34	163.53
	F	1.07	18.97	72.03	2.22	31.91	85.11
	H	1.15	18.26	93.16	2.40	37.87	145.43
	mean	**1.16**	**22.02**	**89.83**	**2.99**	**44.37**	**131.36**
	0-10cm	0.93	10.47	99.50	1.74	27.62	163.28
C1	L	3.16	55.66	124.98	7.11	69.20	122.66
	F	0.80	14.54	73.90	1.99	25.92	69.69
	H	1.09	18.05	73.78	2.19	28.57	76.16
	mean	**1.64**	**26.55**	**86.79**	**3.77**	**41.22**	**89.50**
	0-10cm	0.90	17.40	91.30	1.23	21.04	61.68

5.3.2 Summary and Conclusion

Turnover dynamics at study sites in the Ore Mountains have been influenced by liming activities in 1996 and therefore reflected currently altered soil chemical and microbiological characteristics. On the one hand, the lime-affected F and H horizons showed a decline in microbial biomass along the conversion sequence, on the other hand also lower C/N ratios. Contents of TOC and TN declined in the organic layer along the investigated sequence. Thus, especially the advanced planting and the beech stand revealed intensive decomposition processes and greater portions of N incorporated in organic material of the F and H horizon. Additionally, the upper mineral soil held comparatively high TOC contents following the re-distribution of organic matter subsequent liming. In contrast, the L layer revealed an increase in microbial biomass along the forest conversion sequence and thus, the current influence of canopy species and litter quality. Therefore, in contrast to the lime-affected F and H horizons, the L layer reflected a similar tree species-depending effect and thus, similar relationships as shown for the lowland will be relevant again in the Ore Mountain region once the amelioration effect looses on influence.

6 Humus Chemistry of a conventionally managed Pine Stand and in a Nature Reserve of Beech/Oak

6.1 Objectives

The objectives of this part of the study are

(i) to determine and compare the quality of organic horizons in a Scots pine and a European beech/Common oak stand applying a semi-quantitative method [i.e. by Curiepoint Pyrolysis-GC/MS],

(ii) to determine the specific water-extractable and water-soluble C fractions as well as microbial biomass and activity, and

(iii) to show turnover dynamics and the changes in organic layer quality during the first 4 months after litter shed.

6.2 Results and Discussion

6.2.1 Litter Composition and Initial Degradation of Compounds

Altogether, 150 peaks were interpreted of which 72 - 91 % could be related to single substances. Pyrogrames of all studied horizons (L, F and H) of the pine and beech/oak stand were dominated by typical pyrolysis products of the main litter constituents lignin and cellulose (Fig. 6.2, Fig. 6.3). Generally, a great difference in the pyrogrames of the organic horizons under beech/oak was observed: The substances determined after about 15 min retention time in samples collected in November where missing to a greater extent in samples of March (Fig. 6.2). Thus, rather stable and more recalcitrant organic matter substances seem to be lost or reduced during initial degradation of beech/oak leaves during the winter season. In contrast, under pine the retention time of substances determined in fall and spring revealed no difference prima facie.

6.2.1.1 Lignin

Shortly after litter fall, in November 2001, the total portion of lignin differed not distinctively between sites for the total organic layer. However, specific differences between the pine and the beech/oak stand were determined for single organic horizons as the L layer of newly shed beech/oak litter revealed an evidently higher lignin portion, but under pine the F and H horizon had a higher share of lignin than under beech/oak (Tab. 6.1). In accordance with our study, Berg et al. (1996) determined an evidently higher lignin content in beech litter as compared to pine needles. Yet, beech leaves also contain higher contents of polyphenol and were at the same time observed to decompose faster than pine needles (Lorenz et al., 2004; Pöhhacker, 1995).

Additionally, in a one-year-study of pine needle decomposition aromatic compounds had increased, while no accumulation of aromatics was reported for beech leaves (Haldock and Preston, 1995). Thus, these reports may indicate that (i) lignin under beech may be easier decomposable than under pine, or (ii) that the microbial community under beech may be specialized on the decomposition of lignin.

Tab. 6.1: Portion of lignin derivates (%) in the L, F and H layers under Scots pine and European beech/Common oak in November 2001 and March 2002.

	Scots pine		**European beech/Common oak**	
	November	**March**	**November**	**March**
L	32.8	28.0	56.0	21.1
F	45.0	24.8	30.3	42.0
H	13.2	18.4	7.3	30.3
Total	**30.3**	**23.7**	**31.2**	**31.1**

In respect to single organic horizons, both sites showed evident differences in their dynamic of lignin degradation between fall 2001 and spring 2002: Under beech/oak changes in organic matter quality during the winter season were characterized by the relative reduction of lignin in the L layer along with a clear relative increase in the F and H horizon (Tab. 6.1). This may indicate that (i) the microbial community in the L horizon is specialized on decomposition of lignin [i.e. white-rot fungi], and (ii) the composition of microbial biomass in the F and H layers is different and possibly rather feeding on other organic compounds [i.e. proteins, hemicelluloses and celluloses]. However, these results may be interpreted in two ways as a relative reduction of lignin may indicate a real reduction in the L layer, but on the other hand an increase in other constituents. Yet, the latter interrelation seems not very probable for the L layer. In contrast, in the F layer under pine the relative loss of lignin was most pronounced and the distribution of compound classes in the H horizon was changed towards a higher lignin portion (Tab. 6.1). On the one hand the relative loss in lignin in the F layer may indicate a real loss of lignin structures that might possibly have to undergo a first breakdown of the wax-layer before then, in the F layer, lignin structures may be broken down. On the other hand an increase of other constituents, that possibly may result from the litter decomposition in the L layer, may be indicated. Unfortunately we were not able to distinguish between both options.

The winter-term turnover dynamics under pine were concentrated on the F (and H) horizon (Fig. 6.4). During that time we observed a relative reduction mainly of coniferyl derivates in the F horizon under pine, while the group of other compounds increased. Simultaneously, in the H layer the portion of celluloses decreased, while portions of lignin and the group of other compounds increased (Fig. 6.4). Some of these changes may have methodological reasons and may thus, be within the error range, but the strong change in organic matter quality characterized by the relative loss of lignin in the F layer (45.0 % in fall, 24.8 % in spring) proves that certain changes in the distribution of compound classes had occurred, possibly indicating (i) an active turnover of organic matter and/or (ii) transfer of organic matter particles or solvents.

Although the total lignin portion revealed no change in the organic layer under beech/oak, certain processes of lignin degradation occurred during the 4 months after litter shed as the portion of lignin in the L layer was reduced by more than factor two. At the same time the portion of the group of celluloses and other compounds increased (Fig. 6.4). The intensive lignin degradation within the newly shed beech/oak litter lead to a total loss of sinapyl structures in the L layer by March (Fig. 6.2). This result mirrors the process of de-methoxylisation - occurring already during the first four months of beech/oak litter decomposition (Fig. 6.1).

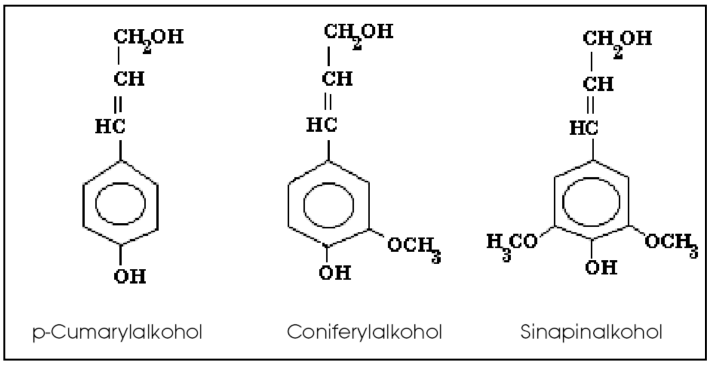


Fig. 6.1: Basic Structures of Lignin: During lignin degradation OCH_3 groups are lost (de-methoxylisation) along a reaction chain from sinapyl to coniferyl- and coumaryl derivates. [Fig. from: Fengel and Wegener, 1989]

Under beech/oak the lignin portion declined from the L towards the H horizon in fall; while in spring the highest lignin share was determined in the F layer (Fig. 6.4). Additionally, the share of coumaryl-, coniferyl- and sinapyl- derivates showed a 4-fold increase in the H layer under beech/oak (Fig. 6.4). Thus, the winter-term decomposition dynamic under beech/oak was characterised by an evident lignin degradation [i.e. de-methoxylisation] in the L layer and

(i) a transfer of lignin to the underlying F and H horizon and/or (ii) a degradation of celluloses in the F and H layer resulting in a relative decrease in celluloses but increase of lignin structures (Fig. 6.4). We arrived at the conclusion that both processes may have taken place as on the one hand the portion of sinapyl derivates increased in the F layer from fall to spring and thus, transfer must have occurred and, on the other hand the relative reduction of celluloses in the H layer was stronger than of other constituents (Fig. 6.4).

In summary, we observed a smaller amount of lignin in pine than in beech/oak litter in fall, when in both stands the main litter fall event had occurred. Although, pine needles tend to be shed throughout the year, litter fall peaks between September and October (see Chap. 8) and thus, the results of our study may indicate a qualitative advantage of pine litter towards beech/oak litter. Vesterdal (1999) reported on similar lignin contents in deciduous and coniferous litter and thus, it has been shown that deciduous litter does not necessarily reveal a better resource quality. The lignin or polyphenol content in relation to N was reported to rule the rate and limit value of litter decomposition (Berg and Mc Claugherty, 2003). Deciduous litter usually reveals a higher C mineralisation rate (e.g. Albers et al., 2004; Koch and Makeschin, 2004a,b; Raich and Tufekciogul, 2000). Yet, differences in decomposition rates between broadleaf and needle litter may be small (Prescott et al., 2000). Lignin is known to be rather resistant to microbial decomposition (Haider, 1996). This result may possibly imply an explanation for the faster decomposition of pine needles as compared to the beech/oak litter during a one year litter bag study (see Chap. 7). Yet, on the other hand the same study revealed a relatively active initial turnover of the newly shed beech/oak litter (Chap. 7) that was partly explained due to the initial turnover of organic compounds [i.e lignin] by pyrolysis-GC-MS during this study. Some species of fungi from the group of Basidiomycetes, white-rot-fungi, are able to decompose lignin to CO_2 (Kögel-Knabner, 1996). As this group of fungi is known to prefer deciduous forest stands, the comparatively active initial C mineralisation and the degradation of lignin derivates as shown by pyrolysis-GC-MS under beech/oak may presumably be explained with the occurrence of white-rot-fungi and is a co-metabolic process as celluloses is broken-down at the same time (Fig. 6.4).

In sum, the changes in lignin during the first four months after litter fall were (i) restricted to changes in portions of the different lignin derivates, i.e. by de-methoxylisation, (ii) changes in the lignin portion between single organic horizons, and (iii) the real loss of lignin was caused by a co-metabolic decomposition as the total lignin portion in the organic layer revealed no evident difference between the two sampling times (Tab. 6.1).

6.2.1.2 Polysaccharides

The comparison of signal intensities of pyrolysis products determined for hemicelluloses, celluloses and monosaccharides shows that (i) their portion on the organic matter quality of the total organic layer did not differ between the pine and the beech/oak stand in fall 2001 and (ii) that winter-term turnover dynamics were more intensive in the L and H horizon under beech/oak than under pine (Fig. 6.2, 6.3; Tab. 6.2).

While the L layer under pine revealed no certain change with time in the relative polysaccharide content, the respective portion increased in the L layer under beech/oak – presumably related to the relative decrease in the lignin content of the newly shed litter. Changes between November and March were also negligible in the F horizon under pine and relatively small in the F layer under beech/oak. Here, in the deciduous stand, the relative decrease in compounds of celluloses origin in the F horizon may possibly be related to the relative increase in lignin structures [i.e. by transfer from the above L layer as can be seen by the increase of sinapyl derivates] as the group of N compounds and other compounds revealed no certain changes (Fig. 6.4).

Tab. 6.2: Portion (%) of compounds of celluloses origin in the L, F and H layers under Scots pine and European beech/Common oak in November 2001 and March 2002.

	Scots pine		**European beech/Common oak**	
	November	**March**	**November**	**March**
L	36.8	30.8	17.3	28.1
F	29.3	30.4	36.6	25.5
H	58.9	42.2	70.4	34.0
Total	**41.7**	**34.5**	**41.4**	**29.2**

Thus, the differences in the portion of polysaccharides between November and March were strongest in the H horizon at both study sites: both sites revealed a relative increase in lignin of that horizon, in N compounds and in the group of other compounds, while the portion of constituents of celluloses origin decreased. This effect was evidently stronger under the deciduous stand, where the portion of compounds of celluloses origin were reduced by factor two (Tab. 6.2, Fig. 6.4). Hence, we arrived at the conclusion that (i) in contrast to lignin, decomposition products of oligo- and polysaccarides were not accumulated in the (F and) H horizon, but either directly transferred with the seepage water or, (ii) the main part is rapidly mineralised by the soil microorganisms.

6.2.1.3 N-containing pyrolysis products

Nitrogen-containing moieties can be preserved in complexes with polyphenols during decomposition and humification processes (Berg and McClaugherty, 2003; Gleixner et al., 1999; van Bergen et al., 1997). The polyphenol portion controls N dynamics and enriches soils with organic matter, where N is retained (Harborne, 1997; Northup et al., 1998). Albers et al. (2004) reported a higher N loss under spruce, while soil under beech seemed to sequester a higher amount of organic nitrogen. Generally, the N-compounds of decomposing litter pass three different processes; e.g. leaching, immobilisation and mobilisation (Berg and Staaf, 1980a,b).

In our study, generally, the relative content of N compounds [i.e. N-containing pyrolysis products (NcPP)] ranged about 5 % and differences between single organic horizons, between sites and between the two sampling occasions were comparatively low (Tab. 6.3). Yet, some certain changes between single organic horizons were observed.

Tab. 6.3: Portion (%) of N compounds (i.e. NcPP) in the L, F and H layers under Scots pine and European beech/Common oak in November 2001 and March 2002.

	Scots pine		**European beech/Common oak**	
	November	**March**	**November**	**March**
L	2.9	2.8	3.6	4.6
F	2.5	4.5	5.1	4.6
H	4.1	7.7	4.8	5.0
Total	**3.2**	**5.0**	**4.5**	**4.7**

In fall under pine, the portion of N-compounds was highest in the F horizon, indicating intensive turnover processes as already stated for lignin. Yet, in March of the following year an increase in nitrogen containing pyrolysis products [NcPP] within the organic horizons was observed (Fig. 6.4) and thus, the F and H horizon had gained portions of N compounds during the winter term (Tab. 6.3). In the beech/oak stand, the portion of NcPPs revealed no evident differences between the organic horizons and no clear change during the winter season winter (Tab. 6.3; Fig. 6.4).

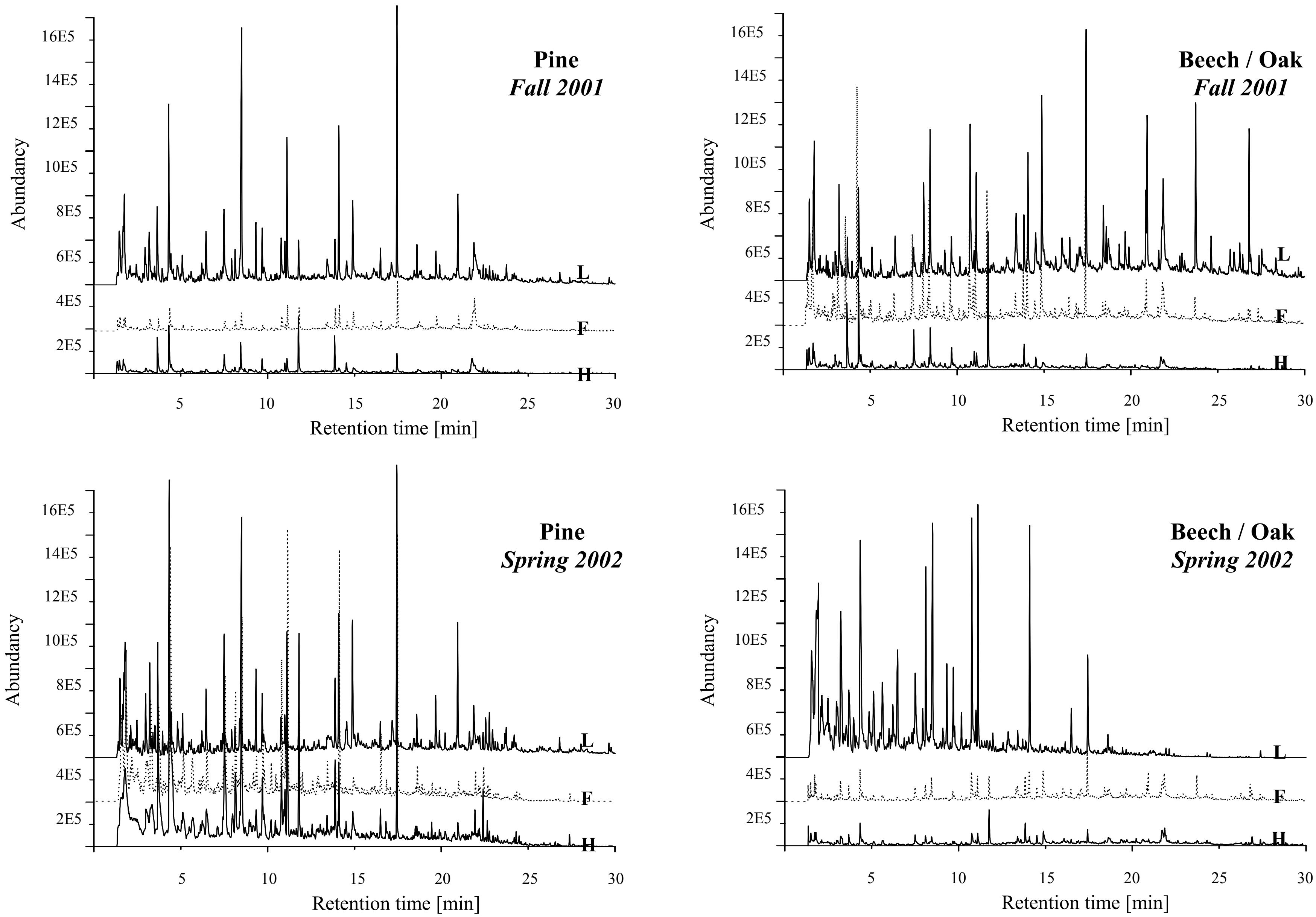


Figure 6.2: Pyrogrammes of L, F and H layers in a Scots pine and in a European Beech / Common Oak stand in fall 2001 and in spring 2002.

(Data processing and graphics by Dr. Falk Liebner).

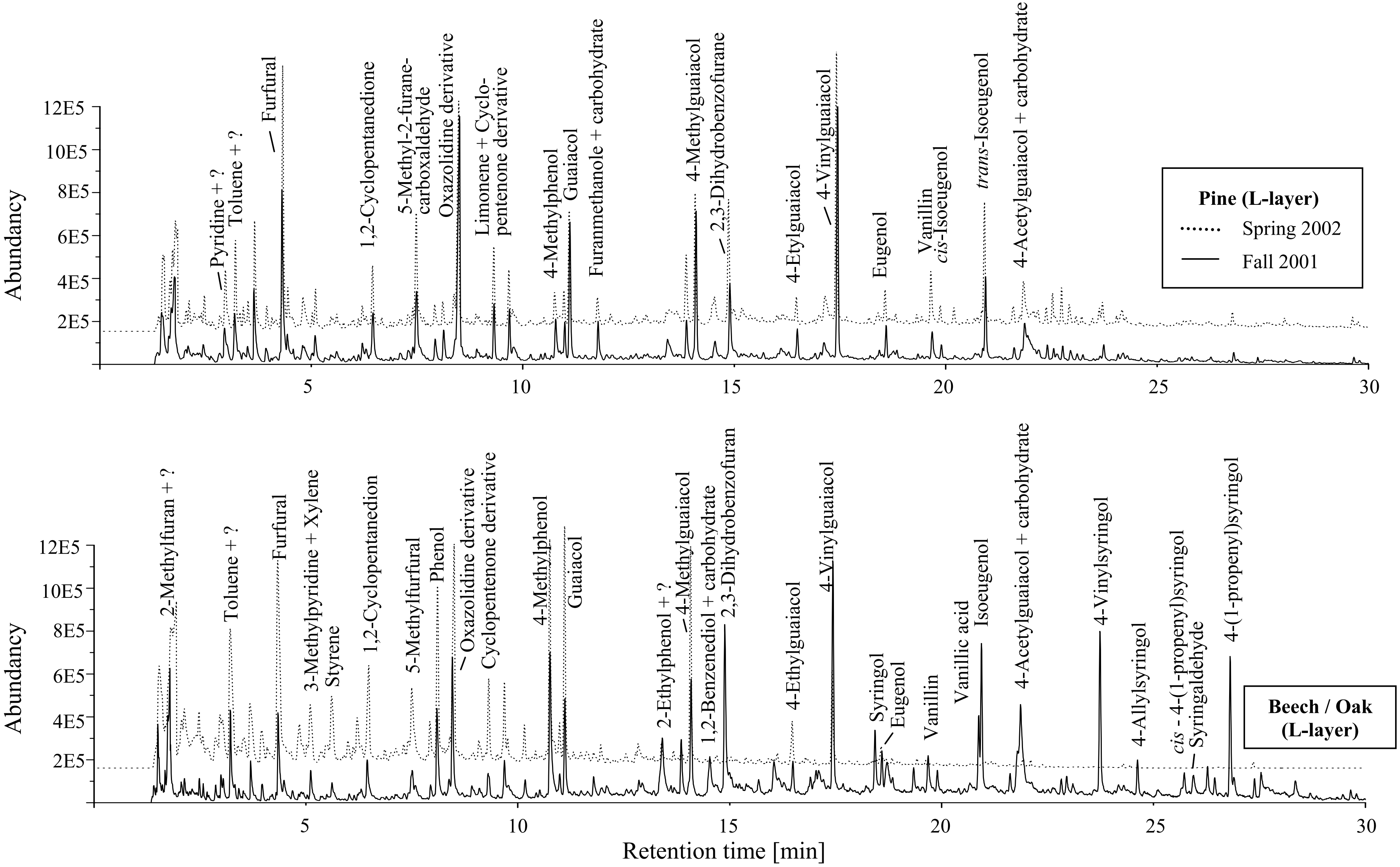


Figure 6.3: Pyrogrammes of L layers in a Scots pine (top) and a European beech/Common oak stand (bottom).

(Data processing and graphics by Dr. Falk Liebner.) ____ Fall 2001, ... Spring 2002

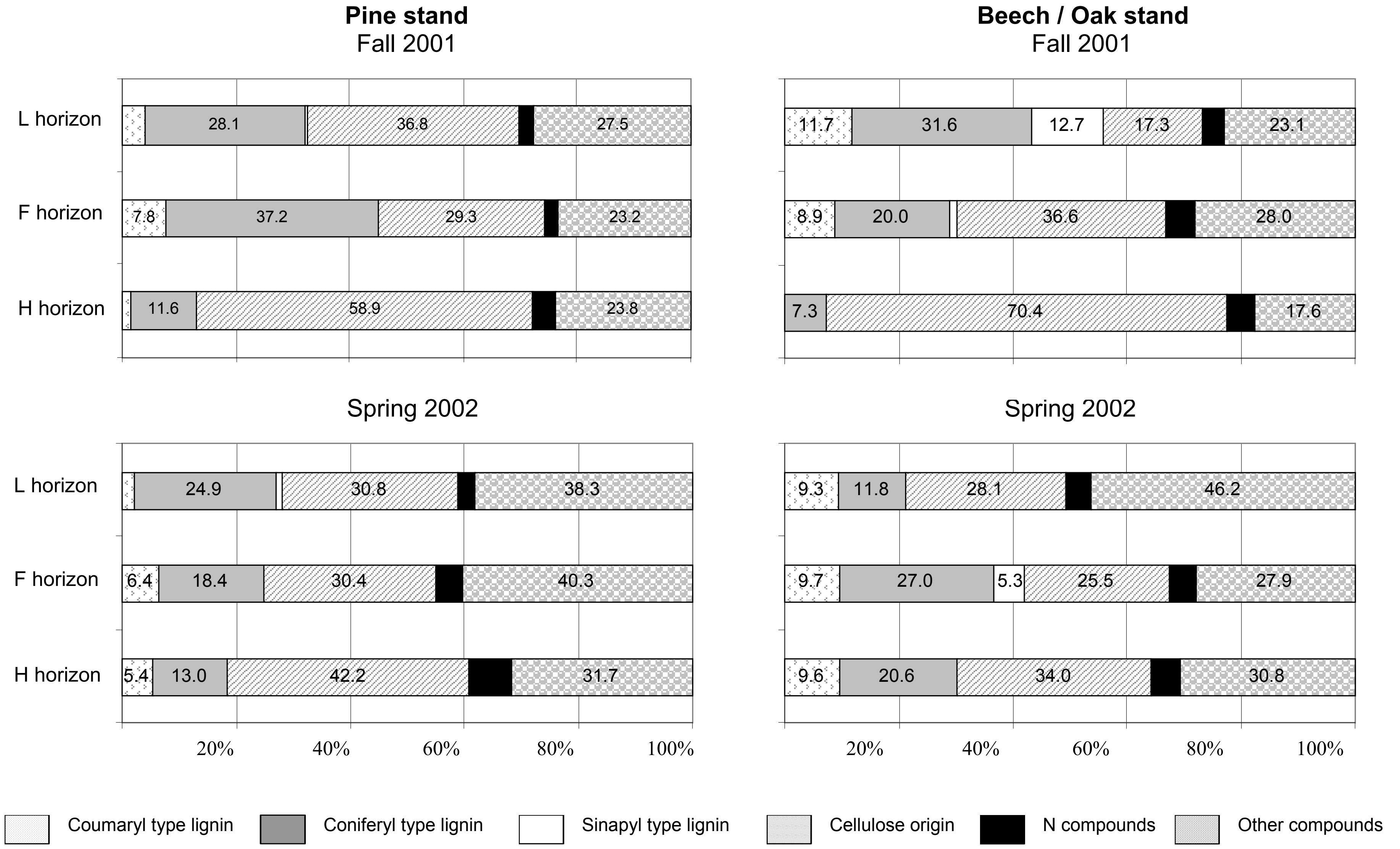


Figure 6.4: Change of the composition of L, F and H horizons under Scots pine and European beech/Common Oak from fall 2001 to spring 2002 (percentages of main substance groups were determined by Curiepoint Pyrolysis - GC / MS).

(Data processing and graphics by Dr. Falk Liebner.)

Litter decomposition is an important link in the global C cycle, as well as for nutrient dynamics and ecosystem stability. According to Kuntze et al. (1994) up to 98 % of soil-N and up to 60 % of P within a soil are bound in organic material. Yet, with 58 % carbon is the main element of litter (Ellenberg et al., 1986). Generally, the C:N:P:S ratio in soil is 100:10:1:1 (Rice, 2002).

In fall under pine, the portion of N-compounds was highest in the F horizon, indicating intensive turnover processes as already stated for lignin. Yet, in March of the following year an increase in nitrogen containing pyrolysis products [NcPP] within the organic horizons was observed (Fig. 6.4) and thus, the F and H horizon had gained portions of N compounds during the winter term (Tab. 6.3). In the beech/oak stand, the portion of NcPPs revealed no evident differences between the organic horizons and no clear change during the winter season winter (Tab. 6.3; Fig. 6.4).

6.2.1.4 Changes in organic matter quality throughout winter

The characterisation of organic matter from pine and beech/oak supports the assumption that litter decomposition under pine during the winter season is pre-dominantly restricted to the F layer as this is where changes in litter composition were found strongest. In contrast, under beech/oak organic matter decomposition during the winter season is concentrated on the L layer, where newly shed litter is decomposed, as well as on the climatically protected H horizon. In the L layer the co-metabolic degradation of lignin seemed to be evident; in the H layer the mineralisation of polysaccharides seemed to dominate (Tab. 6.1, Tab. 6.2). This outcome indicates that the specific composition of microbial biomass and its decomposition strategy are associated to the specific soil horizons.

In May 2001, high C_{mic}/C_{hwe} in the L and F layer under deciduous stands were reported - reflecting high turnover rates in these horizons, while secondary decomposition products are accumulated in the H horizon (Koch and Makeschin, 2004a,b; Chapter 4 and 5). This may support the “lignin theory”: more or less slightly modified, but decomposition-resistant plant components form the humified organic matter fraction in soil (Kögel, 1987). Gleixner et al. (2002) observed the appearance of new microbial-derived polysaccharides in a study using GC-C-IRMS in order to characterise the chemical structure and the isotope composition of organic matter. These authors observed an unexpected long life-time for N-containing (~ 49 years) and polysaccharide-derived (~ 54 years) compounds. This effect was contrary to the widely held opinion that sugars and N-derived compounds show a comparatively fast degradation (Paul and Clark, 1996). Most important compound classes formed from humification products during Curie point pyrolysis are nitrogen containing compounds (pyridins, pyrimidins, indols, oxazolidins derivatives), alkyl phenoles and polyphenoles (cresol, resorcinol, xylenol), hydrated naphthalene derivatives, alkyl and alkenyl benzenes, carboxylic acids and a smaller amount of C10 to C18 alkanes and alkenes. In our study, prove for the formation of new substances due to humification within the four months of the study was the relative increase of such substances determined in all studied horizons. This process was strongest in the L layer under beech/oak, while under pine the formation of new chemical structures was observed in all three organic horizons, although found strongest in the F horizon (Fig. 6.2, Fig. 6.3). The degradation of organic substances results in a vast number of low-molecular products, which - depending on their reactivity and combined with the structural addition of hetero atoms (N, S, O) – can react with other fragments in soil. Thus, during fall/winter the decomposition of organic matter was observed to be concentrated on the L layer under beech/oak and on the F horizon under the pine stand.

Haider and Schulten (1985) detected differences in mass spectra between lignin and fractions of humus and concluded, that the phenolic structure of lignin must be altered to a higher degree during the humification process. In contrast, investigating the structure and development of three different humus forms, Hempfling (1988) concluded that alterations of organic materials during humification is much less distinct than often thought. In accordance with our findings, Leinweber and Schulten (1999) reported a great loss in high-molecular weight compounds such as lipids and lignin along with the depletion of nitrogen in a sandy soil. Thus, our data support findings about the relatively fast initial turnover of so-called recalcitrant organic substances such as lignin in deciduous forest stands [i.e. by white-rot-fungi] and are in accordance with the findings by (Haldock and Preston, 1995; Lorenz et al., 2004; Pöhhacker, 1995).

In sum, the changes in lignin during the first four months after litter fall were (i) restricted to changes in portions of the different lignin derivates, i.e. by de-methoxylisation, (ii) changes in the lignin portion between single organic horizons, and (iii) the real loss of lignin was linked to a co-metabolic decomposition as the total lignin portion in the organic layer revealed no difference between the two sampling times. The degradation of oligo- and polysaccharides seemed to occur (i) during the co-metabolic lignin degradation and was found to be (ii) dominant in the H layer at both stands – possibly related to climatic conditions and a horizon-specific microbial community. The portions in NcPP were not distinct between sites and horizons.

6.2.2 Microbial Biomass and Activity

The content of microbial biomass C is an indicator of the living biomass in soil and commonly used accepted as indicator for organic matter turnover and nutrient cycling (Gregorich et al., 2000; Scheu and Parkinson, 1995; Wardle and Lavelle, 1997). Potential C mineralisation serves as indicator for microbial activity (Saetre et al., 1999; Tate et al., 1993). Generally, microbial biomass and potential C mineralisation under beech/oak exceeded those under pine. In average, the organic layer under the deciduous stand contained 4.9 mg C_{mic} g^{-1} and thus, a by 10.7 % higher microbial biomass than the organic layer under pine revealing 4.4 mg C_{mic} g^{-1} between November and March (Fig. 6.5 and 6.6). These differences were in particular obvious for the L layer, where microbial biomass in the deciduous stand exceeded C_{mic} under pine by 19% during the first 4 months after litter fall (Fig. 6.5).

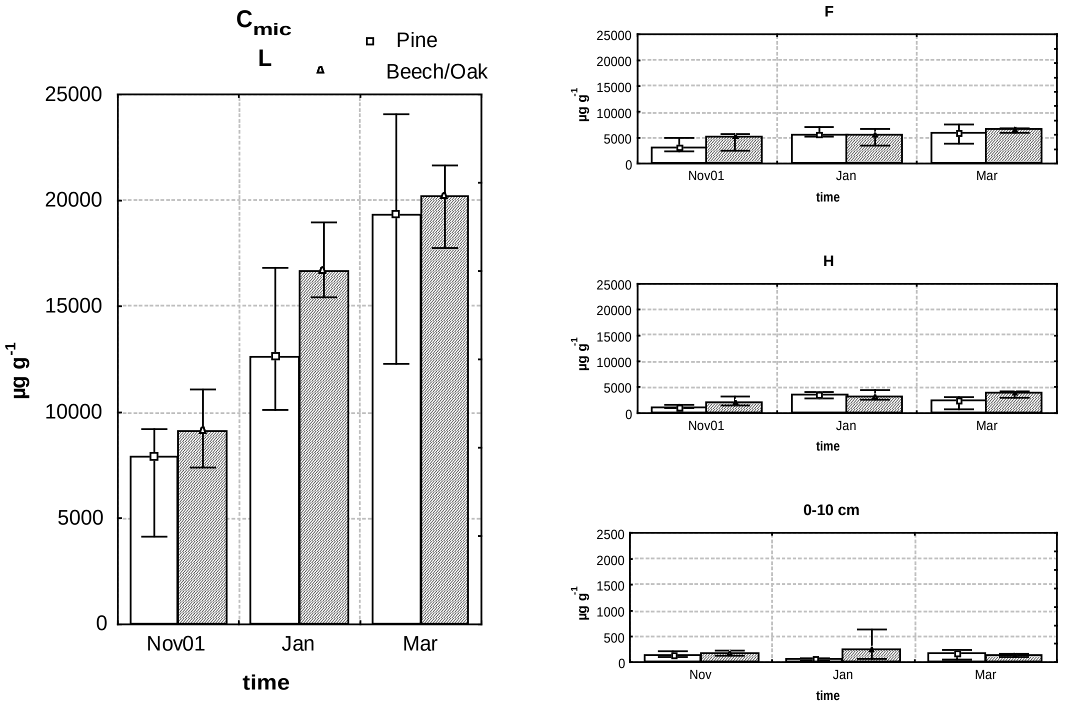


Fig. 6.5: Microbial biomass (C_{mic}) in the organic layer (L, F and H) and upper mineral soil (0-10 cm) in November 2001, January 2002 and March 2002 under the studied Scots pine and the European beech/Common oak stand.

Additionally, potential C mineralisation is by factor 2.7 significantly higher in the L layer under the deciduous stand in November, when newly shed beech/oak litter is rapidly involved into decomposition processes (Fig. 6.6). This result underlines our report on an active organic matter turnover of beech/oak litter right after fall – although being comparatively rich in lignin compounds (Fig. 6.4). In accordance to our results, Zhong and Makeschin (2004) observed a stronger increase of microbial biomass beneath beech trees than beneath pine and spruce after litter shed in November. In January, microbial activity under beech/oak still exceeded the C mineralisation rate under pine evidently (Fig. 6.6). Yet, in March, mineralisation of the pine needles that have been suffering a physical degradation during winter [i.e. by frost and thaw] increased strongly and was by factor 1.3 higher than under beech/oak (Fig. 6.6). Although differences in potential C mineralisation were not evident in the H horizon, in the F layer microbial respiration under beech/oak was by factor 1.6 higher than under pine (Fig. 6.6). This horizon was reported to reveal a most obvious difference between both stands due to a 68 % higher C mineralisation rate during a one-year-study (see Chapter 8), and is thus, an indicative horizon for studies on stand-specific turnover dynamics. In average of the organic layer, microbial respiration under beech/oak accounted for 148.10 µg CO_2 g^{-1} h^{-1} and thus, exceeded the potential C mineralisation of 113.15 µg CO_2 g^{-1} h^{-1} under pine by 30.8 % during the time between November and March.

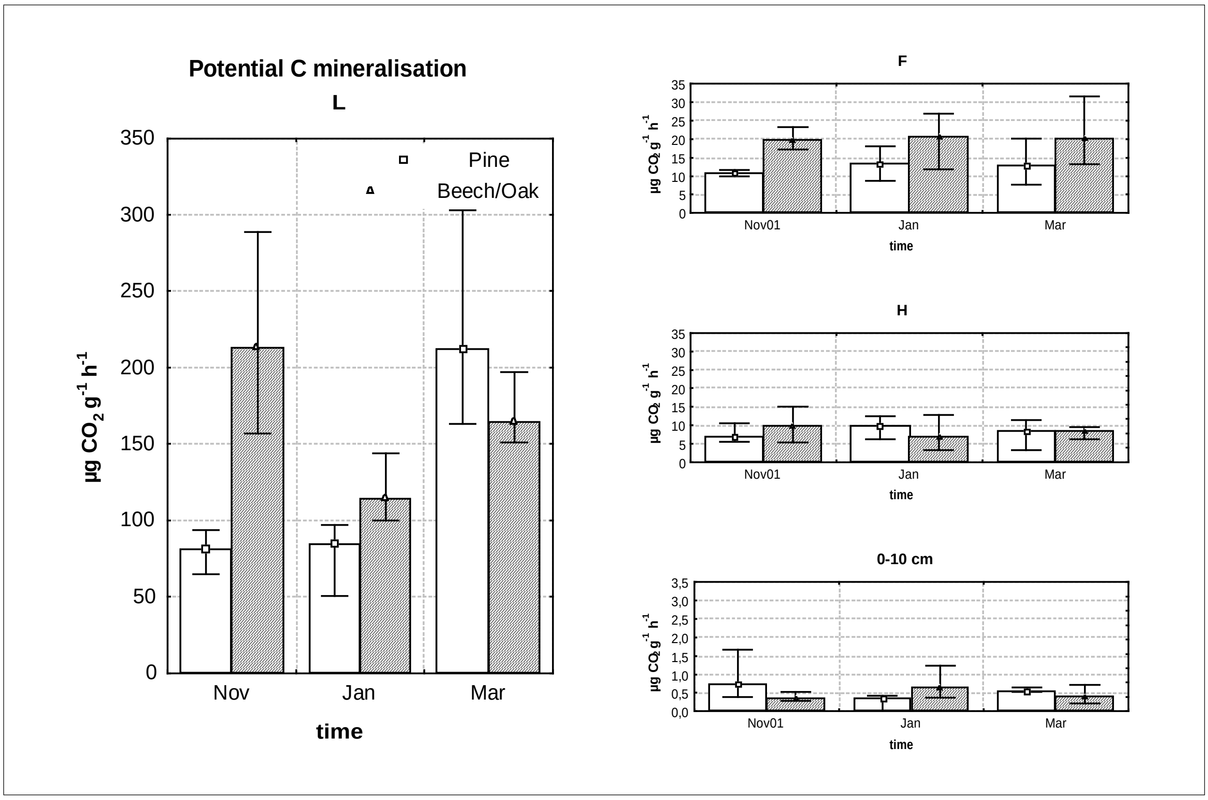


Fig. 6.6: Potential C mineralisation (at 15℃) in the organic layer (L, F and H) and upper mineral soil (0-10 cm) in November 2001, January 2002 and March 2002 under the studied Scots pine and the European beech/Common oak stand.

6.2.3 Water-extractable C Fractions

Water (and salt) extractable C and N fractions served as indicators for medium-term and readily decomposable C and N in the past (Schulz, 1990; Körschens et al., 1998) and have been verified as suitable parameters for the evaluation of organic matter dynamics in soil (Jandl and Sollins, 1997; Landgraf and Klose, 2002; Mazzarino et al., 1993; Zhong and Makeschin, 2004). Yet, their composition and structure have not been fully explained so far (Chodak et. al, 2003) and thus, the turnover rate and attraction of these semi-artificial C pools towards microbial decomposition is not yet entirely known. Recently, the composition of both fractions was compared by pyrolysis-field ionization mass spectrometry and subsequently, the hot water-extractable fraction was approved as better predictor of easily decomposable organic matter than the cold water extract (Landgraf et al., 200_).

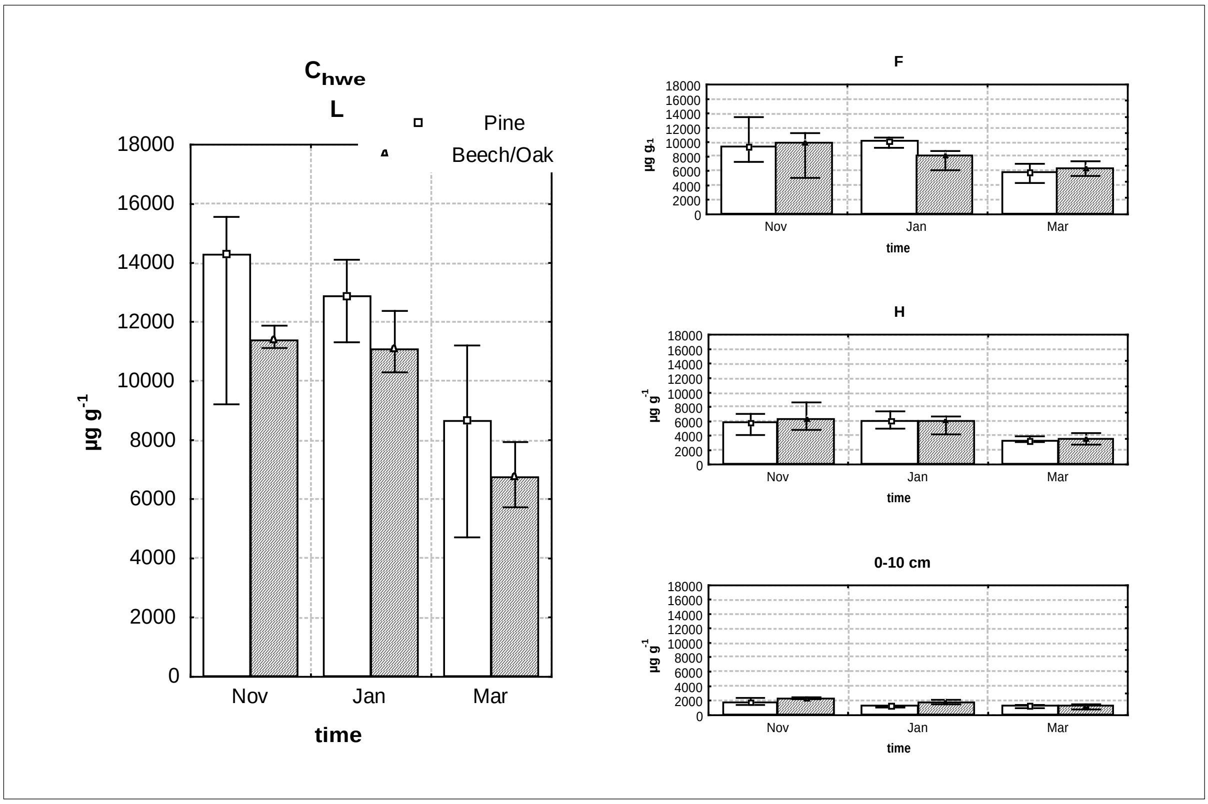


Fig. 6.7: Hot-water-extractable C (C_{hwe}) in the organic layer (L, F and H) and upper mineral soil (0-10 cm) in November 2001, January 2002 and March 2002 under the studied Scots pine and the European Beech/Common oak stand.

In our study, the comparatively high microbial activity under beech/oak resulted in lower contents of water-extractable carbon during the winter-term – especially in the L and F layer of this site (Fig. 6.7 and 6.8). The coherence of a high microbial biomass and lower contents of easily available organic matter is conceivable as these fractions are actively involved into C cycling (Franzlübbers, 2001, Gregorich et al., 2000).

In average of the organic layer, contents of easily decomposable organic matter (as determined by C_{hwe}) revealed a difference of –11.5 % under beech/oak as compared to pine; the cold water-extractable C was in average 23.2 % less under the deciduous stand (Fig. 6.7 and 6.8). Landgraf et al. (200_) determined higher shares of easily decomposable compounds such as carbohydrates, phenols and lignin monomers, and heterocyclic N-containing compounds and peptides in the hot water extract applying pyrolysis-field ionization mass spectrometry (Py-FIMS). The quality of the organic layer under both stands has to be evaluated sophisticated as contents differed: The L and F layer under beech/oak contained 14.3 % and 7.6 % less hot water-extractable C. This outcome indicates a rapid turnover of easily available organic matter in the newly shed deciduous litter (Fig. 6.7). In contrast, the H horizon revealed no distinct difference between the beech/oak and pine stand, although in spring generally easily available organic matter seemed to be used up rapidly under pine as contents were lower at this time than under the deciduous stand (Fig.

6.6 and 6.7). We assume that the turnover of C_{hwe} is related to the strong increase in potential mineralisation under pine at this time (Fig. 6.6).

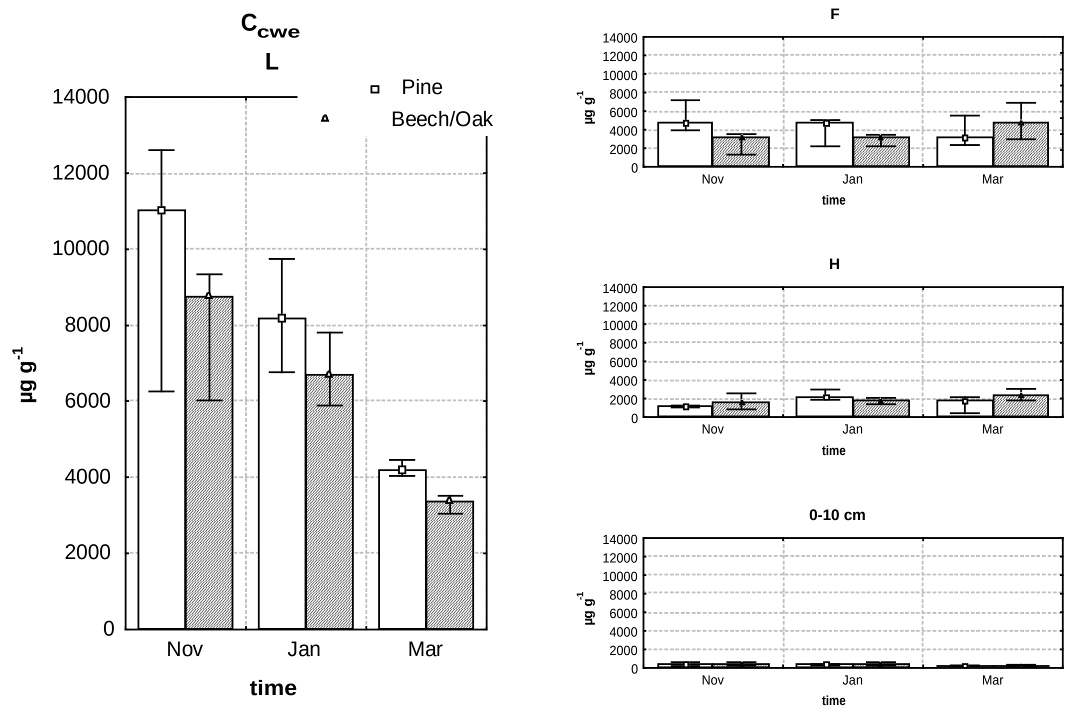


Fig. 6.8: Cold-water-extractable C (C_{cwe}) in the organic layer (L, F and H) and upper mineral soil (0-10 cm) in November 2001, January 2002 and March 2002 under the studied Scots pine and the European beech/Common oak stand.

6.2.4 Water-soluble Organic Carbon

Generally, the water-soluble and thus, potentially transferable C fraction revealed no such great differentiation between the two study sites as determined for the water-extractable fractions. Yet, an evident increase was observed in the L layer in March at both sites, when the WSOC contents under pine exceeded those under beech/oak (Fig. 6.9). At the same time microbial respiration under pine had increased evidently (Fig. 6.6). Thus, at conditions favorable for microbial decomposition [i.e. addition of available litter compounds and/or climatic conditions] water-soluble organic compounds are produced (Anderson and Nilsson, 2001).

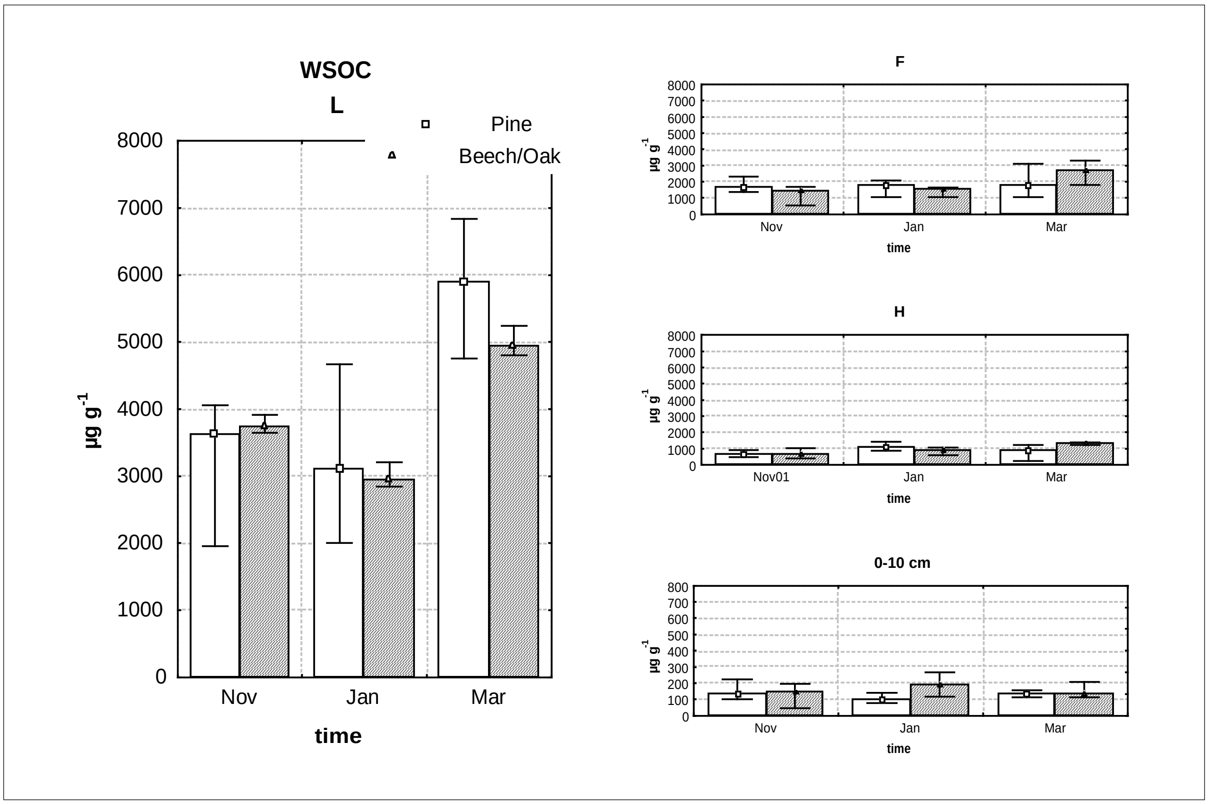


Fig. 6.9: Water-soluble organic C (WSOC) in the organic layer (L, F and H) and upper mineral soil (0-10 cm) in November 2001, January 2002 and March 2002 under the studied Scots pine and the European beech/Common oak stand.

In our study, contents of WSOC ranged in average of the 4 months between 863.4 µg g^{-1} in the H horizon under pine and 4,022.7 µg g^{-1} in the L layer under beech/oak; upper mineral soil contained clearly less WSOC of 132.4 µg g^{-1} (pine) and 158.8 µg g^{-1} (beech/oak) (Fig. 6.9, Annex A31). Thus, the results are evidently higher as compared to arable soils (McGill et al., 1986), but in the range of organic layers in forest soils reported from other studies (Scheuner, 2004). Dissolved organic matter (DOM) supports bacterial growth, although the portion of mineralized water-soluble organic matter was found to be only about 33 % (Qualls and Haines, 1992). Instead, initial litter decomposition is primarily characterized by the loss of water-soluble organic compounds, i.e. by leaching (Berg and Mc Claugherty, 2003; Gödde et al., 1993).

The loss of dissolved organic matter was found to be up to factor 3 greater under conifers than under deciduous stands (Michalzik, 1999; Qualls and Haines, 1992). On the other hand, coniferous needle litter may be more resistant to leaching during the first phase of decay as the wax layer offers protection (Berg and Staaf, 1980a,b). We found in average of the organic layer the difference in WSOC content between the two study sites during winter-term was 7.0 % resulting of the higher microbial activity beneath the deciduous stand.

6.3 Summary and Conclusion

In November 2001, the newly shed beech/oak leaves revealed a nearly twice as high portion of lignin of 56.0 %, while the L layer under pine revealed only 32.8 % lignin. In contrast, the portion of compounds of celluloses origin was in the L layer under pine with 36.8 % evidently higher than with 17.3 % under beech/oak in fall 2001 and slightly lower in the F and H horizons. N-containing pyrolysis products accounted for less than 5 % in the organic horizons under both stands. Thus, no qualitative advantage of beech/oak leaves was detected as compared to pine needles.

However, in sum of the organic layer the total portion of lignin, celluloses and N-containing pyrolysis products did not differ distinctively between the sites. Yet, both sites revealed evident differences in their dynamic of lignin degradation during the winter season: Under beech/oak changes in organic matter quality were characterized by the relative reduction of lignin in the L layer along with a clear relative increase in the F and H horizon. This may indicate that (i) the microbial community in the L horizon is specialized on decomposition of lignin [i.e. white-rot fungi], and (ii) the composition of microbial biomass in the F and H layers is different and possibly rather feeding on other organic compounds [i.e. proteins, hemicelluloses and celluloses]. In contrast, under pine the relative loss of lignin was most pronounced in the F layer and the distribution of compound classes in the H horizon was changed towards a higher lignin portion. On the one hand the relative loss in lignin in the F layer may indicate a real loss of lignin structures that might possibly have to undergo a first breakdown of the wax-layer before then, in the F layer, lignin structures may be broken down. On the other hand an increase of other constituents, that possibly may result from the litter decomposition in the L layer, may be indicated.

During the 4 months observed, the organic layer at both sites revealed a relative increase in lignin in the H horizon, in N compounds and in the group of other compounds, while the relative reduction of constituents of celluloses origin was strongest in that horizon. This effect was evidently stronger under the deciduous stand, where the portion of compounds of celluloses origin was reduced by factor two. Hence, (i) the main part of oligo- and polysaccharides is rapidly mineralised by the soil microorganisms and/or (ii) lignin and other organic compounds have been transferred to the H horizon [i.e. by seapage water or bioturbation]. Differences in the relative content of NcPP between single organic horizons, between sites and between the two sampling occasions were comparatively low.

Microbial biomass and activity in the organic layer under beech/oak exceeded those under the Scots pine stand by 10.7 % and 30.8 %, respectively. These differences were most evident in the L layer. Yet, in March, decomposition of pine needles that have been suffering a physical degradation during winter [i.e. by frost and thaw] is by factor 1.3 higher than under beech/oak. The comparatively high microbial activity under beech/oak resulted in lower contents of water-extractable carbon – especially in the L (and F) layer under beech/oak. In average of the organic layer, C_{hwe} and C_{cwe} revealed by 11.5 % and 23.2 % lower contents under beech/oak than under pine. In contrast, the WSOC content between the two study sites revealed no evident differences – neither with regard to single organic horizons, nor to the total of the organic layer.

Conclusively, the litter quality of beech/oak litter was not in advantage of the pine needles. Yet, the site- and stand-specific microbial community seems to be adapted to the respective litter quality. Thus, microbial activity was evidently higher under the deciduous stand and thus, turnover dynamics during the fall/winter season exceeded those under pine. As the wax layer of pine needles undergoes distinct degradation processes by frost and thaw, mineralisation rates of the litter material increased evidently in March and exceeded those in the L layer under beech/oak at this time. At times favorable for microbial activity readily available organic fractions [i.e. hot water-extractable C] decrease. Thus, shortly after litter fall these available fractions are rapidly involved into the decomposition dynamics. Consistently, the contents of water-extractable C fractions declined during the winter-term. Water-soluble organic matter represents the soil leachate and partly was mineralized. Thus, although differences between pine and beech/oak may be small considering quality of the total organic layer, specific turnover dynamics take place regarding single organic horizons, revealing (i) a high rate of decomposition and organic matter quality changes throughout winter and (ii) specific turnover dynamics depending on forest vegetation.

7 Litter Turnover in a Scots pine and a European beech/Common oak forest in the Saxonian Lowland.

7.1 Objectives

The objectives of this part of the study are

(i) to assess litter amount, microbial biomass and potential C mineralisation as well as contents of water-soluble carbon during a 12 months study comparing a pine stand and a beech/oak forest in nature reserve in the Saxonian lowland, and

(ii) to evaluate mean residence time and turnover rate of both stands.

Tab. 7.1: Basic morphological and chemical properties of the organic layer (L, F and H) and upper mineral soil (0-10 cm) under the Scots pine and European beech/Common oak stand [data obtained during a soil inventory performed in May 2001].

	Scots Pine				European Beech/Common Oak			
	L	F	H	0-10 cm	L	F	H	0-10 cm
thickness [cm]	2.7	2.3	1.7	-	2.3	2.0	3.2	-
mass [t ha^{-1}]	41.3	55.1	83.6	1067.0	26.1	72.1	97.8	1346.8
pH$_{(CaCl2)}$	3.8	3.4	3.4	3.8	4.0	3.3	3.2	3.4
NH$_4$Cl-extr. basic cations [%]	81.5	48.1	25.2	13.9	83.3	60.1	36.4	14.5
TOC/TN	27.5	22.4	23.2	24.7	26.5	22.8	23.0	24.3

7.2 Results and Discussion

7.2.1 Amount of Litter

The total amount of litter collected during one year (November 2001 to October 2002) added up to 502.7 g m^{-2} in the pine and to 625.5 g m^{-2} in the beech/oak stand. The portion of leaves/needles on the total litter amount was 62.4 % and 52.8 % for pine and beech/oak, respectively. However, the total litter amount [i.e., sum of leaves, twigs, seeds] of 6.25 t dry mass ha^{-1} shed in the beech/oak stand exceeded the 5.03 t dry mass ha^{-1} in the pine stand by 24 % (Tab. 8.1). Our results are principally comparable to the data of Reichle (1981), Ellenberg (1986) and Berg et al. (1999a), although within the upper range of published data. Litter fall data do vary in a wide range as they strongly depend on climatic conditions and weather. Yet, comparing deciduous forests with coniferous stands slightly higher amounts of litter in deciduous stands have been observed in various studies (Ellenberg, 1986; Liu et al., 2000) as well as calculated by model projections (Weiss et al., 2000). Thus assuming a C content of 58 % [as reported by Ellenberg, 1986], the addition of litter-derived C was approximately 2.9 t C ha^{-1} and 3.6 t C ha^{-1} in the pine and beech/oak stand, respectively.

7.2.2 Litter Decomposition in the Field

The litter decomposition results of the litter bags exposed to field conditions revealed generally a similar trend as reported for the potential C mineralisation of the collected L layer samples determined at 15 °C incubation in the lab (Fig . 7.1, Fig. 7.2). Yet, litter decay rates did not reflect the peaks observed in C mineralisation in spring and fall (Fig. 7.2).

During the first two months [i.e., November to January] the mass loss of pine needles clearly exceeded mass loss of deciduous litter (Fig. 7.1). This might indicate a stronger effect of sample preparation [i.e., shredding] on the decomposition of pine needles than of leaf litter, that may have enhanced leaching. Yet, until March also the reference litter [beech/oak litter exposed at the pine stand] revealed a higher mass loss than beech/oak litter (Fig. 7.1). This observation supports our assumption of a significant stand structure-specific influence - additional to the impact of resource quality and composition of the site-adapted soil organisms population.

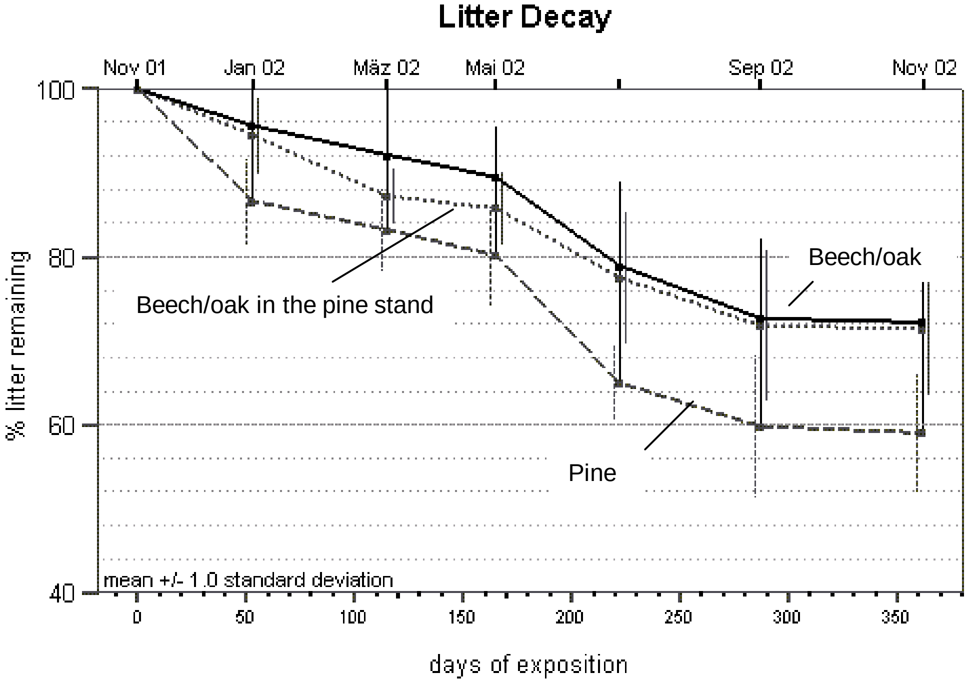


Fig. 7.1: Litter decay rates in a Scots pine and in a European beech/Common oak stand in the Saxonian lowland between November 2001 and November 2002.

The faster decomposition rate of pine as compared to beech/oak was especially obvious during the summer months [i.e., May-July], when only 65.0 % of pine litter, but still 79.0 % and 77.5 % of beech/oak leaves and reference litter remained in the bags (Fig. 7.1). In contrast to the turnover dynamics observed in fall and winter, this difference is assumingly rather related to litter quality than to stand characteristics as the decomposition rate of the reference litter was towards the end of the study [i.e., July to November] similar to the beech/oak litter exposed in the beech/oak stand. Then, until fall 2002, the decomposition rates of pine and beech/oak litter remained at a more or less constant level (Fig. 7.1).

In sum, the mass loss of pine litter during the years course was significantly higher (Games-Howel-Test: $p < 0.039 – 0.000$) than of beech/oak leaves and as compared to the reference litter (Stuhlmann, 2005). At the end of the study, in November 2002, mass loss accounted to 41.2 % of pine litter, 27.8 % of beech/oak and 28.6 % of the reference litter (Fig. 7.1).

Our results confirm findings by Jörgensen (1991) and Wise and Schaefer (1994) who reported a mass loss of about 30 % of beech leaves during the first year as well as by Albers et al. (2004), who documented a mass loss of beech litter of ca. 60 % after a 24 months exposure. Sots pine needle decomposition was characterized by a loss of 25.8 – 28.2 % after 12 months observation (Berg and Staaf, 1980b). The similarities observed in our study in litter decomposition patterns between beech/oak and the beech/oak litter exposed at the pine stand were potentially the result of (i) the impact of litter quality dominating the impact of site characteristics between the pine and the beech/oak stand on litter decomposition during initial decomposition, and (ii) an indicator for a not as flexible microbial population under pine specialized on the consumption of rather site-specific litter.

7.2.3 Mean Residence Time and Turnover Time

The mean residence time (MRT) can be calculated if the in- or outflows of a soil horizon are known [i.e., litter-C input] and equals for the L layer the reciprocal of the decay rate k of leaves [MRT=1/k] (Persson et al., 2000). Thus, assuming an exponential decay function, the MRT is the time that is needed to decompose 63 % of the initial amount of organic matter, where “t_{63}” = $\ln(0.37)/-k$ ˜ $1/k$ (Mund, 2004). In our study, k accounted for 0.54 under pine and for 0.33 under beech/oak after one year exposure of the litter bags. Thus, the MRT obtained for pine litter is 1.85 years and for beech/oak 3.03 years – revealing a faster turnover of pine needles than of beech/oak litter. This result supports our findings of a comparatively active C turnover in the L layer under pine as determined by pot. C mineralization (mainly during summer), while under beech/oak the microbial activity throughout the year is rather found in the F layer – subsequent an active initial phase after litter fall (Fig. 7.2).

As our data do not allow to calculate fluxes for singles horizons, the turnover time for the total organic layer is calculated, representing the time which is necessary for the decomposition of 95 % of the initial amount of leaves (“t_{95}” = ln(0.05)/-k) (Harmon et al. 1986). In availability of the respective data, the turnover rate can easily be calculated by the ratio of TOC stored in the organic layer and the C-input by litter (Tab. 7.2). Yet, this simplification does neither take the natural differences in litter amount during the stand history into account nor the length of the stand specific humus accumulation period.

Tab. 7.2: Turnover time of organic matter within the total organic layer of the Scots pine and European beech/Common oak stand [calculated with TOC stocks determined during the soil inventory in May 2001 and C-input by litter collected between November 2001 and November 2002].

	TOC stored in the organic layer	**C- input (by litter)**	**Turnover Rate**
	[t tha^{-1}]	[t tha^{-1}]	[years]
Pine	47.2	2.92	**16.2**
Beech/Oak	60.4	3.57	**16.9**

Additionally, a possible impact duo to management influences during the past century may have to be taken into consideration. To the best of our knowledge there was no forest litter raking in the pine stand. We assume that it is the second or third generation of pine at that site and that the site was influenced by clearcutting and burning of brushwood during the past about 200 years – resulting in a loss of nutrients. Additionally, the beech/oak reserve is older than the pine stand – as caused by management strategies – and various authors have reported on humus accumulation in old-growth forest stands (Entry and Emmingham, 1998; Berg and McClaugherty, 2003). Yet, these effects are characteristic for forest management during the past stand generations [i.e., beginning in the middle of the 19th century]. However, the relations drawn by the parameters involved clearly reveal (i) a fast decomposition of beech/oak litter during the initial decomposition phase in fall (Fig. 7.2) and, (ii) a slightly slower decomposition beneath a canopy of European beech/Common oak as compared to Scots pine [as adressed to the total organic layer]. Thus, the organic matter in the comparatively thick H horizon beneath beech/oak (Koch and Makeschin, 2004a,b) has been most probably accumulated slowly - during the long-lifetime of the deciduous stand of more than 200 years and may additionally in part result from the vegetation cover before.

7.2.4 Microbial Biomass and Respiration

The microbial biomass (C_{mic}) is a source and sink of biologically mediated nutrients and responsible for transforming soil organic matter (SOM) (Gregorich, et al., 2000). An understanding of the cycling of soil organic carbon is of particular interest for several reasons: (i) the C_{mic} is a transformation pool for at least 80 % of the SOM (Andres, 1984), (ii) the C_{mic} is a functionally relevant carbon pool (as opposed to those defined by various operational methods of separations), and (iii) the C_{mic} is sensitive to changes in soil management [i.e., as forest conversion], and thus, provides an indicator of long term effects on SOM as a whole (Ryan et al., 1995).

In our study, microbial biomass and potential C mineralisation rates in the L layer generally exceeded those of F and H horizons (Fig. 7.2). The comparatively great difference in potential C mineralisation between these horizons is most certainly related to the high carbon and nutrient availability in fresh leaves, but might also be a result of the cutting to pieces of fresh litter material to ensure homogenous samples prior analyses (Schinner et al., 1995; Keplin et al., 1999).

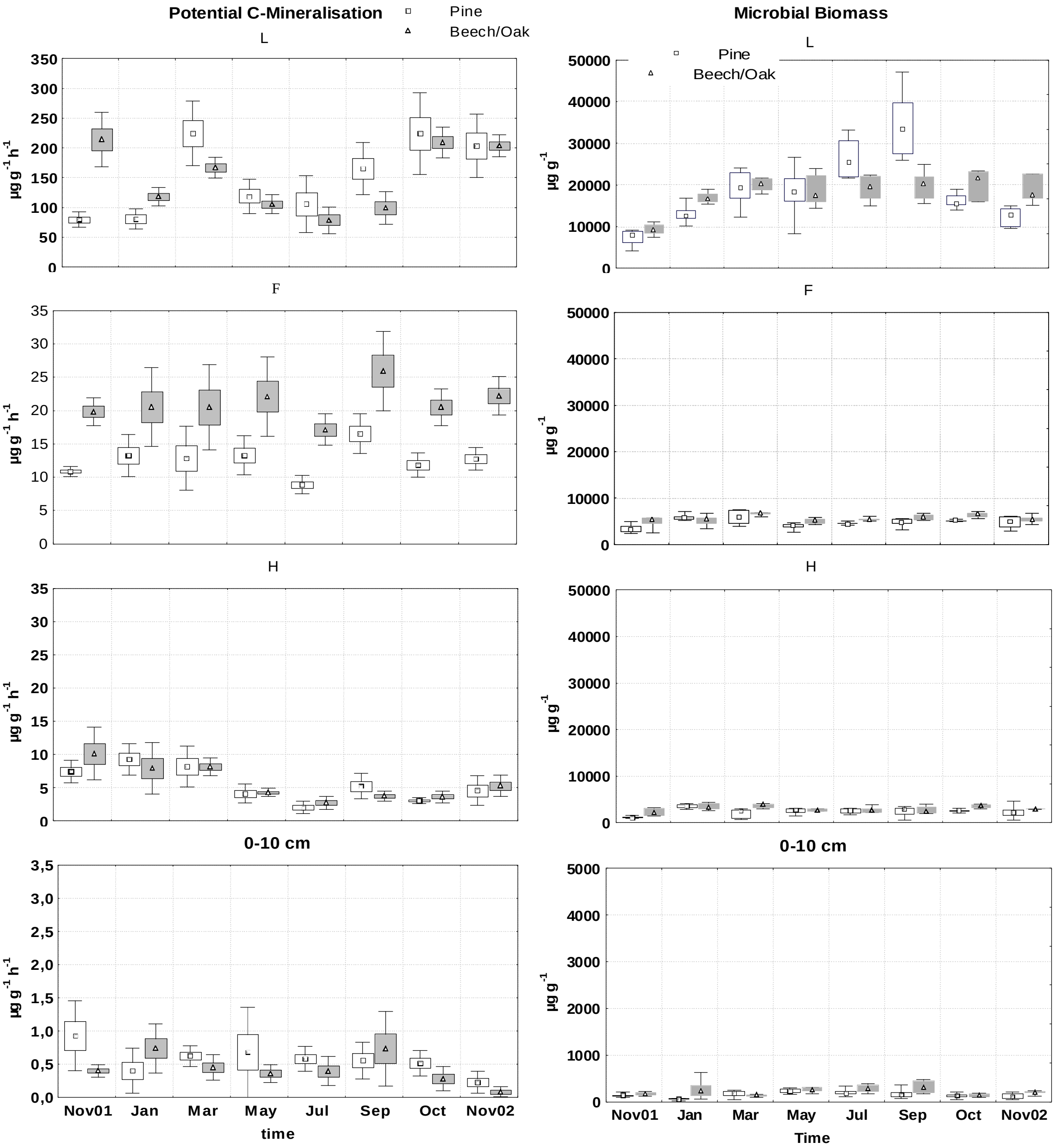


Fig. 7.2: Potential C mineralisation and microbial biomass in organic layers (L, F and H) and upper mineral soils (0-10 cm) in a Scots pine and in a European beech/Common oak stand in the Saxonian lowland during the course of one year between November 2001 and November 2002.

In accordance with Beyer et al. (1993) and Berg et al. (1998), the dynamic of both parameters during one year is characterized by peaks in the L horizon in spring (March) and another one in fall (October). These findings are likely to be related to the favorable climatic conditions [i.e., temperature and precipitation] during the 10 days before soil sampling (Fig. 7.4).

In contrast, a depression of microbial biomass content and potential C mineralisation was observed in summer and winter as caused by drought and cold (Fig. 41 and 42). Yet, some studies on organic matter turnover in forest soils revealed other results, i.e., a maximum of microbial biomass in summer (Diaz-Ravina et al., 1995; Dilly and Munch, 1996) or no clear variation with season (Bauhus and Barthel, 1995). These different results possibly may reflect the impact of stand density and structure.

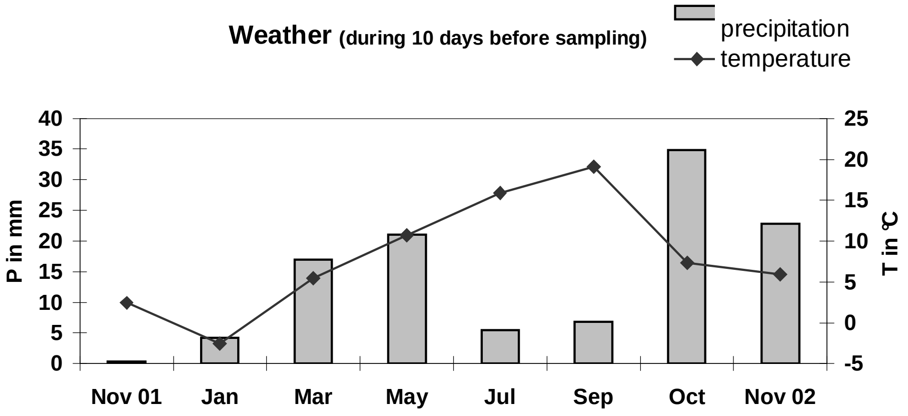


Fig. 7.3: Average monthly air temperature and precipitation at Falkenberg (ca. 1 km from the study sites) during the 10 days before each sampling time [time between November 2001 and November 2002].

Generally, the effects of temperature and moisture extremes were stronger in the organic layer under the comparatively open pine stand than under the closed canopy and thus, rather even conditions under beech/oak.

On average of the year, microbial biomass under pine accounted to 18.4, 4.6 and 2.4 mg g^{-1} and under beech/oak to 18.4, 5.6 and 3.1 mg g^{-1} for L, F and H, respectively (Tab. 8. 3). Thus, for the F and H horizon the results of one year reveal higher C_{mic} contents under beech/oak than under pine (Fig. 7.1). Additionally, although microbial biomass was much less in the upper mineral soil (0-10 cm) than in the organic layers, the content of 0.23 mg g^{-1} under beech/oak accounts for factor 1.5 of the 0.15 mg C_{mic} g^{-1} under pine. This result is most probably related to the higher TOC content within the upper mineral soil in deciduous stands (Chap. 5; Prietzel, 2004). Caused by the different mass of the organic layer between the pine and the beech/oak stand stocks of microbial biomass were by 6.9 % higher in the F horizon under pine; in contrast in the H layer and upper mineral soil of the beech/oak stand C_{mic} exceeded the stocks under pine by 82.1 % and 89.4 %, respectively. In the L layer, no distinct differences were found in sum of the year neither in contents nor in stocks of microbial biomass between the two investigated sites. Yet, dynamics of the microbial population during the year differed and biomass increased during summer especially in the L layer under pine, while the rather even climatic conditions under the closed canopy of beech/oak resulted in a comparatively constant C_{mic} content (Fig. 7.2). In sum of the organic layer, microbial biomass under beech/oak was with 0.87 t C_{mic} ha^{-1} evidently higher than the 0.75 t C_{mic} ha^{-1} under pine (Tab. 8.1).

Potential C mineralisation revealed similar values in mean of the year between pine and beech/oak in the L and the H layer (Fig. 7.2). Yet, the F horizon revealed a potential C mineralisation that was evidently higher under beech/oak than under pine ($p \leq 0.01$) (Fig. 7.2). In sum, microbial activity of the organic layer under pine amounted to 29.3 t CO_2 ha^{-1} a^{-1} and under beech/oak 33.0 t CO_2 ha^{-1} a^{-1} and was thus, in total 12.8 % higher under the deciduous stand (Tab. 8.2). Upper mineral soil revealed no evident differences between sites (Tab. 8.1).

Deciduous litter is commonly known to reveal a higher C mineralisation than coniferous needles. Comparing beech and spruce, Albers et al. (2004) reported on 12 % higher C_{mic} and a by 25 % higher potential C mineralisation under beech as compared to spruce. Similar to our results, a difference in soil respiration between coniferous and deciduous forest stands of 10 % was reported by Raich and Tufekciogul (2000) based on a literature review.

Yet, in our study higher C mineralisation rates were observed under pine than of beech/oak litter (L horizon) during the warmer months [i.e., March to September]. We arrived at the conclusion that this effect can be explained by the comparatively active initial decomposition immediately after litter fall under beech/oak and the comparatively open canopy of pine allowing in summer a higher radiation at the forest floor under pine than under beech/oak. Thus, we assume that under beech/oak fairly easily decomposable compounds [i.e., soluble or small particular organic matter] have been used-up right after litter fall and/or transferred into deeper soil horizons [i.e., F and H horizon] after their initial breakdown in fall [i.e., by seepage water or bioturbation]. This assumption is underlined by the evidently higher potential C mineralisation in sum of the year in the F horizon [i.e., 68.4 % higher under beech/oak as compared to pine] (Fig. 7.2). In contrast, initial litter decomposition (as determined by C mineralisation) under pine started later than under beech/oak, in spring, when the pine litter had been exposed to the climatic influences during fall and winter, and thus, the wax layer had undergone a physical degradation. The microbial activity in the L layer of the pine stand continues to be comparatively high during the summer months. These findings may indicate a higher tolerance of soil microorganisms under pine stands towards drought and certainly reveal the positive impact of ground vegetation (*Calamagrostis epigeios* L.). In the H layer potential C mineralisation rates differed not significantly, but upper mineral soil revealed evidently lower mineralisation rates of 0.56 and 0.43 µg CO_2 g^{-1} h^{-1} for pine and beech/oak, respectively (Fig. 7.2).

7.2.5 Specific Respiration Rate

The relation between potential C mineralization and microbial biomass serves as a measure for the efficiency of the microbial biomass and its maintenance requirement. At both sites the qCO_2 [i.e., specific microbial respiration rate or metabolic quotient] was evidently higher in the L layer than in the F and H layer underneath and in mineral soil. Highest values were found in the L horizon in fall and in spring reflecting a comparatively high availability of rather easily decomposable compounds right after litter shed in the beech/oak stand and after thaw in the pine stand (Tab. 7.3). Yet, on a general scale, our values were lower than the data reported by Klose et al. (2003) for organic layers in fly-ash affected forest sites in the Dübener Heide region and by Anderson and Domsch (1993) for upper mineral soil of forest stands. Yet, Ross and Tate (1993) observed qCO_2 values in a general range < 1 and thus, our results were within the range of data reported (Tab. 7.3).

Tab. 7.3: Specific respiration rate (qCO_2) in organic horizons (L, F and H) and upper mineral soil (0-10 cm) under Scots pine and under European beech/Common oak during a one year course from November 2001 and November 2002.

	qCO_2 (µg CO_2-C mg^{-1} C_{mic} h^{-1})							
	Scots Pine				**European Beech/Common Oak**			
	L	**F**	**H**	**0-10 cm**	**L**	**F**	**H**	**0-10 cm**
Nov 01	2.95	0.89	1.74	1.76	6.33	1.12	1.20	0.62
Jan	1.70	0.65	0.72	1.68	1.91	1.07	0.63	0.73
Mar	3.20	0.61	1.09	1.00	2.19	0.81	0.59	0.79
May	1.78	0.94	0.44	0.81	1.55	1.19	0.41	0.38
Jul	1.10	0.57	0.22	0.79	1.12	0.89	0.27	0.37
Sep	1.31	0.98	0.58	0.89	1.36	1.29	0.38	0.62
Oct	3.80	0.65	0.32	1.07	2.81	0.88	0.28	0.42
Nov 02	3.31	0.73	0.65	1.27	1.86	1.07	0.51	0.59
Mean	**2.39**	**0.75**	**0.72**	**1.16**	**2.39**	**1.04**	**0.53**	**0.57**

The specific respiration rate has been shown to be strongly affected by soil pH (Anderson and Domsch, 1993; Blagodatskaya and Anderson, 1998) and clay content (Wardle and Ghani, 1995), that influence both microbial biomass (Raubuch and Beese, 1995) and microbial respiration (Curtin et al., 1998). Soil $pH_{(CaCl2)}$ of both sites was on average of organic horizons 3.5, and did not differ significantly between sites within the same horizon (Koch and Makeschin, 2004a). Yet, Blagodatskaya and Anderson (1998) reported a higher qCO_2 in the organic layer under spruce as compared to beech. In contrast, in our study no significant differences were determined in the L layer as well as in average of organic horizons (Tab. 7.3).

A difference in the annual average of the ratio between potential C mineralisation and microbial biomass [i.e., microbial maintenance requirement, qCO_2] ratio was observed in F and H layers, indicating a more efficient use of organic material by microbial biomass in the F horizon under pine and in the H horizon under beech/oak (Tab. 7.3). This result indicates that a higher portion of the organic material in F under beech/oak is mineralized (and partly humified) rather than used for the built-up of microbial biomass. In contrast, in the H horizon and in the upper mineral soil (0-10 cm) under beech/oak the qCO_2 was by 26 %, and 51 %, lower than under pine (Tab. 7.3). Thus, under beech/oak resources have been more efficiently used by microbial biomass in later stages of organic matter turnover [i.e., in the H horizon]. In contrast, in the comparatively active F layer under the beech/oak stand the supply need by microbial biomass is higher, indicating a higher energetic input in order to build-up the organic substances of this horizon. However, the differences found in the F and H horizon between the two study sites are compensated focusing on the total organic layer (Tab. 7.3). Thus, both sites reveal different turnover dynamics. However, for the total of the organic layer these differences seem to be balanced.

7.2.6 Water-soluble Organic Carbon

Water (and salt) extractable C and N fractions are suitable parameters for the evaluation of organic matter dynamics in soil (Jandl and Sollins, 1997; Landgraf and Klose, 2002; Mazzarino et al., 1993; Zhong and Makeschin, 2003b, 200_) and served as indicators for medium-term and readily decomposable C and N in the past (Schulz, 1990; Körschens et al., 1998). However, their composition and structure are not entirely known so far (Chodak et. al, 2003).

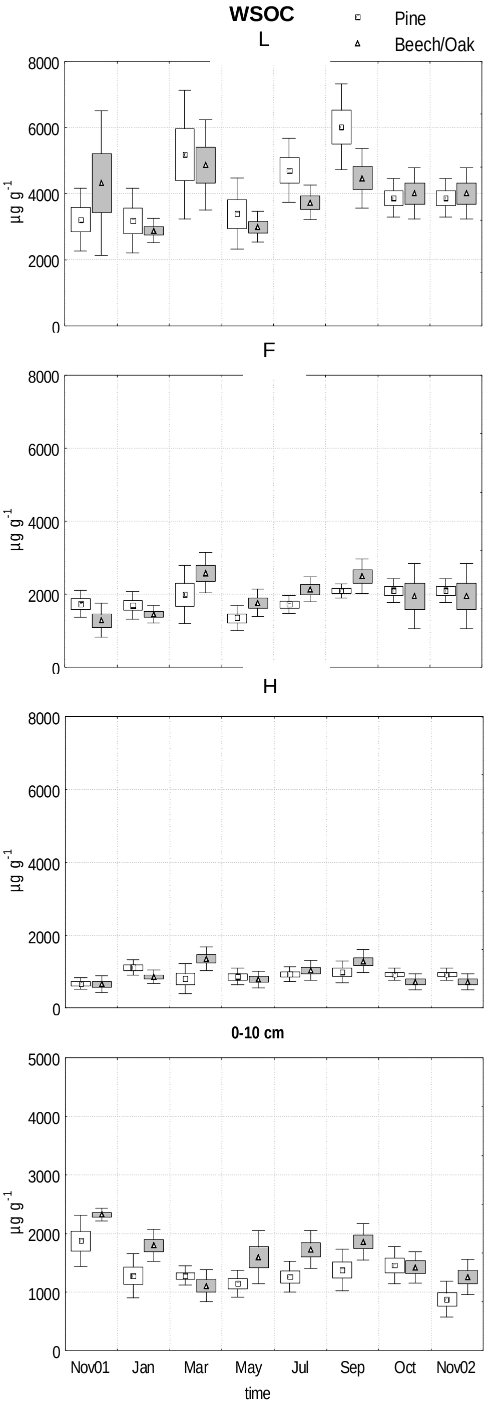


Fig. 7.4: Water-soluble organic carbon (WSOC) in the organic layer (L, F and H) and mineral top soil (0-10 cm) in a Scots pine and in a European beech/Common oak stand in the Saxonian lowland during the course of one year.

The dissolved organic C [i.e., DOC] is generally defined as the < 0.45 µm fraction (Kalbitz, 1996) and thus, includes the organic compounds extracted by the WSOC method. The WSOC represents the non-particular fraction of the cold water extract. Characterized by a peak in spring and fall water-soluble organic carbon (WSOC) followed a similar trend as C_{mic} and potential C mineralisation (Fig. 7.2 and 7.3). These effects get lost by depth. Between the two study sites, no distinct differences were observed for contents (Fig. 7.3) and stocks of WSOC (Tab. 7.4). Yet, rooted in the fact of different mass (Koch and Makeschin, 2004a,b) WSOC stocks differed between single organic horizons and between sites. Thus, the F layer under pine contained a higher amount of water-soluble organic carbon that could be transferred [i.e., by seepage water] and potentially be stored in deeper mineral soil horizons. These mechanisms were shown to depend on the decomposition degree, the proportion of easily degradable organic compounds, lengths and intensity of droughts, microbial activity, sand content, contents of Fe-oxides with a high content of crystal oxides, cation exchange capacity, and soil pH (Kalbitz, 1996; Kalbitz et al., 2000; Michalzik et al., 2001).

Tab. 7.4: Contents and stocks of WSOC in a Scots pine and a European beech/Common oak stand in average of one year from November 2001 to November 2002.

	Pine		**Beech/Oak**	
	contents [µg g^{-1}]	stocks [t ha^{-1}]	contents [µg g^{-1}]	stocks [t ha^{-1}]
L	4 337.64	0.06	4 196.94	0.06
F	1 897.15	0.13	1 913.56	0.10
H	963.05	0.07	956.08	0.10
org. layer		**0.26**		**0.26**
0-10 cm	133.10	0.14	143.78	0.20

Yet, the difference observed is extensively evened-out by the higher WSOC stock in the H layer under beech/oak (Tab. 7.4). In sum, the organic layer under pine contained 0.26 and under beech/oak 0.26 t WSOC ha^{-1} a^{-1} (Tab. 7.4). However, due to the higher TOC stock in the upper mineral soil under the deciduous stand (Koch and Makeschin, 2004 a,b,) the 0-10 cm mineral soil layer under beech/oak included 43 % more water-soluble organic carbon than the respective layer under pine (Tab. 7.4) and therefore holds the basis for a higher long-term C sequestration in mineral soil.

7.3 Summary and Conclusion

In summary, the study confirmed the knowledge about a higher potential C mineralisation and microbial biomass in the organic layer under beech/oak as compared to pine. The amount of aboveground litter was higher in the beech/oak stand than under pine. Litter decomposition in the field added up to a faster turnover of pine needles as compared to beech/oak leaves. Thus, calculation of the mean residence time revealed 3.03 and 1.85 years for the decomposition of beech/oak and of pine litter, respectively, and supported the observation on a higher organic matter accumulation under the beech/oak stand (Koch and

Makeschin 2004a,b). Specific respiration revealed a more efficient resource use in the F layer under pine, but on the other hand in the H layer– resulting in no distinct difference concerning the resource use within the total organic layer. However, in upper mineral soil (0-10 cm) microbial resource use by microbial biomass was twice as efficient under the deciduous stand as under pine. Consistently, for WSOC no significant differences in sum of the organic horizons between the two stands were detected, but upper mineral soil revealed a by 43 % higher stock of water-soluble organic carbon under the deciduous forest. This result indicates a higher content of soluble organic C that might be transferable, but is also related to the higher C stock observed in upper mineral soil under the beech/oak stand (Chapter 4 and 5).

Under beech/oak humus dynamics were characterized by an intensive initial turnover phase right after litter fall, which was followed by higher turnover dynamics in the F (and H) horizon during the years course [determined by potential C mineralisation]. Pine litter decomposition is dominantly starting in spring, following a mechanical/physical breakdown/erosion of the wax layer [i.e., caused by frost and thaw] during winter. Although C mineralisation in the F and H layer was lower under pine than under beech/oak, the L layer revealed a higher turnover dynamic during the summer months.

Resulting of the one year observation microbial biomass and activity were only respectively 2.8 % and 4.8 % higher in the organic layer under beech/oak than under pine, although differences were much greater in terms of stocks [i.e., 9.4 % and 16.0 %]. Yet, the mean residence time calculated was evidently lower indicating a slower decomposition dynamic in the L layer under the deciduous site in the sum of one year. Yet, the turnover rate revealed only little difference and thus, the turnover dynamics in total of the organic layer are only slightly slower under beech/oak than under pine. However, a greater amount of C is turned over under the beech/oak stand. The specific respiration revealed differences in resource use efficiency between the two sites and single organic horizons. We assume that the intensive initial turnover in the L layer under beech/oak and the following high potential C mineralisation in the F horizon are associated to the specific resource quality and composition of the microbial biomass. There is evidence about a higher polyphenol content in beech litter than pine needles (Chapter 6). As a result of this dynamic the stock of TOC (Koch and Makeschin, 2004a,b) and water-soluble organic carbon is higher in the upper mineral soil under the deciduous stand as compared to pine.

Thus, we arrived at the conclusion that (i) under beech/oak a higher amount of litter is transformed by more microbial biomass resulting in a higher potential C mineralisation, (ii) microbial efficiency [as expressed by qCO_2] follows a different pattern between single organic horizons and is twice as high in the upper mineral soil under beech/oak and, (iii) thus, higher amounts of C are stored in the H layer and upper mineral soil (0-10 cm) – providing the basis for the transfer and long-term sequestration of a greater C amount in mineral soil of deciduous stands than under pine.

8 A Balance of C Turnover comparing a Stand of Scots pine and of European beech/Common oak.

(Short Communication)

8.1 Objectives

Whether soils are a net carbon source or sink depends predominantly on their microbial activity, amount of litter fall and management practices (Bouwman and Leemans, 1995*;* Fearnside and Barbosa*,* 1998*;* Gunapala et al*.,* 1998; Mäkipää et al*.,* 1999*).* In order to (i) evaluate turnover dynamics and (ii) to discuss the C balance of the organic layers we investigated turnover rates, microbial biomass and potential C mineralisation in relation to litter quality and available C fractions during a 12 months study comparing a Scots pine stand and a European beech/Common oak forest in a close to nature reserve in the Saxonian lowland.

8.2 Results and Discussion

8.2.1 C-Input by Litter Fall

The total litter amount [i.e., sum of leaves, twigs, seeds] of 6.25 t dry mass ha^{-1} shed in the beech/oak stand exceeded the 5.03 t dry mass ha^{-1} in the pine stand by 24 % (Tab. 8.1). Thus assuming a C content of 58 %, the addition of litter-derived C was approximately 2.9 t C ha^{-1} and 3.6 t C ha^{-1} in the pine and beech/oak stand, respectively (Tab. 8.1). Our results are principally comparable to the data of Ellenberg (1986) and Reichle (1981), although within the upper range. Comparing deciduous forests with pine generally slightly higher amounts of litter in deciduous stands have been observed in various studies (Ellenberg, 1986; Liu et al., 2000) as well as calculated by model projections (Weiss et al., 2000).

8.2.2 Organic Layer Mass and TOC Stocks

Driving factors for the soil humus content are the bedrock material and the soil chemical status, the site-specific climate and stand structure and density as well as abundance and composition of soil microbial and faunal communities (Berg and McClaugherty, 2003; Berger et al., 2002; Heal et al., 1997; Paul and Clark, 1996). We determined a total organic layer weight of 180.0 t ha^{-1} under Scots pine and 196.0 t ha^{-1} under European beech/Common oak, corresponding to C stocks of 47.2 t ha^{-1} and 60.4 t ha^{-1} for the coniferous and deciduous stand, respectively (Tab. 8.2). In comparison, Klose and Makeschin (2003), Koch et al. (2002) as well as Scheuner (2004) observed C stocks between 17.5 and 29.0 t C ha^{-1} in the organic layers in the NE-German lowland; in contrast higher stocks of 88 t ha^{-1} and up to 137.8 t C ha^{-1} were determined in Thuringian forests by Reinhardt and Makeschin (2003) and by Zhong und Makeschin (2003a). Long-term observations of the “Solling project” revealed an organic layer mass between 48 and 111 t ha^{-1} under spruce and 34 to 56 t ha^{-1} under beech corresponding to about 17.0 to 55.5 t C ha^{-1} (Meiwes et al., 2002). Thus, our results are within the range of reported data. The comparison with the literature data from studies in NE-Germany and SE-Germany indicates a strong influence of temperature, but even stronger of precipitation. This factor was defined as principal key component influencing the stand-specific AET and litter production and thus, humus stocks in forest soils (Hofmann and Anders, 1996; Persson et al., 2000).

Tab. 8.1: Litter collected in a Scots pine and a European beech/Common oak stand in the Saxonian lowland during the course of one year from November 2001 and November 2002 [a set of six litter collectors of 0.25 cm² each was installed at both sites].

		Scots Pine			**European Beech/Common Oak**	
Months	**Needles**	**Seeds**	**Twigs**	**Leaves**	**Seeds**	**Twigs**
		(g 1.5 m^{-2})			(g 1.5 m^{-2})	
Oct 01	74.87	4.74	0.61	69.85	145.62	9.46
	± 4.82	± 1.94	± 0.16	± 1.44	± 7.05	± 1.97
Nov-01	33.20	0.00	2.63	101.50	45.70	4.10
	± 1.70	± 0.00	± 0.41	± 7.59	± 4.00	± 0.91
Jan-02	27.20	11.10	12.30	109.20	60.80	47.00
	± 0.49	± 4.53	± 1.63	± 3.57	± 2.89	± 3.43
Mar 02	32.39	13.80	31.57	1.17	15.58	46.96
	± 1.26	± 3.33	± 5.38	± 0.31	± 1.44	± 10.95
May 02	13.30	12.80	47.00	7.70	2.30	0.90
	± 0.38	± 3.61	± 17.09	± 0.20	± 0.72	± 0.18
Jul 02	56.70	92.54	9.21	31.22	7.98	16.68
	± 1.11	± 9.83	± 1.23	± 2.82	± 1.08	± 6.09
Sep 02	70.85	11.80	23.50	16.70	5.60	14.30
	± 1.73	± 3.16	± 0.87	± 0.66	± 1.13	± 2.16
Oct 02	162.00	6.80	3.10	157.90	8.00	12.00
	± 4.99	± 2.78	± 0.26	± 6.72	± 1.94	± 2.22
Total [g 1.5 m^{-2} a^{-1}]	**470.51**	**153.58**	**129.92**	**495.24**	**291.58**	**151.40**

In our study, the thickness and mass of the organic layer as well as the total C stock of the organic layer under deciduous stands exceeded that under conifers (Tab. 8.2). The difference observed was dominated by the massive H layer of 3.2 cm under the beech/oak stand. In contrast, the H layer under the Scots pine stand was only 1.7 cm thick. The Scots pine stand was afforested after clear-cutting. Thus, it is possible that this site suffered a loss of humus and nutrients. Yet, we found no evident differences in organic layer mass and basic chemical properties between both study sites in one year. However, these effects may play a role in most coniferous stands in NE-Germany. Yet, as our data of humus mass are within the range of reported data, we suppose these are not the dominant effects. Due to management practices both stands differed in their age [i.e., pine 74 yrs., beech/oak 168/211 yrs.]. Thus, the differences observed in the thickness and mass of the organic layer are contributed to (i) the stand age, (ii) effects of stand density, and (iii) the stand-specific humus dynamics.

The higher amount of C stored in the H layers beneath deciduous [i.e., beech] stands have also been reported from other studies (Persson et al., 2000; Reinhardt and Makeschin, 2003; Vedrova, 1995). Thus, the H layer of forest soils seems to play a significant role in soil C sequestration. In contrast, Fischer et al. (2002) observed a decline of humus stocks along a forest conversion sequence in the NE-German lowland.

In mean of one year, the organic layer under the deciduous stand was by 6 % heavier. This difference is not evident. Yet, including 8 study sites Koch and Makeschin (2004a,b) observed a generally increasing trend of organic layer thickness and mass along the forest conversion sequences. However, contradictory results were reported regarding to the organic layer mass and morphology beneath coniferous and deciduous stands (e.g. Fischer et al., 2002; Koch and Makeschin, 2004a,b; Reinhardt and Makeschin, 2003). Thus, we arrived at the conclusion that the impact of climate, soil type, stand structure and litter amount may be stronger than of tree species and litter quality.

Tab. 8.2: Mass, contents and stocks of TOC in the organic layer (L, F, and H) and upper mineral soil (0-10 cm) in a Scots pine and a European beech/Common oak stand in the Saxonian lowland – data obtained from an topsoil inventory in May 2001.

	Pine		**Beech/Oak**	
	contents [µg g^{-1}]	stocks [t ha^{-1}]	contents [µg g^{-1}]	stocks [t ha^{-1}]
L	416 900.00	17.22	416 600.00	10.88
F	325 966.67	17.97	354 800.00	25.57
H	143 650.00	12.01	245 150.00	23.97
org. layer		**47.20**		**60.42**
0-10 cm	16 303.67	17.40	22 136.33	29.81

Additionally, although deciduous litter is commonly known to be easier to decompose, resource quality is not necessarily better. Especially European beech was reported to contain high amounts of lignin as compared to other deciduous trees and to Scots pine (Berg et al., 1996) and thus, to be similar in litter quality to some coniferous species (Thomasius and Schmidt, 1996; Vesterdal, 1999). This relation was also observed for the litter of the two stands involved performing pyrolysis-GC/MS: the lignin content of the beech/oak litter was with 56 % nearly twice as high as for pine with 33 % determined in fall 2001 (Chapter 6). Therefore, we predict that during beech/oak litter decomposition the limit value reached is lower then during the pine needle decomposition (Berg et al., 1993; Berg and Ekbohm, 1991; Berg and McClaugherty, 2003), resulting in a higher amount of secondary decomposition products. This relation may explain the comparatively mighty and heavy H layer under beech/oak as compared to the pine stand.

8.2.3 Microbial Biomass and Activity

Microbial biomass and activity were shown to be higher beneath deciduous forest stands (Heal et al., 1997; Matteucci et al., 2000; Persson et al., 2000; Saetre et al., 1999; Smolander and Kitunen, 2002). Additionally, microbial biomass is strongly influenced by the wheather [i.e., temperature and precipitation] and thus, may vary between seasons and years (Bauhus and Barthel, 1995; Berg et al, 1998; Beyer et al., 1993; Diaz-Ravina et al., 1995; Dilly and Munch, 1996). On average of one year, in our study microbial biomass under pine accounted for 18.4, 4.6 and 2.4 mg g^{-1} and under beech/oak to 18.4, 5.6 and 3.1 mg g^{-1} for L, F and H, respectively (Tab. 8.3). These rather small differences were not proved significant.

In sum, C_{mic} accounted for 0.75 t ha^{-1} in the organic layer under pine and for 0.87 t ha^{-1} under beech/oak (Tab. 8.3; Fig. 8.1). Additionally, upper mineral soil contained nearly twice as much microbial biomass under the deciduous stand than under Scots pine (Tab. 8.3). In sum, the soil under the beech/oak stand contained by 16 % higher microbial biomass in average of one year as compared to the pine soil. While, the litter horizon of both sites seems to be similar attractive for the microbial community in the years average, the F and H layer under the deciduous stand contain higher amounts of C_{mic}.

Potential C mineralisation revealed similar values between pine and beech/oak in L and H layers (Tab. 8.3). Yet, in the years average the F horizon revealed a by 68 % evidently higher C mineralisation under beech/oak ($p \leq 0.01$) and microbial activity in the H horizon was comparable between both stands (Tab. 8.3). In sum, heterotrophic respiration from the organic layer under pine amounted to 29.3 t CO_2 ha^{-1} a^{-1} and under beech/oak 33.0 t CO_2 ha^{-1} a^{-1} and was thus, 12.8 % higher under the deciduous stand. Upper mineral soil revealed no evident differences between sites (Tab. 8.1, Fig. 8.1).

Thus, the organic layer under the deciduous stand revealed a higher microbial biomass (and activity) than under the Scots pine stand (Tab. 8.2). These results are well comparable to literature data, reported on e.g. 15 % higher microbial biomass (Saetre et al., 1999;

Smolander and Kitunen, 2002) and on 10 % to about 25 % higher C mineralisation (Raich und Tufekciogul, 2000; Albers et al., 2004) beneath deciduous than coniferous trees.

During the years course, the effects of temperature and moisture extremes were generally stronger in the organic layer under the comparatively open pine stand than under the close canopy and thus, rather even conditions under beech/oak.

8.2.4 Water-extractable and Water-soluble C Fractions

In a number of studies, hot water extractable organic matter has been evaluated as relative easily to decompose by microbial biomass (Behm, 1988; Franko, 1997; Gregorich et al., 2003; Körschens et al., 1998; Leinweber et al., 1995; Manzke, 1995; Sparling et al., 1998). Leinweber et al. (1995) and Landgraf et al. (200_) determined the structural chemical composition of the hot water-extractable organic matter as carbohydrates and N-containing compounds, such as amino-N species and amides using a combined method of ^{13}C-NMR and pyrolysis-field ionization mass spectrometry (Py-FIMS). Thus, sources of C_{hwe} are roots and root exudates, decomposed SOM and microbial biomass. Principally, the same is valid for the cold water fraction. Yet, as a difference, cold water extraction was shown to deliver also low humified material (Wu et al., 2003), while the hot water extract also liberates metal-organic complexes (Scheuner, 2004). The hot water-extractable pool accounts for a maximum of about 4 to 10 % of the SOC (Landgraf, 2001; Scheuner, 2004; Chapter 5); cold water-extractable C was determined of being by factor 2 to 3 (Scheuner, 2004) and 4 to 6 lower than C_{hwe} in forest soils (Chapter 5). The WSOC fraction describes a readily available energy source for microbial biomass (Coleman et al., 1983) and is tracked in this study in its function as pre-stage of DOC.

During the one year observed, hot-water-extractable C (C_{hwe}) generally increased, despite the temporarily decline in March (Fig. 8.1). This effect may be explained by more favorable conditions for C_{mic} and C mineralisation due to higher precipitation and temperatures combined with a sufficient supply of decomposable litter at this time.

In sum of the year, C_{hwe} stocks under pine exceeded those under beech/oak revealing values of 1.59 t ha^{-1} and 1.50 t ha^{-1} for pine and beech/oak, respectively. Within the organic layer, this difference is mainly driven by the concentrations observed within the L horizon (Tab. 8.3, Fig. 8.2). Yet, significant differences were only determined in upper mineral soil ($p \leq 0.01$). Also readily decomposable C (C_{cwe}) under pine surpassed the stocks under beech/oak with 0.53 t ha^{-1} and 0.45 t ha^{-1} for the organic layer under pine and beech/oak, respectively (significant at $p \leq 0.01$ in the F layer). Yet, water-soluble organic carbon (WSOC) stocks revealed no difference in the organic layer between the two study sites (Tab. 8.3). In

Tab. 8.3: Contents and stocks of potential C mineralisation, C_{mic}, C_{hwe}, C_{cwe}, and WSOC in the organic layer (L, F and H) and upper mineral soil (0-10 cm) a stand of Scots pine and of European beech/Common oak in average of one year between November 2001 and November 2002.

Calculation of CO_2 release by heterotrophic respiration from November 2001 to November 2002

	Pine		**Beech/Oak**	
	Content	**Stock**	**Content**	**Stock**
	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]
L	150.33	18.17	149.50	17.87
F	12.53	7.60	21.10	9.96
H	5.49	3.50	5.74	5.21
org. layer		**29.27**		**33.01**
0-10 cm	0.56	5.23	0.43	5.07

Calculation of C bound in microbial biomass from November 2001 to November 2002

	Pine		**Beech/Oak**	
	Content	**Stock**	**Content**	**Stock**
	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]
L	18 390.70	0.25	18 369.51	0.25
F	4 633.26	0.32	5 559.89	0.30
H	2 395.44	0.17	3 058.61	0.32
org. layer		**0.75**		**0.87**
0-10 cm	154.39	0.16	231.67	0.31

Calculation of TOC_{hwe} from November 2001 to November 2002

	Pine		**Beech/Oak**	
	Content	**Stock**	**Content**	**Stock**
	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]
L	18 222.20	0.25	15 524.48	0.21
F	12 464.35	0.86	11 326.25	0.61
H	6 553.91	0.48	6 535.54	0.68
org. layer		**1.59**		**1.50**
0-10 cm	1 320.38	1.41	1 637.48	2.21

Calculation of TOC_{cwe} from November 2001 to November 2002

	Pine		**Beech/Oak**	
	Content	**Stock**	**Content**	**Stock**
	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]
L	8 922.89	0.12	7 248.83	0.10
F	4 064.13	0.28	3 289.10	0.18
H	1 681.00	0.12	1 675.62	0.17
org. layer		**0.53**		**0.45**
0-10 cm	258.90	0.28	290.04	0.39

Calculation of WSOC from November 2001 to November 2002

	Pine		**Beech/Oak**	
	Content	**Stock**	**Content**	**Stock**
	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]	[µg CO2 g^{-1} h^{-1}]	[t ha^{-1} a^{-1}]
L	4 337.64	0.06	4 196.94	0.06
F	1 897.15	0.13	1 913.56	0.10
H	963.05	0.07	956.08	0.10
org. layer		**0.26**		**0.26**
0-10 cm	133.10	0.14	143.78	0.20

contrast, upper mineral soil showed evidently higher water-extractable and water-soluble C under the deciduous stand ($p \leq 0.01$) (Tab. 8.3).

Although cold-water-extractable C (C_{cwe}) revealed a similar pattern in fall and winter in the pine and beech/oak stand, contents of this readily decomposable C fraction declined from November to March in beech/oak and then leveled out into relatively constant values. In contrast, C_{cwe} contents in the L layer under pine revealed a clear increase similar as observed for microbial biomass (Fig. 7.2, 8.1).

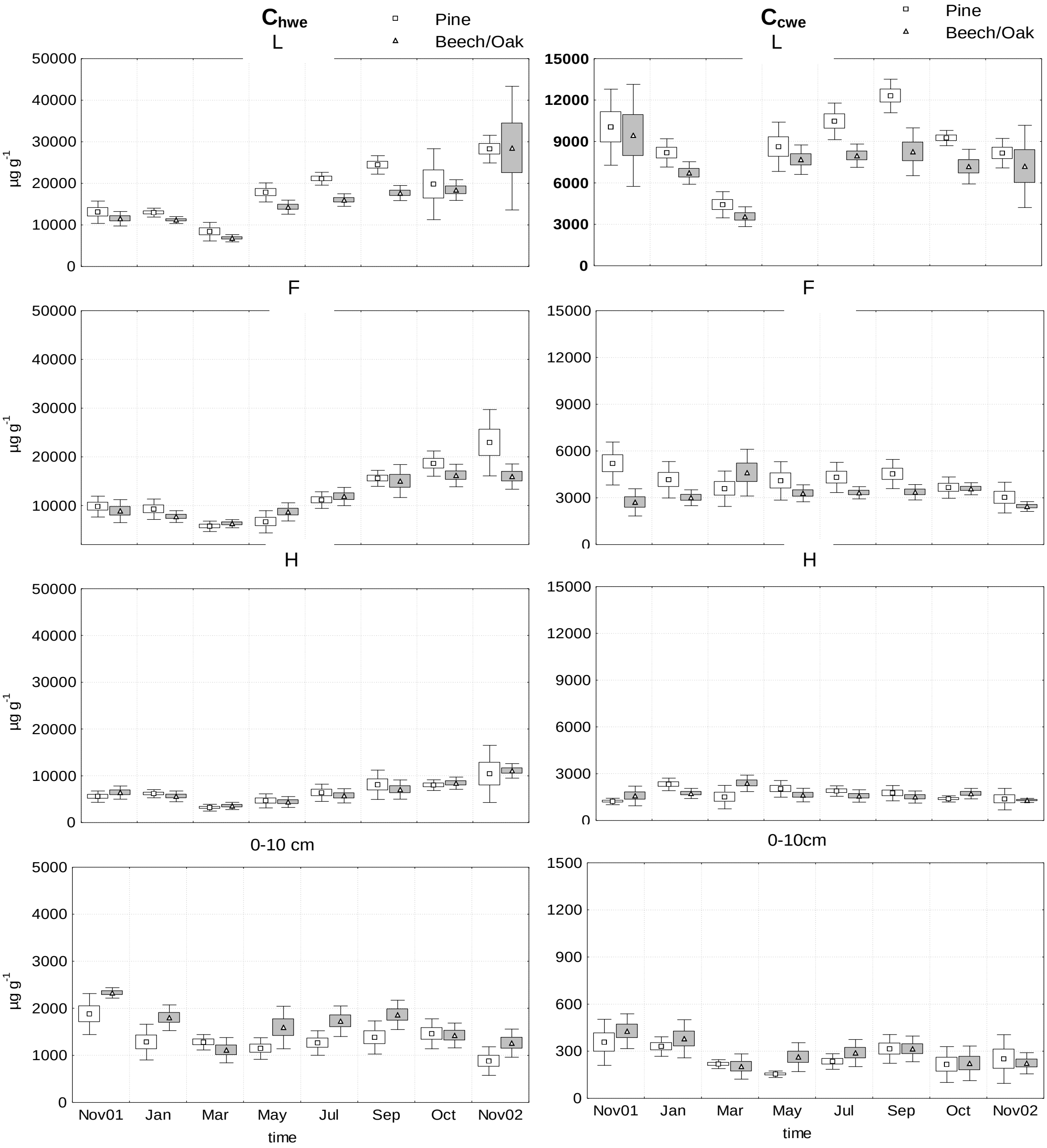


Fig. 8.1: Hot- and cold-water-extractable C (C_{hwe} and C_{cwe}) in the organic layer (L, F and H) and upper mineral soil (0-10 cm) in a Scots pine and in a European beech/Common oak stand in the Saxonian lowland during the course of one year from November 2001 to November 2002.

It is conceivable to us that fast turnover dynamics of organic matter may possibly just as well result in low C_{hwe} contents as available C is quickly used-up. During the comparatively dry summer, amounts of medium-term decomposable C (C_{hwe}) revealed an increase in the L and F horizons in both stands, while C_{cwe} only increased in the L horizon at the pine stand and all other investigated organic horizons remained at a constant level (Fig. 8.1). During this time the qCO_2 revealed e.g., in the L layer under pine comparatively low values < 2 (Tab. 7.3) indicating an efficient use of C sources by a microbial biomass, that is most probably well adapted to the dry conditions under the relatively open pine stand during the summer and is also reflected by a low C_{mic}/C_{hwe} ratio in the L layer under the pine stand (Tab. 5.3). Thus, the results indicate an accumulation of readily degradable (C_{cwe}) and medium-term (C_{hwe}) C fractions, when microbial biomass is working efficiently and microbial respiration is restricted by climatic conditions.

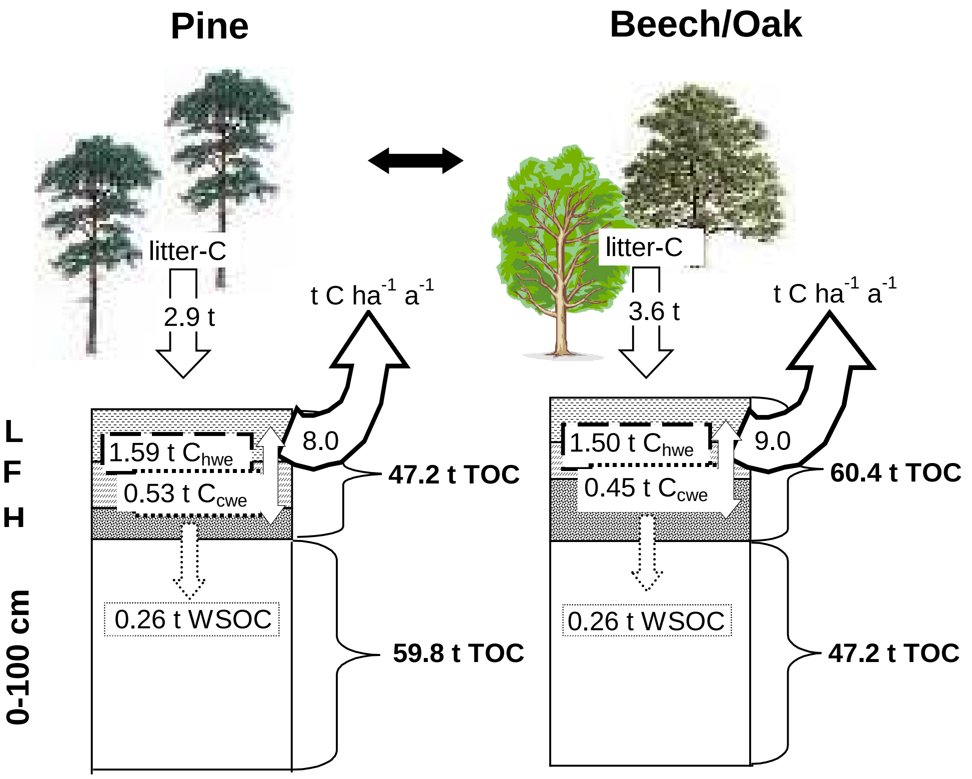


Fig. 8.2: Litter C-input, total organic carbon (TOC), water-extractable C fractions (C_{hwe} and C_{cwe}), water-soluble organic C (WSOC), microbial biomass (C_{mic}) and potential C mineralisation calculated over one year from November 2001 to November 2002 in a Scots pine and a European beech/ Common oak stand in the Saxonian lowland (C-output determined as potential c mineralisation at 15℃).

Landgraf et al. (200_) reported that hot-water extracted more easily available substances such as carbohydrates, phenols and lignin monomers and organic N-compounds, and therefore may be a better predictor of rather easily decomposable organic matter than the cold water extract. This was also reflected by our data as the ratio between C_{mic}/C_{hwe} was generally lower in our study than the ratio between C_{mic}/C_{cwe}; in fact microbial biomass may exceed the cold water extract extensively (Tab. 5.3 and Tab. 5.6).

A higher amount of litter-derived C enters the organic layer under beech/oak, that is very actively turned over. Thus, a higher C mineralisation results in a higher C outflow (Fig. 8.2). These active turnover processes may promote the sequestration of C in mineral soil beneath deciduous stands. In result, the upper 10 cm of mineral soil under beech/oak contained nearly twice as much C than under pine. The active C pool [i.e., C_{hwe}, C_{cwe} and WSOC] is involved into the intensive decomposition of organic matter, resulting in lower stocks of the water-extractable fractions in the organic layer under the deciduous stand.

8.3 Summary and Conclusion

Summarizing, humus dynamics under beech/oak are characterized by an intensive initial turnover phase right after litter fall and intensive C mineralisation in the F layer during later stages of litter decomposition. Pine litter degradation is mainly starting in spring, following a mechanical/physical breakdown/erosion of the wax layer [i.e., caused by frost and thaw] during winter. Litter decomposition under pine is mainly restricted to the L layer and exceeds values of beech/oak as microbial activity is rather high during the summer months in that stand. Yet, higher litter amounts, fast initial turnover dynamics in the L horizon, intensive C decomposition processes in later stages of litter decomposition and higher microbial activity in the H horizon lead to a breakdown of deciduous organic matter, which in later phases could potentially be sequestered in the mineral soil under the beech/oak stand.

Conclusively, the results indicate a more active turnover of a higher amount of organic compounds under deciduous forest in contrast to the pine stand. Resulting of the higher C mineralisation, that was evaluated as the dominant C outflow (Persson et al., 2000), the C release to the atmosphere is by 12.8 % higher in the organic layer under beech/oak as compared to pine. This coherence is mainly driven by elevated respiratory activity in F horizon of the beech/oak stand (Koch and Makeschin, 2004a,b). The specific resource quality [i.e., higher lignin content] and higher stand age may contribute towards an explanation for the evidently higher accumulation of secondary decomposition products in the H layer under beech/oak. Additionally, the C stored in upper mineral soil was nearly twice as high under the deciduous stand as under pine. Therefore, our results indicate (i) higher turnover dynamics under the deciduous stand, keeping (ii) humus and nutrients in a close cycle, and enhancing (iii) long-term C sequestration in mineral soil.

9 Concluding Discussion

In German forests the soil stores more than half of the total ecosystem C (Baritz, 1998; Baritz et al., 1999; Baritz and Strich, 2000) due to an average accumulation of about 4 to 43 t C ha^{-1} in the organic layer and 49 to 173 t C ha^{-1} in mineral soil (BML, 1997). The amount of C accumulated is related to the C inputs by (i) aboveground litter (Buchmann, 2000; Berg and McClaugherty, 2003), (ii) addition of dead root material and root exudates (Bottner et al., 1999; Helal and Sauerbeck, 1986; Leuschner et al., 1998), (iii) by leaching of DOC with stand precipitation (Kalbitz et al., 2000; Michalzik, 1999), by (iv) C turnover by microbial decomposition (Couteaux et al., 2001; Persson et al., 2000), and (v) C output by leaching and erosion (Entry and Emmingham, 1998; Michel and Matzner, 1999). Therefore, our study included the determination of C stocks, aboveground litter addition, microbial decomposition rates and of soluble and water-extractable C fractions with emphasis on evaluating these parameters with regard to forest conversion.

9.1 The Impact of Forest Conversion on Humus Accumulation

Humus Morphology and TOC Stocks

- The investigated stands revealed **humus forms** of raw mor-like moder to typical moder, which are common humus forms as 13.7 % of forest soils in Germany represent raw-mor-like moder and 34.8% moder humus (BMELF, 1996). Along the forest conversion sequences a trend of increasing **thickness and mass** of the organic layers was observed that was dominated by the distinct characteristics of the H layer. The soil inventory performed in May 2001 revealed that the portion of organic matter accumulated in the H layers was higher under deciduous stands than under conifers. The H horizon stored 45 % of the aboveground organic matter under the beech stand in the Ore Mountain region and 74 % under the beech and 50 % under the beech/oak stand in the Saxonian lowland (Tab. 4.1). As a result, in the lowland the portion of the TOC stored in the H layer on the total organic layer C stock was 61.0 % in the beech stand and 39.7 % in the beech/oak stand (Tab. 4.2). In contrast, only 25.4 % of TOC in the organic layer were stored in the H horizon of the Scots pine stand. This different distribution of C in the organic layer of the different forest stands accompanied by a trend of decreasing thickness and mass of L and F layers along the conversion sequences reflects the initially active turnover of deciduous litter. Similar results were reported from the so-called “green-eyes” [i.e., single beech stands planted in spruce-dominated forest districts] in Thuringia, where conifer stands showed a higher mass in the L horizon, while beech stands had a higher mass in the H horizon (Reinhardt and Makeschin, 2003).

- According to the Soil Federal Inventory (BZE), about 62 % of forest soils have moderate active or rather inactive humus forms (BML, 1997). The humus form serves as an index for turnover dynamics and the vertical distribution of organic matter in soil, but is only secondarily a suitable measure for the soils total C stock. It is not the rate but rather the type of decomposition that determines the amount and form of humus (Weetman, 1980). Mor humus forms are the consequences of primarily fungal decomposition leading to an incomplete decomposition and immobilisation of nutrients; mull humus forms result from passage through soil animals [i.e., earthworms] and consequently from mainly bacterial decomposition (Prescott et al., 2000). Driving factors for the soils humus content are the bedrock material and soil chemical status, site-specific climate and thus, stand structure and density as well as abundance and composition of soil microbial and faunal communities (Berg and McClaugherty, 2003; Berger et al., 2002; Heal et al., 1997; Paul and Clark, 1996). In our study, consistently with the thickness and mass, the **total C stock** of the organic layer under deciduous stands exceeded that under conifers. The specific function of the H layer for humus accumulation and C sequestration and the higher amount of C stored in the H layers beneath deciduous [i.e., beech] stands have also been reported from other studies (Persson et al., 2000; Reinhardt and Makeschin, 2003; Vedrova, 1995). In contrast, Fischer et al. (2002) observed a decline of humus stocks along a forest conversion sequence in the NE-German lowland. This result seems conceivable to us due to the commonly reported higher mineralisation rate of deciduous litter. Litter quality, microbial biomass and microbial activity are reported to be higher in deciduous stands than in stands of spruce or pine (Albers et al., 2004; Anders et al., 1997; Berg et al., 1984; Berg and McClaugherty, 2003; Matteucci et al., 2000; Persson et al., 2000; Prescott et al., 2000; Saetre et al., 1999; Thomasius and Schmidt, 1996). Yet, decomposition dynamics are related to site-specific characteristics including base saturation and soil moisture, stand density, litter quantity and quality, and the microbial community. Thus, the amount of humus accumulated under forest stands may differ depending on a number of factors and is not necessarily dominated by the impact of stand species and litter quality. Furthermore, an increase in humus accumulation with stand age was reported (Entry and Emmingham, 1998). The deciduous stands studied in our investigation are 2-3 times older than the Scots pine stand due to management strategies.

- The comparison of organic layer mass between May 2001 and the findings in the pine and beech/oak stands from the one year study led to the conclusion that **humus accumulation** along forest conversion sequences does not only depend on tree species but also on site-specific chemical, geomorphic and climatic conditions. Soil moisture and temperature were defined as key factors controlling the soil C content (Berg et al., 1993; Buchmann, 2000; Matteucci et al., 2000; Persson et al., 2000; Hofmann und Anders, 2002; Dalias et al., 2003). Particularly the pleistocene lowland shows a small-distance mosaic in hydromorphic properties due to the changing clay content of the substrate and the existence of clay lenses or ligaments. This may explain the comparatively high amount of C stored in the H layer under beech at site C2 of this study and under the advanced planting of beech/oak at site B3 (Chapter 3). These sites accumulated amounts of 231.5 t and 240.8 t organic matter ha^{-1} in the organic layer (Tab. 4.1). Both stands stock on soil type Pseudogley and Podsol-Pseudogley (Chap. 3).

- Along the forest conversion sequences, the comparatively dense advanced plantings revealed even higher TOC stocks in the organic layer than the pure stands. Although a positive effect of a subsequent planting of deciduous trees into coniferous forest stands on decomposition dynamics was reported (Prescott et al., 2000; Prietzel, 2004), this effect may be related to a higher litter production at these two-storey sites along with site-specific climate conditions due to a denser stand structure. These factors may explain the higher C accumulation under advanced plantings. Additionally, the input of root-derived C sources is higher under advanced plantings (and deciduous stands) (Anders et al., 2004). A generally higher TOC content in the upper mineral soil (0-10 cm) under deciduous stands and advanced plantings as compared to coniferous sites was observed in our study. The higher decomposition activity of soil fauna and microorganisms under deciduous stands results in a bioturbative transfer of SOM into the mineral soil.

- Furthermore, we cannot entirely exclude the **impacts** of litter raking, of the burning of brushwood during the clear-cutting epoch and the deposition of industry-, combustion- and traffic-derived compounds. Soil acidification, heavy metal toxicity, and higher N loads were reported to lead to a retarded humus mineralisation (Meiwes et al., 2002). Some of these compounds were included in fly ash deriving from coal-fired power plants that was deposited in a vast area of the Dübener Heide during the last century (Neumeister et al., 1997). Detailed information on the impact of fly-ash deposition on forest stands were presented by Klose et al. (2001), Klose and Makeschin (2003), Klose et al. (2003), Klose et al. (200_) and Koch et al. (2002). Yet, determination of the ferromagnetic susceptibility of randomly selected samples performed during this study revealed currently no evident fly ash influence on the investigated forest sites. Additionally, due to the small distance of ca. 500 m between the pine stand (A2) and the beech/oak stand (C3), deposition-related differences are less likely to have contributed. Thus, we conclude that the higher mass and TOC contents of the H layers under deciduous stands observed in this study reflect dominantly site- and stand-related differences in humus dynamics due to stand characteristics such as stand density and litter quality.

- In spite of the small-scale changes in site characteristics, the stand-specific impact on the C stock accumulated in the organic layer became obvious in higher organic layer mass and C stocks under deciduous stands. This was also observed between sites that were similar in their site characteristics [i.e., sites A2 and C3]. An increase of the TOC accumulated in the organic layers along the conversion sequences from 47.2 t C ha^{-1} under Scots pine to 51.8 t C ha^{-1} under European beech, and 60.4 t C ha^{-1} under European beech/Common oak was determined in our study (Fig. 4.1). Baritz (1998) presented an overview on C stocks relative to humus forms and calculated a mean of about 30-40 t C ha^{-1} stored in the organic layer of forest sites. The higher C stocks, detected in our study especially under deciduous stands, are most probably related to the climate [i.e., higher precipitation resulting in a higher litter production], to a higher stand density as well as stand age. Conclusively, the vertical and horizontal distribution of C stocks may vary in a wide range (Baritz, 1998; Baritz et al., 1999; Chodak et al., 2002). Klose and Makeschin (2003), Koch et al. (2002) and Scheuner (2004) observed C stocks between 17.5 and 29.0 t C ha^{-1} in the organic layers in the NE-German lowland. In contrast, comparatively high stocks of 88 t ha^{-1} up to 137.8 t C ha^{-1} were determined in Thuringian forests by Reinhardt and Makeschin (2003) and by Zhong und Makeschin (2003a). Long-term observations of the “Solling project” revealed an organic layer mass between 48 and 111 t ha^{-1} under spruce and 34 to 56 t ha^{-1} under beech corresponding to about 17 to 55.5 t C ha^{-1} (Meiwes et al., 2002). The relatively large differences in C stocks in forest soils observed in these studies indicate a primary influence of forest stand type [i.e. pine vs. spruce] that defines stand density and litter quality, and reflects the impact of site-specific characteristics such as climate, soil moisture and soil type (Hofmann and Anders, 1996).

Effect of Liming

- In the middle **Ore Mountain** region, a large-scale amelioration by **liming** was carried out in 1996 that continued to affect soil properties. Thus, soil chemical and microbial characteristics of the organic layer and organic matter turnover dynamics were still altered at the time of soil sampling in May 2001. We observed an increase in thickness and mass of the organic layer along the forest conversion sequence, but no horizon-specific differentiation as found in the lowland. Especially the recent F and H layers have been affected by the liming. While microbial biomass and activity increased clearly in the L horizon along the conversion sequence from spruce to beech according to the trend observed in the lowland, C_{mic} decreased in the lime-affected F and H layers and potential C mineralisation revealed no certain trend. Concomitantly, total C and N contents were similar along the sequence in the L layer, but decreased in the F and H layers. This result reflects that following liming a rapid organic matter turnover had occurred (Kreutzer, 1995; Rehfuess, 1990) in horizons that currently are F and H, but at the time of the amelioration most probably have been L and F layers. Emanating from the lime-input, base saturation and pH increased. Thus, following liming, the microbial community may have changed towards a higher portion of bacteria (Paul and Clark, 1996) and microbial activity increased (Rehfuess, 1990, Kreutzer, 1995). In contrast, the non-lime-affected L layer revealed a similar stand-specific differentiation in its microbial characteristics along the conversion sequence as observed in the lowland.

→ In the Ore Mountain region the stand-specific differentiation in chemical and microbial properties of the organic layers have been lastingly leveled out due to the liming. We assume that the stronger effect observed in soils under the advanced planting and the deciduous stand is more related to the distribution of the lime or to the different reaction of the stand-specific microbial biomass to the liming than to the litter quality as the trends observed in the Ore Mountain region are contrary to the results along conversion sequences in the Saxonian lowland. Unfortunately we were not able to detect the primary factor so that both have to be taken into consideration. Focusing on the stand-specific differentiation in the L layer, we draw the conclusion that the effects documented for the lowland will be relevant in the Ore Mountain region once the lime looses its effect. Yet, due to the different climate and site-characteristics [i.e., climate more humid, higher clay content and soils more cohesive] the comparability to the lowland region and transferability of results are restricted and further research will be necessary when the liming effect has lost influence.

→ In sum, a higher amount of humus was accumulated under advanced plantings and pure deciduous stands as compared to the Scots pine stand in the lowland. The advanced plantings showed a dense forest structure, probably resulting in a high amount of litter, a high input of root-derived C, and revealed a stand-specific climate due to their two-storey stand structure and close canopy. The higher amount of organic matter found under pure beech and beech/oak stands is dominated by the characteristics of the H layer. Yet, at the same time potential C mineralisation increased along the conversion sequences. Reason for the C accumulation under pure deciduous stands may be (i) litter quality, (ii) site characteristics such as soil type, base saturation, soil moisture, (ii) a stand-specific microbial community revealing specific turnover dynamics, (iii) forest management influencing stand age and density, and (iv) depositions.

9.2 Impact of Organic Matter Quality on Turnover Dynamics

Litter quality has a strong impact on decomposition dynamics, litter decay rate and on the composition of the microbial biomass (Berg and McClaugherty, 2003; Heal et al., 1997; Swift et al., 1979). Newly shed plant litter often was found to decompose at a rate of about 0.1 – 0.2 % per day decreasing following a single negative exponential model (Olson, 1963). It may reach very low **turnover rates** of only 10^{-6} % per day (Berg and Meentenmeyer, 2002). During the decomposition process, organic matter quality decreases as soluble and easily available compounds are lost or decomposed and a recalcitrant SOM pool remains. This pool contains a high portion of lignin and lignified carbohydrates as well as nitrogen, incorporated into humic compounds (Haider, 1996, Kögel-Knabner, 1996).

- In our study, the **structural-chemical composition** of the plant litter material (determined by **pyrolysis-GC/MS**) revealed an evidently higher lignin portion of 56 % in beech/oak leaves than in the pine needles with 33 %. Also Berg et al. (1996) observed nearly twice as much lignin in beech leaves than in pine needles. Thus, according to the reports of a lower limit value during decomposition of lignin-rich litter by Berg (i.e., Berg and Staaf, 1980b; Berg et al., 1984; Berg et al., 1993; Berg and McClaugherty, 2003) differences in limit values of litter decomposition and thus humus formation between Scots pine and European beech/Common oak are expected to be observed. Yet, during the early stages of litter decay, turnover rates are pre-dominantly controlled by climate rather than by litter quality (Berg and McClaugherty, 2003; Prescott et al., 2000). This effect was reflected during the litter bag study by the fast decomposition of the pine needles – assumingly caused by a higher radiation during summer leading to higher temperatures and lower moisture in that topsoil. In contrast, the higher mass loss immediately after litter shed in fall and in winter compared to the summer months in both stands was presumably related to the depletion of soluble organic substances, i.e., by leaching (Kalbitz et al., 2000; Qualls at al., 2001).

- Shortly after litter fall we observed specific decomposition dynamics which occurred also during the winter season, when microbial biomass is relatively inactive (Díaz-Ravinã et al., 1995; Chapter 6). Therefore, the processes observed may have occurred at a comparatively low rate. During the first four months after litter fall a total loss of sinapyl derivates was observed in the L layer of beech/oak. This result is in contrast to the reports by Hammel (1997), reporting that the degradation of lignin does not occur during the initial decomposition phase. Yet, in our study the portion of coumaryl and coniferyl structures increased in the F horizon by factors of 1.7 and 2.1, respectively (Fig. 6.4). Also the sinapyl structures revealed a pro-rata increase in the F layer. These results serve as prove of specific decomposition dynamics during the winter season: **Demethoxylisation of lignin** in the L layer shortly after litter fall and a simultaneously occurring demethoxylisation of lignins and/or decomposition of other compounds [i.e., celluloses, N-containing compounds] in the F layer (Chapter 6). Thus, it is concluded that lignin was subjected to a co-metabolic decomposition (Haider 1996; Kögel-Knabner, 1996) during the first four months after litter shed. In addition, these decomposition dynamics were also reflected by relatively high potential C mineralisation in the L and F layer under the deciduous stand subsequent litter fall (Chapter 6).

→ We assume that rather stable and more recalcitrant organic substances [i.e., lignins] are partially decomposed (demethoxylised) and then undergo further decomposition processes in later decomposition phases [i.e., in the F and H layer]. The accumulation of humified organic substances in the H layer indicates, that structural modified but widely decomposion resistant organic structures were stored here (Kögel, 1987; Kögel-Knabner, 1996), representing a great portion of the slow and recalcitrant C pool. The higher portion of lignin derivates found in the H layer in March than in November may suggest (i) a transfer of humified organic material within the organic layer and/or (ii) simultaneous decomposition processes of other compounds in the H layer under beech/oak. We assume an equilibrium between accumulation and turnover of organic matter in the beech/oak stand that is not yet reached in the younger pine stand. The mechanisms of C sequestration in mineral soils were the object of various other studies, which showed that C sequestration is mainly related to the soils sesquioxide and humus content as well as pH (Jardine et al., 1989; Guggenberger und Zech, 1994, Sollins et al., 1996). Additionally, the higher amount of fairly stable/recalcitrant organic matter accumulated in the H layer under beech/oak may be related to the evidently higher age of this stand (Entry und Emmingham, 1998; Berg und McClaugherty, 2003). During the over-mature phase of deciduous forest stands, that in comparison to our conventional managed forest stands grow usually older and are thus, able to accumulate a higher amount of humus, the C stored is partly released again (Schulze et al., 2000a), in particular where microclimatic conditions allow an enhancement of C mineralisation [i.e., in gaps in the stand structure (Bauhus et al., 2004; Müller und Wagner, 2003; Müller, 2004)].

- During litter decomposition downward the humus profile, the chemical composition of the substrate changes and thus, microbial succession towards a community adapted to the organic matter with a given chemical composition (Berg and Meentenmeyer, 2002). Climatic influences are not dominant during this later phase of decomposition [i.e., in the F and H layer] but a high **N content** as well as high initial lignin concentration promote the formation of polyphenol-protein-complexes (Berg and Meentenmeyer, 2002; Couteaux et al., 2001; Harborne, 1997; Heal et al., 1997; Kögel-Knabner, 1996; Melillo et al., 1982; Sariyildiz, 2003; Prescott et al., 2000) and thus, control the litter-specific limit value [i.e., the point when total mass loss virtually stops] (Berg et al., 1993; Berg and Ekbohm, 1991; Berg and McClaugherty, 2003). Studying the impact of N deposition on C dynamics of two different soils, Scheuner (2004) found indications that forest soils establish a new C and N balance when the N input reaches a point of saturation. Although pyrolysis-GC/MS was not a sensitive measure of differences in N content between the pine and beech/oak litter involved in our study, the comparison of TN contents determined in May 2001 revealed higher N contents in the F (by 9 %) and especially in the H layer (by 73 %) under the beech/oak stand (Tab. 5.2). In the L layer, the N content differed not significantly between both sites. On the one hand, the accumulation of N in the H layer is related to decomposition processes resulting in an incorporation in microbial biomass and humic compounds of N down the humus profile. On the other hand, we assume that newly shed litter originally was rich in organic N compounds which were rapidly decomposed as indicated by the higher microbial activity in the L layer under beech/oak observed in fall (Chapter 6). Nevertheless, the high N content of the H layer under beech/oak indicated a lower limit value of the litter type and delivers a further plausible explanation for the humus accumulation under the deciduous stand. As a higher N content was also observed under the beech stand in the Saxonian lowland, this turnover mechanism seems to be characteristic for deciduous stands of the Dübener Heide. Additionally, the formation of higher amounts of polyphenol-protein-complexes is suggested by the initially higher lignin content of the beech/oak content as compared to pine needles (Chapter 6). Yet, the structural analysis of the H layer did not reflect this assumption. Therefore, it needs to be taken into consideration, that the fixation of N in humic substances and thus, lower C/N ratios down the humus profile are common mechanisms of litter decomposition (Rehfues, 1990). During the longer life-time of the deciduous stands in this study, older organic compounds may have been accumulated in the H layer, which were involved in more intensive turnover processes over a longer time period. Conclusively, further research is necessary on mechanisms and processes during late decomposition phases and limit values in different forest stands.

- Another well established measure of organic matter quality is the **C/N ratio** (Berg, 1998; Riek and Wolf, 2005). Generally, a narrow C/N ratio indicates good conditions for C mineralisation due to organic matter quality. Although, the C/N ratio has been reported to be lower under deciduous than under coniferous trees (Smolander and Kitunen, 2002), some of the deciduous stands involved in our study showed similar C/N ratios as the pine stand (Chapter 5). Therefore, the TOC/TN ratios of these stands may be related to similar soil chemical properties (Koch and Makeschin, 2004a,b). Comparing the C/N ratios of the different C fractions determined, we noticed a higher N portion with increasing availability of the C pool determined. Thus, easily available C fractions contain more N, and thus, promote microbial mineralisation of these compounds. While no distinct differences were observed between the pine and the pure deciduous stands [i.e., beech and beech/oak], the organic layers under advanced plantings tended to show generally lower C/N ratios. These stands have a two-storey structure and a higher stand density resulting in higher amounts and variety of litter.

· In the central **Ore Mountain region**, C/N ratios generally declined, most likely related to the lime-induced higher microbial decomposition under deciduous litter influenced stands. Subsequent to liming, an intensive organic matter decomposition, presumably higher bioturbation and transfer of organic matter into the mineral soil has occurred in the central Ore Mountain region (see also Rehfuess, 1990; Makeschin und Rodenkirchen, 1994). TOC and TN contents are by factor of about 3 to 10 higher in the upper 10 cm of the mineral soil than in the lowland region of Saxony (Tab. 5.2, Tab. 5.5). Yet, this result may partly be related to the higher clay content of the substrate itself in the mountain region that promotes a stabilisation of organic matter in clay-humus-complexes (Scheffer and Schachtschabel, 2001). Nevertheless, following liming a redistribution of SOM down the profile towards the mineral soil was reported (Rehfuess, 1990). Furthermore, in the lime-affected F and H layers evidently higher amounts of TN are concentrated and incorporated into the organic matter, indicating intensive decomposition processes that have occurred in the past. The short- and medium-term available C and N fractions increased in the L layer along the conversion sequence; in the F and H layer decreased the hot water-extractable fraction while no changes were observed in the cold water-extractable C and N. Hot water-extractable C has been proved to be a more suitable indicator for active turnover than C_{cwe} as its compounds are more attractive to microorganisms (Landgraf et al., 200_). Thus, the lime-affected organic horizons revealed an intensive microbial decomposition resulting in a vast use-up of available compounds. The observed effects are well described in studies on the impact of liming on forest soils. Following the lime-induced increase in base saturation and pH, microbial biomass and activity rose and therefore, the organic layer becomes rapidly involved in decomposition processes. This results in narrow C/N ratios as N is incorporated into the newly formed organic substance (Zöttl, 1963; Kreutzer, 1995; Rehfuess, 1990).

→ In summary, the a-priory stand-specific differentiation of microbial parameters and C and N fractions determined along the conversion sequence in the Ore Mountain region are essentially leveled out. It is assumed that the stronger impact on deciduous litter reflects the effects of liming on pH and base status rather than the litter quality. In contrast to the lime-affected F and H layer, the L layer showed a current influence of stand vegetation on decomposition dynamics similar to our findings in the Saxonian lowland.

· In decomposition models, organic matter is commonly assigned to different **C pools** according to the availability of organic compounds and the turnover dynamics. The active C pool comprised between 3 – 8 % of the SOC with an average field mean residence time [MRT] of 100 days. The slow pool comprised 50 % of the SOC in the surface and up to 65 % in subsoils, and revealed a field MRT of 12 – 80 years, and the resistant C pools decreased from an average of 50 % in the surface to 30 % in subsoils (Brady and Weil, 2002; Collins et al., 2000). Regulating mechanisms for the immobilisation of SOM are the formation of polyphenol-protein-complexes mainly in the organic layer (Haider, 1996; Kögel-Knabner, 1996), and the stabilisation of organic matter in Al-Fe-complexes in mineral soils (Baldock et al., 1992; Kaiser et al., 2002; Sollins et al., 1996). In our study, different readily available C fractions were determined, representing parts of the active pool, in order to predict the decomposition dynamics. The relation between these fractions and the total SOM were found to be greater in May (during the soil inventory) than the annual average. This result is probably related to the higher availability of soluble and readily decomposable compounds in the very early phases of decomposition after litter shed, and to climatic influences [i.e., cold temperatures and precipitation effects] during the winter season followed by a high microbial activity in spring. On average of one year, organic matter quality as expressed by the portion of the active pool on the total SOM was higher in the organic layer under pine than under beech/oak.

Tab. 9.1: Contents of water-extractable and water-soluble organic C relative to the TOC pool.

Horizon/	**Scots pine** [% of TOC]			**European beech/Common oak** [% of TOC]		
depth	**C_{hwe}**	**C_{cwe}**	**WSOC**	**C_{hwe}**	**C_{cwe}**	**WSOC**
L	4.4	2.1	1.0	3.7	1.7	1.0
F	3.8	1.2	0.6	3.2	0.9	0.5
H	4.6	1.2	0.7	2.7	0.7	0.4
0-10 cm	8.1	1.6	0.8	7.4	1.3	0.6
mean	5.2	1.5	0.8	4.2	1.2	0.6

Especially in the H layer under pine, a higher portion of readily decomposable compounds on the TOC was determined (Tab 9.1). We predict that a reasonable amount of these active fractions derived from the turnover of roots and root exudates from the *Calamagrostis epigeios* (L.) cover under this stand (Kuzyakov et al., 2001). Whether the higher litter quality of the other organic horizons and upper mineral soils is also caused by root-derived C input or related to the quality of the pine needles itself, could not be clarified in this study. It should be subjected to further investigations.

→ Summarizing, the stand-specific litter and organic matter quality was determined to be better under pine than under beech/oak as determined by the lignin content of the newly shed litter and the relations between active C fractions and SOM. Furthermore, the deciduous litter revealed high N contents, which presumably led to a higher immobilisation of organic matter in the later decomposition phases by formation of polyphenol-protein-compounds. This relation was also valid for the advanced plantings and the pure beech stand in the lowland, although the N content of the organic layers was highest in the mixed stands. According to a report by Berg and Meentenmeyer (2002), a higher remaining amount of organic matter with a lower limit value is predicted along forest conversion sequences. In the Ore mountains, due to the liming impact, organic matter probably was consumed to a higher degree under these stands resulting in an incorporation of N in the F and H layers, while the not lime-affected L layer revealed an increase in C/N.

9.3 The Role of microbial Biomass for the C Turnover in different Forest Stands

Turnover of total C and N

The relation between microbial biomass C and N and the total C and N in soil is an approved indicator for long-term organic matter turnover dynamics in soil (Insam und Domsch, 1988; Scheu und Parkinson, 1995; Bauhus et al., 1998; Ross et al., 1999). In our study the portion of microbial biomass was generally 1 % to 5 % of TOC and thus, within the range of the results in the literature (Bauhus 1998; Scheuner, 2004; Scheu and Parkinson, 1995). Along the forest conversion sequences, **C_{mic}/TOC** and **N_{mic}/TN** increased in the L and F layers indicating that deciduous litter provided a greater substrate supply for microbial biomass growth and a higher turnover dynamics in these horizons under deciduous stands. In spring 2001, the underlying H horizon showed the opposite trend with higher decomposition dynamics under pine (Chapter 5). Yet, on annual average [i.e., from November 2001 to November 2002] the proportions between microbial biomass C and the water-extractable C as well as the water-soluble C fractions were higher in the H horizon under beech/oak than under pine (Tab. 9.1). On annual average, the contents of C_{mic} were higher under beech/oak than under pine, and C_{hwe} and C_{cwe} were similar in the H horizon at the two sites. In spring 2001, however, microbial biomass was higher, and water-extractable C fractions lower under pine than under beech/oak. The high contents of rather readily available C found under deciduous stands in spring are most likely related to higher decomposition dynamics in these stands right after litter fall. Microbial biomass is strongly influenced by the weather [i.e., temperature and precipitation] and thus, may vary between seasons and years (Bauhus and Barthel, 1995; Berg et al, 1998; Beyer et al., 1993; Diaz-Ravina et al., 1995; Dilly and Munch, 1996). Hence, the proportions between microbial biomass and the different C fractions were, on annual average, greater than those found in May 2001. Additionally, the comparison between May 2001 and May 2002 revealed that microbial biomass was clearly lower in spring 2001, caused by the dry weather conditions as e.g. reflected by the dry mass of the soil samples.

Furthermore, under the Scots pine stand the H horizon was evidently influenced by the *Calamagrostis* ground cover. We assumed that the organic matter in this horizon may have been influenced by addition of root material and exudates (Kuzyakov et al., 2001). This resulted in a greater proportion of fairly readily available organic C [i.e., C_{hwe}, C_{cwe} and WSOC] on the TOC (Tab. 9.1). Therefore, in later decomposition phases, organic matter under the Scots pine stand seemed to be more attractive for microbial growth than under the European beech/Common oak stand. From the C mineralisation data, we concluded that pine needles have to undergo a primary degradation of the wax layer to permit the use of easily available compounds during microbial decomposition (Chapter 6). In contrast, easily available compounds seemed to be well accessible in beech/oak litter during the early phases, but then in later phases immobilisation of humus compounds took place. This assumption is supported by the high lignin content in the beech/oak litter in November 2001 and thus, the formation of polyphenol-protein-complexes may be a conceivable explanation. This result is further supported by the higher TN contents in the F and especially H layer under deciduous stands, while the L horizon revealed similar N contents under pine and beech as well as beech/oak in May 2001 (Chapter 5).

→ Considering the **C_{mic}/TOC ratio** as an indicator for the turnover activity in soils, results of this study indicated an initial rapid decomposition of deciduous litter in the L and F layer followed by a phase where organic material was accumulated in the H layer. In comparison to the beech/oak stand, the higher C_{mic}/TOC ratio determined in May 2001 in the H layer under pine supports our hypothesis of a rapid turnover of pine needles once subjected to initial decomposition processes. This hypothesis is further supported by findings of Scheu und Parkinson (1995), who observed a decline of the C_{mic}/TOC ratio within the soil profile from the organic layer towards the upper mineral soil under aspen, while under pine the highest C_{mic}/TOC ratio was determined in the upper mineral soil. Although, in our study a general decline of the C_{mic}/TOC ratio was observed under pine and beech/oak, the H horizon under pine revealed a higher ratio than the F layer and upper mineral soil (Tab. 9.2). Immobilisation of nutrients and the formation of resistant polymeric compounds are the main processes of this late decomposition phase (Haider, 1996; Heal et al., 1997; Mindermann, 1968). This phase is more controlled by the lignin-content (Kögel-Knabner, 1996) and the initial N content of the litter (Berg et al., 1982) than by the nutrient content or the portion of soluble compounds (Berg, 2000; Preston et al., 2000). The high microbial activity in the H layer under pine may thus, indicate that less protein-polyphenol-complexes are formed, and therefore, a higher availability of organic substances which continues to the later decomposition phase (as derived from root biomass and exudates). It may also reflect an adapted microbial community that is able to access these secondary decomposition products and additionally (ii) to maintain itself with a low energetic input [i.e., lower qCO_2 than in the H horizon under pine] (Tab. 7.3). Although the latter assumption is supported by the higher specific respiration in the H layer and upper mineral soil beneath pine, we were not able to distinguish between these factors, and therefore both have to be taken into consideration.

Turnover of medium-term and readily available C and N

- Various studies demonstrated that hot water extractable organic C is relatively easy to decompose by microbial biomass (Behm, 1988; Franko, 1997; Gregorich et al., 2000; Körschens et al., 1998; Leinweber et al., 1995; Manzke, 1995; Sparling et al., 1998). Leinweber et al. (1995) determined the structural chemical composition of the hot water-extractable organic C as carbohydrates and N-containing compounds, such as amino-N species and amides using a combined method of ^{13}C-NMR and pyrolysis-field ionization mass spectrometry (Py-FIMS). Thus, sources of C_{hwe} are roots and root exudates, decomposed SOM and the microbial biomass. The cold water extract principally is composed of two fractions: particulate organic carbon (POC) and water-soluble organic carbon (WSOC). The particulate fraction is root-derived (Gale and Cambardella, 2000) and was found to be only weakly attached to minerals. Thus, POC is easily decomposable (Schulten and Leinweber, 1999). The water-soluble C fraction represents an immediately available energy source for microbial biomass growth (Coleman et al., 1983). As a difference to the hot-water extract, cold water extraction was shown to deliver low humified material (Wu et al., 2003), while the hot water extract also liberates metal-organic complexes (Scheuner, 2004). The hot water-extractable pool accounts for about 4 to 10 % of the SOC (Landgraf, 2001; Scheuner, 2004; chapter 5); cold water-extractable C was found to be by factor of 2 to 3 (Scheuner, 2004) and up to 4 to 6 lower than C_{hwe} in forest soils (Chapter 5). The dissolved organic C [i.e., DOC] is generally defined as the < 0.45 µm fraction (Kalbitz, 1996) and thus, includes the organic compounds extracted by the WSOC method. Yet, WSOC was determined as part of the cold water extract and may thus, differ evidently from the conventional DOC as determined as soil leachate (Rennert and Mansfeld, 2003). Landgraf et al. (200_) proved that the hot water-extractable fraction of C and N contained more easily available substances such as carbohydrates, phenols and lignin monomers and organic N-compounds than the cold water-extractable fraction, and therefore, presumably serves as a better predictor of easily decomposable organic matter than the cold water extract. Various studies evaluated the relationship between microbial biomass and the different C fractions by correlation analysis, showing a generally close link between these pools in different soil types and different land use systems (Körschens et al., 1998; Manzke, 1995; Scheuner, 2004; Sparling et al., 1998; Zhong and Makeschin, 2003b). Concomitantly, in our study **correlation analysis** between microbial biomass, potential C mineralisation and the water-extractable C and N fractions identified principal relationships in the investigated forest soils and thus, led to the conclusion that these C fractions may represent primary sources for microbial biomass growth. Additionally, structure-chemical analysis showed that microbial biomass was extracted by both water extracts (Leinweber et al., 1996; Landgraf et al., 200_). Yet, in respect to stand vegetation and different organic horizons no specific pattern were found. This may also be related to the relatively small number of replicates of the statistical analysis when the data were divided into groups for single horizons and single study sites [i.e., n = 6].

For the total organic layer however, strong relations were found (Fig. 9.1). Thus, further research is necessary on the determination of relations between microbial biomass and different C fractions in different phases of litter decomposition.

In our study, relationships between microbial biomass and the different C fractions were determined for the total organic layer (Fig. 9.1), but failed to reveal a distinct pattern for individual organic horizons or forest conversion practices (Chapter 5). A similar effect was reported by Scheuner (2004) and Scheuner and Makeschin (2004) studying C and N dynamics in two different lowland soils under Scots pine. As no general preference of microbial biomass towards a certain organic fraction in soil was found, these authors concluded, that the composition of the microbial biomass may differ depending on the soil type, which will result in different decomposition dynamics. Additionally, the composition of the microbial biomass may vary as related to litter quality, vegetation cover and decomposition stage (Paul and Clark, 1996). Furthermore, the amount of microbial biomass is not a total measure for the turnover activity as the efficiency of different groups of microorganisms may vary too (Friedel and Scheller, 2002; Frostegård et al., 1993). Whether decomposition dynamics are controlled by a single factor or a combination of various factors could not be clarified in this study, and needs to be subjected to further investigations.

Surprisingly, the tree cluster analyses performed on the data obtained during the year from November 2001 to November 2002 revealed two big clusters, i.e., one of microbial biomass and one of the respective C fractions, and showed a weaker link between microbial biomass or activity and the hot water extract, than to the cold water extract (Fig. 8.2). Additionally, the microbial parameters [i.e., microbial biomass and potential C mineralisation] were closer linked between the two study sites than e.g. microbial C was related to one of the water-extractable or -soluble energy source at one of the two sites. Similar results were observed for the C_{hwe} contents. The close linkage between C_{cwe} and WSOC is plausible as WSOC was determined as part of C_{cwe}.

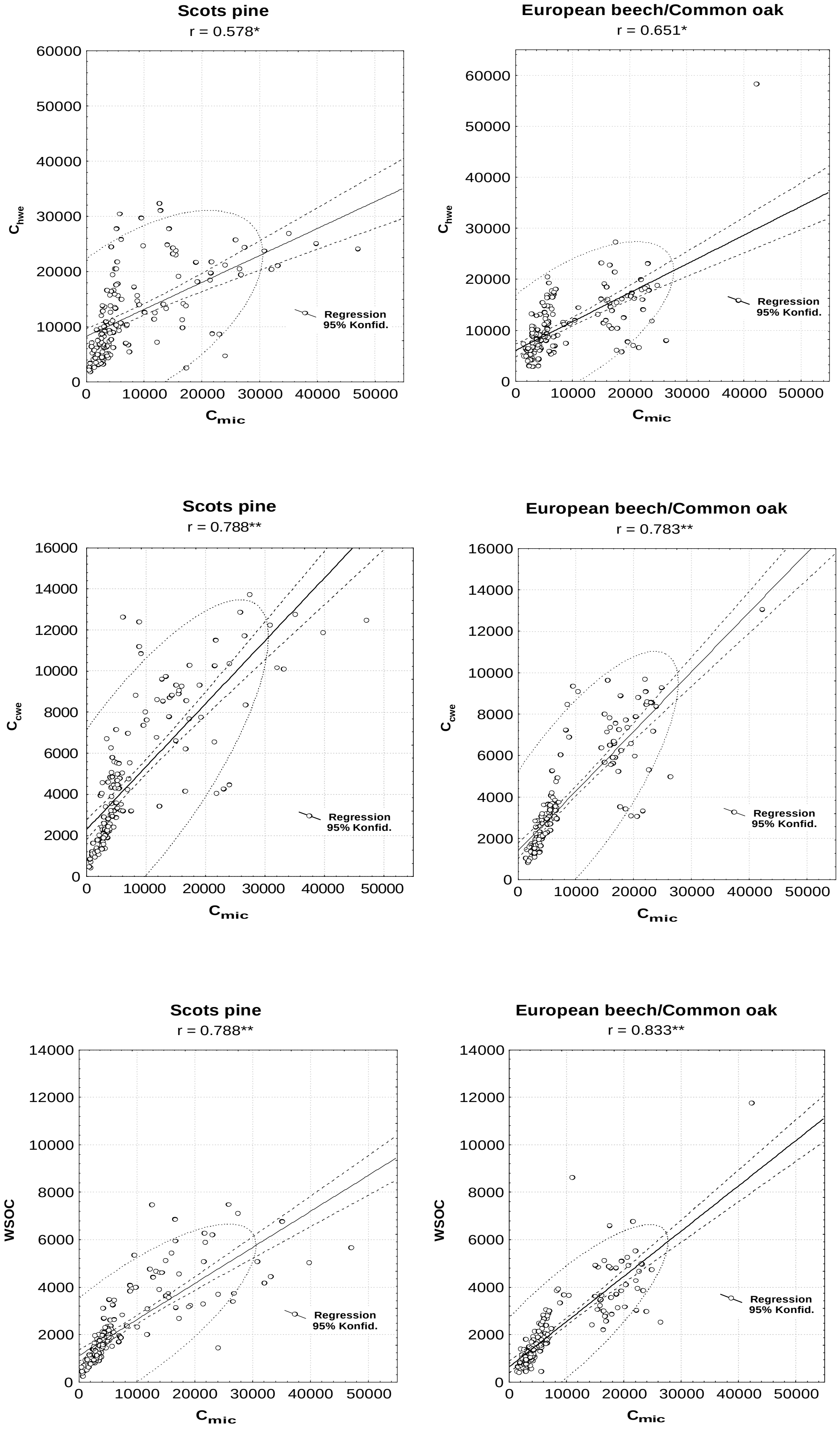


Fig. 9.1: Regression between C_{mic} and the respective water-extractable and water-soluble C sources (C_{hwe}, C_{cwe} and WSOC) for the organic layer (L, F and H horizon) under pine and beech/oak between November 2001 and November 2002.

- In May 2001, the **portion of microbial biomass on the hot water-extractable C** ranged between 16 % and 30 %, and on the cold water extract between 87 % and 130 % (Tab. 5.3, Tab. 5.6). Yet, on average of the 12-month study (from November 2001 to November 2002), the amount of C_{mic} as related to the C_{hwe} and C_{cwe} contents was higher than in spring 2001 and exceeded the hot and cold water-extractable energy source in the L layer and partly also in F and H horizons (Tab. 9.2). The overlap of the water-extractable C fraction and the microbial biomass pool was evidently higher for the cold-water extract than for the hot-water extract. Therefore, the C_{mic}/C_{hwe} ratio is recommended as a more suitable parameter to indicate the turnover of organic matter in different forest stands. Our findings support the structure-chemical evaluation by Landgraf et al. (200_).

- The results of this study revealed that the ratios of C_{mic} to the hot-water-extract differed along the forest conversion sequences: The higher C_{mic}/C_{hwe}, C_{mic}/C_{cwe} and C_{mic}/WSOC ratios under the deciduous stands generally reflect higher turnover rates. The ratio of C_{mic} to the respective C pools is controlled by the growth and mortality of the microbial biomass (Bosatta and Ågren, 1994). The comparison between Scots pine and European beech/Common oak showed that similar amounts of microbial biomass are related to lower pool sizes of the respective water-extractable and water-soluble C in the L layer of the beech/oak stands. In the F and H layer, a higher microbial biomass has to compete for lower contents of the various readily available C pools and is thus, subjected to a lower substrate quality. Because the contents of water-extractable and water-soluble organic C in the H layer under beech/oak were not significantly different from those under pine, the higher portion of microbial-C on the various readily available C pools may also indicate a difference in microbial biomass composition between both stands. This hypothesis is supported by the lower qCO_2 in the H layer and upper mineral soil under beech/oak indicating a lower energetic requirement of the microbial biomass under beech/oak. The comparison with the results of the soil inventory performed in May 2001 revealed a difference in the H horizon, where the C_{mic}/C ratios were higher in May 2001 under pine than under the deciduous stands. This result may be related to the germination of the ground vegetation under Scots pine in spring resulting in a change in the substrate quality and thus, enhanced microbial biomass growth.

Tab. 9.2: Relationship between microbial biomass and the different C fractions determined during one year between November 2001 and November 2002.

	Scots Pine				**European beech/Common oak**			
	C_{mic}/TOC	**C_{mic}/C_{hwe}**	**C_{mic}/C_{cwe}**	**C_{mic}/WSOC**	**C_{mic}/TOC**	**C_{mic}/C_{hwe}**	**C_{mic}/C_{cwe}**	**C_{mic}/WSOC**
		[%]				**[%]**		
L	4.41	100.92	206.11	423.98	4.41	118.33	253.41	437.69
F	1.42	37.17	114.00	244.22	1.57	49.09	169.04	290.55
H	1.67	36.55	142.50	248.73	1.25	46.80	182.54	319.91
0-10 cm	0.95	11.69	59.63	116.00	1.05	14.15	79.88	161.13

→ Results indicate that the microbial community in the H layer under beech/oak has a different composition than under pine, and revealed lower maintenance requirements. The higher C_{mic}/C ratios indicated a higher decomposition dynamic in all horizons studied and thus, resulting in organic matter that has undergone intensive turnover processes containing lower amounts of readily available pools. As a result of the fast initial turnover in fall, substrate quality seems to be lower in the organic layer under deciduous stands as organic materials are subjected to the second decomposition phase. Additionally, the comparatively high ratios of N_{mic}/TN, N_{mic}/N_{hwe} and N_{mic}/N_{cwe} emphazised the importance of the microbial biomass in the nitrogen cycle.

9.4 Indicators for the Impact of Forest Conversion on Humus Dynamics

- In order to evaluate the soil chemical and microbial parameters obtained and to define indicators differentiating decomposition dynamics along the studied forest sequences, **discriminant functions** were calculated along each of the three sequences for the soil inventory performed in May 2001. Results revealed a clear differentiation in top soils [organic layer and upper mineral soil (0–10 cm)] as 58.4 – 75.9 % of the variance and 82 – 90 % of the statistical spread could be explained by grouping into forest types.

- In contrast to the soils studied in the Saxonian lowland, in the Ore Mountain region comparatively low coefficients of the discriminance function reflected the impact of liming on decomposition processes, and did not allow an evaluation of the soil parameters.

→ In the lowland region, TOC, TN, and hot-water-extractable C and N fractions were shown to be relevant for discriminating between forest types along both sequences and thus, were recommended as sensitive indicators for forest conversion.

9.5 Decomposition Dynamics and Humus Formation in a coniferous and a deciduous Stand

Litter Decomposition

- Litter decomposition is usually studied using mini-containers (Eisenbeis, 1993), containers (Herlitzius and Herlitzius, 1977) or **litter bags** (Falconer et al., 1933; Bockock and Gilbert, 1957). All of these approaches impact litter decay rates and therefore, a suitable **method needs to be selected** depending on the objectives of the study, after evaluating possible advantages and disadvantages. Mini containers, for example, are based on only small amounts of litter, not sufficient for further analysis in the lab, and express a comparatively strong impact on the climatic conditions inside the container (La France, 2002). Containers are too compact for exposition within the L layer; they might be more suitable for studies on root turnover or including the entire organic layer. Taking these factors into consideration, the litter bag method was chosen for our study. In choosing a suitable **mesh size** for the litter bags, we had to meet a compromise between the higher impact on climatic conditions inside the litter bag [i.e., smaller mesh sizes] that could prevent aeration and promote fungi growth, and the determination of meso- and macrofauna entering the litter bags [i.e., larger mesh sizes] (Dunger, 1997; Pöhhacker, 1995). Therefore we selected a mesh size of 1 mm, which allows an involvement of the soil fauna in litter decomposition (Beck, 1984), and reduces the effects on climatic conditions inside the bag (Dunger, 1997). Due to litter compaction, leaching may be reduced as the water flow through the litter bag is interrupted (Krumrei et al., 2004). The size of litter bags and mass of litter used was calculated based on the mean annual litter fall of about 4 t ha^{-1} a^{-1} determined during a long-term observation in the Solling region of Germany (Ellenberg, 1986). Discussing the results of the litter bag study, a methodological problem needs to be considered as deciduous litter tends to agglutinate in the litter bags. In order to assure the comparability to the results obtained in the lab, the litter **material was shredded** and homogenized before exposition in the field (Dunger, 1997; Schinner und Sonnleitner, 1996; Weaver, 1999). Shredding resulted in a ripping up of the litter material and cutting through of the wax layer. Thus, an effect of this litter pretreatment and homogenization on the initial decomposition phase cannot be excluded. This effect may have been stronger on pine needles than on beech/oak leaves, and may explain, in part, the initially high mass loss of 16.8 % for pine needles between November 2001 and March 2002 (Chapter 6).

- In contrast to **litter decomposition rates** estimated from the potential C mineralization studies in the lab, decomposition rates determined in litter bags exposed to field conditions are a product of leaching, litter fragmentation by the soil fauna and of microbial decomposition (Swift et al., 1979; Cadish and Giller, 1997). During the initial stage, litter decomposition is dominated by the loss of soluble substances by leaching (Yavitt & Fahey 1986, Berg et al. 1982) and thus, is controlled by litter quality, and more importantly, by climatic conditions. In pine stands, the early phase of litter decomposition, that is yet not controlled by the lignin content, was reported to include the first year of decomposition, and was characterized by a mass loss of about 30-40 % (Berg, 2000; Johannson, 1994). For beech litter the passage from the first to the second decomposition phase accounted to about 20 % mass loss (Laskowski et al., 1995; Irmler, 2000). A higher loss of soluble or easily decomposable organic compounds from coniferous litter relative to deciduous litter was reported from DOC studies by Michalzik et al. (2001). These findings were supported by higher contents of water-extractable C in the pine litter determined in November 2001 in our study. In contrast, WSOC was higher under beech/oak. Leaching was observed to be responsible for one (Berg et al., 1982) to two thirds (Gödde et al., 1993) of the mass loss during the initial phase.

- The **mass loss** of the pine needles accounted for 42.2 % within the 12 months but only for 27.8 % for beech/oak leaves (Fig. 7.1). Using the model of Meentemeyer (1978), a similar turnover rate of 42 % of pine needles, and of 32 % for beech leaves was calculated (Stuhlmann, 2005). According to the passage from the first to the second decomposition phase as determined by mass loss, the lignin content controlled litter decay (Berg et al., 1996) in our study from July on. The influence of litter quality on this first decomposition phase, that is characterized by the loss of soluble organic substances, was further proved by discriminant analysis, which separated the parameters studied clearly between pine litter and beech/oak as well as beech/oak exposed in pine [i.e., reference litter] (Stuhlmann, 2005). Litter decomposition under pine was highest, especially during the summer months (here May to July), accounting to 15.9 % mass loss compared to 10.1 % of beech/oak litter, or 7.9 % of the beech/oak litter exposed in the pine stand (reference litter). These results reflect the impact of litter quality, otherwise the reference litter would have been decomposed as rapid as the pine litter during the summer months. A mass loss of about 30 % of beech leaves within one year was also reported by Jörgensen (1991) and by Wise und Schäfer (1994). In addition, Stuhlmann (2005) presented an overview on decay rates of different litter types and growth regions revealing *k* values between 0.28 and 0.59 for Scots pine needles (Berg and Staaf, 1980; Bergmann, 1998; Eisenbeis et al., 1996; Hasegawa and Takeda, 1996; Krumrei, 2003), between 0.25 and 0.31 for European beech (Cortez, 1998; Franke and Beck, 1989; Herlitzius and Herlitzius, 1977; Irmler, 200) and of about 0.43 to 0.49 for Common oak (Cortez, 1998; Howard and Howard, 1974). In our study, *k* accounted for 0.54 under pine and for 0.33 under beech/oak after one year exposure of the litter bags. Thus, the MRT calculated was 1.85 years for pine litter and 3.03 years for beech/oak, revealing a faster turnover of pine needles than of beech/oak litter. Both *k* values are within the upper range of published data, assumingly due to the higher leaching rate at the beginning caused by the shredding of litter prior to initiating this experiment. Therefore, the actual MRT may be longer. Our results indicated that, despite of the intensive initial decomposition phase of deciduous litter in fall, pine needles are decomposed nearly twice as rapid as deciduous litter. Concomitantly, potential C mineralisation under pine exceeded those under beech/oak during the summer months, reflecting a rapid turnover of pine needles during this decomposition phase. In contrast, the results of the potential C mineralisation indicated no difference between stands. However, a higher C mineralisation in deciduous stands was reported by various authors (Beck, 1989; Heal, 1997; Matteucci et al., 2000; Persson et al., 2000; Saetre et al., 1999; Smolander and Kitunen, 2002). Yet, litter source quality of European beech was reported to similar to that of coniferous needles (Albers et al., 2004; Berg et al., 1996; Vesterdal, 1999). In our study it was shown that litter quality under Scots pine was actually better than those under European beech/Common oak. Our observations are supported by reports of a more rapid decomposition of coniferous than deciduous litter (Krumrei et al., 2004; Albers et al., 2004; Lorenz et al., 2004). Nevertheless, the total annual mineralisation rate was in the same order of magnitude for beech/oak and pine. Therefore, we concluded that the higher litter decay rate of pine needles is also related to a higher amount of compounds lost by leaching. As the reference litter [i.e., beech/oak exposed in the pine stand] showed with 28.6 % a similar mass loss during the year as the beech/oak litter exposed in the beech/oak stand, the difference in the decomposition rate of the litter in different forest stands may be stronger related to the litter resource quality than to the stand and site characteristics during the first year. This relationship is also reflected by the similar indicator values determined for the L layer of both stands (Tab. 9.3).

Decomposition Dynamics in the Organic Layer

- During the course of the year **microbial activity** in both stands showed [i.e., Scots pine and European beech/Common oak] a peak in spring and fall, while potential C mineralisation was reduced to about 50 % during winter and summer. Some studies on organic matter turnover in forest soils revealed other results, i.e., a maximum of microbial biomass in summer (Diaz-Ravina et al., 1995; Dilly and Munch, 1996) or no clear variation with season (Bauhus and Barthel, 1995). Other authors observed the same effect of an increase in microbial biomass and activity in spring and fall (Beyer et al., 1993; Berg et al, 1998; Persson et al., 2000). Generally, the effects of extreme temperature and moisture conditions were stronger in the organic layer under the comparatively open pine stand than under the closed canopy and fairly constant conditions under beech/oak. Thus, during the summer months microbial biomass and activity increased evidently in the L layer under the pine stand. In contrast, both parameters did not vary much during the summer months under the closed canopy of the deciduous stand.

- A higher potential C mineralisation was observed in the F layer under beech/oak, accompanied by a 38 % higher energy demand (**qCO_2**) as compared to the pine stand in the mean of one year (Tab. 9.3). In contrast, the qCO2 under beech/oak was 25 % and 50 % lower in the H layer and upper mineral soil (0-10 cm), respectively. The L layer revealed no distinct differences.

→ The examination of the **specific respiration** confirmed the assumption of a stand-specific turnover dynamics. In contrast to the pine stand, the organic material under beech/oak is initially turned over rapidly and then, in later decomposition phases [i.e., H horizon] slowly decomposed and to a higher rate incorporated into microbial biomass. Hence these results support the hypothesis that protein-polyphenol-complexes are formed following the initial decomposition phase in the L layer and intensive turnover in the F layer and accumulated in the H horizon. This means that lignin is initially decomposed in a co-metabolic process and its derivates are then accumulated (Kögel-Knabner, 1987, 1996, 2002; Haider, 1996, 1999).

During the course of **one year, the decomposition of organic matter** was characterized by an active initial C mineralisation in the L layer under beech/oak shortly after litter shed that from March on was similar to the mineralisation rate under pine. In the F layer, potential C mineralisation under beech/oak exceeded with a rate of 21.10 $\mu g\ g^{-1}\ h^{-1}$ the rate under pine with only 12.53 $\mu g\ g^{-1}\ h^{-1}$ by 68 %. On the one hand, a resulting thick and mighty H layer under the deciduous stand was observed, on the other hand was the microbial activity in this horizon still comparable to this of the thin H layer under pine and the C_{mic}/C ratio higher.

Humus Formation

The humus mass differed between the soil inventory in May 2001 and the average of the whole year for single organic horizons but not for the entire organic layer. The mass of **organic layer** under beech/oak exceeded the mass under pine in spring by 9 %, and in average of the year by 6 %. However, although in accordance with the literature data, these results are not considered evident.

In spring, the mass of the L layer under beech/oak was lower than under pine, while the potential C mineralisation and microbial biomass were higher. But in the mean of the year, no distinct differences were observed in the L layer. Thus, the characteristics of the L layer in spring were affected by the initially active turnover phase under beech/oak, which continued to have an effect after the litter fall. The differences observed between both stands at this time aligned during the course of the year due to the evidently higher turnover activity in the pine stand during the summer months [i.e., potential C mineralisation and result of the litter bag study]. The pine stand had a comparatively open vegetation structure and thus, allows a better warming of the forest ground which in turn, enhanced microbial biomass growth and activity.

- Emanating from the active initial turnover phase in the L layer, the F layer under beech/oak was thicker and heavier in spring. Yet, in the mean of the one year this horizon had a higher microbial activity (by 68 %) and consequently, nearly one third lower mass (by 30 %) than the pine site.

- The mass of H layer under European beech/Common oak observed in May 2001 was nearly twice as high than in the mean of the year, resulting from the evidently higher organic matter turnover rate in the F layer under the deciduous stand.

Tab. 9.3: Specific parameters characterizing organic matter turnover for the organic layers (L, F and H horizon) and upper mineral soil (0-10 cm) in the Scots pine and European beech/Common oak stand as mean between November 2001 and November 2002.

Horizon/ depth	**Scots Pine [µg g^{-1}]**	**Eur. Beech/ Com. Oak [µg g^{-1}]**	**Beech/Oak as compared to Pine [%]**	**Parameter**
L	13.80	13.64	-1.2	mass^1
	416900.00	416600.00	-0.1	TOC^2
	18390.70	18369.51	-0.1	C_{mic}^3
	100.92	118.33	**17.2**	C_{mic}/C_{hwe}^4
	2.39	2.39	0.0	qCO_2
	150.33	149.50	-0.6	pot. C mineralisation rate^3
F	69.21	54.68	-21.0	mass^1
	325966.67	354800.00	8.8	TOC^2
	4633.26	5559.89	**20.0**	C_{mic}^3
	37.17	49.09	**32.1**	C_{mic}/C_{hwe}^4
	0.75	1.04	**38.7**	qCO_2
	12.53	21.10	**68.4**	pot. C mineralisation rate^3
H	72.64	103.62	42.6	mass^1
	143650.00	245150.00	**70.7**	TOC^2
	2395.44	3058.61	**27.7**	C_{mic}^3
	36.55	46.80	**28.0**	C_{mic}/C_{hwe}^4
	0.72	0.53	**-26.4**	qCO_2
	5.49	5.74	**4.6**	pot. C mineralisation rate^3
0-10 cm	1067.00	1346.80	26.2	mass^1
	16303.67	22136.33	**35.8**	TOC^2
	154.39	231.67	**50.1**	C_{mic}^3
	11.69	14.15	**21.0**	C_{mic}/C_{hwe}^4
	1.16	0.57	**-50.9**	qCO_2
	0.56	0.43	**-23.2**	pot. C mineralisation rate^3

[1] mass in t ha^{-1}, data obtained from 8 sampling periods between November 2001 and November 2002

[2] content in µg g^{-1}, data obtained from the top soil inventory performed in May 2001

[3] content in µg g^{-1}, data obtained from 8 sampling periods between November 2001 and November 2002

[4] values in %, obtained from TOC^2 and C_{mic}^3 data

→ The comparison of the results of both study stages as well as the observation during the one-year course may explain the described differences in thickness and mass of the single organic horizons under the deciduous and pine stands. After an active turnover phase in the beech/oak stand in fall, we found an intensive decomposition of the organic material in the F layer which is sheltered against climatic extremes. Subsequently, secondary decomposition products are accumulated as fine organic matter in the H layer of this site. In contrast, the results under pine indicated a retarded but fairly intensive decomposition in the L layer, followed by a phase of relative stagnancy (F layer), and in turn, again an active turnover phase in the comparatively thin H layer.

· As a general approach, the negative exponential model is used to describe the rate of decomposition (Berg and McClaugherty, 2003; Jenkinson, 1977; Melillo et al., 1989; Minderman, 1968; Olsen, 1963). In forest soils, usually, a portion of the litter entering the forest floor is not completely decomposed, but is modified into relative stable humus compounds which may decompose slowly or accumulate. To understand why these H layers are better developed at site than at the other, we need to understand the decomposition process, its mechanisms and control factors. Aber and Mellilo (1991) presented a general model of the decomposition process occurring in two phases: Soluble organic substances are lost in the early phase by leaching, followed by a second decomposition phase, which is characterized by an immobilisation of nutrients, a slower decay rate and a net loss of lignin and net N mineralisation (Prescott et al., 2000). Thus, the initial phase of litter decomposition is primarily characterized by the loss of soluble compounds [i.e., DOC] (Berg and Mc Claugherty, 2003; Gödde et al., 1993) and thus, controlled by litter quality (La France, 2002). Comparing different forest stands, the loss of dissolved organic matter was reported to be up to a factor of 3 greater under conifers than under deciduous stands (Michalzik, 1999; Qualls and Haines, 1992). On the other hand, coniferous needle litter is more resistant to leaching during the first phase of decay as the wax layer offers protection (Berg and Staaf, 1980a,b). Thus, it was concluded that the rapid initial decomposition as indicated by a high C mineralisation rate of the newly shed beech/oak litter is related to the loss of dissolved and soluble organic compounds as well as to an enhanced access to these compounds. In contrast, pine needles are protected by the wax layer and have to undergo a physical degradation during winter before easily available substances can be transferred and mineralized during the summer months. The initially rapid mass loss of pine needles observed during the litter bag exposition is a consequence of the shredding, which resulted in a partly removal of the wax layer and fragmentation of the needles, allowing a rapid loss of soluble compounds by leaching. Consequently, the contents of hot and cold water-extractable organic substances increased in the L layer under pine during the summer months. These results supported the hypothesis of a loss of readily availably compounds by leaching and microbial consumption. During that phase, readily available compounds are rapidly lost [i.e., cellulose], and lignin may have been enriched relative to the former compounds (Prescott et al., 2000).

In contrast, beech/oak litter seemed to enter more rapidly the second turnover phase as microbial biomass activity was reduced in the L layer in spring and an evidently higher C mineralisation was observed in the F layer throughout the year as compared to pine. It was also reported from other studies, that pine needles turn to the second decomposition phase when a higher amount of litter has already been decomposed [i.e., at a higher mass loss] (Johannson, 1994; Berg, 2000) than beech leaves (Laskowski et al., 1995; Irmler, 2000). Nevertheless, the reduction of microbial activity in the L layer under beech/oak may have also been related to the drying out of litter material during the summer months inhibiting microbial biomass growth and activity (Pöhhacker, 1995). The second turnover phase is characterized by a co-metabolic decomposition of lignin, lignified carbohydrates and secondary decomposition products (Haider, 1996; Hasegawa and Takeda, 1996; Kögel-

Knabner, 1996). The F horizon under the deciduous stand revealed a by 38 % higher specific respiration than under pine. Thus, a higher portion of the organic material was mineralized (and partly humified) than built into microbial biomass. The microbial biomass of this horizon is presumably composed of species coping with the comparatively old organic matter.

9.6 C Balance and Potential C sequestration

- In the mean of one year, potential **C mineralisation** (expressed as C stocks) under beech/oak was by 13 % higher than under pine. Concomitantly, **C_{mic} stocks** were in sum of the organic horizons by 16 % higher under beech as compared to pine. These results are well comparable to literature data, reporting a 15 % higher microbial biomass (Saetre et al., 1999; Smolander and Kitunen, 2002) and a 10 % to about 25 % higher C mineralisation (Raich und Tufekciogul, 2000; Albers et al., 2004) under deciduous than coniferous trees. At the same time, C_{hwe} and C_{cwe} stocks were by 6 % and 15 % lower in the organic layer under the deciduous stand. These data support the relationship discussed for the contents of the respective parameters: The higher microbial activity under deciduous stands resulted in a higher use of readily available C pools, and indicated a higher decomposition dynamic.

- **Aboveground litter** has been collected and quantified in the Scots pine and European beech/Common oak stand during one year and set in relation to the C stock in the organic layer. Due to the higher C stocks and litter amounts under the deciduous stand, the **turnover rate** was with 16.9 years slightly higher than under pine with 16.2 years. Thus, the turnover of beech/oak leaves requires a longer period of time than the pine needles. As the beech/oak stand is older than the pine stand, this longer time period may be responsible for the accumulation of organic matter in the H layer, that subsequently may contain older organic matter than the H horizon under Scots pine.

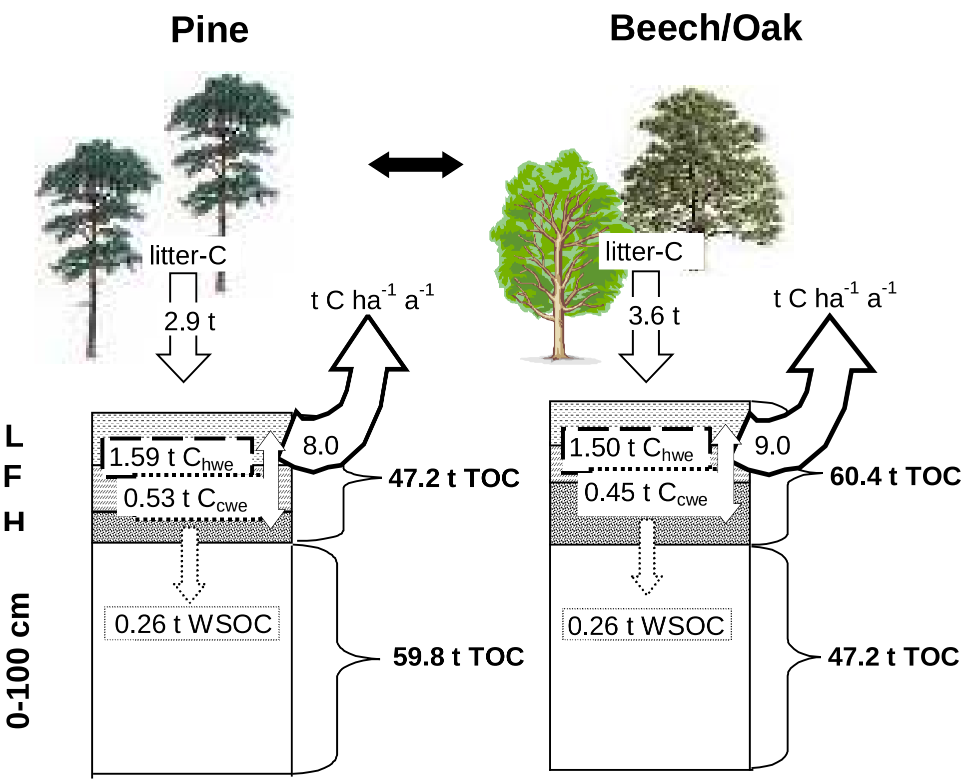


Fig. 9.3: Balance of aboveground C-input from litter fall, total, water-extractable and water-soluble C as well as C-output by potential C mineralisation in the organic layer under Scots pine and European beech/Common oak. [Data obtained between November 2001 and November 2002, C-output was determined as potential C mineralisation by 15 °C].

· The potential CO_2 efflux following C mineralisation is probably the dominant outflow of C from the soil, although DOC leaching and particulate transports should not be neglected (Persson et al., 2000). Thus, the **ratio between C inflow and C outflow** can be predicted taking litter fall and potential C mineralisation into consideration. The calculation revealed a higher ratio for beech/oak, indicating that a higher amount of C remains in the soil. Yet, assuming that the 60.4 t ha^{-1} organic matter under beech/oak were accumulated during the past 200 years, we concluded that an annually amount of about 300 kg organic matter was accumulated. In contrast, this amount is about twice under pine amounting to about 600 kg. Yet, strong management impacts have to be taken into consideration especially during the reforestation of the pine stand (see Chapter 9.7). The result is contradictory to our observations and thus, it is conceivable, that the history of both stands is difficult to compare. The organic layer under the pine stand may need a long time to recover from the assumed clear cutting and the humus loss due to the burning of brushwood (Chapter 9.7).

→ Therefore, the study revealed (i) a higher input of C in deciduous stands subjected to a higher decomposition dynamic, (ii) a higher release of C by potential C mineralisation, and (iii) a higher accumulation of C under beech/oak, which was dominantly sequestered in the H horizon and upper mineral soil. The specific turnover dynamics in the organic layer under deciduous stands provide the basis for a long-term C sequestration in mineral soil as greater amounts of the C inputs are accumulated than under pine.

9.7 Managing Humus – Conclusions

The management of humus entails two rather divergent considerations:

1) influence the turnover activity in terms of a balanced system, to improve seedbeds and to promote long-term site productivity, and
2) conservation of the humus in order to maintain the nutrient pool for the growing stand vegetation and to enhance C sequestration (Prescott et al., 2000).

In order to evaluate the results obtained in this study on the effects of forest conversion on humus dynamics, we need to focus on the stand history, and reveal future scenarios as we work with natural ecosystems that were influenced by various anthropogenic factors over long periods of time.

Stand History

- While at the beginning of the middle age, the composition of tree species was not altered yet (Amarell, 2000) and stand structures were still extensively natural, during the middle age forest management was affected by the promotion of composite forest systems (*Mittelwald*). Thus, the portion of oak increased relatively to beech and pine (Amarell, 2000). European beech gained areas again since the beginning of the 18th century, when the potato was introduced replacing the oak-mast of lifestocks (Schubert et al., 1960). Servitudes were very common in the forest district of *Falkenberg* until the late 19th century and thus, vast areas have been devastated and subsequently re-planted with Scots pine (Schubert et al., 1960). It is assumed that until that time also the Scots pine stand investigated in our study was a semi-natural mixed stand mainly of beech and oak according to the potential natural vegetation (pnV). Thus, the currently 78 years old pine stand may represent the second or third generation of pine at this site. The widely planted Scots pine stands were managed in clear-cutting systems and covered about 83 % of the forest first-storey in the forest district *Falkenberg* in 1994 (Zimmermann, 2000). The clear-cutting practice included the clearance of the site, burning of brushwood and afterwards reforestation (afforestation) of the site. During these practices, nutrients were lost by (i) removal of the stand vegetation and (ii) accelerated mineralisation of the remaining humus due to the exposure of humus to the microclimate of the cleared area (*climatic exposition*) resulting in higher radiation at the forest ground and soil moisture (Rehfuess, 1990). Additionally, the often practiced piling up of brushwood, ground vegetation and organic layer and subsequent burning resulted in a further degradation of the sites nutrient balance. The nutrients of the ash were washed out and finally lost (Thomasius and Schmidt, 1996). Hence, the Scots pine site we studied has most probably lost a considerably high amount of organic matter and nutrients during the last 200 years, which is similar to the age of the continuously stocked, semi-natural European beech/Common oak stand. It is therefore possible to assume that the organic layer under this site would naturally be thicker. Presumably, the H layer under pine is younger than under beech/oak; not only due to the different stand age, but also due to litter raking which may have influenced the organic layer. Additionally, regeneration of the beech/oak stand may even have been natural and thus, the H layer of this site might even be older than the forest stand.

Managing Humus

- The accumulation of poorly degraded litter and other negative effects lead to a reduced resilience of these secondary (and tertiary) coniferous stands and have increased their susceptibility to environmental stress factors (Führer, 1990). These circumstances may explain, in part, the contradictory results of decreasing organic layer mass along forest conversion sites in the NE-German lowland as reported by Fischer et al. (2002). However, these forest areas have also been influenced by clear-cutting systems over a long time. Therefore, it seems conceivable that the differences in climate and nutrient status have a dominant impact on organic matter accumulation (Persson et al., 2000), and may explain different trends observed in lowland sites. The predicted recovery of forest floor organic matter following clear cutting to pre-harvest levels has been reported to vary in range between <5 to 80 years depending on the degree of disturbances (Aber et al., 1978; Crowell and Freedman, 1998; Prescott et al., 2000). Heinsdorf (2002) observed a humus loss of about 21 to 25 % after clear cutting and during the subsequent establishment of the new forest stand until the age of ca. 20 to 30. Thus, the Scots pine stand may have reached the recovery level by now, building-up a stand typical organic layer.

- Furthermore, management-derived impacts arise due to the possible ploughing in order to prepare the site for reforestation. According to Heinsdorf (2002) and to Prescott et al., (2000) the organic layer is stronger influenced by a humus loss due to ploughing than to the clear cut itself.

- During the first years after reforestation, organic matter was reported to be lost to the site as the young plants have a high nutrient demand (Heinsdorf, 2002; Thomasius and Schmidt, 1996). Then, during the later phases of stand development, the stand closes its roof cover, litter input increases and the stand reaches the maturity phase (*Reifephase*) with a characteristic stand climate. During this time, organic matter is accumulated, known to be a common process during the stand development. Thus, older stands usually have accumulated higher amounts of humus than young stands (Entry and Emmingham, 1998).

- Although, deciduous litter has widely been observed to reveal higher C mineralisation rates and thus, to promote decomposition, mixed stands were reported to accumulate less humus and keep nutrients in a close cycle (Heusohn, 1929; Scheu and Parkinson, 1995; Prescott et al., 2000;). However, an accumulation of humus was observed at underplanted sites and sites with advanced plantings (Albers et al., 2004; Koch and Makeschin, 2004a,b; Prietzel, 2004). The mass of organic matter accumulated under mixed stands is related to the stand density and thus, amounts of leaf litter and root-derived C inputs. Therefore, forest conversion in advanced plantings initially leads to an accumulation of humus and thus, C sequestration in the forest ground. This effect is accompanied by a shift towards better resource quality and higher decomposition dynamics. As a result, Prietzel (2004) determined higher C contents in the upper mineral soil after beech and oak were planted within pine stands. These positive effects on quality and dynamics of humus and C sequestration were confirmed by this study.

- The deciduous stands in our study showed a lower C accumulation in their organic layer as compared to the advanced plantings and the pure coniferous stand. This may indicate that humus was lost when the two-storey sites [i.e., advanced plantings] are thinned and conifers are removed. The effect of thinning may lead to a humus reduction (Piene and van Cleve, 1978), depending on the intensity of thinning and the remaining stand density. Hence, the reduction of organic layer mass along the second phase of forest conversion from the advanced plantings to pure deciduous stands may be plausible when stand density decreases and litter addition (aboveground and belowground) is reduced, and the generally harder decomposable conifer litter is omitted. The beech/oak litter contained more lignin, and the turnover rates supported the finding of a higher accumulation of secondary turnover products [i.e., polyphenol-protein-complexes] in the H layer, resulting in a higher organic layer mass under beech/oak than under Scots pine. We cannot precisely say what factors have influenced the Scots pine site during the last 200 years. The beech/oak stand represents the semi-natural stage from where forest conversion (by re-forestation) may have started 200 years ago, while the Scots pine stand represents the initial phase of current management strategies towards forest conversion. Reviewing the history and estimating the future development of these stands, and comparing the humus dynamics under Scots pine and European beech/Common oak, it is still difficult to answer the question if pure deciduous stands will store higher C amounts in their organic layer than conifer stand. Also other studies documented contrasting results concerning this issue (Albers et al., 2004; Fischer et al., 2002; Koch and Makeschin, 2004a,b; Reinhardt and Makeschin, 2003). Yet, we can describe the stand-specific turnover dynamics of litter, revealing higher amounts of secondary decomposition products accumulated in the H layer and higher C stocks in the upper mineral soil under deciduous stands than under conifers. Additionally, differences in the SOM distribution between coniferous and deciduous stands were described by different studies, were deciduous stands showed a relatively thin organic layer, and more C was stored in the mineral soil (Fischer, et al., 2002; Heinsdorf, 2002; Koch and Makeschin, 2004a,b).

· The amount of organic matter accumulated in the organic layer strongly depends on the climate [i.e., temperature and soil moisture] (Hofmann and Anders, 1996; Persson et al., 2000). Although these factors depend pre-dominantly on the region, they can additionally be influenced by the management of stand density and stand structure. Thus, the mass of organic matter accumulated on top of the soil may differ as related to forest conversion between different regions, e.g. forests in NE-Germany produce lower amounts of litter due to the lower precipitation resulting in generally lower humus stocks (compare with Heinsdorf, 2002).

→ For the investigated stands of north Saxony, the stand-specific humus dynamics result in higher C contents and stocks in the H layers and upper mineral soil under advanced plantings and deciduous stands relative to pine stands. Yet, projecting the results of this study to estimate the future development of these forests, the central factor controlling C sequestration in soils seem to be management impacts rather than the stand vegetation [i.e., the difference between pine and beech or beech/oak]. However, it is possible that the impact of litter quality may be greater comparing Scots pine with other deciduous trees of better litter quality, e.g. pure oak, hornbeam, lime-tree.

9.8 Further Research

A number of factors were discussed that were not investigated in this study. In addition, some hypotheses may require further research in order to optain results valid for a wide variety of different forest types and regions.

Due to the longer life-time of the deciduous stands, the H layer may have accumulated far older substances that have been involved into more intensive turnover processes. Conclusively, further research is necessary on mechanisms and processes during late decomposition phases and limit values in different forest stands. In this context it might be promising to apply ^{13}C isotope methods in order receive information on the age of single organic horizons and thus, to promote the comparability of humus dynamics between different stands.

Furthermore, it seems useful to gather information about the composition of microbial biomass, its preferences as related to resource quality and efficiency of SOM turnover. In this context, further research is required on the quality of different litter types. Although a lot has been done comparing the decomposition of spruce and beech litter, there is a lack of information on pine and oak litter. In order to receive comparable information, the litter quality should be studied applying pyrolyses methods, and results should be discussed relative to the stand- and horizon-specific composition and efficiency of the microbial biomass.

Furthermore, the relationship between microbial biomass and the different C fractions obtained by water extraction methods needs to be clarified as related to different land use systems, plant species and decomposition phases. Statistical analyses only allow quantitative comparisons, while the approaches by Leinweber et al. (1995) and Landgraf et al. (200_) contributed positively towards clarifying the composition of the C fractions extracted and their relationship to microbial turnover. Thus, it may be promising to determine the structural-chemical composition of different organic matter fractions using Pyrolysis methods in order describe the quality of the fraction obtained and to study their microbial decomposition under lab conditions.

Some studies were contrary to our results concerning a higher accumulation of secondary decomposition products in the H layer under deciduous stands. The reasons for the accumulation under pure deciduous stands may be seen in (i) litter quality, (ii) site characteristics such as soil type, base saturation, soil moisture, (iii) a stand-specific microbial community revealing specific turnover dynamics, (iv) management impacts, and (v) a different reaction e.g. of the microbial community to deposition of N-compounds, fly ashes and SO_2. Unfortunately we were not able to track these impacts and thus, further studies, possibly along a regional transect, should be conducted on humus accumulation and dynamics.

Once the liming impact has lost influence in the Ore Mountains, a repetition of our approach may contribute towards the regionalization of the results.

10 Summary

Forest management aims to promote long-term C sequestration in soil and humus. Current forest conversion policies in Saxony aim to convert the wide spread coniferous stands into semi-natural deciduous forests mainly of European beech and Common oak (Sächsische Landesanstalt für Forsten, 1999; Thomasius, 1996). These forests are recorded of being ecologically stable and to fulfil the demands for a multi-functional forestry. However, very few investigations have been undertaken to explain the effects of forest conversion on stocks and especially on dynamics of SOM (Bauhus et al., 2004; Chodak et al., 2002; Elmer et al., 2004; Fischer et al., 2002; Koch and Makeschin, 2004a,b). Forest conversion includes the long-term replacement of conifers by deciduous trees via advanced plantings and also changes stand structure and possibly density i.e., by the creation of continuous forest structures. Additionally, hardwood trees usually grow older and thus, forest conversion may result in a higher stand age and influence humus accumulation and dynamics.

It was thus, the aim of this study to show species- and management-specific effects on humus dynamics and to evaluate top soils as possible C sink. All study sites involved were arranged along sequences representing the development from pure and conventionally managed Scots pine or Norway spruce stands (type A) to more or less structured European beech or European beech/Common oak stands (type C) via advanced plantings (type B). The forest conversion sequences are situated in the Ore mountain region and owland of Saxony.

Basic focus in the different investigations was on:

1) The development of the humus forms and organic matter mass, microbial biomass and activity and total as well as easily available C fractions in the organic layers and upper mineral soil along forest conversion sequences,
2) the determination of the role of microbial biomass for the turnover of different C and N fractions in coniferous and deciduous stands as well as advanced plantings,
3) the definition of indicators for the influence of forest conversion on carbon and nitrogen cycling in soils,
4) the assessment of microbial biomass, potential carbon mineralisation, and organic matter turnover rates in relation to the litter quality during the course of one year comparing a coniferous and a deciduous stand
5) the evaluation of the impact of litter quality on decomposition dynamics and,
6) the evaluation of the soils under different forest stands as source or sink for C.

Therefore, the following steps and investigations were conducted during the study:

(a) Basic chemical properties were determined in August 2000 in order to ensure the comparability of study sites involved during the study.

(b) In May 2001 a profound soil inventory was performed along three forest conversion sequences in order to assess morphology and mass of the organic layers as well as stocks of the different C fractions as well as microbial biomass and activity.

(c) A detailed investigation on C turnover and humus accumulation followed in two representative stands of forest conversion in the Saxonian lowland during one year between fall 2001 and fall 2002. This part of the study involved two sites representing the initial phase [i.e., conventional stand of Scots pine] and site-representative target phase [i.e., European beech/Common oak stand] of forest conversion. Special focus during this phase of the study was on turnover rates as well as microbial activity and C fractions in the organic layer and mineral top soils comparing both stands. In order to receive further information on the impact of litter quality and on initial turnover dynamics a litter decay study with litter bags and a chemical characterization of the organic horizons by pyrolysis-GC-MS were performed.

The principal results of the study can be summarized as follows:

Along the forest conversion sequences an increasing trend in **thickness and mass** of the organic layers was observed, that was dominated by the evident H layers under deciduous stands. As a result, the portion of the TOC stored in the H layer on the total organic layer C stock was thus, 61 % in the beech stand and 39.7 % in the beech/oak stand in the lowland. In contrast, only 25.4 % of TOC in the organic layer were stored in the H horizon of the Scots pine stand. Thus, the H layer indicates to have a significant importance in terms of C sequestration.

The intermediate stages of forest conversion, **advanced plantings**, revealed even higher TOC stocks in the organic layer than the pure stands. This effect was discussed in this study in relation to higher litter production (above- and belowground) along with the site-specific climate due to a dense stand structure of these two-storey sites.

In the lowland, higher **TOC contents in the upper mineral soil** (0-10 cm) under deciduous stands and advanced plantings as compared to coniferous stands were observed. The higher decomposition activity of soil microorganisms under deciduous stands seems to allow for a bioturbative transfer of SOM towards the mineral soil.

Aboveground litter has been quantified in the Scots pine and European beech/Common oak stand during one year and set in relation to the C stock in the organic layer. In result the amount of litter shed in beech/oak exceeded those in the pine stand and also the **turnover rate** was with 16.9 years higher under the deciduous stand than under pine with 16.2 years. Thus, the turnover of beech/oak leaves requires a longer period of time than the pine needles. Additionally over a long period of time [i.e. difference in age between both sands ca. 120 years] may contribute towards an explanation of the higher amount of organic matter accumulated in the H layer under the beech/oak stand. In contrast, it has to be considered that the pine stand has suffered a loss of humus and nutrients caused by the clear-cutting practice.

During the litter bag study, the **mass loss** of the pine needles accounted for 42.2 % but only for 27.8 % for beech/oak leaves during the first year of decomposition. The litter decomposition under pine was especially during the summer months (here May to July) with 15.9 % mass loss higher than as compared to the mass loss of 10.1 % of beech/oak and 7.9 % of the beech/oak litter exposed in the pine stand [i.e., reference litter]. This effect reflects the impact of litter quality and/or of a stand-specific microbial community; otherwise the reference litter would have been used up as rapid as the pine needles during the summer months. The **MRT** calculated for pine litter accounts for 1.85 years and for beech/oak 3.03 years – revealing a faster turnover of pine needles than of beech/oak litter. However, this result needs to be related also to the presumed, method-derived higher leaching rate of the before shredded litter (Chap. 7).

The structural-chemical composition of the plant litter material (as determined by pyrolysis-GC/MS) revealed an evidently higher lignin portion of 56 % in beech/oak leaves than in the pine needles with 33 %. Thus, by evaluation of the **resource quality**, differences in the limit values of humus turnover are predicted and may contribute towards an explanation of the faster turnover of beech/oak litter.

Initial decomposition dynamics revealed a demethoxylisation of lignin in the L layer within the four months after litter fall. Simultaneously demethoxylisation of lignins and/or decomposition of other compounds [i.e. celluloses, N-containing compounds] took place in the F layer. Thus, it is concluded that lignin was subject to a - assumingly co-metabolic - decomposition during the winter-term litter shed. The accumulation of humified organic substances in the H layer indicates, that structural modified but widely decomposition resistant organic structures were stored here, possibly representing a great portion of the slow and recalcitrant C pool.

Along the forest conversion sequences **C_{mic}/C and N_{mic}/N** increased. Thus, it was shown that deciduous litter delivered a greater resource supply for microbial biomass growth and indicated higher turnover dynamics in these horizons under deciduous stands. In comparison between Scots pine and European beech/Common oak, under beech/oak a similar amount of microbial biomass is related to lower pool sizes of the respective water-extractable and water-soluble C in the L layer; in the F and H layer, a higher microbial biomass has to compete for lower contents of the different easily available C pools and is thus, facing a lower resource quality. As the contents of water-extractable and water-soluble organic C determined in the H layer beneath beech/oak were not significantly different from that under pine, the higher portion of microbial-C as related to the respective easily available C pools may just as well indicate a difference in microbial biomass composition between sites. This is backed-up by the lower qCO_2 in the H layer and upper mineral soil under beech/oak indicating a lower energetic input of microbial biomass in order to maintain itself.

Humus dynamics revealed subsequent an active turnover phase in the beech/oak stand in fall an intensive decomposition of the organic material in the (against climatic extremes sheltered) F layer. Subsequently, secondary decomposition products are accumulated in the H layer of this site. In contrast, the results under pine indicate a retarded, but as intensive decomposition in the L layer, followed by a phase of relative stagnancy (F layer) and in turn again active turnover phase in the comparatively thin H layer. However, on the one hand, a thick and mighty H layer under the deciduous stand was observed, on the other hand the microbial activity in this horizon was still comparable to this under pine and the C_{mic}/C ratio even higher. Thus, microbial biomass in the H layer under beech/oak (i) seemed to be able to maintain itself with a lower energetic input, feeding on a lower resource quality and/or (ii) was adopted to these specific circumstances.

In the **mean of one year** potential C mineralisation (expressed in stocks) under beech/oak was by 13 % higher than under pine. Concomitantly, C_{mic} stocks were in sum of the organic horizons by 16 % higher under beech as compared to pine. At the same time C_{hwe} and C_{cwe} stocks were by 6 % and 15 % lower in the organic layer under the deciduous stand. Thus, the higher microbial activity under deciduous stands results in a higher use of the easily available C pool and indicates higher turnover dynamics.

For **parameter evaluation and definition of indicators** of key differences in decomposition dynamics, the discriminance function was calculated along each of the three investigated sequences during the soil inventory performed in May 2001. Results revealed a clear differentiation of the investigated parameters along forest conversion sequences in top soils [i.e., organic layer and upper mineral soil (0–10 cm)] as 58.4 – 75.9 % of variance and 82 – 90 % of data spread could be explained by grouping into forest types. In contrast to the soils studied in the Saxonian lowland, in the Ore Mountain region comparatively low coefficients of the discriminance function reflect the compensating impact of liming on decomposition processes and did not allow a specific evaluation of the parameters. In the lowland, TOC and TN as well as their hot water-extractable fractions were evaluated as relevant for discriminance along both sequences and thus, are recommended as sensitive indicators for forest conversion in this study.

In the middle **Ore Mountain region** an area-wide amelioration by liming was carried out in 1996, that lastingly continuous to affect the soil properties. Thus, soil chemical and microbial characteristics of the organic layer and turnover dynamics were still altered at the time of soil sampling in May 2001. We observed an increase in thickness and mass of the organic layer along the conversion sequence, but no horizon-specific differentiation as found in the lowland. Especially the to date F and H layers have been affected by the liming. A re-distribution of organic matter and subsequent storage in the upper mineral soil followed the intensive decomposition dynamics in lime-affected organic horizons. Focusing on the stand-specific differentiation in the L layer we arrived at the conclusion, that the effects documented for the lowland will be relevant in the Ore Mountain region once the lime looses its effect.

In sum, the study revealed (i) a higher litter-derived C input in deciduous stands, (ii) a higher release of C by potential C mineralisation, (ii) lower mean residence time and turnover rate under deciduous stands, leading towards (iii) a higher accumulation of C under deciduous stands – sequestered in the H horizon and upper mineral soil. In sum, the specific turnover dynamics in the organic layer under deciduous stands provide the basis for a long-term C sequestration in mineral soil as a greater share of the C input is accumulated than under pine. The specific mechanisms of C storage in the H layer under the beech/oak stand were explained in detail by explaining humus dynamics in the different horizons throughout the year. Assumingly, the Scots pine site has suffered strong management influences [i.e., litter raking, clear cutting, piling up and burning of brushwood] resulting in an extensive loss of humus and nutrients. The difference to the beech/oak stand in humus accumulated in the organic layer today accounts for 16 t C ha^{-1}. Therefore considering the differences in the history of both stands, the organic layer studied may be compared in respect to their humus dynamics, but not to their balance. The comparison with literature data revealed, that the organic layer under Scots pine probably has recovered by now and can start semi-natural, stand-specific turnover dynamics and C accumulation.

Therefore, it can be concluded from this study:

(i) Litter decomposition under deciduous trees [i.e., beech, oak] is subjected to principally different mechanisms than under conifers [i.e., pine].

(ii) Microbial activity and the ratio of microbial biomass to the different C-Fractions indicate higher turnover dynamics in the upper horizons of the organic layer under deciduous trees [i.e., beech, oak].

(iii) Subsequent the evident higher microbial activity in the F layer under beech/oak a higher amount of C is stored in the H layer and (upper) mineral soil under deciduous trees.

(iv) The amount and portion of the long-term sequestered organic matter is thus, substantially influenced by the quality of the litter, that is litter quality [i.e., lignin and N content] control the stand-specific humus dynamics.

(v) Management impacts, such as litter raking, clear cutting, advanced planting and the interference of timber cuts have a significant influence on the turnover activity, that means that the amount litter and the stand-specific climate influence the amount of organic matter accumulated at the forest ground.

(vi) The effects documented for the lowland will presumably be relevant in the Ore Mountain region once the lime looses its effect.

11 Zusammenfassung

Es ist ein Ziel der Walbewirtschaftung, die langfristige C-Speicherung in Boden und Humus zu fördern. Die aktuellen Waldumbaustrategien in Sachsen zielen auf eine Umwandlung der weit verbreiteten Nadelholzbestände in naturnahe Laubholzbestände - dominiert von Rotbuche und Traubeneiche (Sächsische Landesanstalt für Forsten, 1999; Thomasius, 1996). Es wurde belegt, dass diese Wälder ökologisch stabil sind und den Anforderungen einer multi-funktionalen Forstwirtschaft weitgehend gerecht werden. Allerdings wurden bislang wenige Untersuchungen durchgeführt, die die Effekte des Waldumbaus auf die Vorräte und besonders die Dynamik der organischen Substanz im Boden erklären (Bauhus et al., 2004; Chodak et al., 2002; Elmer et al., 2004; Fischer et al., 2002; Koch and Makeschin, 2004a,b). Waldumbau besteht in dem langfristigen Ersatz von Nadelholz durch Laubholz über die Stufe der Voranbauten und führt darüber hinaus zu Veränderungen von Bestandesstruktur und teilweise –dichte durch die Etablierung dauerwaldartiger Strukturen. Da Laubholzbestände (Bu, Ei) üblicherweise älter werden, kann Waldumbau zu insgesamt älteren Beständen führen und die Humusakkumulation beeinflussen.

Ziel dieser Arbeit war es daher, baumarten- und bewirtschaftungsspezifische Effekte auf den Humus und die C-Speicherung im Waldboden aufzuzeigen. Die Untersuchungsflächen wurden entlang von Waldumbausequenzen gruppiert, die die Entwicklung von konventionell bewirtschafteten Kiefern- und Fichten-Reinbeständen (Typ A) zu mehr oder weniger strukturierten Rotbuchen- und Rotbuchen-/Traubeneichenbeständen (Typ C) über Voranbauten (Typ B) widerspiegeln.

Im Zentrum der einzelnen Untersuchen stand:

1) Die Entwicklung der Humusformen und Auflagegewichte, der mikrobiellen Biomasse und Aktivität sowie der Gesamt- und relativ leicht verfügbaren C- und N-Fraktionen in den organischen Auflagen und oberen Mineralböden entlang der Waldumbausequenzen,
2) Die Bedeutung der mikrobiellen Biomasse für den Umsatz der verschiedenen C- und N-Fraktionen in den unterschiedlichen Beständen,
3) Die Bestimmung von Indikatoren für den Einfluss des Waldumbaus auf den Kohlenstoff- und Stickstoffumsatz im Boden,
4) Die Erhebung der mikrobiellen Biomasse, der potentiellen C-Mineralisierung und der Umsatzraten organischer Substanz in Relation zur Qualität der Streu in einem Nadelholz- und einem Laubholzbestand im Laufe eines Jahres,
5) Die Evaluierung des Einflusses der Streuqualität auf die Abbaudynamik,
6) Die Bewertung der bestockungsabhängigen C-Umsatzrate und Bilanz der C-Umsetzungen.

An diesen Untersuchungszielen orientiert, wurden folgende Arbeitsschritte und Untersuchungen durchgeführt:

a) Grundlegende chemische Parameter wurden im August 2000 erhoben, um die Vergleichbarkeit der Untersuchungsflächen zu gewährleisten.
b) Im Mai 2001 wurde eine Inventur entlang von drei Waldumbau-Sequenzen durchgeführt und Humusmorphologie, Auflagegewichte sowie Vorräte der verschiedenen C-Fraktionen und mikrobielle Biomasse und Aktivität bestimmt.
c) Darauf folgte eine detaillierte Untersuchung des C-Umsatzes und der C-Akkumulation in zwei repräsentativen Beständen des Waldumbaus im Sächsischen Tiefland (Referenzfläche: Kiefernbestand und Zielfläche: Buchen/Eichen-Bestand) im Verlauf eines Jahres von Herbst 2001 bis Herbst 2002. Im Mittelpunkt dieser Untersuchung stand der Vergleich der Umsatzraten und mikrobiellen Aktivitäten und C-Fraktionen in den organischen Auflagen und oberen Mineralböden beider Bestände. Um weitere Informationen über den Einfluss der Streuqualität auf den initialen Streuabbau zu erhalten, wurden ein Streuabbauversuch mit Netzbeuteln und eine Charakterisierung der Streuqualität durch Pyrolyse-GC/MS durchgeführt.

Im Folgenden werden die wichtigsten Untersuchungsergebnisse zusammenführend dargestellt und diskutiert.

Entlang der Waldumbau-Sequenzen zeigten **Mächtigkeit und Gewicht** der organischen Auflagen einen zunehmenden Trend, der durch die mächtigen Oh-Horizonte in laubholzbestockten Beständen dominiert wurde. Im Ergebnis nahm der TOC-Anteil der Auflage in den Oh-Lagen im Tiefland 61 % im Bu-Bestand und 39.7 % im BuEi-Bestand ein; im Gegensatz dazu waren nur 25.4 % des TOC der organischen Auflage unter Ki im Oh-Horizont gespeichert.

Die organischen Auflagen der Zwischenstadien des Waldumbaus, **Voranbauten**, zeigten höhere **C-Vorräte** als die Reinbestände. Dieser Effekt wurde in der vorliegenden Arbeit auf die höhere Streuproduktion (ober- und unterirdisch) sowie das spezifische Bestandesinnenklima dieser zweischichtigen, dicht bestockten Bestände bezogen.

In den oberen **Mineralböden** (0-10 cm) unter Laubholzbeständen und Voranbauten wurde ein höherer **TOC-Gehalt** als unter dem Ki-Bestand festgestellt. Die beobachtete höhere Abbauaktivität der Bodenmikroorganismen unter den Laubholzbeständen ermöglicht demzufolge den Transfer höherer C-Mengen in den Mineralboden hinein.

Die oberirdische Streu des Kiefern- und des Buchen/Eichenbestandes wurde im Verlauf eines Jahres quantifiziert und in Beziehung zum TOC-Vorrat der organischen Auflage gesetzt. Im Ergebnis ist die Streumenge unter BuEi höher als unter Ki und die **Umsatzrate** [i.e., *turnover rate*] im Laubholzbestand mit 16.9 Jahren ebenfalls höher als unter dem Kiefernbestand mit 16.2 Jahren. D.h., der Umsatz der Bu/Ei-Streu benötigt insgesamt einen längeren Zeitraum als der der Kiefernnadeln. Über einen vergleichsweise langen Zeitraum [Altersunterschied beider Bestände ca. 120 Jahre] kann dieser relativ geringe Unterschied in der Umsatzrate, zur Erklärung der größeren Menge organischer Substanz im Oh-Horizont unter dem Bu/Ei-Bestand beitragen. Im Gegensatz dazu ist davon auszugehen, dass der Kiefernbestand einen Verlust an Humus und Nährstoffen durch die Kahlschlagswirtschaft erfahren hat.

Der Massenverlust der Streu ergab 41.2 % für Ki-Nadeln, aber nur 27.8 % für Bu/Ei-Laub während des ersten Dekompositionsjahres. Der Streuabbau unter Ki war insbesondere während der Sommermonate (Mai bis Juli) mit einem Verlust von 15.9 % Masse höher als der der BuEi-Streu mit 10.1 % und der 7.9 % Massenverlust der BuEi-Streu, welche im Ki-Bestand exponiert wurde (Referenzstreu). Dieser Effekt reflektiert den Einfluss der Streuqualität und/oder der bestandesspezifischen Zersetzergemeinschaft; andererweise wäre die Referenzstreu während der Sommermonate ebenso rasch umgesetzt worden wie die Ki-Nadeln. Die mittlere Verweilzeit [i.e., *mean residence time*] zeigte 1.85 Jahre für die Ki-Nadeln und 3.03 Jahre für das BuEi-Laub – und ergab daher einen rascheren Umsatz der Ki-Streu als des BuEi-Laubes. Dieses Ergebnis ist jedoch auch vor dem Hintergrund einer methodisch bedingten, vermutlich höheren Leachingrate aus der zerkleinerten Streu zu diskutieren.

Die strukturchemische Zusammensetzung der L-Lage im Herbst (bestimmt durch Pyrolyse-GC/MS) ergab einen deutlich höheren **Ligningehalt** von 56 % in der Bu/Ei-Streu, als in den Ki-Nadeln mit 33 %. Daher werden durch die Erhebung der Stoffqualität Unterschiede im Grenzwert [i.e., *limit value*] der Streuumsetzung vermutet.

Die **initiale Abbaudynamik** zeigte eine Demethoxylierung von Lignin in der L-Lage direkt nach Streufall sowie eine parallel stattfindende Demethoxylierung von Lignin und/oder Dekomposition anderer Stoffe [wie Cellulose, N-enthaltende Verbindungen] in der Of-Lage. Daraus wird geschlussfolgert, dass Lignin während der ersten vier Monate nach Streufall einem - vermutlich co-metabolischem - Abbau unterlag. Die Akkumulation humifizierter organischer Substanzen im Oh-Horizont indiziert, dass strukturell modifizierte, aber weitgehend abbauresistente organische Stoffe hier gespeichert sind und einen Teil des langsam abbaubaren und weitgehend abbauresistenten C Pools darstellen.

Entlang der Waldumbausequenzen nahmen die **C_{mic}/C- und N_{mic}/N-**Verhältnisse besonders in der L-Lage zu, d.h. (i) das die Laubstreu einen größere Nährstoffverfügbarkeit für das Wachstum der mikrobiellen Biomasse bot und (ii) indiziert zugleich eine höhere Abbauaktivität unter BuEi. Der Vergleich zwischen Kiefer und Buche/Eiche zeigte in der L-Lage beider Bestände einen vergleichbar großen Pool mikrobieller Biomasse, welcher unter Bu/Ei in Relation zu geringeren Poolgrößen der entsprechenden wasserextrahierbaren und wasserlöslichen C-Fraktionen stand; in den F- und H-Horizonten, muss eine höhere mikrobielle Biomasse um geringere Mengen der relativ leichtverfügbaren C-Fraktionen konkurrieren und somit mit einer geringeren Stoffqualität zurechtkommen. Da sich die Gehalte wasserextrahierbarer und wasserlöslicher organischer C-Verbindungen im Oh-Horizont unter BuEi nicht signifikant von denen im Oh unter Ki unterschieden, kann der höhere Anteil mikrobieller Biomasse im Verhältnis zu den vergleichsweise leicht verfügbaren C-Fraktionen auch einen Unterschied in der Zusammensetzung der Zersetzergemeinschaft beider Beständen indizieren. Diese Vermutung wird durch den geringeren **metabolischen Quotienten (qCO_2)** in der Oh-Lage und im oberen Mineralboden unter BuEi unterstützt, welcher auf einen geringern Erhaltungsbedarf der mikrobiellen Biomasse weist.

Die **Humusdynamik** zeigte, einer aktiven Abbauphase unter dem Bu/Ei-Bestand im Herbst folgend, eine intensive Dekomposition organischer Substanz im (vor Witterungsextremen geschützten) Of-Horizont. In der Folge werden sekundäre Abbauprodukte in der Oh-Lage dieses Bestandes akkumuliert. Obwohl der Oh-Horizont unter dem Laubholzbestand vergleichsweise mächtig und schwer war, war die mikrobielle Aktivität in diesem Horizont vergleichbar mit der unter Kiefer und die C_{mic}/C-Verhältnisse höher. Dies deutet wiederum darauf hin, dass die mikrobielle Biomasse in der Oh-Lage unter Bu/Ei in der Lage ist, sich mit einem geringeren energetischen Input zu erhalten und von einer geringeren Stoffqualität zu ernähren. Die Ergebnisse unter Kiefer indizieren im Gegensatz dazu einen verzögerten, aber vergleichbar intensiven Streuabbau im L-Horizont, gefolgt von einer Phase relativer Stagnation in der Of-Lage und wiederum aktiver Umsatzphase im vergleichsweise geringmächtigen Oh-Horizont.

Im Mittel eines Jahres war die potentielle C-Mineralisation [absolut] unter Bu/Ei um 13% höher, als unter Kiefer. Ebenso waren die C_{mic}-Vorräte in der Summe der organischen Auflagehorizonte um 16 % höher unter Bu/Ei als unter Ki. Im selben Zeitraum waren die C_{hwe}- und C_{cwe}-Vorräte der organischen Auflage unter Bu/Ei entsprechend um 6 % und 16 % geringer als unter Ki. Daraus wird geschlussfolgert, dass die höhere mikrobielle Biomasse unter dem Laubholzbestand zu einem höheren Umsatz leicht verfügbarer Ressourcen führt und indiziert eine insgesamt höhere Abbaudynamik.

Zur **Evaluierung der erhobenen Parameter und Definition von Schlüsselindikatoren** der Abbaudynamik wurde die kanonische Diskriminanzfunktion für die drei Waldumbausequenzen, die während der Humusinventur im Mai 2001 untersucht worden waren, berechnet. Die Ergebnisse zeigten eine deutliche Differenzierung der untersuchten Parameter für die Oberböden [organische Auflage und 0-10 cm Mineralboden] entlang der Waldumbausequenzen, da 58.4 – 75.9 % der Varianz und 82 – 90 % der Datenstreuung durch die Gruppierung in „Bestandestypen“ erklärt werden konnte. Im Unterschied zu den untersuchten Böden im Sächsischen Tiefland, reflektierten die vergleichsweise geringen Diskriminanzkoeffizienten der Böden im mittleren Erzgebirge den kompensatorischen Einfluss der Kalkung auf den Abbauprozess und ermöglichen keine Evaluierung der einzelnen Parameter. Im Tiefland wurden TOC und TN sowie deren heißwasserextrahierbare Fraktion als relevant für die Diskriminanz entlang beider Waldumbausequenzen bewertet und daher in dieser Arbeit als sensitive Indikatoren für den Waldumbau empfohlen.

Im **Mittleren Erzgebirge** erfolgte 1996 eine flächendeckende **Meliorationskalkung**, deren Wirkung bis heute nachhält. Dadurch zeigen die Streuumsetzungen und die organischen Auflagen veränderte chemische und mikrobiologische Eigenschaften. Wir beobachteten z.B. eine Zunahme in Mächtigkeit und Gewicht der organischen Auflagen entlang der Waldumbausequenz, aber keine horizontspezifische Differenzierung analog der Ergebnisse im Tiefland in den kalkungsbeeinflussten Of- und Oh-Horizonten Eine Umverteilung organischer Substanz und daraus resultierende Speicherung in den oberen Mineralböden ist die Folge einer intensiven Abbaudynamik in den gekalkten organischen Horizonten. Mit Fokus auf die bestockungsspezifische Differenzierung der L-Lagen kann man schlußfolgern, dass die für das Sächsische Tiefland dokumentierten Effekte auch im Erzgebirge wieder relevant sein werden, wenn der Kalk an Wirkung verliert.

Zusammenfassend zeigte die Untersuchung (i) einen höheren C-Input über die Laubstreu in die Laubholzbestände, (ii) eine höhere C-Freisetzung durch die C-Mineralisierung, (ii) eine höhere Akkumulation von C unter laubholzbestockten Beständen – welcher im Oh-Horizont und im oberen Mineralboden gespeichert wird. Die spezifische Abbaudynamik in der organischen Auflage unter Buche/Eiche bildet die Grundvorraussetzung für eine langfristige C-Sequestrierung im Mineralboden, da hier schließlich eine größere Menge C akkumuliert wird als unter Kiefer. Die Mechanismen, welche zur C-Sequestrierung in der Oh-Lage unter Bu/Ei führen, konnten in dieser Untersuchung detailliert durch die Humusdynamik der unterschiedlichen Horizonte im Verlauf eines Jahres erklärt werden. Die kiefernbestockte Fläche unterlag vermutlich vergleichsweise intensiven Bewirtschaftungseinflüssen [Streunutzung, Kahlschlagswirtschaft, Bildung und Verbrennung von Reisighaufen] und hat im Ergebnis Humus und Nährstoffe verloren. Der aktuelle Unterschied in der Humusmasse akkumuliert in der organischen

Auflage ergibt 16 t ha^{-1} zum BuEi-Bestand. Aufgrund dieser unterschiedlichen Bestandesgeschichte können die untersuchten organischen Auflagen zwar hinsichtlich ihrer Abbaudynamik verglichen werden, jedoch nur sehr bedingt in der Bilanz. Der Vergleich mit Literaturdaten deutet darauf hin, das die organische Auflage unter Kiefer sich wahrscheinlich mittlerweile soweit erholt hat, dass nun eine naturnahe, bestandestypische Abbaudynamik und C-Akkumulation beginnen kann.

Es kann daher aus dieser Arbeit geschlussfolgert werden:

(i) Der Streuabbau unter Laubholz (Bu, Ei) unterliegt grundsätzlich anderen Mechanismen als unter Nadelholz (Ki).

(ii) Die mikrobielle Aktivität und das Verhältnis aus mikrobieller Biomase und den C-Fraktionen indizieren eine höhere Abbaudynamik in den oberen Horizonten der organischen Auflage unter Laubholz.

(iii) In Folge der deutlich höheren mikrobiellen Aktivität im Of-Horizont wird eine größere Menge C im Oh-Horizont und im (oberen) Mineralboden unter Laubholz gespeichert.

(iv) Die Menge bzw. der Anteil der langfristig gespeicherten organischen Substanz wird wesentlich durch die Streuqualität bestimmt, d.h. die Qualität der Streu (Ligningehalt, N-Gehalt) steuert die bestandesspezifische Humusdynamik.

(v) Bewirtschaftungseinflüsse, z.B. Streunutzung, Kahlschlag, Voranbau oder Nutzungseingriffe haben eine bedeutende Wirkung auf die Umsatzaktivität, d.h. die Menge der Streu auf dem Waldboden und das bestandesspezifische Innenklima beeinflussen die Masse organischer Substanz auf dem Waldboden.

(vi) Die für das Sächsische Tiefland dokumentierten Effekte werden vermutlich auch im Erzgebirge wieder relevant sein werden, wenn der Kalk an Wirkung verliert.

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Anex

Site Characteristics

A1: Coarse- and fine soil portions.
(method: Rosenkranz, Einsele and Harreß, 1988): 10 samples of 100 cm³ each, samples dried at 40℃ to weight constancy (soil sampling in *Falkenberg* in May/June 2001 by Koch, Streich & Kunze; analyses by Chr. Fenger).

A2: Volume, dry mass and density.
(soil sampling in *Falkenberg* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A3: Soil texture.
Silt- and clay fraction obtained by laser granulometer (Coulter 100 LS), sand fraction obtained by sieving (soil sampling in *Falkenberg* in May/June 2001 by Koch, Streich & Kunze; analyses by Chr. Fenger).

A4: Thickness and mass of the organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A5: pH (in H_2O and $CaCl_2$) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm) (mean of n=6 ± standard deviation).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann & K. Walter).

A6: Cation exchange capacity in organic layers (L, F and H horizon) and mineral top soil (0-10 cm) (mean of n=6).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann & R. Rüger).

Soil-C Inventory

A7: Contents of total organic carbon (TOC) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by M. Unger).

A8: Contents of total nitrogen (TN) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by M. Unger).

A9: Contents of microbial biomass (C_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A10: Contents of microbial nitrogen (N_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A11: Potential C mineralisation in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A12: Contents of hot-water-extractable C (C_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A13: Contents of cold-water-extractable C (C_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A14: Contents of hot-water-extractable N (N_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A15: Contents of hot-water-extractable N (N_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A16: Stocks of total organic carbon (TOC) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by M. Unger).

A17: Stocks of total nitrogen (TN) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by M. Unger).

A18: Stocks of microbial biomass (C_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A19: Stocks of microbial nitrogen (N_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A20: Absolut potential C mineralisation in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A21: Stocks of hot-water-extractable C (C_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A22: Stocks of cold-water-extractable C (C_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A23: Stocks of hot-water-extractable N (N_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

A24: Stocks of hot-water-extractable N (N_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

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A25: Thickness and mass of the organic layers (L, F and H horizon).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A26: Potential C mineralisation in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A27: Contents of microbial biomass (C_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A28: Contents of microbial nitrogen (N_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A29: Contents of hot-water-extractable C (C_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A30: Contents of cold-water-extractable C (C_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A31: Contents of water-soluble organic carbon (WSOC) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A32: Contents of hot-water-extractable N (N_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A33: Contents of cold-water-extractable N (N_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A34: Absolut potential C mineralisation in the organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A35: Stocks of microbial biomass (C_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A36: Stocks of microbial nitrogen (N_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A37: Stocks of hot-water-extractable C (C_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A38: Stocks of cold-water-extractable C (C_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A39: Stocks of water-soluble organic carbon (WSOC) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A40: Stocks of hot-water-extractable N (N_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A41: Stocks of cold-water-extractable N (N_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

A 42: Amount of litter between fall 2001 and fall 2002.
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch & Stuhlmann; analyses by I. Weimann).

A 43: Litter decomposition: remaining litter (%) and litter decay rate constant “*k*”.
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 and data processing by Chr. Stuhlmann & J. Koch).

Table A1: Coarse- and fine soil portions.
(method: Rosenkranz, Einsele and Harreß, 1988): 10 samples of 100 cm^3 each, samples dried at 40°C to weight constancy (soil sampling in *Falkenberg* in May/June 2001 by Koch, Streich & Kunze; analyses by Chr. Fenger).

Site	Depth	Mass			
		Stones	**Fine Soil**	**Stones***	**Fine Soil***
		(g)		%	
A2 (502 b^4)	0-10 cm	34.45	553.08	6.23	93.77
	10-30 cm	34.49	653.14	5.28	94.72
	30-50 cm	55.67	762.45	7.30	92.70
	50-100 cm	44.22	776.02	5.70	94.30
B2 (585 a^3/a^4)	0-10 cm	74.94	753.94	9.94	90.06
	10-30 cm	45.60	660.69	6.90	93.10
	30-50 cm	42.71	686.86	6.22	93.78
	50-100 cm	14.35	781.57	1.84	98.16
B3 (752 a^3)	0-10 cm	29.79	1171.13	2.54	97.46
	10-30 cm	125.28	1620.98	7.73	92.27
	30-50 cm	268.45	1654.47	16.23	83.77
	50-100 cm	142.38	1717.06	8.29	91.71
C2 (624 a^4)	0-10 cm	15.95	789.33	2.02	97.98
	10-30 cm	39.37	817.29	4.82	95.18
	30-50 cm	45.72	814.67	5.61	94.39
	50-100 cm	25.11	870.53	2.88	97.12
C3 (593 a^1)	0-10 cm	15.43	674.81	2.29	97.71
	10-30 cm	50.13	672.55	7.45	92.55
	30-50 cm	57.54	774.92	7.43	92.57
	50-100 cm	55.71	791.56	7.04	92.96

* Difference to 100% caused by sieving.

Table A2: Volume, dry mass and density.
(soil sampling in *Falkenberg* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

Site	Depth	Volume (cm^3)	Dry mass raw soil (g)	Dry mass Fine Soil (g)	Density I (kg/l)	Density II ρb (g/cm^3)
A2	0-10 cm	500	553.08	517.77	1.04	1.11
(502 b^4)	10-30 cm	500	653.14	618.70	1.24	1.31
	30-50 cm	500	762.45	706.90	1.41	1.52
	50-100 cm	500	776.02	731.58	1.46	1.55
B2	0-10 cm	500	753.94	678.96	1.36	1.51
(585 a^3/a^4)	10-30 cm	500	660.69	615.34	1.23	1.32
	30-50 cm	500	686.86	644.33	1.29	1.37
	50-100 cm	500	781.57	767.39	1.53	1.56
C2	0-10 cm	500	1171.13	1141.75	2.28	2.34
(752 a^3)	10-30 cm	500	1620.98	1495.76	2.99	3.24
	30-50 cm	500	1654.47	1385.75	2.77	3.31
	50-100 cm	500	1717.06	1576.69	3.15	3.43
B3	0-10 cm	1000	789.33	773.45	0.77	0.79
(624 a^4)	10-30 cm	1000	817.29	777.90	0.78	0.82
	30-50 cm	1000	814.67	771.01	0.77	0.81
	50-100 cm	1000	870.53	847.02	0.85	0.87
C3	0-10 cm	500	674.81	660.14	1.32	1.35
(593 a^1)	10-30 cm	500	672.55	622.73	1.25	1.35
	30-50 cm	500	774.92	719.84	1.44	1.55
	50-100 cm	500	791.56	736.24	1.47	1.58

Table A3: Soil texture.
Silt- and clay fraction obtained by laser granulometer (Coulter 100 LS), sand fraction obtained by sieving (soil sampling in *Falkenberg* in May/June 2001 by Koch, Streich & Kunze; analyses by Chr. Fenger).

Site	**Depth**	**Clay** up to 2	**Fine Silt** up to 6.3	**Middle Silt** up to 20	**Coarse Silt** up to 63	**Very Fine Sand** up to 125	**Fine Sand** up to 200	**Middle Sand** up to 630	**Coarse Sand** up to 2000
		µm							
Ore mountains:									
A1	0-10 cm	4.3	8.9	20.5	20.4	6.9	10.5	16.5	18.9
	10-30 cm	7.1	13	22.8	17.4	5.2	8.9	13.5	17.3
	30-50 cm	7.5	14.4	23.8	18.1	4.7	7.8	13.3	15.2
	50-100 cm	6	11.9	19	11.5	6.2	12	19.3	20.2
B1	0-10 cm	7.1	14.1	24	20.7	4.9	9.1	14.8	10.3
	10-30 cm	9.1	16.4	21.6	15.8	4.8	8.1	11.5	17.6
	30-50 cm	8.4	15.5	23.2	15.4	6.7	10.9	12.5	14.1
	50-100 cm	6.6	14.3	27.4	17.4	7.1	11.2	10.3	12.9
C1	0-10 cm	7.8	14.3	26.9	18.3	7.5	11.6	10	11.1
	10-30 cm	7.8	14.3	26.9	18.3	7.5	11.6	10	11.1
	30-50 cm	9.3	17.7	26.9	17.3	6	9.4	9.2	10.1
	50-100 cm	6.8	13.2	24.9	19.8	6.6	10.5	11.2	13.6
Saxonian Lowland:									
A2	0-10 cm	2.9	4.7	8.5	10.2	12.2	27.4	39.6	6.8
	10-30 cm	4.4	7.3	7.2	2.2	7.7	15.8	54.4	8.8
	30-50 cm	2.7	4.3	7.3	6.2	6	23.2	48.1	8.2
	50-100 cm	0.7	1.2	1.4	1.1	3.5	15.9	67.8	12
B2	0-10 cm	2.1	3.9	7.4	7.3	12	25.3	48.2	5.7
	10-30 cm	3.6	5.4	8.1	7.7	12.7	32.2	38.7	4.2
	30-50 cm	2.7	3.6	5.7	6.7	16.6	26.6	52.8	1.8
	50-100 cm	2.7	3.9	6.1	6.2	10	28.2	50.6	2.2
B3	0-10 cm	4.1	6.6	13	14.7	7.5	15.5	40.9	5.3
	10-30 cm	4.7	6.6	11.4	15.5	9	24	32.5	5.2
	30-50 cm	4.4	6.2	9.8	9	11.6	27.2	35.8	7.6
	50-100 cm	5.8	7.3	8.6	6.2	11	25.3	40.1	6.7
C2	0-10 cm	8.2	12	18.3	15.1	4.4	17.5	25.9	3
	10-30 cm	10.9	15.5	19.2	8	2.8	15.3	26.2	4.8
	30-50 cm	11.1	16	25.2	15.9	8	14.7	13.7	3.3
	50-100 cm	10.3	15.3	24.4	15.2	8	15.2	15	4.6
C3	0-10 cm	2.1	3.7	6.8	6.5	15	31.9	41.8	7.3
	10-30 cm	4	6.5	8.3	6.2	15.5	26.4	42.6	6
	30-50 cm	2.4	3.4	4.7	2.9	12.4	36.1	45.2	5.4
	50-100 cm	2.1	3.5	4.4	2.7	13.9	31.9	45	10.4

Table A4: Thickness and mass of the organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		thickness [cm]	**mass** [t ha^{-1}]
Ore mountains:			
A1	L (Oi)	2.0	23.9
	F (Oe)	1.7	37.8
	H (Oa)	2.0	40.6
	0-10 cm		432.2
B1	L (Oi)	2.3	33.6
	F (Oe)	2.8	36.5
	H (Oa)	1.4	36.7
	0-10 cm		601.3
C1	L (Oi)	2.3	20.8
	F (Oe)	2.7	45.5
	H (Oa)	2.2	54.1
	0-10 cm		309.0
Lowland			
A2	L (Oi)	2.7	41.3
	F (Oe)	2.3	55.1
	H (Oa)	1.7	83.6
	0-10 cm		1067.0
B2	L (Oi)	3.0	32.3
	F (Oe)	2.0	58.3
	H (Oa)	2.3	92.8
	0-10 cm		1386.8
C2	L (Oi)	2.0	16.8
	F (Oe)	2.0	43.2
	H (Oa)	3.0	171.5
	0-10 cm		1573.4
B3	L (Oi)	2.3	35.1
	F (Oe)	3.0	70.1
	H (Oa)	4.0	135.6
	0-10 cm		1154.5
C3	L (Oi)	2.3	26.1
	F (Oe)	2.0	72.1
	H (Oa)	3.2	97.8
	0-10 cm		1346.8

Table A5: pH (in H_2O and $CaCl_2$) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm) (mean of n=6 ± standard deviation).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann & K. Walter).

		pH	
Ore mountains:		**(H_2O)**	**($CaCl_2$)**
A1	L (Oi)	5.02	4.29
		± 0.37	± 0.28
	F (Oe)	4.25	3.49
		± 0.07	± 0.10
	H (Oa)	4.00	3.18
		± 0.18	± 0.18
	0-10 cm	3.91	3.23
		± 0.12	± 0.11
B1	L (Oi)	6.19	5.52
		± 0.16	± 0.21
	F (Oe)	5.35	4.78
		± 0.12	± 0.10
	H (Oa)	4.49	3.36
		± 0.70	± 0.38
	0-10 cm	3.87	3.31
		± 0.20	± 0.08
C1	L (Oi)	5.55	5.13
		± 0.09	± 0.09
	F (Oe)	5.34	4.77
		± 0.11	± 0.24
	H (Oa)	4.78	3.84
		± 0.64	± 0.88
	0-10 cm	4.93	4.36
		± 0.57	± 0.65

		pH	
Saxonian Lowland:		**(H_2O)**	**($CaCl_2$)**
A2	L (Oi)	4.49	3.75
		± 0.11	± 0.17
	F (Oe)	4.13	3.36
		± 0.11	± 0.07
	H (Oa)	4.25	3.37
		± 0.05	± 0.04
	0-10 cm	4.17	3.76
		± 0.11	± 0.44
B2	L (Oi)	5.18	4.80
		± 0.20	± 0.11
	F (Oe)	4.48	3.81
		± 0.40	± 0.16
	H (Oa)	4.34	3.73
		± 0.10	± 0.47
	0-10 cm	4.27	3.49
		± 0.21	± 0.20
C2	L (Oi)	5.11	4.21
		± 0.21	± 0.63
	F (Oe)	4.93	3.47
		± 0.83	± 0.06
	H (Oa)	4.43	3.19
		± 0.07	± 0.04
	0-10 cm	4.15	3.33
		± 0.02	± 0.01
B3	L (Oi)	4.88	3.99
		± 0.16	± 0.57
	F (Oe)	4.20	3.20
		± 0.13	± 0.04
	H (Oa)	4.06	3.08
		± 0.08	± 0.05
	0-10 cm	4.13	3.32
		± 0.12	± 0.14
C3	L (Oi)	4.88	4.04
		± 0.12	± 0.09
	F (Oe)	4.14	3.30
		± 0.13	± 0.03
	H (Oa)	4.04	3.16
		± 0.08	± 0.02
	0-10 cm	4.14	3.43
		± 0.03	± 0.07

Table A6: Cation exchange capacity in organic layers (L, F and H horizon) and mineral top soil (0-10 cm) (n=6).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann & R. Rüger).

		Cation Exchange Capacity												
Site	**Horizon/ Depth**	**H** [µg g^{-1}]	**Na** [µg g^{-1}]	**K** [µg g^{-1}]	**Ca** [µg g^{-1}]	**Mg** [µg g^{-1}]	**Al** [µg g^{-1}]	**Fe** [µg g^{-1}]	**Mn** [µg g^{-1}]	**AKe** [µg g^{-1}]	**BS** Xs [%]	**ES** Xs [%]	**Sum** Ca+Mg+K+Na	**Sum** Al+Mn+Fe+H
Ore mountains:														
A1	L (Oi)	1.5	2.1	10.4	382.2	92.7	1.2	0.9	13.2	504.1	**96.7**	94.2	487.3	16.8
	F (Oe)	17.2	1.4	8.9	214.1	73.6	20.8	6.2	2.5	344.7	**86.5**	83.5	298.0	46.7
	H (Oa)	31.8	1.3	6.7	104.0	46.5	57.5	8.8	0.6	257.2	**61.6**	58.5	158.5	98.7
	0-10 cm	36.2	0.5	2.1	26.5	13.2	62.7	6.4	1.0	148.6	**28.4**	26.7	42.3	106.4
B1	L (Oi)	0.0	0.9	19.4	420.2	190.1	0.4	0.4	13.5	644.9	**97.8**	94.6	630.5	14.3
	F (Oe)	0.0	1.1	9.3	313.7	215.8	0.4	0.5	32.3	573.0	**94.2**	92.4	539.8	33.2
	H (Oa)	9.3	0.9	7.0	73.6	55.7	57.8	1.7	0.7	206.6	**66.4**	62.6	137.2	69.4
	0-10 cm	11.3	0.7	2.1	9.5	5.5	104.8	6.4	0.2	140.5	**12.7**	10.6	17.9	122.7
C1	L (Oi)	0.0	1.8	27.6	362.2	89.2	1.6	0.4	40.2	523.1	**91.9**	86.3	480.8	42.3
	F (Oe)	0.0	1.3	9.2	396.4	111.5	1.7	0.5	6.3	526.8	**98.4**	96.4	518.2	8.6
	H (Oa)	2.4	0.9	6.8	162.0	27.6	5.8	0.2	4.7	210.3	**93.7**	90.0	197.3	13.0
	0-10 cm	1.4	0.4	1.5	94.4	7.1	13.2	0.5	2.1	120.5	**85.8**	84.3	103.4	17.1
Saxonian Lowland														
A2	L (Oi)	8.3	1.1	14.6	132.4	18.3	8.6	1.4	19.5	204.2	**81.5**	73.8	166.4	37.8
	F (Oe)	19.4	0.8	7.8	70.4	8.5	62.4	7.3	5.3	181.9	**48.1**	43.4	87.5	94.4
	H (Oa)	13.9	0.5	3.9	21.4	2.0	63.1	4.9	0.7	110.5	**25.2**	21.2	27.9	82.6
	0-10 cm	6.4	0.1	0.8	2.8	0.0	15.5	1.3	0.1	27.0	**13.9**	10.4	3.8	23.3
B2	L (Oi)	0.0	1.2	22.2	328.1	48.9	0.7	0.1	43.7	444.9	**90.0**	84.7	400.4	44.5
	F (Oe)	7.2	1.1	12.3	167.5	17.6	24.6	1.7	36.4	268.3	**74.0**	69.0	198.5	69.9
	H (Oa)	13.7	1.3	10.5	42.9	4.5	91.5	7.3	4.0	175.6	**33.6**	26.9	59.1	116.5
	0-10 cm	5.2	0.2	1.0	2.2	0.0	21.5	1.0	0.6	31.7	**10.6**	6.9	3.4	28.3
C2	L (Oi)	0.4	0.7	22.6	348.8	57.5	0.0	0.0	51.1	481.1	**89.3**	84.5	429.7	51.5
	F (Oe)	14.1	1.2	11.1	110.5	9.5	39.0	4.1	9.7	199.1	**66.4**	60.2	132.3	66.9
	H (Oa)	16.3	0.0	4.5	22.7	0.0	81.3	4.9	0.3	130.1	**21.0**	17.5	27.3	102.8
	0-10 cm	12.4	0.0	1.1	4.4	1.1	22.7	1.7	0.1	43.5	**14.8**	12.3	6.6	37.0
B3	L (Oi)	1.7	1.0	21.0	267.7	39.3	2.0	0.3	22.7	355.8	**92.5**	86.3	329.1	26.7
	F (Oe)	24.4	0.2	7.6	112.3	10.3	80.3	9.0	2.6	246.7	**52.9**	49.7	130.4	116.3
	H (Oa)	23.5	0.1	6.5	45.9	2.7	74.5	4.6	0.2	158.1	**34.9**	30.8	55.2	102.9
	0-10 cm	10.7	0.1	0.6	4.3	0.0	4.8	0.2	0.0	20.7	**24.2**	20.6	5.0	15.7
C3	L (Oi)	5.2	1.0	15.0	209.2	35.9	7.0	0.9	39.4	313.7	**83.3**	78.1	261.2	52.5
	F (Oe)	20.1	0.8	7.0	107.8	15.2	51.1	6.0	9.6	217.6	**60.1**	56.5	130.8	86.8
	H (Oa)	21.9	0.3	4.7	49.4	8.7	80.5	6.0	2.2	173.7	**36.4**	33.5	63.2	110.5
	0-10 cm	9.3	0.3	0.9	3.8	0.1	18.4	1.8	0.5	35.0	**14.5**	11.2	5.1	29.9

Table A7: Contents of total organic carbon (TOC) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by M. Unger).

		TOC [µg g^{-1} dw]			
Site		**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**464180.00**	**438856.67**	**357880.00**	**94279.33**
	SD	± 16231.38	± 21283.22	± 60814.30	± 16739.55
B1	mean	**448236.67**	**319573.33**	**282923.33**	**43325.33**
	SD	± 28085.97	± 29682.68	± 44557.84	± 4035.40
C1	mean	**473386.67**	**327300.00**	**221763.33**	**48529.33**
	SD	± 12649.62	± 31249.64	± 52413.98	± 6860.73
	Saxonian lowland:				
A2	mean	**416900.00**	**325966.67**	**143650.00**	**16303.67**
	SD	± 44960.02	± 27008.35	± 2144.63	± 6615.90
B2	mean	**415630.00**	**344150.00**	**232106.67**	**15515.67**
	SD	± 16020.38	± 18676.19	± 47561.80	± 6850.50
C2	mean	**446410.00**	**293560.00**	**184460.00**	**34954.67**
	SD	± 28207.28	± 10420.61	± 28282.86	± 14366.60
B3	mean	**485923.33**	**375830.00**	**190003.33**	**14013.33**
	SD	± 12312.76	± 32309.08	± 22033.26	± 6440.75
C3	mean	**416600.00**	**354800.00**	**245150.00**	**22136.33**
	SD	± 42278.30	± 42399.31	± 16296.73	± 7369.45

Table A8: Contents of total nitrogen (TN) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by M. Unger).

		TN [µg g^{-1} dw]			
Site		**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**19244.67**	**19071.00**	**14845.33**	**4272.33**
	SD	± 620.42	± 764.77	± 2527.63	± 595.35
B1	mean	**17057.00**	**16350.00**	**13628.67**	**2179.33**
	SD	± 539.91	± 907.87	± 2436.22	± 192.99
C1	mean	**15506.33**	**16836.33**	**11081.67**	**2811.00**
	SD	± 513.39	± 1216.93	± 2020.68	± 362.81
	Saxonian lowland:				
A2	mean	**15180.67**	**14255.33**	**6164.00**	**673.33**
	SD	± 838.79	± 1223.67	± 444.75	± 286.72
B2	mean	**15729.67**	**17024.67**	**10964.00**	**687.67**
	SD	± 950.49	± 1137.15	± 1955.21	± 223.58
C2	mean	**15941.00**	**15122.67**	**8353.00**	**1453.33**
	SD	± 735.94	± 483.74	± 1279.92	± 618.15
B3	mean	**16755.67**	**16018.00**	**7433.67**	**585.33**
	SD	± 1330.20	± 1450.70	± 1308.10	± 275.54
C3	mean	**15546.33**	**15589.67**	**10663.67**	**898.67**
	SD	± 655.74	± 1919.62	± 790.36	± 202.07

Table A9: Contents of microbial biomass (C_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		C_{mic} [µg g^{-1} dw]			
Site		**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**5367.74**	**5247.70**	**4000.93**	**469.27**
	SD	±548.57	±304.15	±479.14	±37.11
B1	mean	**6051.93**	**3413.20**	**3138.17**	**398.26**
	SD	±1091.72	±352.41	±329.39	±79.85
C1	mean	**14917.03**	**2603.07**	**2171.68**	**430.87**
	SD	±7158.55	±715.03	±956.40	±34.44
	Saxonian lowland:				
A2	mean	**5000.86**	**1331.49**	**2590.01**	**147.19**
	SD	±2808.76	±550.37	±247.95	±72.15
B2	mean	**5570.21**	**2310.38**	**2524.79**	**106.37**
	SD	±1122.73	±286.29	±538.13	±49.00
C2	mean	**14145.97**	**5571.64**	**2455.17**	**312.73**
	SD	±2418.7	±220.64	±243.31	±129.61
B3	mean	**4953.77**	**1574.77**	**2167.70**	**9.60**
	SD	±3453.35	±565.05	±251.01	±7.85
C3	mean	**9123.89**	**3515.35**	**1961.55**	**172.72**
	SD	±3325.15	±385.95	±237.92	±24.77

Table A10: Contents of microbial nitrogen (N_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		N_{mic} [µg g^{-1} dw]			
Site		**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**486.39**	**520.72**	**408.64**	**39.70**
	SD	±68.95	±44.77	±74.16	±2.16
B1	mean	**731.99**	**367.14**	**327.37**	**37.88**
	SD	±69.33	±65.05	±38.01	±7.90
C1	mean	**1096.24**	**335.56**	**243.18**	**34.63**
	SD	±359.62	±30.50	±141.62	±7.41
	Saxonian lowland:				
A2	mean	**702.10**	**353.37**	**122.72**	**8.40**
	SD	±235.56	±55.47	±25.33	±6.49
B2	mean	**838.14**	**509.17**	**162.13**	**7.11**
	SD	±150.00	±42.12	±20.50	±3.24
C2	mean	**1404.28**	**551.76**	**205.87**	**26.06**
	SD	**±188.60**	**±19.45**	**±26.43**	**±14.83**
B3	mean	**667.67**	**277.14**	**95.66**	**4.75**
	SD	±344.58	±60.06	±32.92	±2.00
C3	mean	**862.22**	**298.36**	**156.55**	**10.38**
	SD	±277.44	±75.92	±31.21	±1.91

Table A11: Potential C mineralisation in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		Potential C mineralisation [µg g^{-1} dw h^{-1}]			
Site		**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**16.98**	**15.52**	**3.73**	**0.73**
	SD	±2.52	±7.89	±0.92	±0.37
B1	mean	**56.78**	**16.16**	**3.45**	**0.81**
	SD	±9.83	±2.48	±0.46	±0.27
C1	mean	**71.59**	**15.69**	**3.38**	**1.23**
	SD	±8.53	±1.90	±0.64	±0.56
	Saxonian lowland:				
A2	mean	**53.22**	**13.78**	**3.68**	**0.66**
	SD	±23.09	±2.09	±0.65	±0.15
B2	mean	**48.34**	**21.05**	**5.52**	**0.77**
	SD	±10.66	±3.85	±0.47	±0.27
C2	mean	**109.51**	**26.29**	**5.20**	**0.87**
	SD	±17.39	±3.00	±0.81	±0.50
B3	mean	**65.39**	**10.72**	**3.45**	**0.69**
	SD	±27.08	±5.74	±0.34	±0.13
C3	mean	**91.02**	**12.78**	**4.92**	**0.96**
	SD	±39.96	±1.51	±0.67	±0.23

Table A12: Contents of hot-water-extractable C (C_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

			C_{hwe} [µg g^{-1} dw]		
Site		**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**20072.69**	**20520.28**	**18585.05**	**5959.18**
	SD	±4078.39	± 2524.77	± 2152.78	± 668.45
B1	mean	**20564.86**	**18141.06**	**17602.13**	**3869.65**
	SD	± 2223.70	± 1417.34	± 2909.40	± 331.96
C1	mean	**29902.20**	**17898.40**	**14255.87**	**2590.62**
	SD	± 11646.54	± 1993.90	± 4487.28	± 709.98
	Saxonian lowland:				
A2	mean	**25434.51**	**20643.98**	**10012.25**	**1059.61**
	SD	± 2758.58	± 2375.00	± 279.15	± 81.94
B2	mean	**30809.80**	**22082.65**	**13337.13**	**1869.53**
	SD	± 5338.33	± 1699.16	± 723.63	± 433.28
C2	mean	**26701.21**	**22402.40**	**20270.81**	**1755.33**
	SD	8797.12	1156.32	7764.90	156.33
B3	mean	**19949.03**	**17954.15**	**13630.98**	**1188.47**
	SD	± 3607.14	± 1916.54	± 2605.52	± 535.41
C3	mean	**21377.09**	**16586.46**	**11996.46**	**1298.10**
	SD	± 2548.27	± 840.44	± 605.82	± 372.15

Table A13: Contents of cold-water-extractable C (C_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

			C_{cwe} [µg g^{-1} dw]		
Site		**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**4176.91**	**3995.76**	**3178.72**	**1146.00**
	SD	± 1131.82	± 647.25	± 154.26	± 445.99
B1	mean	**5398.40**	**4852.84**	**3604.94**	**447.75**
	SD	± 808.96	± 731.93	± 999.85	± 149.94
C1	mean	**11812.74**	**3596.21**	**3519.18**	**637.90**
	SD	± 2090.62	± 473.74	± 1038.78	± 316.82
	Saxonian lowland:				
A2	mean	**5808.23**	**3270.29**	**1392.26**	**203.67**
	SD	± 1469.46	± 555.27	± 125.61	± 30.78
B2	mean	**9074.21**	**3581.27**	**1754.90**	**519.85**
	SD	± 1984.75	± 340.06	± 69.88	± 204.48
C2	mean	**9336.51**	**3550.23**	**2372.71**	**342.87**
	SD	± 4224.52	± 286.03	± 287.19	± 53.97
B3	mean	**4098.03**	**3224.89**	**2012.92**	**399.35**
	SD	± 1596.77	± 408.86	± 394.91	± 308.93
C3	mean	**8718.37**	**3264.15**	**2376.41**	**426.02**
	SD	± 1367.70	± 237.15	± 217.08	± 146.00

Table A14: Contents of hot-water-extractable N (N_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		N_{hwe} [µg g^{-1} dw]			
Site	**Site**	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**1200.86**	**1168.56**	**970.34**	**270.94**
	SD	± 285.34	± 192.97	± 86.99	± 52.24
B1	mean	**1155.59**	**1150.55**	**864.52**	**137.17**
	SD	± 180.18	± 84.71	± 165.67	± 13.54
C1	mean	**1584.28**	**1294.56**	**851.12**	**164.58**
	SD	± 350.67	± 104.93	± 179.79	± 39.66
	Saxonian lowland:				
A2	mean	**1389.14**	**1097.61**	**494.52**	**39.99**
	SD	± 91.43	± 91.12	± 22.29	± 4.70
B2	mean	**1768.74**	**1468.54**	**693.93**	**98.82**
	SD	± 96.08	± 71.61	± 29.50	± 34.57
C2	mean	**1252.26**	**1189.36**	**936.52**	**78.20**
	SD	± 411.92	± 59.18	± 390.77	± 9.84
B3	mean	**1475.62**	**1348.10**	**735.79**	**51.17**
	SD	± 277.31	± 77.54	± 132.70	± 24.15
C3	mean	**1406.69**	**963.80**	**575.55**	**52.63**
	SD	± 204.90	± 42.57	± 40.47	± 12.98

Table A15: Contents of hot-water-extractable N (N_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		N_{cwe} [µg g^{-1} dw]			
Site	**Site**	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
	Ore mountains:				
A1	mean	**315.83**	**257.79**	**169.42**	**65.62**
	SD	± 84.70	± 68.78	± 15.87	± 34.98
B1	mean	**447.61**	**431.37**	**225.10**	**23.20**
	SD	± 112.62	± 63.57	± 82.52	± 7.36
C1	mean	**893.73**	**481.52**	**319.30**	**56.15**
	SD	± 98.23	± 46.23	± 79.48	± 29.04
	Saxonian lowland:				
A2	mean	**562.01**	**352.42**	**114.38**	**11.89**
	SD	± 147.63	± 54.22	± 15.67	± 2.35
B2	mean	**889.64**	**477.59**	**146.60**	**31.56**
	SD	± 50.08	± 45.09	± 6.94	± 11.87
C2	mean	**751.70**	**399.74**	**178.26**	**19.41**
	SD	± 147.50	± 37.83	± 12.22	± 2.31
B3	mean	**516.38**	**484.26**	**183.51**	**24.81**
	SD	± 188.10	± 75.47	± 35.54	± 17.67
C3	mean	**1001.55**	**335.31**	**145.04**	**26.60**
	SD	± 205.71	± 32.16	± 13.72	± 8.09

Table A16: Stocks of total organic carbon (TOC) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by M. Unger).

	TOC [t ha^{-1}]			
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	11.12	16.58	14.52	40.75
B1	15.06	11.67	10.39	26.05
C1	9.84	14.91	11.99	15.00
Saxonian lowland:				
A2	17.22	17.97	12.01	17.40
B2	13.41	20.07	21.55	21.52
C2	7.50	12.69	31.63	55.00
B3	17.05	26.35	25.76	16.18
C3	10.88	25.57	23.97	29.81

Table A17: Stocks of total nitrogen (TN) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by M. Unger).

	TN [t ha^{-1}]			
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	0.46	0.72	0.60	1.85
B1	0.57	0.60	0.50	1.31
C1	0.46	0.77	0.60	0.87
Saxonian lowland:				
A2	0.63	0.79	0.52	0.72
B2	0.51	0.99	1.02	0.95
C2	0.27	0.65	1.43	2.29
B3	0.59	1.12	1.01	0.68
C3	0.41	1.12	1.04	1.21

Table A18: Stocks of microbial biomass (C_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		C_{mic} [kg ha^{-1}]		
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	128.54	198.22	162.36	202.83
B1	203.34	124.67	115.30	239.48
C1	310.17	118.55	117.46	133.14
Saxonian lowland:				
A2	206.60	73.41	216.58	157.04
B2	179.72	134.71	234.38	147.50
C2	237.65	240.89	421.01	492.05
B3	173.77	110.41	293.90	11.09
C3	238.38	253.36	191.82	232.62

Table A19: Stocks of microbial nitrogen (N_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		N_{mic} [kg ha^{-1}]		
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	11.65	19.67	16.58	17.16
B1	24.59	13.41	12.03	22.78
C1	22.79	15.28	13.15	10.70
Saxonian lowland:				
A2	29.01	19.48	10.26	8.96
B2	27.04	29.69	15.05	9.86
C2	23.59	23.86	35.30	41.00
B3	23.42	19.43	12.97	5.48
C3	22.53	21.50	15.31	13.98

Table A20: Absolut potential C mineralisation in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

	Potential C mineralisation [kg ha^{-1} d^{-1}]			
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	9.76	14.07	3.63	7.59
B1	45.79	14.17	3.04	11.65
C1	35.73	17.15	4.39	9.09
Saxonian lowland:				
A2	52.76	18.24	7.38	16.91
B2	37.43	29.45	12.30	25.67
C2	44.15	27.28	21.40	33.02
B3	55.05	18.04	11.23	19.11
C3	57.07	22.11	11.54	31.00

Table A21: Stocks of hot-water-extractable C (C_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

	C_{hwe} [kg ha^{-1}]			
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	480.67	775.09	754.20	2575.76
B1	690.95	662.59	646.72	2326.86
C1	621.77	815.15	771.07	800.50
Saxonian lowland:				
A2	1050.79	1138.21	837.23	1130.54
B2	994.08	1287.59	1238.11	2592.60
C2	448.58	968.58	3476.01	2761.88
B3	699.77	1258.80	1848.10	1372.09
C3	558.51	1195.44	1173.15	1748.29

Table A22: Stocks of cold-water-extractable C (C_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

	C_{cwe} [kg ha^{-1}]			
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	100.02	150.93	129.00	495.34
B1	181.38	177.25	132.45	269.23
C1	245.63	163.78	190.34	197.11
Saxonian lowland:				
A2	239.96	180.31	116.42	217.31
B2	292.78	208.82	162.91	720.91
C2	156.85	153.50	406.87	539.48
B3	143.75	226.10	272.91	461.05
C3	227.78	235.26	232.39	573.77

Table A23: Stocks of hot-water-extractable N (N_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		N_{hwe} [kg ha^{-1}]		
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	28.76	44.14	39.38	117.11
B1	38.83	42.02	31.76	82.48
C1	32.94	58.96	46.03	50.85
Saxonian lowland:				
A2	57.39	60.52	41.35	42.66
B2	57.07	85.63	64.42	137.05
C2	21.04	51.42	160.59	123.04
B3	51.76	94.52	99.76	59.07
C3	36.75	69.46	56.28	70.88

Table A24: Stocks of hot-water-extractable N (N_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* and *Heinzebank* in May/June 2001 by Koch, Streich & Kunze; analyses by I. Weimann).

		N_{cwe} [kg ha^{-1}]		
Site	**L(Oi)**	**F(Oe)**	**H(Oa)**	**0-10 cm**
Ore mountains:				
A1	7.56	9.74	6.88	28.36
B1	15.04	15.76	8.27	13.95
C1	18.58	21.93	17.27	17.35
Saxonian lowland:				
A2	23.22	19.43	9.56	12.69
B2	28.70	27.85	13.61	43.76
C2	12.63	17.28	30.57	30.54
B3	18.11	33.95	24.88	28.64
C3	26.17	24.17	14.18	35.83

Humus Dynamics under Pine and Beech/Oak during one Year

Table A25: Thickness and mass of the organic layers (L, F and H horizon).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

				11/01			
Site	**Horizon**						
		thickness	**area**	**fresh sample mass**		**dw**	**mass**
		[cm]	**[cm²]**	**prior processing**	**after processing**	**[%]**	**[t ha^{-1}]**
Pine	**L(Oi)**	2.00	1600	571.80	427.60	27.46	9.81
		4.00	1600	1439.80	967.20	27.37	24.63
		1.50	1600	1034.70	910.20	32.81	21.22
		1.50	1600	742.20	618.90	35.97	16.69
		1.50	1600	788.50	667.20	45.88	22.61
		1.50	1600	653.90	551.90	29.90	12.22
	mean	2.00	1600				**17.86**
	SD						± 5.96
	F(Oe)	3.00	1600	2088.00	1588.50	44.88	58.56
		5.00	1600	2972.30	1603.00	38.94	72.33
		4.00	2000	2642.00	1925.40	41.65	55.02
		3.00	1600	1695.20	1319.70	46.63	49.40
		3.00	1600	1653.20	1393.30	56.04	57.90
		3.00	1600	1790.80	1432.10	51.33	57.45
	mean	3.50	1667				**58.45**
	SD						± 7.59
	H(Oa)	3.00	1600	2327.30	1981.90	67.57	98.29
		1.00	1600	1041.20	951.80	62.36	40.58
		2.50	1600	3678.90	3095.90	68.88	158.37
		2.50	1600	2331.70	1857.00	71.51	104.21
		1.00	1600	1817.20	1604.20	73.44	83.41
		4.00	1600	2111.20	1790.70	64.49	85.09
	mean	2.33	1600				**94.99**
	SD						± 38.22
Beech/ Oak	**L(Oi)**	3.00	2000	681.60	504.00	27.53	9.38
		2.00	2000	717.20	525.50	32.33	11.59
		2.00	2000	592.30	404.80	33.69	9.98
		2.50	2000	759.60	617.80	33.11	12.57
		3.00	2000	815.40	641.80	31.67	12.91
		2.00	2000	684.40	550.90	36.43	12.47
	mean	2.42	2000				**11.48**
	SD						± 1.48
	F(Oe)	2.00	1200	1512.50	1166.70	42.57	53.66
		2.00	1200	1280.20	1070.60	42.80	45.66
		1.00	1200	974.60	876.80	52.65	42.76
		2.00	1200	1142.30	1019.30	45.89	43.68
		1.50	1200	1288.80	1113.10	43.24	46.44
		2.00	1200	1663.50	1517.60	59.25	82.14
	mean	1.75	1200				**52.39**
	SD						± 15.07
	H(Oa)	3.00	1200	1606.00	1478.80	47.10	63.04
		3.00	1200	2003.00	1827.50	52.94	88.37
		3.50	1200	2010.70	1923.50	67.43	112.98
		4.00	1200	2359.80	2226.00	63.42	124.72
		3.00	1200	1303.30	1225.40	56.06	60.89
		3.50	1200	2817.90	2681.90	69.91	164.17
	mean	3.33	1200				**102.36**
	SD						± 39.74

01/02

Site	Horizon	thickness [cm]	area [cm²]	fresh sample mass prior processing	fresh sample mass after processing	dw [%]	mass $[t\ ha^{-1}]$
Pine	**L(Oi)**	1.00	2800	829.10	340.10	35.52	10.52
		2.00	2000	592.60	233.10	36.02	10.67
		1.00	2400	787.90	220.70	32.63	10.71
		2.00	2400	847.40	214.20	34.69	12.25
		1.00	2000	831.70	197.80	29.70	12.35
		1.00	2800	784.50	229.80	35.24	9.87
	mean	1.33	2400				**11.06**
	SD						± 1.00
	F(Oe)	3.00	1200	1805.60	1141.70	39.50	59.43
		6.00	1200	2430.10	1572.70	34.81	70.49
		4.00	1600	1572.60	963.00	39.62	38.94
		3.00	1200	1286.70	903.30	50.24	53.87
		2.00	1600	1652.80	1255.50	39.15	40.45
		3.00	1200	1835.90	1212.20	35.66	54.56
	mean	3.50	1333				**52.96**
	SD						± 11.88
	H(Oa)	2.00	1600	1455.70	1181.00	51.35	46.72
		1.00	2000	1142.60	980.50	48.30	27.59
		1.00	2400	1180.50	886.90	36.34	17.88
		1.50	1200	1370.10	1188.20	55.27	63.10
		2.00	2000	2080.30	1857.70	57.51	59.82
		3.00	1200	2439.40	2129.60	53.51	108.79
	mean	1.75	1733				**53.98**
	SD						± 32.17
Beech/ Oak	**L(Oi)**	1.00	2000	660.40	455.90	32.00	10.57
		2.00	2000	670.80	548.30	31.23	10.47
		1.50	2000	672.80	493.30	35.50	11.94
		3.00	2000	502.50	321.10	36.01	9.05
		1.00	2000	632.70	382.30	35.55	11.25
		3.00	2000	552.20	406.80	34.61	9.56
	mean	1.92	2000				**10.47**
	SD						± 1.06
	F(Oe)	2.00	2000	1535.20	1221.30	36.57	28.07
		2.00	2000	1098.20	867.30	39.05	21.44
		1.50	2000	1085.10	831.80	34.92	18.95
		2.00	1200	1123.40	812.20	34.20	32.02
		2.00	1200	1009.00	784.90	40.36	33.66
		2.00	2000	1047.10	808.40	33.93	17.77
	mean	1.92	1733				**25.32**
	SD						± 6.85
	H(Oa)	3.00	1200	2026.20	1846.20	50.36	85.03
		3.00	2000	2712.40	2460.00	51.24	69.50
		4.00	1200	2321.90	2121.70	45.34	87.73
		4.00	800	1679.40	1538.10	46.61	97.85
		3.00	800	1286.10	1191.90	49.00	78.77
		4.00	1200	1792.50	1606.00	50.86	75.98
	mean	3.50	1200				**82.48**
	SD						± 9.95

03/02

Site	Horizon	thickness [cm]	area [cm^2]	fresh sample mass prior processing	 after processing	dw [%]	mass [t ha^{-1}]
Pine	**L(Oi)**	1.00	2400	272.30	135.20	53.70	6.09
		1.00	2800	377.60	264.80	35.94	4.85
		1.00	2400	411.10	310.50	46.00	7.88
		1.00	2400	391.40	265.50	46.20	7.53
		1.00	2400	398.40	297.30	56.76	9.42
		2.00	1600	419.50	321.80	56.56	14.83
	mean	1.17	2333				**8.43**
	SD						± 3.50
	F(Oe)	2.00	1200	1065.60	615.20	34.70	30.81
		3.00	800	980.10	774.74	36.90	45.20
		4.00	600	1043.90	612.30	36.76	63.95
		4.00	1200	1011.00	681.50	37.62	31.69
		3.50	1200	1679.00	980.00	50.30	70.37
		5.00	800	1427.00	984.70	48.35	86.24
	mean	3.58	967				**54.71**
	SD						± 22.43
	H(Oa)	1.00	1200	1036.20	854.50	56.98	49.20
		2.00	800	1165.50	979.30	50.62	73.74
		4.00	800	1325.10	1081.40	80.72	133.70
		1.50	2000	944.20	765.60	58.16	27.46
		6.00	600	2148.80	1656.40	79.98	286.45
		1.00	2000	754.60	651.70	59.33	22.38
	mean	2.58	1233				**98.82**
	SD						± 100.45
Beech/ Oak	**L(Oi)**	2.00	2400	643.70	509.10	49.47	13.27
		2.00	2000	623.00	444.30	45.61	14.21
		2.00	2400	483.60	338.90	43.69	8.80
		2.00	2000	540.80	327.60	40.14	10.85
		2.00	2000	575.50	422.50	42.53	12.24
		2.00	2400	427.10	315.50	46.49	8.27
	mean	2.00	2200				**11.27**
	SD						± 2.40
	F(Oe)	2.50	1200	854.70	625.60	40.56	28.89
		2.50	1200	891.20	696.70	39.14	29.07
		2.50	1200	1204.10	808.50	33.86	33.98
		3.00	1200	1117.20	793.20	38.75	36.07
		4.00	1600	1252.90	915.20	38.47	30.13
		4.00	1200	1481.70	1291.20	41.50	51.24
	mean	3.08	1267				**34.90**
	SD						± 8.51
	H(Oa)	3.00	800	1297.00	1145.00	54.63	88.58
		3.50	1200	1544.30	1239.70	49.80	64.09
		4.00	800	1970.70	1614.50	46.68	114.99
		2.50	1200	1273.60	1103.10	56.22	59.67
		3.50	1200	1173.50	951.70	52.19	51.04
		3.00	1000	1483.20	1279.60	49.36	73.22
	mean	3.25	1033				**75.26**
	SD						± 23.30

05/02

Site	Horizon						
		thickness	area	fresh sample mass		dw	mass
		[cm]	[cm^2]	prior processing	after processing	[%]	[t ha^{-1}]
Pine	**L(Oi)**	2.00	2000	312.70	235.70	26.42	4.13
		1.00	2800	280.00	220.00	42.08	4.21
		1.00	2800	315.00	250.00	36.83	4.14
		1.00	2800	350.00	270.00	33.42	4.18
		1.50	2000	340.00	270.00	36.67	6.23
		3.00	1600	680.00	600.00	33.76	14.35
	mean	1.58	2333				**6.21**
	SD						± 4.07
	F(Oe)	3.00	1200	1150.00	740.00	37.01	35.47
		4.00	800	1300.00	820.00	52.43	85.19
		7.00	800	1260.00	780.00	48.98	77.14
		6.00	800	900.00	600.00	41.36	46.52
		4.00	1200	930.00	560.00	44.29	34.33
		5.00	1200	960.00	640.00	41.86	33.49
	mean	4.83	1000				**52.02**
	SD						± 23.20
	H(Oa)	2.00	1200	1420.00	1060.00	60.65	71.77
		2.00	1200	890.00	740.00	62.50	46.35
		1.00	2000	750.00	630.00	54.83	20.56
		1.00	1200	745.00	650.00	46.72	29.00
		1.00	2000	680.00	530.00	51.94	17.66
		1.00	2400	1030.00	900.00	71.41	30.65
	mean	1.33	1667				**36.00**
	SD						± 20.19
Beech/ Oak	**L(Oi)**	1.50	2400	458.90	356.10	45.89	8.77
		2.00	1800	503.60	412.50	41.51	11.61
		2.00	2400	506.70	433.30	47.66	10.06
		1.50	2400	428.90	354.50	40.71	7.28
		1.00	2400	470.00	310.00	43.24	8.47
		1.50	2000	490.00	1360.00	37.71	9.24
	mean	1.58	2233				**9.24**
	SD						± 1.48
	F(Oe)	4.00	800	972.90	737.50	40.52	49.28
		3.00	1200	957.70	786.20	41.04	32.76
		2.50	1600	1113.00	980.70	48.35	33.64
		2.50	1600	787.80	676.90	38.67	19.04
		2.00	1600	1030.00	770.00	37.64	24.23
		3.50	1200	1070.00	820.00	32.34	28.84
	mean	2.92	1333				**31.30**
	SD						± 10.36
	H(Oa)	5.00	600	1696.10	1356.80	56.83	160.65
		5.00	600	1345.90	966.10	50.00	112.16
		3.00	1200	1377.60	1263.90	62.14	71.34
		3.00	1200	1264.50	1112.20	53.61	56.49
		3.00	1600	1540.00	1200.00	53.50	51.50
		3.00	1200	1490.00	1170.00	47.23	58.65
	mean	3.67	1067				**85.13**
	SD						± 43.07

		07/02		
Site	**Horizon**	**05/02**	**09/02** **mass** **[t ha^{-1}]**	**07/02** [1]
Pine	**L(Oi)**	4.13	10.81	7.47
		4.21	7.29	5.75
		4.14	20.85	12.49
		4.18	15.63	9.90
		6.23	11.54	8.89
		14.35	23.93	19.14
	mean	**6.21**	**15.01**	**10.61**
	SD			± 4.76
	F(Oe)	35.47	161.86	98.67
		85.19	109.44	97.32
		77.14	99.75	88.44
		46.52	73.26	59.89
		34.33	85.41	59.87
		33.49	147.69	90.59
	mean	**52.02**	**112.90**	**82.46**
	SD			± 17.92
	H(Oa)	71.77	108.47	90.12
		46.35	85.55	65.95
		20.56	64.02	42.29
		29.00	44.35	36.67
		17.66	54.78	36.22
		30.65	159.18	94.91
	mean	**36.00**	**86.06**	**61.03**
	SD			± 26.75
Beech/ Oak	**L(Oi)**	8.77	23.54	16.16
		11.61	39.34	25.48
		10.06	23.86	16.96
		7.28	19.14	13.21
		8.47	20.04	14.25
		9.24	34.45	21.85
	mean	**9.24**	**26.73**	**17.98**
	SD			± 4.74
	F(Oe)	49.28	74.00	61.64
		32.76	104.97	68.86
		33.64	80.78	57.21
		19.04	58.89	38.96
		24.23	73.50	48.86
		28.84	156.04	92.44
	mean	**31.30**	**91.36**	**61.33**
	SD			± 18.42
	H(Oa)	160.65	267.71	214.18
		112.16	252.36	182.26
		71.34	95.31	83.33
		56.49	114.64	85.57
		51.50	246.40	148.95
		58.65	209.95	134.30
	mean	**85.13**	**197.73**	**141.43**
	SD			± 52.08

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[1] Data obtained by interpolation of 05/02 and 09/02 as samples of 07/02 were lost by the flood in Tharandt on 12th of August 2002.

09/02

Site	Horizon	thickness	area	fresh sample mass		dw	mass
		[cm]	[cm²]	prior processing	after processing	[%]	[t ha^{-1}]
Pine	**L(Oi)**	2.00	1600	312.70	125.00	55.32	10.81
		1.00	1600	280.00	151.30	41.67	7.29
		2.00	800	315.00	102.00	52.94	20.85
		4.00	800	350.00	88.30	35.71	15.63
		1.00	1600	340.00	72.00	54.29	11.54
		1.00	1200	680.00	119.60	42.22	23.93
	mean	1.83	1267				**15.01**
	SD						± 6.37
	F(Oe)	6.00	400	1150.00	196.00	56.30	161.86
		3.00	800	1300.00	379.80	67.35	109.44
		4.00	800	1260.00	340.30	63.33	99.75
		2.00	800	900.00	429.20	65.12	73.26
		6.00	600	930.00	271.30	55.10	85.41
		5.00	400	960.00	274.10	61.54	147.69
	mean	4.33	633				**112.90**
	SD						± 34.99
	H(Oa)	1.00	1200	1420.00	826.20	91.67	108.47
		1.00	800	890.00	428.40	76.90	85.55
		2.00	800	750.00	597.30	68.29	64.02
		1.00	1200	745.00	282.50	71.43	44.35
		1.00	800	680.00	323.40	64.44	54.78
		2.00	400	1030.00	413.70	61.82	159.18
	mean	1.33	867				**86.06**
	SD						± 42.55
Beech/ Oak	**L(Oi)**	1.00	1200	458.90	71.90	61.57	23.54
		2.00	800	503.60	68.60	62.50	39.34
		2.00	1200	506.70	128.10	56.50	23.86
		1.50	1200	428.90	130.80	53.56	19.14
		1.00	1200	470.00	118.40	51.16	20.04
		2.00	800	490.00	63.60	56.25	34.45
	mean	1.58	1067				**26.73**
	SD						± 8.24
	F(Oe)	2.00	800	972.90	412.80	60.85	74.00
		2.00	600	957.70	377.40	65.77	104.97
		3.00	800	1113.00	332.10	58.06	80.78
		2.00	800	787.80	474.60	59.80	58.89
		3.00	800	1030.00	309.40	57.08	73.50
		4.00	400	1070.00	262.20	58.33	156.04
	mean	2.67	700				**91.36**
	SD						± 35.09
	H(Oa)	3.00	400	1696.10	779.30	63.14	267.71
		3.00	400	1345.90	655.90	75.00	252.36
		1.00	1200	1377.60	609.00	83.03	95.31
		2.00	800	1264.50	711.10	72.53	114.64
		4.00	400	1540.00	379.90	64.00	246.40
		4.00	400	1490.00	609.50	56.36	209.95
	mean	2.83	600				**197.73**
	SD						± 74.56

10/02

Site	**Horizon**	**thickness**	**area**	**fresh sample mass**		**dw**	**mass**
		[cm]	**[cm²]**	**prior processing**	**after processing**	**[%]**	**[t ha^{-1}]**
Pine	**L(Oi)**	2.00	1200	557.10	341.00	28.66	13.31
		2.00	1200	853.80	471.00	30.13	21.44
		2.00	1200	976.60	458.60	29.76	24.22
		2.00	1200	776.30	408.00	26.47	17.12
		2.00	1200	1011.00	391.10	28.03	23.62
		2.00	1200	813.90	592.60	25.69	17.42
	mean	2.00	1200				**19.52**
	SD						± 4.27
	F(Oe)	3.50	800	846.80	628.70	49.92	52.84
		4.00	800	1053.20	628.10	44.73	58.88
		5.00	800	1227.30	725.20	43.39	66.57
		4.00	800	1601.80	848.40	49.93	99.97
		4.00	800	1150.50	616.10	48.05	69.10
		2.50	1200	723.30	465.60	42.57	25.66
	mean	3.83	867				**62.17**
	SD						± 24.19
	H(Oa)	0.50	1600	529.00	478.50	63.89	21.12
		1.00	1600	815.40	703.60	61.73	31.46
		1.00	1600	670.40	610.60	57.12	23.93
		0.50	1600	603.40	526.60	63.04	23.77
		1.00	1600	867.60	804.70	61.75	33.48
		0.50	1600	586.30	521.70	65.26	23.92
	mean	0.75	1600				**26.28**
	SD						± 4.95
Beech/ Oak	**L(Oi)**	3.00	1200	317.00	216.80	29.76	7.86
		2.00	1200	395.50	335.90	30.40	10.02
		2.50	1200	519.00	415.50	29.73	12.86
		1.50	1200	508.90	420.80	25.85	10.96
		2.00	1200	659.00	501.50	27.12	14.89
		1.50	1200	630.90	509.40	35.15	18.48
	mean	2.08	1200				**12.51**
	SD						± 3.78
	F(Oe)	2.00	1200	977.00	710.90	39.60	32.24
		2.50	1200	562.30	452.90	50.31	23.57
		2.50	1200	705.30	525.50	53.78	31.61
		2.50	800	968.80	660.30	46.26	56.02
		1.00	800	925.30	676.00	41.14	47.58
		3.00	800	1048.10	728.40	54.02	70.78
	mean	2.25	1000				**43.63**
	SD						± 17.79
	H(Oa)	1.00	800	471.50	447.30	55.63	32.78
		1.50	400	573.90	547.30	48.53	69.62
		1.00	800	667.50	624.40	56.96	47.53
		1.00	800	913.80	731.50	48.50	55.40
		1.00	800	860.10	825.50	56.23	60.45
		1.00	800	1225.00	928.50	52.86	80.94
	mean	1.08	733				**57.79**
	SD						± 16.85

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Site	Horizon	thickness	area	fresh sample mass		dw	mass
		[cm]	[cm²]	prior processing	after processing	[%]	[t ha^{-1}]
Pine	**L(Oi)**	1.50	1200	670.20	267.00	28.37	15.85
		1.50	1600	583.20	301.20	28.91	10.54
		4.00	600	746.00	305.90	29.45	36.62
		4.00	800	724.40	203.90	31.73	28.74
		1.00	1600	496.70	296.50	29.86	9.27
		4.00	800	703.70	202.00	33.07	29.09
	mean	2.67	1100				**21.68**
	SD						± 11.31
	F(Oe)	4.00	800	920.40	572.10	60.64	69.77
		6.00	600	1165.76	1018.50	33.81	65.69
		4.00	800	1183.50	809.40	68.65	101.55
		5.00	800	1230.70	83.20	38.39	59.06
		4.00	800	1356.40	729.60	45.85	77.75
		8.00	400	1137.80	723.50	33.13	94.24
	mean	5.17	700				**78.01**
	SD						± 16.71
	H(Oa)	2.00	800	1179.30	1000.90	64.02	94.38
		3.00	800	1344.20	1211.40	54.98	92.38
		1.00	800	1106.50	917.10	41.98	58.07
		2.00	800	1021.50	687.00	43.01	54.92
		1.00	1200	792.40	628.30	87.15	57.55
		6.00	400	1631.90	1217.00	94.71	386.41
	mean	2.50	800				**123.95**
	SD						± 129.82
Beech/ Oak	**L(Oi)**	3.00	1200	411.30	288.10	11.37	3.90
		3.00	800	417.70	308.10	28.98	15.13
		4.00	800	447.30	337.40	25.91	14.49
		2.00	1600	518.90	401.70	26.90	8.73
		2.00	1200	335.60	225.90	24.18	6.76
		3.00	1200	367.00	287.10	24.88	7.61
	mean	2.83	1133				**9.44**
	SD						± 4.46
	F(Oe)	5.00	800	1290.50	903.10	40.11	64.71
		2.00	1200	752.80	602.90	43.93	27.56
		3.00	800	1052.20	777.20	45.72	60.14
		3.00	800	884.10	684.40	38.27	42.29
		4.00	800	642.60	397.90	47.64	38.27
		4.00	800	854.20	613.50	44.34	47.34
	mean	3.50	867				**46.72**
	SD						± 13.87
	H(Oa)	5.00	800	1882.90	1760.40	51.39	120.95
		3.00	800	1453.90	1384.00	52.55	95.51
		3.00	800	1181.00	1105.00	59.52	87.87
		3.00	800	1183.00	1112.40	53.59	79.25
		3.00	800	915.30	817.80	58.28	66.69
		3.00	800	1135.80	1085.50	49.57	70.37
	mean	3.33	800				**86.77**
	SD						± 19.87

Table A26: Potential C mineralisation in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		Potential C mineralisation [µg g^{-1} dw h^{-1}]							
		L(Oi)		F(Oe)		H(Oa)		0-10 cm	
Sampling		**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	**mean**	**79.74**	**214.18**	**10.84**	**19.83**	**7.43**	**10.13**	**0.93**	**0.40**
	SD	± 12.58	± 45.55	± 0.74	± 2.07	± 1.72	± 3.96	± 0.53	± 0.09
Jan-02	**mean**	**80.66**	**118.28**	**13.28**	**20.51**	**9.29**	**7.92**	**0.40**	**0.74**
	SD	± 17.11	± 15.52	± 3.17	± 5.90	± 2.36	± 3.88	± 0.34	± 0.37
Mar 02	**mean**	**224.30**	**166.87**	**12.85**	**20.52**	**8.22**	**8.15**	**0.62**	**0.45**
	SD	± 53.98	± 17.47	± 4.81	± 6.40	± 3.07	± 1.33	± 0.16	± 0.19
May 02	**mean**	**118.83**	**105.43**	**13.29**	**22.10**	**4.11**	**4.28**	**0.68**	**0.36**
	SD	± 29.15	± 15.94	± 2.90	± 5.94	± 1.43	± 0.63	± 0.68	± 0.13
Jul-02	**mean**	**106.03**	**78.71**	**8.87**	**17.12**	**2.02**	**2.73**	**0.58**	**0.40**
	SD	± 47.58	± 22.31	± 1.39	± 2.36	± 0.96	± 0.96	± 0.18	± 0.22
Sep-02	**mean**	**165.50**	**99.36**	**16.56**	**25.93**	**5.25**	**3.75**	**0.56**	**0.73**
	SD	± 44.10	± 27.45	± 2.97	± 5.97	± 1.92	± 0.79	± 0.28	± 0.56
Oct 02	**mean**	**224.14**	**209.28**	**11.81**	**20.52**	**3.06**	**3.63**	**0.51**	**0.28**
	SD	± 68.82	± 25.66	± 1.83	± 2.76	± 0.45	± 0.88	± 0.19	± 0.18
Nov-02	**mean**	**203.49**	**203.91**	**12.75**	**22.22**	**4.58**	**5.31**	**0.23**	**0.08**
	SD	± 53.18	± 18.28	± 1.71	± 2.88	± 2.26	± 1.62	± 0.17	± 0.08
Mean of the year[2]		**150.33**	**149.50**	**12.53**	**21.10**	**5.49**	**5.74**	**0.56**	**0.43**

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[2]: from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A27: Contents of microbial biomass (C_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		C_{mic} [µg g^{-1} dw]							
		L(Oi)		F(Oe)		H(Oa)		0-10 cm	
Sampling		**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	**mean**	**7364.22**	**9239.59**	**3341.53**	**4829.17**	**1164.69**	**2306.68**	**143.87**	**176.10**
	SD	± 2002.12	± 1373.11	± 999.91	± 1258.62	± 248.48	± 819.46	± 38.88	± 37.60
Jan-02	**mean**	**12984.75**	**16920.64**	**5598.31**	**5230.77**	**3516.67**	**3448.21**	**64.38**	**276.04**
	SD	± 2298.66	± 1319.38	± 1047.01	± 1120.88	± 453.71	± 704.75	± 35.68	± 204.23
Mar 02	**mean**	**19110.55**	**20806.23**	**5769.77**	**6896.93**	**2066.88**	**3739.52**	**170.90**	**154.06**
	SD	± 4613.20	± 3099.43	± 1652.57	± 1025.72	± 1090.80	± 515.33	± 70.52	± 43.13
May 02	**mean**	**18181.68**	**18557.59**	**3843.58**	**5057.18**	**2528.71**	**2863.19**	**230.23**	**258.12**
	SD	± 6104.28	± 3738.58	± 739.06	± 579.08	± 624.00	± 524.34	± 57.61	± 55.60
Jul-02	**mean**	**26387.18**	**19235.47**	**4227.70**	**5269.46**	**2504.61**	**2789.00**	**200.94**	**289.86**
	SD	± 4822.39	± 2978.47	± 730.20	± 605.53	± 552.98	± 634.43	± 74.77	± 88.06
Sep-02	**mean**	**34592.68**	**19913.36**	**4611.83**	**5481.73**	**2480.51**	**2714.81**	**171.66**	**321.60**
	SD	± 7960.32	± 3487.05	± 886.04	± 1339.43	± 1094.52	± 826.96	± 108.01	± 132.47
Oct 02	**mean**	**16093.37**	**20343.44**	**4991.13**	**6337.52**	**2588.18**	**3557.84**	**131.72**	**180.02**
	SD	± 1788.31	± 3523.49	± 464.14	± 524.11	± 369.51	± 413.81	± 60.18	± 121.07
Nov-02	**mean**	**12411.13**	**21939.74**	**4682.22**	**5376.36**	**2313.28**	**3049.60**	**121.44**	**197.59**
	SD	± 2251.28	± 10302.35	± 1285.06	± 849.47	± 1407.98	± 336.28	± 71.30	± 46.80
Mean of the year[2]		**18390.70**	**18369.51**	**4633.26**	**5559.89**	**2395.44**	**3058.61**	**154.39**	**231.67**

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[2]: from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A28: Contents of microbial nitrogen (N_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		N_{mic} [µg g^{-1} dw]							
		L(Oi)		**F(Oe)**		**H(Oa)**		**0-10 cm**	
Sampling		**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	**mean**	**762.93**	**788.26**	**397.96**	**455.94**	**125.19**	**179.78**	**5.35**	**13.83**
	SD	± 250.21	± 54.80	± 120.22	± 135.13	± 27.75	± 73.39	± 4.47	± 4.24
Jan-02	**mean**	**811.17**	**1175.77**	**289.72**	**370.38**	**173.82**	**823.07**	**3.86**	**16.77**
	SD	± 198.23	± 131.93	± 51.14	± 82.72	± 50.00	± 183.83	± 11.11	± 14.86
Mar 02	**mean**	**581.56**	**737.52**	**244.80**	**399.99**	**70.16**	**190.24**	**5.16**	**5.54**
	SD	± 147.32	± 143.01	± 99.34	± 58.22	± 42.10	± 36.49	± 2.79	± 1.69
May 02	**mean**	**683.54**	**472.37**	**190.09**	**296.65**	**104.08**	**105.08**	**4.78**	**9.54**
	SD	± 231.35	± 80.55	± 36.41	± 93.42	± 33.26	± 14.11	± 1.51	± 2.29
Jul-02	**mean**	**883.20**	**624.73**	**167.39**	**264.77**	**96.20**	**100.08**	**4.86**	**10.39**
	SD	± 206.05	± 78.92	± 32.60	± 49.05	± 23.76	± 18.47	± 2.73	± 3.59
Sep-02	**mean**	**1082.87**	**777.09**	**144.68**	**232.88**	**88.33**	**95.07**	**4.94**	**11.24**
	SD	± 272.67	± 127.84	± 39.17	± 55.27	± 42.66	± 25.90	± 4.40	± 5.18
Oct 02	**mean**	**580.33**	**902.39**	**215.18**	**336.76**	**101.40**	**151.56**	**5.56**	**5.30**
	SD	± 135.74	± 156.85	± 20.13	± 40.81	± 9.91	± 26.81	± 2.72	± 5.92
Nov-02	**mean**	**398.39**	**855.28**	**160.79**	**236.68**	**83.49**	**126.06**	**3.91**	**4.09**
	SD	± 149.20	± 451.80	± 45.48	± 15.17	± 50.97	± 16.16	± 1.76	± 1.49
Mean of the year^{2}		**723.00**	**791.68**	**226.33**	**324.26**	**105.33**	**221.37**	**4.80**	**9.59**

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[2]: from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A29: Contents of hot-water-extractable C (C_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		C_{hwe} [µg g^{-1} dw]							
		L(Oi)		**F(Oe)**		**H(Oa)**		**0-10 cm**	
Sampling		**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	**mean**	**13060.03**	**11494.88**	**9793.70**	**8871.32**	**5557.38**	**6422.02**	**1877.37**	**2326.57**
	SD	± 2688.96	± 1742.84	± 2142.80	± 2360.46	± 1208.74	± 1408.21	± 435.36	± 110.83
Jan-02	**mean**	**12957.52**	**11172.08**	**9254.83**	**7734.32**	**6176.58**	**5614.48**	**1281.22**	**1799.25**
	SD	± 1070.62	± 832.32	± 2088.56	± 1210.26	± 857.27	± 1157.33	± 378.79	± 271.74
Mar 02	**mean**	**8369.97**	**6792.88**	**5743.82**	**6291.95**	**3193.63**	**3562.28**	**1279.97**	**1110.05**
	SD	± 2239.33	± 878.31	± 1069.93	± 840.77	± 720.25	± 781.19	± 164.06	± 268.99
May 02	**mean**	**17829.12**	**14269.53**	**6658.88**	**8693.68**	**4647.70**	**4399.90**	**1145.33**	**1592.53**
	SD	± 2293.11	± 1682.77	± 2277.48	± 1859.46	± 1496.78	± 1154.06	± 229.02	± 452.43
Jul-02	**mean**	**21121.16**	**15961.53**	**11126.80**	**11862.48**	**6367.36**	**5729.55**	**1262.65**	**1726.87**
	SD	± 1544.83	± 1510.70	± 1707.02	± 1878.54	± 1837.14	± 1507.39	± 260.77	± 324.34
Sep-02	**mean**	**24413.20**	**17653.53**	**15594.72**	**15031.27**	**8087.02**	**7059.20**	**1379.97**	**1861.20**
	SD	± 2219.12	± 1815.24	± 1651.85	± 3374.67	± 3126.32	± 2048.10	± 352.54	± 310.98
Oct 02	**mean**	**19790.95**	**18379.90**	**18625.05**	**16173.48**	**8003.75**	**8437.62**	**1458.45**	**1422.85**
	SD	± 8525.81	± 2480.88	± 2595.25	± 2310.05	± 1151.16	± 1308.12	± 318.48	± 264.43
Nov-02	**mean**	**28235.67**	**28471.47**	**22917.00**	**15951.50**	**10397.83**	**11059.23**	**878.08**	**1260.53**
	SD	± 3315.42	± 14861.48	± 6812.94	± 2588.13	± 6105.90	± 1553.77	± 303.10	± 299.49
Mean of the year[2]		**18222.20**	**15524.48**	**12464.35**	**11326.25**	**6553.91**	**6535.54**	**1320.38**	**1637.48**

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[2] from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A30: Contents of cold-water-extractable C (C_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		C_{cwe} [µg g^{-1} dw]							
		L(Oi)		F(Oe)		H(Oa)		0-10 cm	
Sampling		**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	**mean**	**10035.87**	**9444.38**	**5196.30**	**2708.38**	**1218.30**	**1574.68**	**356.48**	**427.23**
	SD	± 2750.81	± 3698.26	± 1380.24	± 872.40	± 211.06	± 631.43	± 147.08	± 110.84
Jan-02	**mean**	**8172.78**	**6717.08**	**4157.22**	**3004.48**	**2310.80**	**1732.80**	**329.65**	**379.13**
	SD	± 1021.03	± 818.51	± 1171.19	± 511.29	± 400.80	± 320.97	± 61.98	± 120.83
Mar 02	**mean**	**4415.22**	**3554.80**	**3580.50**	**4612.08**	**1503.02**	**2385.25**	**217.70**	**202.80**
	SD	± 944.50	± 719.16	± 1132.28	± 1498.01	± 750.68	± 526.37	± 28.59	± 80.47
May 02	**mean**	**8614.13**	**7680.43**	**4087.20**	**3287.25**	**2027.55**	**1630.32**	**153.30**	**262.65**
	SD	± 1785.59	± 1064.15	± 1232.12	± 543.28	± 534.65	± 433.94	± 20.35	± 92.06
Jul-02	**mean**	**10454.51**	**7967.15**	**4305.67**	**3322.68**	**1888.83**	**1568.02**	**233.96**	**288.55**
	SD	± 1327.47	± 843.67	± 965.66	± 391.85	± 333.79	± 398.49	± 49.58	± 86.20
Sep-02	**mean**	**12294.88**	**8253.87**	**4524.13**	**3358.10**	**1750.10**	**1505.72**	**314.62**	**314.45**
	SD	± 1212.27	± 1726.52	± 933.37	± 495.21	± 491.81	± 387.43	± 91.97	± 81.81
Oct 02	**mean**	**9247.57**	**7179.83**	**3649.32**	**3578.78**	**1381.77**	**1721.38**	**215.18**	**222.48**
	SD	± 553.99	± 1252.28	± 686.35	± 385.37	± 200.00	± 333.58	± 114.15	± 110.28
Nov-02	**mean**	**8148.17**	**7193.08**	**3012.73**	**2440.92**	**1367.62**	**1286.77**	**250.28**	**223.00**
	SD	± 1070.07	± 2977.86	± 984.78	± 314.17	± 684.53	± 130.86	± 154.88	± 67.54
Mean of the year[2]		**8922.89**	**7248.83**	**4064.13**	**3289.08**	**1681.00**	**1675.62**	**258.90**	**290.04**

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[2] from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A31: Contents of water-soluble organic carbon (WSOC) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		WSOC [µg g^{-1} dw]							
		L(Oi)		F(Oe)		H(Oa)		0-10 cm	
Sampling		**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	**mean**	**3217.35**	**4321.53**	**1733.13**	**1285.92**	**674.87**	**658.22**	**153.28**	**137.98**
	SD	± 947.27	± 2191.43	± 374.26	± 464.17	± 160.99	± 236.70	± 52.67	± 52.41
Jan-02	**mean**	**3181.08**	**2881.17**	**1690.00**	**1446.10**	**1110.67**	**858.47**	**108.10**	**187.83**
	SD	± 984.56	± 364.97	± 373.33	± 229.47	± 211.99	± 183.84	± 23.11	± 54.37
Mar 02	**mean**	**5175.60**	**4865.25**	**1990.18**	**2583.00**	**804.55**	**1349.15**	**135.78**	**150.53**
	SD	± 1952.62	± 1364.86	± 806.71	± 556.03	± 416.24	± 323.33	± 15.84	± 36.84
May 02	**mean**	**3387.40**	**2990.73**	**1347.37**	**1766.95**	**865.05**	**784.73**	**99.18**	**129.27**
	SD	± 1074.20	± 464.50	± 344.49	± 380.00	± 225.27	± 229.25	± 9.51	± 33.14
Jul-02	**mean**	**4703.81**	**3728.81**	**1719.34**	**2129.60**	**929.31**	**1035.65**	**143.85**	**155.37**
	SD	± 977.43	± 527.17	± 246.21	± 344.89	± 204.83	± 264.28	± 36.96	± 30.67
Sep-02	**mean**	**6020.22**	**4466.88**	**2091.32**	**2492.25**	**993.57**	**1286.57**	**188.52**	**181.47**
	SD	± 1296.94	± 898.95	± 191.50	± 475.18	± 298.74	± 317.80	± 69.87	± 35.67
Oct 02	**mean**	**3869.32**	**4008.00**	**2100.02**	**1948.00**	**925.92**	**723.13**	**132.55**	**128.33**
	SD	± 582.13	± 776.96	± 320.11	± 902.23	± 164.82	± 219.31	± 38.78	± 25.32
Nov-02	**mean**	**5146.37**	**6313.12**	**2505.83**	**1656.70**	**1400.47**	**952.72**	**103.53**	**79.45**
	SD	± 1229.97	± 2755.73	± 844.71	± 215.07	± 632.18	± 129.70	± 24.19	± 20.40
Mean of the year[2]		**4337.64**	**4196.94**	**1897.15**	**1913.56**	**963.05**	**956.08**	**133.10**	**143.78**

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[2] from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A32: Contents of hot-water-extractable N (N_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		N_{hwe} [µg g^{-1} dw]							
		L(Oi)		F(Oe)		H(Oa)		0-10 cm	
Sampling		**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	**mean**	**1503.38**	**1341.12**	**1049.47**	**1115.37**	**392.75**	**546.02**	**76.03**	**101.77**
	SD	± 398.64	± 139.27	± 190.38	± 254.85	± 79.52	± 179.14	± 19.21	± 7.40
Jan-02	**mean**	**1518.08**	**1422.88**	**1101.27**	**1031.08**	**656.75**	**645.43**	**47.67**	**103.65**
	SD	± 233.92	± 161.35	± 240.87	± 139.48	± 89.70	± 159.82	± 12.06	± 40.76
Mar 02	**mean**	**1294.37**	**1361.62**	**1152.30**	**1428.95**	**431.90**	**623.50**	**48.55**	**43.45**
	SD	± 275.48	± 191.66	± 244.57	± 182.87	± 243.99	± 89.34	± 6.54	± 9.68
May 02	**mean**	**1639.07**	**1458.52**	**1135.87**	**1325.45**	**569.15**	**591.60**	**44.07**	**83.55**
	SD	± 298.43	± 234.08	± 304.64	± 136.38	± 191.07	± 86.66	± 11.52	± 19.45
Jul-02	**mean**	**1785.68**	**1776.49**	**1181.96**	**1288.79**	**557.32**	**528.44**	**50.55**	**83.03**
	SD	± 314.65	± 99.98	± 187.31	± 136.58	± 164.85	± 86.13	± 13.42	± 16.50
Sep-02	**mean**	**1932.28**	**2094.47**	**1228.05**	**1252.13**	**545.48**	**465.28**	**57.03**	**82.52**
	SD	± 358.17	± 239.56	± 153.62	± 275.12	± 228.24	± 102.02	± 17.63	± 21.34
Oct 02	**mean**	**1975.17**	**2167.65**	**1312.52**	**1359.72**	**485.92**	**557.15**	**53.43**	**66.47**
	SD	± 323.72	± 195.75	± 145.28	± 219.83	± 56.94	± 58.19	± 13.50	± 22.02
Nov-02	**mean**	**1034.00**	**1373.53**	**999.18**	**972.85**	**425.73**	**522.35**	**27.88**	**50.95**
	SD	± 117.06	± 710.80	± 261.38	± 114.91	± 247.04	± 61.75	± 10.06	± 10.81
Mean of the year[2]		**1585.25**	**1624.53**	**1145.08**	**1221.79**	**508.13**	**559.97**	**50.65**	**76.92**

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[2]: from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A33: Contents of cold-water-extractable N (N_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		N_{cwe} [µg g^{-1} dw]							
		L(Oi)		**F(Oe)**		**H(Oa)**		**0-10 cm**	
Sampling		**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	**mean**	**673.47**	**631.42**	**362.60**	**259.17**	**79.12**	**98.22**	**18.73**	**22.42**
	SD	± 225.15	± 90.17	± 90.84	± 77.12	± 15.27	± 38.07	± 7.49	± 6.46
Jan-02	**mean**	**1106.67**	**677.43**	**333.57**	**277.37**	**142.85**	**117.73**	**21.12**	**25.77**
	SD	± 264.42	± 83.93	± 99.92	± 30.26	± 29.93	± 21.50	± 3.61	± 9.16
Mar 02	**mean**	**747.43**	**1009.58**	**419.62**	**607.57**	**124.88**	**203.60**	**13.02**	**12.28**
	SD	± 130.32	± 196.22	± 146.36	± 145.76	± 72.86	± 33.51	± 2.90	± 3.28
May 02	**mean**	**920.20**	**850.75**	**490.05**	**550.63**	**186.95**	**152.72**	**11.43**	**20.63**
	SD	± 216.02	± 123.44	± 161.71	± 68.08	± 74.91	± 18.02	± 4.91	± 5.22
Jul-02	**mean**	**935.08**	**1014.07**	**465.73**	**464.81**	**167.04**	**129.63**	**13.88**	**19.79**
	SD	± 158.72	± 93.89	± 102.31	± 31.43	± 51.12	± 20.33	± 3.61	± 5.23
Sep-02	**mean**	**949.95**	**1177.38**	**441.40**	**378.98**	**147.13**	**106.55**	**16.33**	**18.95**
	SD	± 107.32	± 209.83	± 76.37	± 73.56	± 54.20	± 25.47	± 4.08	± 5.53
Oct 02	**mean**	**715.18**	**857.10**	**461.08**	**350.93**	**128.52**	**104.23**	**21.25**	**15.25**
	SD	± 182.93	± 114.89	± 31.91	± 85.10	± 18.03	± 18.63	± 15.25	± 6.87
Nov-02	**mean**	**468.73**	**402.37**	**280.00**	**267.28**	**105.53**	**93.20**	**13.40**	**14.18**
	SD	± 57.93	± 172.38	± 87.02	± 34.68	± 50.01	± 12.27	± 6.07	± 4.83
Mean of the year[2]		814.59	827.51	406.76	394.59	135.25	125.74	16.15	18.66

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[2]: from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A34: Absolut potential C mineralisation in the organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		Potential C mineralisation [kg ha^{-1} d^{-1})							
Sampling		**L(Oi)**		**F(Oe)**		**H(Oa)**		**0-10 cm**	
		Pine	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	mean	**26.41**	**70.12**	**18.01**	**26.02**	**12.95**	**25.20**	**23.78**	**12.89**
	SD	± 4.16	± 14.91	± 1.23	± 2.72	± 2.99	± 9.84	± 13.58	± 3.07
Jan-02	mean	**26.71**	**38.72**	**22.06**	**23.82**	**16.19**	**19.71**	**10.21**	**23.86**
	SD	± 5.67	± 5.08	± 5.26	± 6.85	± 4.12	± 9.65	± 8.80	± 11.91
Mar 02	mean	**74.27**	**54.63**	**21.34**	**26.93**	**14.33**	**20.27**	**15.96**	**14.48**
	SD	± 17.88	± 5.72	± 7.98	± 8.40	± 5.35	± 3.30	± 3.98	± 6.24
May 02	mean	**39.35**	**34.52**	**22.07**	**29.00**	**7.17**	**10.66**	**17.46**	**11.52**
	SD	± 9.65	± 5.22	± 4.82	± 7.79	± 2.50	± 1.57	± 7.37	± 4.21
Jul-02	mean	**35.11**	**25.77**	**14.74**	**22.47**	**3.51**	**6.78**	**14.88**	**12.80**
	SD	± 15.75	± 7.30	± 2.31	± 3.09	± 1.67	± 2.38	± 4.73	± 7.10
Sep-02	mean	**54.80**	**32.53**	**27.51**	**34.03**	**9.15**	**9.32**	**14.26**	**23.73**
	SD	± 14.60	± 8.99	± 4.93	± 7.84	± 3.35	± 1.95	± 7.07	± 8.13
Oct 02	mean	**74.22**	**68.52**	**19.62**	**26.93**	**5.33**	**9.02**	**13.18**	**9.04**
	SD	± 22.79	± 8.40	± 3.04	± 3.62	± 0.78	± 2.19	± 4.86	± 5.95
Nov-02	mean	**67.38**	**66.76**	**21.17**	**29.16**	**7.99**	**13.22**	**5.81**	**2.70**
	SD	± 17.61	± 5.99	± 2.84	± 3.78	± 3.93	± 4.04	± 4.31	± 2.45
Mean of the year[2]		**49.78**	**48.95**	**20.82**	**27.30**	**9.58**	**14.27**	**14.44**	**13.88**

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[2] from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A35: Stocks of microbial biomass (C_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		C_{mic} [kg h^{-1}]							
Sampling		**L(Oi)**		**F(Oe)**		**H(Oa)**		**0-10 cm**	
		Pine	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	mean	**101.61**	**126.04**	**231.27**	**264.06**	**84.60**	**239.02**	**153.51**	**237.18**
	SD	± 27.62	± 18.73	± 69.20	± 68.82	± 18.05	± 84.91	± 41.49	± 50.64
Jan-02	mean	**179.16**	**230.82**	**387.46**	**253.01**	**255.45**	**357.30**	**68.69**	**371.77**
	SD	± 31.72	± 18.00	± 72.46	± 54.22	± 32.96	± 73.03	± 38.07	± 275.06
Mar 02	mean	**263.68**	**283.83**	**399.33**	**377.13**	**150.14**	**387.48**	**182.35**	**207.48**
	SD	± 63.65	± 42.28	± 114.37	± 56.09	± 79.24	± 53.40	± 75.25	± 58.08
May 02	mean	**250.86**	**253.15**	**266.01**	**276.53**	**183.68**	**296.68**	**245.66**	**347.64**
	SD	± 84.22	± 51.00	± 51.15	± 31.66	± 45.33	± 54.33	± 61.47	± 74.88
Jul-02	mean	**364.08**	**262.40**	**292.60**	**288.14**	**181.93**	**288.99**	**214.41**	**390.39**
	SD	± 66.54	± 40.63	± 50.54	± 33.11	± 40.17	± 65.74	± 79.78	± 118.61
Sep-02	mean	**477.30**	**271.65**	**319.19**	**299.74**	**180.18**	**281.31**	**183.16**	**433.13**
	SD	± 109.83	± 47.57	± 61.32	± 73.24	± 79.51	± 85.69	± 115.25	± 178.41
Oct 02	mean	**222.05**	**277.51**	**345.44**	**346.54**	**188.00**	**368.66**	**140.55**	**242.45**
	SD	± 24.67	± 48.07	± 32.12	± 28.66	± 26.84	± 42.88	± 64.22	± 163.06
Nov-02	mean	**171.24**	**299.29**	**324.06**	**293.98**	**168.04**	**316.00**	**129.58**	**266.11**
	SD	± 31.06	± 140.54	± 88.94	± 46.45	± 82.28	± 34.85	± 76.08	± 63.02
Mean of the year[2]		**253.75**	**250.59**	**320.67**	**299.89**	**174.00**	**316.93**	**164.74**	**312.02**

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[2]: from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A36: Stocks of microbial nitrogen (N_{mic}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		N_{mic} [kg ha^{-1}]							
Sampling		**L(Oi)**		**F(Oe)**		**H(Oa)**		**0-10 cm**	
		Pine	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	mean	**10.53**	**10.75**	**27.54**	**24.93**	**9.09**	**18.63**	**5.71**	**18.62**
	SD	± 3.45	± 0.75	± 8.32	± 7.39	± 2.02	± 7.60	± 4.76	± 5.72
Jan-02	mean	**11.19**	**16.04**	**20.05**	**17.92**	**12.63**	**85.29**	**412.14**	**22.58**
	SD	± 2.74	± 1.80	± 3.54	± 4.00	± 3.63	± 19.05	± 118.55	± 20.02
Mar 02	mean	**8.02**	**10.06**	**16.94**	**21.87**	**5.10**	**19.71**	**5.51**	**7.46**
	SD	± 2.03	± 1.95	± 6.88	± 3.18	± 3.06	± 3.78	± 2.98	± 2.28
May 02	mean	**9.43**	**6.44**	**13.16**	**16.22**	**7.56**	**10.89**	**5.10**	**12.85**
	SD	± 3.19	± 1.10	± 2.52	± 5.11	± 2.42	± 1.46	± 1.61	± 3.08
Jul-02	mean	**12.19**	**8.52**	**11.58**	**14.48**	**6.99**	**10.37**	**5.19**	**14.00**
	SD	± 2.84	± 1.08	± 2.26	± 2.68	± 1.73	± 1.91	± 2.91	± 4.84
Sep-02	mean	**14.94**	**10.60**	**10.01**	**12.73**	**6.42**	**9.85**	**5.27**	**15.14**
	SD	± 3.76	± 1.74	± 2.71	± 3.02	± 3.10	± 2.68	± 4.69	± 6.98
Oct 02	mean	**8.01**	**12.31**	**14.89**	**18.41**	**7.37**	**15.70**	**5.93**	**7.14**
	SD	± 1.87	± 2.14	± 1.39	± 2.23	± 0.72	± 2.78	± 2.90	± 7.97
Nov-02	mean	**5.50**	**11.67**	**11.13**	**12.94**	**6.06**	**13.06**	**4.18**	**5.50**
	SD	± 2.06	± 6.16	± 3.15	± 0.83	± 3.70	± 1.67	± 1.88	± 2.01
Mean of the year^2		**9.98**	**10.80**	**15.66**	**17.44**	**7.65**	**22.94**	**56.13**	**12.91**

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[2]: from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A37: Stocks of hot-water-extractable C (C_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		C_{hwe} [kg ha^{-1}]							
Sampling		**L(Oi)**		**F(Oe)**		**H(Oa)**		**0-10 cm**	
		Pine	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	mean	**180.20**	**156.81**	**677.82**	**485.09**	**403.69**	**665.44**	**2003.15**	**3133.42**
	SD	± 37.10	± 23.77	± 148.30	± 129.07	± 87.80	± 145.92	± 464.53	± 149.27
Jan-02	mean	**178.78**	**152.40**	**640.53**	**374.11**	**448.66**	**581.77**	**1367.06**	**2423.23**
	SD	± 14.77	± 11.35	± 144.55	± 58.54	± 62.27	± 119.92	± 404.17	± 365.97
Mar 02	mean	**115.49**	**92.66**	**397.53**	**344.05**	**231.98**	**369.12**	**1365.72**	**1495.02**
	SD	± 30.90	± 11.98	± 74.05	± 45.97	± 52.32	± 80.95	± 175.05	± 362.28
May 02	mean	**246.00**	**194.66**	**460.86**	**475.38**	**337.61**	**455.91**	**1222.07**	**2144.82**
	SD	± 31.64	± 22.96	± 157.62	± 101.68	± 108.73	± 119.58	± 244.37	± 609.33
Jul-02	mean	**291.42**	**217.74**	**770.09**	**648.65**	**462.52**	**593.69**	**1347.25**	**2325.74**
	SD	± 21.32	± 20.61	± 118.14	± 102.72	± 133.45	± 156.19	± 278.24	± 436.83
Sep-02	mean	**336.85**	**240.82**	**1079.31**	**821.92**	**587.44**	**731.47**	**1472.42**	**2506.66**
	SD	± 30.62	± 24.76	± 114.32	± 184.53	± 227.09	± 212.22	± 376.16	± 418.83
Oct 02	mean	**273.07**	**250.73**	**1289.04**	**884.37**	**581.39**	**874.30**	**1556.17**	**1916.29**
	SD	± 117.64	± 33.84	± 179.62	± 126.31	± 83.62	± 135.55	± 339.81	± 356.14
Nov-02	mean	**389.59**	**388.39**	**1586.09**	**872.24**	**755.30**	**1145.94**	**936.91**	**1697.69**
	SD	± 45.75	± 202.73	± 471.52	± 141.52	± 443.53	± 161.00	± 323.41	± 403.36
Mean of the year[2]		**251.42**	**211.78**	**862.66**	**613.22**	**476.07**	**677.20**	**1408.84**	**2205.36**

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[2]: from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A38: Stocks of cold-water-extractable C (C_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		C_{cwe} [kg ha^{-1}]							
Sampling		**L(Oi)**		**F(Oe)**		**H(Oa)**		**0-10 cm**	
		Pine	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	mean	**138.47**	**128.83**	**359.64**	**148.10**	**88.50**	**163.17**	**380.37**	**575.40**
	SD	± 37.95	± 50.45	± 95.53	± 47.70	± 15.33	± 65.43	± 156.94	± 149.27
Jan-02	mean	**112.77**	**91.63**	**287.72**	**145.33**	**167.86**	**179.55**	**351.74**	**510.62**
	SD	± 14.09	± 11.17	± 81.06	± 24.73	± 29.11	± 33.26	± 66.14	± 162.74
Mar 02	mean	**60.92**	**48.49**	**247.81**	**252.19**	**109.18**	**247.16**	**232.29**	**273.13**
	SD	± 13.03	± 9.81	± 78.37	± 81.91	± 54.53	± 54.54	± 30.51	± 108.37
May 02	mean	**118.86**	**104.77**	**282.88**	**179.75**	**147.28**	**168.93**	**163.57**	**353.74**
	SD	± 24.64	± 14.52	± 85.28	± 29.71	± 38.84	± 44.96	± 21.71	± 123.99
Jul-02	mean	**144.25**	**108.68**	**298.00**	**181.69**	**137.20**	**162.48**	**249.63**	**388.62**
	SD	± 18.32	± 11.51	± 66.83	± 21.43	± 24.25	± 41.29	± 52.90	± 116.09
Sep-02	mean	**169.64**	**112.59**	**313.12**	**183.62**	**127.13**	**156.02**	**335.70**	**423.50**
	SD	± 16.73	± 23.55	± 64.60	± 27.08	± 35.73	± 40.14	± 98.13	± 110.18
Oct 02	mean	**127.59**	**97.94**	**252.57**	**195.69**	**100.37**	**178.37**	**229.60**	**299.64**
	SD	± 7.64	± 17.08	± 47.50	± 21.07	± 14.53	± 34.57	± 121.80	± 148.53
Nov-02	mean	**112.43**	**98.12**	**208.51**	**133.47**	**99.34**	**133.33**	**267.05**	**300.34**
	SD	± 14.76	± 40.62	± 68.16	± 17.18	± 49.72	± 13.56	± 165.25	± 90.96
Mean of the year[2]		**123.12**	**98.88**	**281.28**	**177.48**	**122.11**	**173.63**	**276.24**	**390.62**

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[2] : from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A39: Stocks of water-soluble organic carbon (WSOC) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		WSOC [kg ha^{-1}]							
Sampling		**L(Oi)**		**F(Oe)**		**H(Oa)**		**0-10 cm**	
		Pine	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	mean	**44.39**	**58.95**	**119.95**	**70.31**	**49.02**	**68.20**	**163.55**	**185.84**
	SD	± 13.07	± 29.89	± 25.90	± 25.38	± 11.69	± 24.53	± 56.20	± 70.59
Jan-02	mean	**43.89**	**39.30**	**116.97**	**69.95**	**80.68**	**88.95**	**115.34**	**252.97**
	SD	± 13.58	± 4.98	± 25.84	± 11.10	± 15.40	± 19.05	± 24.65	± 73.22
Mar 02	mean	**71.41**	**66.37**	**137.74**	**141.24**	**58.44**	**139.80**	**144.88**	**202.74**
	SD	± 26.94	± 18.62	± 55.83	± 30.40	± 30.24	± 33.50	± 16.90	± 49.61
May 02	mean	**46.74**	**40.80**	**93.25**	**96.62**	**62.84**	**81.31**	**105.83**	**174.10**
	SD	± 14.82	± 6.34	± 23.84	± 20.78	± 16.36	± 23.75	± 10.15	± 44.63
Jul-02	mean	**64.90**	**50.87**	**119.00**	**116.45**	**67.50**	**107.31**	**153.49**	**209.25**
	SD	± 13.49	± 7.19	± 17.04	± 18.86	± 14.88	± 27.38	± 39.44	± 41.31
Sep-02	mean	**83.07**	**60.93**	**144.74**	**136.28**	**72.17**	**133.31**	**201.15**	**244.40**
	SD	± 17.89	± 12.26	± 13.25	± 25.98	± 21.70	± 32.93	± 74.55	± 48.05
Oct 02	mean	**53.39**	**54.67**	**145.34**	**106.52**	**67.26**	**74.93**	**141.43**	**172.84**
	SD	± 8.03	± 10.60	± 22.15	± 49.33	± 11.97	± 22.72	± 41.37	± 34.10
Nov-02	mean	**71.01**	**86.12**	**173.43**	**90.59**	**101.73**	**98.72**	**110.47**	**107.00**
	SD	± 16.97	± 37.59	± 58.46	± 11.76	± 45.92	± 13.44	± 25.81	± 27.47
Mean of the year[2]		**59.85**	**57.25**	**131.30**	**103.49**	**69.96**	**99.07**	**142.02**	**193.64**

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[2] from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A40: Stocks of hot-water-extractable N (N_{hwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		N_{hwe} [kg ha^{-1}]							
Sampling		**L(Oi)**		**F(Oe)**		**H(Oa)**		**0-10 cm**	
		Pine	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	mean	**20.74**	**18.29**	**72.63**	**60.99**	**28.53**	**56.58**	**81.13**	**137.06**
	SD	± 5.50	± 1.90	± 13.18	± 13.94	± 5.78	± 18.56	± 20.50	± 9.97
Jan-02	mean	**20.95**	**19.41**	**76.22**	**49.87**	**47.71**	**66.88**	**50.86**	**139.60**
	SD	± 3.23	± 2.20	± 16.67	± 6.75	± 6.52	± 16.56	± 12.87	± 54.89
Mar 02	mean	**17.86**	**18.57**	**79.75**	**78.14**	**31.37**	**64.61**	**51.80**	**58.52**
	SD	± 3.80	± 2.61	± 16.93	± 10.00	± 17.72	± 9.26	± 6.97	± 13.04
May 02	mean	**22.62**	**19.90**	**78.61**	**72.48**	**41.34**	**61.30**	**47.02**	**112.53**
	SD	± 4.12	± 3.19	± 21.08	± 7.46	± 13.88	± 8.98	± 12.29	± 26.19
Jul-02	mean	**24.64**	**24.23**	**81.80**	**70.47**	**40.48**	**54.76**	**53.94**	**111.83**
	SD	± 4.34	± 1.36	± 12.96	± 7.47	± 11.97	± 8.92	± 14.32	± 22.22
Sep-02	mean	**26.66**	**28.57**	**84.99**	**68.47**	**39.62**	**48.21**	**60.85**	**111.13**
	SD	± 4.94	± 3.27	± 10.63	± 15.04	± 16.58	± 10.57	± 18.82	± 28.74
Oct 02	mean	**27.25**	**29.57**	**90.84**	**74.35**	**35.30**	**57.73**	**57.01**	**89.52**
	SD	± 4.47	± 2.67	± 10.06	± 12.02	± 4.14	± 6.03	± 14.40	± 29.65
Nov-02	mean	**14.27**	**18.74**	**69.15**	**53.20**	**30.93**	**54.13**	**29.75**	**68.62**
	SD	± 1.62	± 9.70	± 18.09	± 6.28	± 17.94	± 6.40	± 10.74	± 14.55
Mean of the year^{2}		**21.87**	**22.16**	**79.25**	**65.99**	**36.91**	**58.02**	**54.05**	**103.60**

[2:] from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A41: Stocks of cold-water-extractable N (N_{cwe}) in organic layers (L, F and H horizon) and mineral top soil (0-10 cm).
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by Koch, Weimann & Stuhlmann; analyses by I. Weimann).

		N_{cwe} [kg ha^{-1}]							
Sampling		**L(Oi)**		**F(Oe)**		**H(Oa)**		**0-10 cm**	
		Pine	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**	**Pine**	**Beech/Oak**
Nov-01	mean	**9.29**	**8.61**	**25.10**	**14.17**	**5.75**	**10.18**	**19.99**	**30.19**
	SD	± 3.11	± 1.23	± 6.29	± 4.22	± 1.11	± 3.94	± 7.99	± 8.70
Jan-02	mean	**15.27**	**9.24**	**23.09**	**13.42**	**10.38**	**12.20**	**22.53**	**34.70**
	SD	± 3.65	± 1.14	± 6.92	± 1.46	± 2.17	± 2.23	± 3.85	± 12.33
Mar 02	mean	**10.31**	**13.77**	**29.04**	**33.22**	**9.07**	**21.10**	**13.89**	**16.54**
	SD	± 1.80	± 2.68	± 10.13	± 7.97	± 5.29	± 3.47	± 3.10	± 4.42
May 02	mean	**12.70**	**11.61**	**33.92**	**30.11**	**13.58**	**15.82**	**12.20**	**27.79**
	SD	± 2.98	± 1.68	± 11.19	± 3.72	± 5.44	± 1.87	± 5.24	± 7.03
Jul-02	mean	**12.90**	**13.83**	**32.23**	**25.42**	**12.13**	**13.43**	**14.81**	**26.66**
	SD	± 2.19	± 1.28	± 7.08	± 1.72	± 3.71	± 2.11	± 3.85	± 7.04
Sep-02	mean	**13.11**	**16.06**	**30.55**	**20.72**	**10.69**	**11.04**	**17.43**	**25.52**
	SD	± 1.48	± 2.86	± 5.29	± 4.02	± 3.94	± 2.64	± 4.35	± 7.45
Oct 02	mean	**9.87**	**11.69**	**31.91**	**19.19**	**9.34**	**10.80**	**22.67**	**20.54**
	SD	± 2.52	± 1.57	± 2.21	± 4.65	± 1.31	± 1.93	± 16.28	± 9.25
Nov-02	mean	**6.47**	**5.49**	**19.38**	**14.62**	**7.67**	**9.66**	**14.30**	**19.10**
	SD	± 0.80	± 2.35	± 6.02	± 1.90	± 3.63	± 1.27	± 6.48	± 6.51
Mean of the year[2]		**11.24**	**11.29**	**28.15**	**21.36**	**9.82**	**13.03**	**17.23**	**25.13**

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[2] from litter shed in November 2001 to some days before the main litter shed event in November 2002.

Table A 42: Amount of litter between fall 2001 and fall 2002.
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 by J. Koch & Chr. Stuhlmann; analyses by I. Weimann)

	Scots Pine			European Beech/Common Oak		
Months	**Needles**	**Seeds**	**Twigs**	**Leaves**	**Seeds**	**Twigs**
		(g 1.5 m^{-2})			(g 1.5 m^{-2})	
Oct 01	74.87	4.74	0.61	69.85	145.62	9.46
	± 4.82	± 1.94	± 0.16	± 1.44	± 7.05	± 1.97
Nov-01	33.20	0.00	2.63	101.50	45.70	4.10
	± 1.70	± 0.00	± 0.41	± 7.59	± 4.00	± 0.91
Jan-02	27.20	11.10	12.30	109.20	60.80	47.00
	± 0.49	± 4.53	± 1.63	± 3.57	± 2.89	± 3.43
Mar 02	32.39	13.80	31.57	1.17	15.58	46.96
	± 1.26	± 3.33	± 5.38	± 0.31	± 1.44	± 10.95
May 02	13.30	12.80	47.00	7.70	2.30	0.90
	± 0.38	± 3.61	± 17.09	± 0.20	± 0.72	± 0.18
Jul 02	56.70	92.54	9.21	31.22	7.98	16.68
	± 1.11	± 9.83	± 1.23	± 2.82	± 1.08	± 6.09
Sep 02	70.85	11.80	23.50	16.70	5.60	14.30
	± 1.73	± 3.16	± 0.87	± 0.66	± 1.13	± 2.16
Oct 02	162.00	6.80	3.10	157.90	8.00	12.00
	± 4.99	± 2.78	± 0.26	± 6.72	± 1.94	± 2.22
Total [g 1.5 m^{-2} a^{-1}]	**470.51**	**153.58**	**129.92**	**495.24**	**291.58**	**151.40**
	Pine			**Beech/Oak**		
Total litter [t ha^{-1} a^{-1}]	**=**	**5.03**		**=**	**6.25**	
Leaf/Needle	**Pine**			**Beech/Oak**		
litter [t ha^{-1} a^{-1}]	**=**	**3.14**		**=**	**3.30**	

Table A 43: Litter decomposition: remaining litter (%) and litter decay rate constant “*k*”.
(The decay rate constant “*k*” is the exponent of the experimental function that describes the loss of leaf litter from litter bags over time.)
(soil sampling in *Falkenberg* in November 2001,January 2001, March, May, July, September, October and November 2002 and data processing by Chr. Stuhlmann & J. Koch)

Litter	Sampling	Date	Days of Exposition	Y_0 (%)	Y_t (%)	Y_t / Y_0	k (a^{-1})
Pine	11/01	23.11.01	0	100	100.00	1.00	#
	01/02	15.01.02	53		86.65	1.15	0.99
	03/02	17.03.02	115		83.21	1.20	0.58
	05/02	06.05.02	165		80.18	1.25	0.49
	07/02	02.07.02	222		65.01	1.54	0.71
	09/02	05.09.02	287		59.79	1.67	0.65
	11/02	19.11.02	**362**		58.76	1.70	***0.54***
Beech/Oak	11/01	23.11.01	0	100	100.00	1.00	#
	01/02	15.01.02	53		95.6203094	1.05	0.31
	03/02	17.03.02	115		92.1314216	1.09	0.26
	05/02	06.05.02	165		89.5293259	1.12	0.24
	07/02	02.07.02	222		78.966263	1.27	0.39
	09/02	05.09.02	287		72.6611678	1.38	0.41
	11/02	19.11.02	**362**		72.2294654	1.38	***0.33***
Reference litter (beech/oak in pine stand)	11/01	23.11.01	0	100	100	1.00	#
	01/02	15.01.02	53		94.5077007	1.06	0.39
	03/02	17.03.02	115		87.2137687	1.15	0.43
	05/02	06.05.02	165		85.8062349	1.17	0.34
	07/02	02.07.02	222		77.5187513	1.29	0.42
	09/02	05.09.02	287		71.8182511	1.39	0.42
	11/02	19.11.02	**362**		71.3820078	1.40	***0.34***

Erklärung

Hiermit versichere ich, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebener Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als diese kenntlich gemacht worden. Bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts habe ich Unterstützungsleistungen von folgenden Personen erhalten: Dr. Falk Liebner (Institut für Pflanzen- und Holzchemie der Fakultät FGH, TU Dresden) zur Auswertung der Pyrolyseergebnisse und Erstellung der Abb. 6.2, 6.3 und 6.4. (Dies geht aus dem Vorwort der Arbeit hervor und ist an den entsprechenden Abbildungsbeschriftungen kenntlich gemacht worden.)

Weitere Personen waren an der geistigen Herstellung der vorliegenden Arbeit nicht beteiligt. Insbesondere habe ich nicht die Hilfe eines oder mehrer Promotionsberater(s) in Anspruch genommen. Dritte haben von mir weder unmittelbar noch mittelbar geldwerte Leistungen für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen.

Die Arbeit wurde bisher weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde zum Zwecke der Promotion vorgelegt.

Ich bestätige, dass ich die Promotionsordnung der Fakultät Forst-, Geo- und Hydrowissenschaften der TU Dresden anerkenne.

Dessau, 15.12.2005

Juliane Koch