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Soil Properties and Nutrient Dynamics of *Quercus* Dominated Forests in North-East Austria

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Declaration

I, the undersigned, hereby declare to the University of Natural Resources and Life Sciences, Vienna (BOKU) that this is my original research work and all sources of materials used are duly acknowledged. This work has not been submitted to any other educational institution for any achieving academic degree awards.

Name: Shuai Yan

Signature:

Please and date: Vienna, January 2013

Abstract (English)

After many decades of forestry directed primarily at timber production in North-East Austria, there is growing interest again in increasing utilization of forest biomass for energy. Concomitant information on soil properties and possible effects of increasing biomass extraction is lacking in this area. The nutrient demand of tree growth is predominantly met by uptake from the nutrient pool of the mineral soil. This study focuses on above-ground standing biomass nutrient status and soil properties in order to learn more on the temporal dynamics of plant nutrients in *Quercus* dominated forests. Nine permanent, *Quercus petraea* dominated, plots were selected for this study. Three soil types (according to WRB: Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) were considered representative for the study area and sampled. Each soil profile was divided into litter layer as well as geometric soil horizons of 0-5, 5-10, 10-20, 20-40 and 40-50 cm. This study (i) quantified above-ground biomass and nutrient pools of N, K, Ca, Mg, Na, Al, Fe Mn, P and S of this study area; (ii) determined litter and root biomass, soil acidity, soil bulk density, soil N and C; (iii) quantified exchangeable cations K, Ca, Mg, Na, Al, Fe, and Mn as well as CEC in the soils of this study area; (iv) calculated wood: bark ratio of *Quercus petraea*;(v) identified the effects of stand age on exchangeable cations. This study showed that the nutrient pools in the mineral soil are at present sufficient to increasing the harvesting of biomass for energy. Stand age had no significant influence on mineral nutrient levels in the soil. The levels of nutrients in particular exchangeable cations in this study areas are reasonably high and do not indicate the necessity for additional fertilization under current silvicultural practices.

Key words: *Quercus* forests; stand age; soil types; soil properties; nutrients; exchangeable cations; Austria

Abstract (Deutsch)

Nach vielen Jahrzehnten der Ausrichtung der Forstwirtschaft auf Qualitätsholzproduktion in Nord-Ost Österreich gibt es wieder ein wachsendes Interesse an Nutzung von Waldbiomasse zur Energieproduktion. In dieser Gegend mangelt es an umfassendem Wissen über Bodeneigenschaften und mögliche Effekte des verstärkten Biomasseentzuges. Der Nährstoffbedarf des Baumwachstums wird vorwiegend über die Aufnahme vom Nährstoffvorrat im Mineralboden gedeckt. Diese Studie ist auf den Nährstoffstatus der oberirdischen stehenden Biomasse und die Bodeneigenschaften fokussiert, um mehr über die zeitliche Dynamik der Pflanzennährstoffe in eichendominierten Wäldern zu erfahren. Neun permanente, eicheneichendominierte Untersuchungsflächen wurden für diese Studie ausgewählt. Drei Boden-Referenzgruppen (laut WRB: Eutric Cambisol, Calcic Chernozem und Haplic Luvisol) wurden für das Studiengebiet als repräsentativ angenommen und beprobt. Jedes Bodenprofil wurde in Auflage- und geometrische Bodenhorizonte von 0-5, 5-10, 10-20, 20-40 und 40-50 cm geteilt. Diese Studie (i) quantifiziert oberirdische Biomasse und die Nährstoffvorräte von N, K, Ca, Mg, Na, Al, Fe, Mn, P und S dieses Studiengebietes; (ii) erfasst Streu- und Wurzelbiomasse, Bodenazidität, Lagerungsdichte, Boden-N und C; (iii) quantifiziert austauschbare Kationen K, Ca, Mg, Na, Al, Fe und Mn sowie die KAK in den Böden des Studiengebietes; (iv) berechnet das Holz: Rinden-Verhältnis der Traubeneiche; (v) identifiziert den Einfluss des Bestandesalters auf die austauschbaren Kationen. Diese Studie zeigt, dass aus Sicht der aktuellen Nährstoffvorräte im Mineralboden keine Einwände bestehen, um die Nutzung von Biomasse zur Energiegewinnung zu intensivieren. Das Bestandesalter hatte keinen signifikanten Einfluss auf Mineralnährstoffstände im Boden. Der Stand der Nährstoffe, speziell der austauschbaren Kationen, ist in diesem Studiengebiet genügend hoch und weist nicht auf die Notwendigkeit einer zusätzlichen Düngung unter aktuellen waldbaulichen Maßnahmen hin.

Schlüsselwörter: Eichenwälder, Bestandesalter, Bodentypen, Bodeneigenschaften, Nährstoffe, Austauschbare Kationen, Österreich

Abstract (Chinese)

中文摘要

奥地利东北部的森林多年以来主要是作为木材来直接使用。随着人们对能源的需求，这一区域也越来越多地将森林再一次发展为生物能的原材料供应源。但这一区域对土壤的研究以及土壤性质对生物量收获的影响还有待深入地研究。树木生长所需要的营养成分主要通过植物对土壤矿物质的摄取和吸收。该研究面向地上植被的营养成分和土壤的性质，期待揭示更多栓皮栎林植被营养的动态循环。九块以无梗花栎为主要树种的样地被选为该研究的实验样地。该区域的代表性土壤类型为：艳色雏形土、钙质黑钙土和高活性淋溶土。我们对每类土壤类型分别进行采样。土壤剖面被分为腐殖层和0-5、5-10、10-20、20-40和40-50厘米的几何形土壤层面。该研究（i）定量评定了地面植被总生物量和地面植被氮、钾、钙、镁、钠、铝、铁和锰等营养库；(ii)确定了地面凋谢物、根生物量、土壤酸度、土壤容重以及土壤的氮和碳；(iii)定量评定了土壤可交换阳离子钾、钙、镁、钠、铝、铁和锰的总量及土壤阳离子交换量；(iv)通过模型模拟计算了无梗花栎的木质和树皮比率；(v)揭示了树龄对可交换阳离子的影响。该研究证明矿质土壤的当前营养库可以满足对能源需求增大而额外收获的生物量。树龄对土壤营养库没有显著地影响。土壤的营养库，特别是可交换阳离子在研究区域相当高。该研究不建议在当前的森林经营中额外施肥。

关键词：栓皮栎林、林龄、土壤类型、土壤性质、营养成分、可交换阳离子、奥地利

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1. Introduction

1.1. Background Information

Sustainable forest management has been the key element of Austrian forestry ever since overexploitation and imminent exhaustion of wood by the voracious demand of industrialization in the first half of the 19th century instigated the strict Austrian Federal Forest Law (AFFL) of 1852. At that time forest soils at large were heavily degraded by excessive non-wood biomass extraction such as litter raking, lopping or potash burning for the glass industry (Glatzel, 1991). When fossil fuels and mineral fertilizer came in use, forestry focused on the production of high quality timber in long rotation management and forest soils recovered over time. At present in the context of global climate change legislation Austrian and European Union rules aim at an increase in energetic use of biomass for local and regional thermal needs as well as for bio-fuels use in the transport sector. This project, funded by Austrian Federal Ministry of Agriculture, Forestry, Environment and Water management, investigates soil nutrient status of representative *Quercus* forests in North-East Austria.

During the last decade increased utilization of forest biomass for energy became a hot topic. As one of the six key thematic areas of scientific research and international collaboration, bio-energy had been pointed out at the recent IUFRO (Internal Union of Forest Research Organizations) World Congress Seoul Resolution in August 2010 (IUFRO, 2010). In Austria, large percentage of forest land, traditional utilization of biomass and people's desire to live in a sound environment have supported the positive development of bio-energy. Particularly there is growing interest in increased utilization of forest biomass for energy in North-East Austria.

Quercus is an important tree species for sustainable forestry with reasonable biomass productivity and high economic value in many European countries. Recent studies investigated the nutrients content in different parts of plants in several common European deciduous species (Andre and Ponette, 2003; Andre *et al.*, 2010). It was confirmed that in *Quercus* stands woody biomass of over-story vegetation was distributed in the following order: stem wood > live branch > stem bark > roots > foliage > dead branch > current twig (Son *et al.*, 2004). Concomitant information on soil properties in North-East Austria and possible effects of increasing biomass extraction is lacking.

Soil nutrient status is in principle linked with the growth of the above-ground biomass. Losses of plant nutrients exceeding the natural replenishment due to deposition and weathering will ultimately lead to declining growth rates. The nutrients demand which is determined by the growth of tree components is from the mineral soil nutrients pool. In even aged forest stands, nutrient uptake is a function of stand age. During early growth there is a distinct species effect whereas later nutrient uptake becomes a function of growth rate irrespective of species (Kadeba, 1991; Ranger *et al.*, 1995; Ranger, 1997; Ranger *et al.*, 2002; Peri *et al.*, 2006). Until canopy closure, substantial amounts of mineral nutrients are needed to build up the foliage and thin branch infrastructure. Once the canopy is closed, up to two thirds of the nutrients required for growth can be obtained by retranslocation from older or dying tissues, an efficient mechanism that leads to a reduction in the demands that are further reduced by the cycle through the litter layer (Miller, 1995). When the site specific leaf area index is reached, the net demand declines because biomass increment is predominantly wood with a much lower nutrient content than foliage and fine branches. During the later stages, before harvesting, mineral nutrients are increasingly recycled as leaf area stays constant or even declines and the wood-bark ratio gradually increases. Obviously nutritional problems are most likely accruing in the early fast growing period when the green crown is being constructed. Base on this the study hypotheses for this dissertation were formulated. As the timespan of decades needed for experiments by far exceeds the possibilities of doctoral research, the Chronosequence approach was used to get information on how the change of mineral nutrient demand during forest stand growth is reflected in soil nutrient status.

1.2. Study Hypotheses

The nutrient demand of tree growth is predominantly met by uptake from the nutrient pool of the soil. Based on the general assumption that stand age and silvicultural interventions affect the soil properties due to incorporation of nutrients in the plant biomass, the hypotheses to test in this study were:

1) plant uptake causes nutrient and exchangeable cations depletion during the rapid growing period (up to 40 years) in contrast to the stable growing period (41-80 years) within the same soil type and similar forest species composition;
2) forest soil in the mature and senescing period (>81 years) hold the highest nutrients and exchangeable cation pools due to decreased plant uptake and increased forest litter decomposition;
3) due to large amount of nutrient absorption by fine roots in the shallow soil horizons, stand age may influence the nutrients and exchangeable cations in the top soil horizons (soil depth < 20 cm), but not in the deep soil horizons (soil depth > 20 cm);
4) nutrient contents and exchangeable cations in the forest soil differ among soil types and rank in following order: cambisol < luvisol < chernozem
5) the changing mineral nutrient demand during forest stand growth is reflected in soil nutrient status.

1.3. Research Objectives

Objectives of this study were:

1) classification of soil types under *Quercus* dominated deciduous forest in North-East Austria according to the international taxonomic standard WRB (FAO–ISRIC, 2006);

2) quantification of litter biomass, selected chemical and physical properties of mineral soils and selected nutrient pools in above-ground standing biomass;
3) identification of effects of stand age, soil type and soil horizons on soil properties (humus, soil acidity, bulk density, contents of soil nitrogen (N), soil carbon (C), exchangeable cations, CEC and base saturation) and biomass nutrients;
4) to test whether the changing mineral nutrient demand during forest stand growth is reflected in soil nutrient status;
5) to learn more on the temporal dynamics of plant nutrients as a basis for sustainable biomass harvesting in *Quercus* dominated forests in North-East Austria by focusing on nutrient pools in mineral soils and above-ground standing biomass.

1.4. Expected Results

This study was part of a biomass project “Untersuchungen zur Dynamik der Biomassen- und Kohlenstoffvorräte in Niederwäldern mit Überhälter, Mittel- und Hochwäldern; Investigations to the dynamics of the biomass and C pools in coppice with reserves stands, coppice with standards stands and high forest” which I have mentioned above. Expected results from this study are:

1) Information on soil nutrient pools in deciduous forest which has been considered a potential source of woody biomass as a source for renewable, sustainable energy in North-East Austria.
2) Information on the effect of stand age on soil parameters for instance mineral nutrient levels in the soil based on the chronosequence approach.
3) Information on macronutrients pools in the above-ground standing biomass as reference for forest management and silvicultural goals of increased biomass extraction.
4) Advice for sustainable forest management in terms of sustainability of mineral nutrient status in a dynamic context.

2. Background Information and Literature Review

2.1. Development of Bio-energy

Energy is a basic necessity as important as food and water for human beings. The world population is facing challenges resulting from global climate change, rising energy demand and degradation of the environment. Diversifying energy supply could help to relieve pressures. Concern of environments, risk of nuclear radiation, pressures for fossil fuel independence, unstable price and change of energy policy are promoting an increasing potential for sustainable and renewable energy all over the world. Derived from biological sources, bio-energy is renewable energy to be used for heat, electricity, and vehicle fuel. The Food and Agricultural Organization (FAO) defines bio-energy as *sources of energy (electricity and solid, liquid, or gaseous fuels) derived from biomass, plant or animal based materials such as crops, crop residues, trees, animal fats, by products and wastes* (FAO, 2004). These materials are often obtained from agriculture and forests, but can also be derived from industrial and municipal sources. As mentioned in the introduction part, bio-energy is considered a potentially important energy source to meet energy demand. The following list indicates some basic characteristics of bio-energy:

1) One form of renewable energy among many from other sources (wind, solar, hydraulic, geothermal etc.).
2) If produced sustainably, saves greenhouse gas emissions.
3) Biomass for energy is mainly provided by forestry (which provides half of the EU's renewable energy), agriculture and organic waste (EU-Commission, 2009).
4) Feedstock for bio-energy is storable; bio-energy can thus be produced constantly and is a reliable source of energy.
5) Biomass is globally amply available.

6) Biomass can be either in solid, liquid or gaseous form and can be used to produce electricity, direct heating, or transport fuels.

Increasing security of energy supply and reducing greenhouse gas emissions are two major objectives for many countries to develop bio-energy. Bio-energy developments present both opportunities and challenges for economic development and the environment. Research and policy-making play a major role in ensuring that bio-energy becomes a sustainable alternative for rural development (FAO, 2009; Vargas, 2010). Figure 2.1 shows the sustainable bio-energy related interventions: synthesis of concluding remarks.

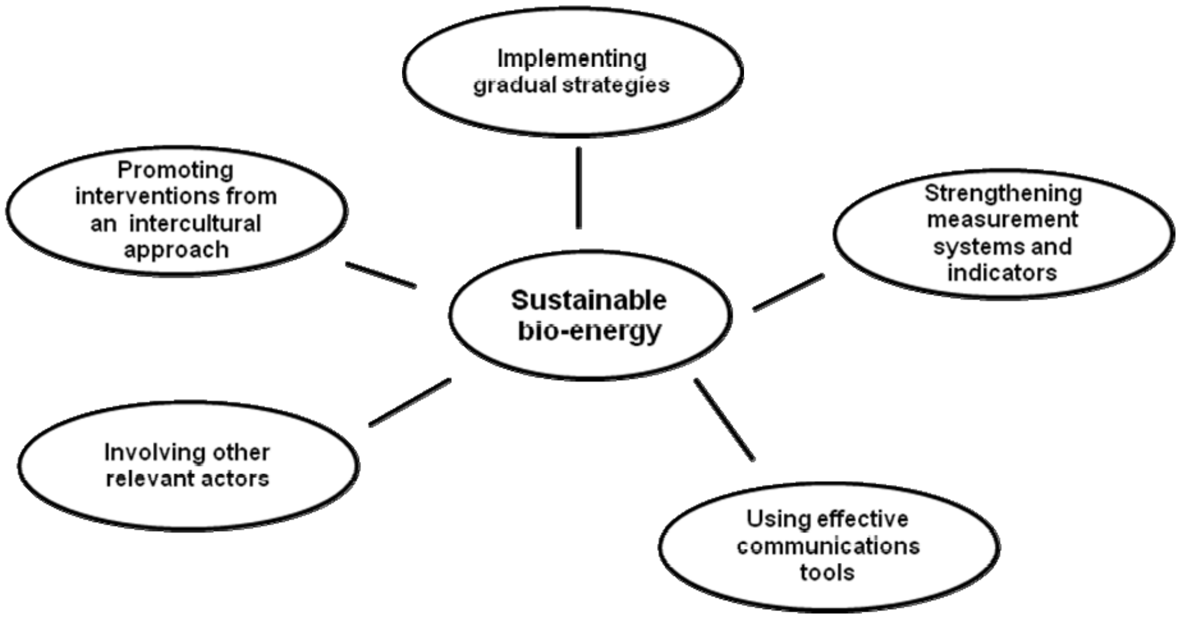


Figure 2. 1 Sustainable bio-energy related interventions: synthesis of concluding remarks (FAO, 2009; Vargas, 2010).

The European Union bio-energy policy: central piece of legislation is the Renewable Energy Directive 2009/28/EC. It sets ambitious binding targets for all member states that the EU will reach a 20% share of renewable energy by 2020. The directive requires member states to plan their development for each type of renewable energy, including bio-energy, by elaborating National Renewable Energy Action Plans. Moreover, provisions for cooperation between member states help them to achieve their targets more cost-effectively (EU-Commission, 2009). The source of energy from forestry is comparatively higher than from agriculture in European Union countries (Figure 2.2).

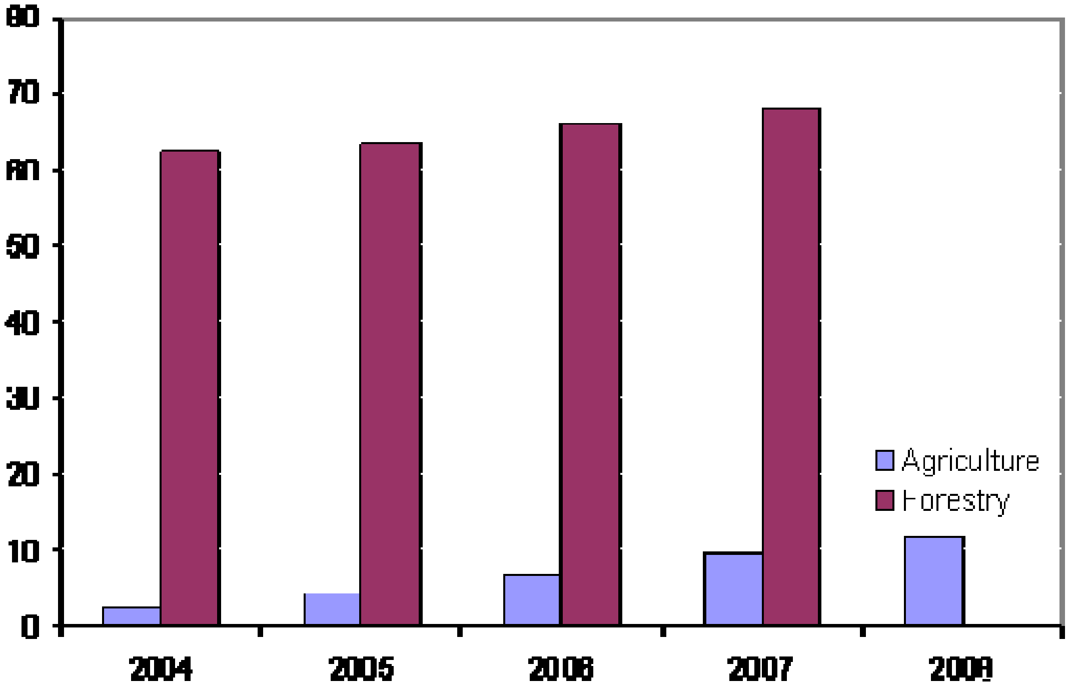


Figure 2. 2 Production of energy from EU forestry and agriculture, million tonnes oil equivalent (EU-Commission, 2009).

If development in a sustainable way, bio-energy has the potential to produce both electricity and fuel with fewer risks than those associated with oil, coal and nuclear technologies. But a rapid global expansion of bio-energy development could have unwanted environmental and economic consequences, possibly including reduced global capacity to produce food, fibre, and industrial materials. Such challenges represent an opportunity of improve the resilience of the agriculture and forestry sectors. Our current antiquated energy production system relies on supplies that lack diversity and are finite, polluting and highly centralized. Minimizing global warming pollution: the energy choices should give priority to production methods and material that producing the lowest amount of global warming pollution per unit of energy and offer the greatest overall potential for emission reductions.

1) Combine bio-energy with efficiency, conservation and smart growth: to achieve timely reductions in both global warming pollution and fossil fuel dependence, expanded bio-energy use must be pursued in conjunction with aggressive increase in energy efficiency, reduced energy demand through conservation and reforms in transportation and land use policies.
2) Protecting public health: It should evaluate the health risks and potential unintended consequences of bio-energy production and use and make choices that maintain and improve public health.
3) Promote ecologically sound bio-energy systems: i) to protect air, water and soil quality; ii) to protect biodiversity and ecosystem services; iii) to wisely use biotechnology; iv) to limit the risk of invasive species.
4) Ensure bio-energy investments expand economic opportunity: i) to create opportunities for stable economic development; ii) to promote a responsible shift to bio-energy production through effective government policies and investments.

Bio-energy could contribute to the sustainable development of both developing and developed countries. It could support the achievement of the Millennium Development Goals (MDG) which set by UN.

2.2. Forest Biomass

There are much interests and demands in estimating forest biomass because the forests play a key role in regulating worldwide nutrient and C cycles (Cairns *et al.*, 1997) and providing raw matetiral for the bio-energy industry (Gielen *et al.*, 2001; Berndes and Hansson, 2007; Gan, 2007; Scarlat and Dallemand, 2011). In the last decade accumulation of C in different ecosystems, including forest, had been a hot topic around the world and the stock of C bound in biomass and in the soil had been estimated in numberous studies (Cannell, 1999; Mund *et al.*, 2002; Pussinen *et al.*, 2002; Agren and Hyvonen, 2003; Pan *et al.*, 2011; Uri *et al.*, 2012). Forests are important sources to provide wood for products and energy. In 2005 about 382 million m^3 overbark were removed from forests in the 27 European Union (EU) member countries as industrial roundwood and 98 million m^3 overbark as woodfuel (FAO, 2010). The demand for wood by forest industries has been projected to increase by 15-35% in 2030 compared to 2010 in EU member countries (Verkerk *et al.*, 2011). Forest waste should not be collected for energetic use by forest managers. It must be left in the forest where it becomes organic material for the next generation of forests.

Forest biomass is considered an important resource to meet the renewable bio-energy target because:

1) wood and wood waste represent currently most of all renewable bio-energy (Figure 2.2).
2) forests are arguably not managed to their full extent as fellings are generally well below the annual increment.

Forest biomass can be converted to energy and energy products in a number of ways:

1) direct combustion, forest biomass can be burned in tratitional wood-stoves industrial boilers to produce energy to be used on site and provide surplus energy delivered to the power grid.
2) pellets, forest biomass can be converted to wood pellets that can be used in both residential and commercial heating units.
3) gasification, forest biomass can undergo several forms of gasification to creat energy and energy products, slow pyrolysis, fast pyrolysis, reforming, Fischer-Tropsch , hydrolysis and fermentation.
4) co-firing, forest biomass and forest biomass based products (bio-oil) can be mixed with traditional fossil fuels in boiler systems to generate energy on-site.

5) second generation bio-fuels, produced from sustainable feedstock, celllulosic ethanol, biohydrogen, biomethanol, Dimethylfuran (DMF).

Considering the utilization of forest biomass as source materials for bio-energy, wood demand and supply, sustainabiliy, C emission and climate and policy (Lutz and Edgewater, 2011) should be analysed to provide a sustainable woody biomass energy solution (Figure 2.3). Wood demand and supply asked the role of forests in the traditional market for forest products and the developing market for energy, the potential and expected demand for traditional wood products and for wood as an energy feedstock. Sustainability means the long-term ability of the nation's forests to provide multiple benefits. Sustained healthy forestlands are needed not only to provide wood for energy and traditional uses, but also to provide wildlife habitat, clean water, clean air, recreation and to preserve some heritages. C and climate change explores the role of forests in sequestering C, which reduces C emissions that contribute to climate change. In terms of energy production, questions have been raised about the long-term presumption that energy from woody biomass is C neutral, citing concerns that the potential for degrading the clearing natural forests could acturally increase atmospheric C. Others postulate that forest C stocks are always depleted by harvesting but that C stock depletion is reversed gradually over a period of years by regrowth of the harvested stands. Policy initiatives have led to a large number of laws and regulations that lay out a patchwork of mandated, incentives and barriers of the use of woody biomass for energy. Energy and C policies can have dramatic economic impacts as well as environmental impacts (Lutz and Edgewater, 2011).

The realistic potential from European forests is estimated at 744 million m^3 yr^{-1} overbark in 2010, which represents 58% of the theoretical potential (Verkerk *et al.*, 2011). It was reported that the realisable biomass potential could range from 623 to 895 million m^3 yr^{-1} overbark in 2030 (Verkerk *et al.*, 2011). The large range between the estimated low and high stock stresses the importance of mobilisation efforts in policy and practice.

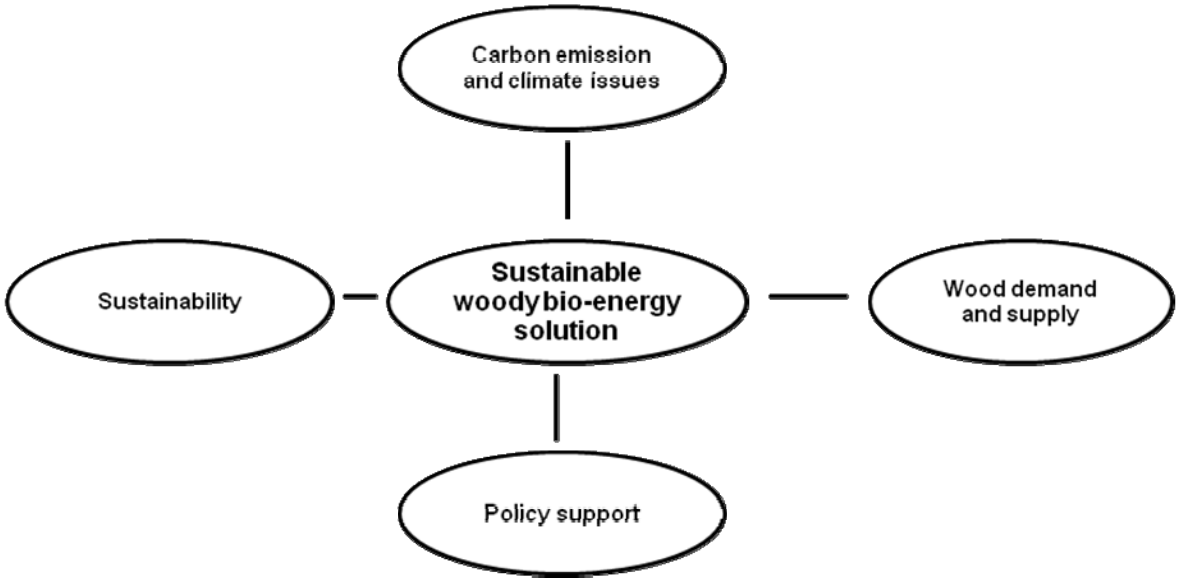


Figure 2. 3 Aspects of developing sustainable woody biomass energy solutions (Lutz and Edgewater, 2011).

2.3. Soil Properties

An important factor influcing the productivity of our planet's various ecosystems is the nature of their soil. Soil is vital for the existence of many forms of life that have evolved on our planet. Soil contains mineral particles, air, water, dead organic matter and various types of living organisms (Figure 2.4) (Taylor and McClennan, 1985). The formation of a soil is influenced by organisms, climate, topography, parent material and time. The composition and proportion of different components greatly influences soil physical and chemical properties.

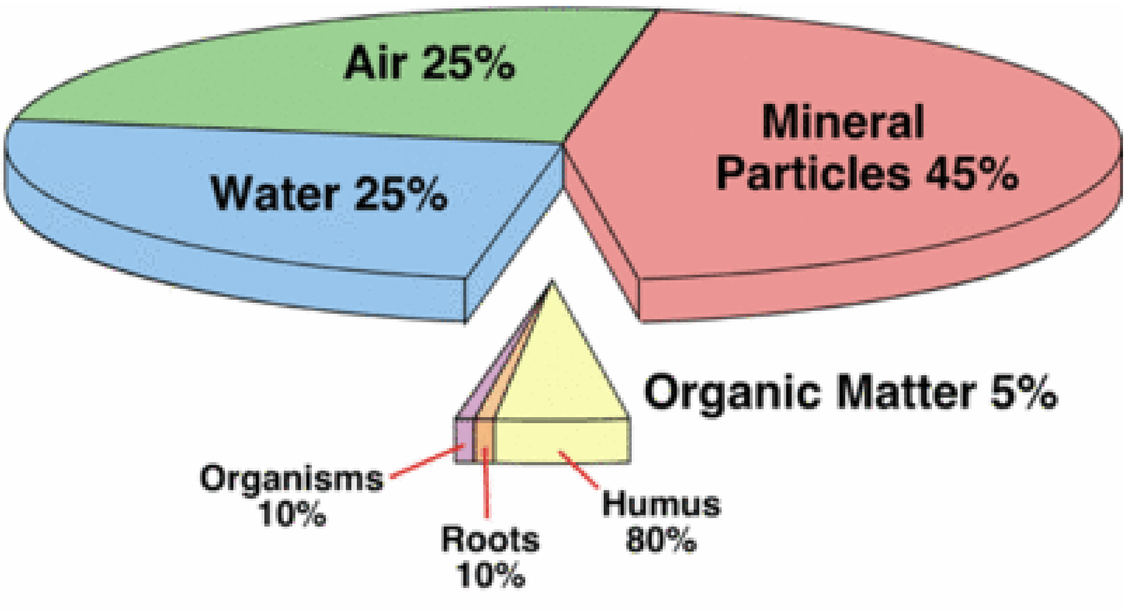


Figure 2. 4 Soil composition: mineral particles, air, water and organic matter by volume (http://www.physicalgeography.net/fundamentals/10t.html).

Soil physical properties include: horizonation, soil colour, soil texture, soil structure, soil consistence and soil bulk density. Soil horizons are discrete layers that make up a soil profile (Figure 2.5). They are typically parallel with the ground surface. Sometimes soil horizons could show the evidence of the actions of the soil forming processes. In well aerated soils, oxidized or ferric iron (Fe^{3+}) compounds are responsible for the brown, yellow and red colours.

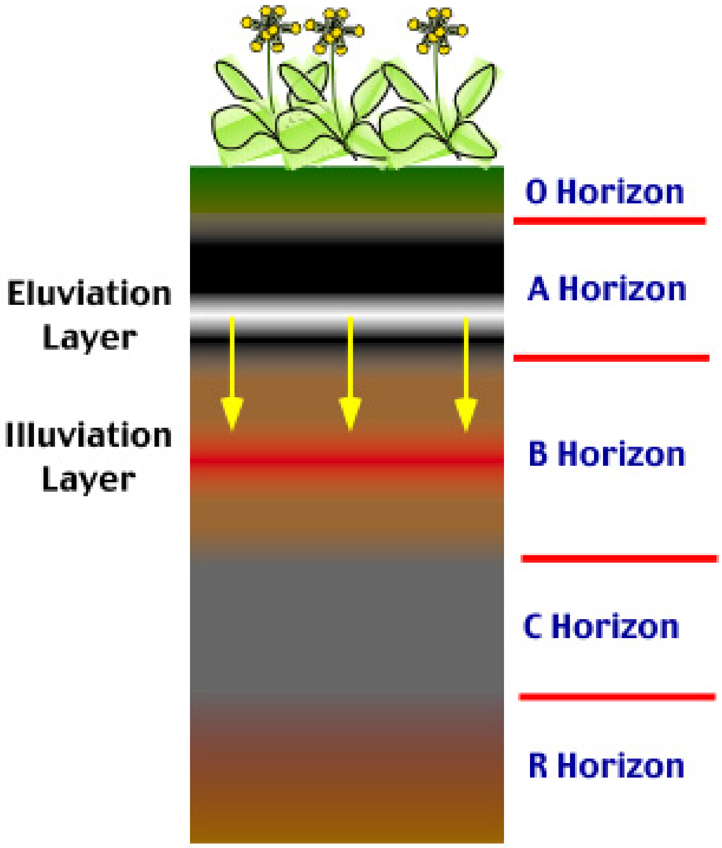


Figure 2. 5 Illustration of soil profile (http://www.eoearth.org).

Soil texture refers to the proportion of the soil separates that makes up the mineral component of soil. These separates are called sand, silt and clay. For all mineral soils, the proportion of sand, silt and clay always adds up to 100%. These percentages are grouped into soil texture classes, which have been organized into a soil texture triangle. The soil separates can become aggregated together into discrete structural units called “peds”. These peds are organized into a repeating pattern that is referred to as soil structure. Between peds are cracks called “pores” through which soil air and water are conducted. Soil structure is most commonly described in terms of the shape of the individual peds that occur within a soil horizon. Soil consistence refers to the ease with which an individual ped can be crushed by the fingers. Soil consistence, and its description, depends on soil moisture content. Soil bulk density is the proportion of the weight of a soil relative to its volume (http://www.eoearth.org).

Soil chemical properties include: soil acidity; role of silicate clay minerals; cation exchange capacity; base saturation, exchangeable acidity, soil organic matter (SOM), flocculation et al. Soil pH is a measure of the active hydrogen ion (H^+) concentration. It is an indication of the acidity or alkalinity of a soil, and also known as soil reaction. It was reported that soil acidity might affect the availability of N to plant by affecting the activity of microorganisms involved in ammonification, nitrification, denitrification, immobilization and non-symbiotic N fixation (Robson and Abbott, 1989). Soil pH influences how efficiently a plant growth in a soil by affecting nutrient availability and potential toxicity, disease organism activity, microorganism activity and potential plants damage by some herbicides. CEC is a measure of the capacity of the soil to hold some nutrients. It plays a role in soil fertility. The cations held on the organic matter and clay surfaces act as a reserve of nutrients, continually resupplying the soil solution with nutrients required by plants. High CEC is associated with high clay contents and high organic matter levels. SOM acts like a bank for many essential plants nutrients by (i) providing exchange plots for actions such as K and Mg; (ii) releasing N during breakdown; (iii) providing virtually all of the manganese and born that crops require throughout the growing season. The pool of plant-available nutrients in the soil is replenished by mineralization of SOM, weathering of soil minerals and deposition. SOM is commonly recognized as one of the key chemical parameters of soil quality, yet quantitative assessment of its contribution to soil quality is often lacking (Schoenholtz *et al.*, 2000). Climate and substrate quality affect decomposition of SOM. Through its role in aggregate stability it influences soil porosity and thus gas exchange reactions and water relations. SOM is a critical pool in the C cycle and a repository of nutrients and through its influence on many fundamental biological and chemical processes it plays a pivotal role in nutrient release and availability (Johnson, 1985; Schoenholtz *et al.*, 2000). Many soil chemical properties directly influence microbiological processes (e.g. via nutrient and C supply), these processes together with soil physical-chemical processes determine (i) the capacity of soils to hold, supply and cycle nutrients (including C) and (ii) the movement and availability of water (Schoenholtz *et al.*, 2000). Soil chemical indicators are used mostly in the context of nutrient relations and may therefore also be referred to as “indices of nutrients supply” (Schoenholtz *et al.*, 2000).

2.4. The World Reference Base for Soil Resources (WRB)

The international Union of Soil Sciences (IUSS) endorsed the international standard taxonomic soil classification system, which is called the World Reference Base for Soil Resources (WRB) (FAO–ISRIC, 2006). The first edition of WRB was issued in 1998. The second edition which is used for this study was from 2006 (FAO–ISRIC, 2006). The WRB was influenced heavily from modern soil classification concepts, including the United States Department of Agriculture (USDA) Soil Taxonomy, the legend for the FAO Soil Map of the World 1988. The classification is based mainly on soil morphology as expression pedogenesis (FAO–ISRIC, 2006). Soil climate is not part of this system, except insofar as climate influences soil profile characteristics. The general principles are as follows (FAO–ISRIC, 2006):

1) The classification of soils is based on soil properties defined in terms of diagnostic horizons, properties and materials, which to the greatest extent possible should be measurable and observable in the field.
2) The selection of diagnostic characteristics takes into account their relationship with soil forming processes. It is recognized that an understanding of soil-forming processes contributes to a better characterization of soils but that they should not, as such, be used as differentiating criteria.
3) To the extent possible at a high level of generalization, diagnostic features are selected that are of significance for soil management.
4) Climate parameters are not applied in the classification of soils. It is fully realized that they should be used for interpretation purposes, in dynamic combination with soil properties, but they should not form part of soil definitions.
5) The WRB is a comprehensive classification system that enables people to accommodate their national classification system.
6) Many Reference Soil Groups (RSG) in the WRB are representative of major soil regions so as to provide a comprehensive overview of the world's soil cover.

7) The Reference Base is not meant to substitute for national soil classification systems but rather to serve as a common denominator for communication at an international level.
8) Definitions and descriptions of soil units reflect variations in soil characteristics both vertically and laterally so as to account for spatial linkages within the landscape.

The WRB soil types are: Acrisols; Albeluvisols; Alisols; Andosols; Anthrosols; Arenosols; Calcisols; Cambisols; Chernozems; Cryosols; Durisols; Ferralsols; Fluvisols; Gleysols; Gypsisols; Histosols; Kastanozems; Leptosols; Lixisols; Luvisols; Nitisols; Phaeozems; Planosols; Plinthosols; Podzols; Regosols; Solonchaks; Stagnosols; Technosols; Umbrisols; and Vertisols (FAO–ISRIC, 2006).

2.5. Soil Nitrogen, Carbon and Exchangeable Cations

Soil and forest help to secure and renew each other in the nature. Forest productivity and soil quality are relied on the chemical and physical properties of soils (Schoenholtz *et al.*, 2000). Forest soil scientists have long been concerned with soil C, soil N and exchangeable cations because these are often the master variables determining soil fertility (Johnson, 1985; Pritchett and Fisher, 1987; Smethurst, 2000; Johnson and Curtis, 2001). N and C are most widely used to indicate soil condition and forest growth (Klemmedson, 1975; Robinson *et al.*, 2002; Merino *et al.*, 2004). Land use related processes of soil erosion, organic matter depletion, salinization, nutrient imbalance, compaction and hard-setting, anaerobiosisty are causing soil regression and degradation. However there are many other causes for changes in the nutrient status of the forest soil: bedrock weathering, biomass removal, soil erosion, increased nutrient demand by fast growing species, soil acidification and alkalinisation, silvicultural practices (e.g. altering species compositions), nutrient leaching and run-off, deposition of aerosols, soil moisture regime.

2.5.1. Soil Nitrogen

N and mineral nutrients are crucial for plants to constitute their tissue, promote growth and enhance disease resistance. N is a major component of all amino acids, which are the building blocks of proteins. Over 90% of the N in the surface layer of most soils occurs in organic forms, with most of the remainder being present as NH_4^- which is held within the lattice structures of clay minerals. Leaf tissues are strong sinks for N and greater evapotraspiration increases plant N uptake (Zhang and Allen, 1996; Dong *et al.*, 2001). Sustained retention of N in the soil is important to minimize undesired nitrate leaching into freshwater and groundwater resources (Borken and Matzner, 2004; Prietzel *et al.*, 2008). Soil N was considered as basic indicator of soil quality (Doran *et al.*, 1994; Schoenholtz *et al.*, 2000). N cycle and transformation in terrestrial ecosystem include the following process: fixation, mineralization, ammonification, nitrification, immobilization, plant uptake, leaching, volatilization, and denitrification. Figure 2.6 shows the N-cycles in soil.

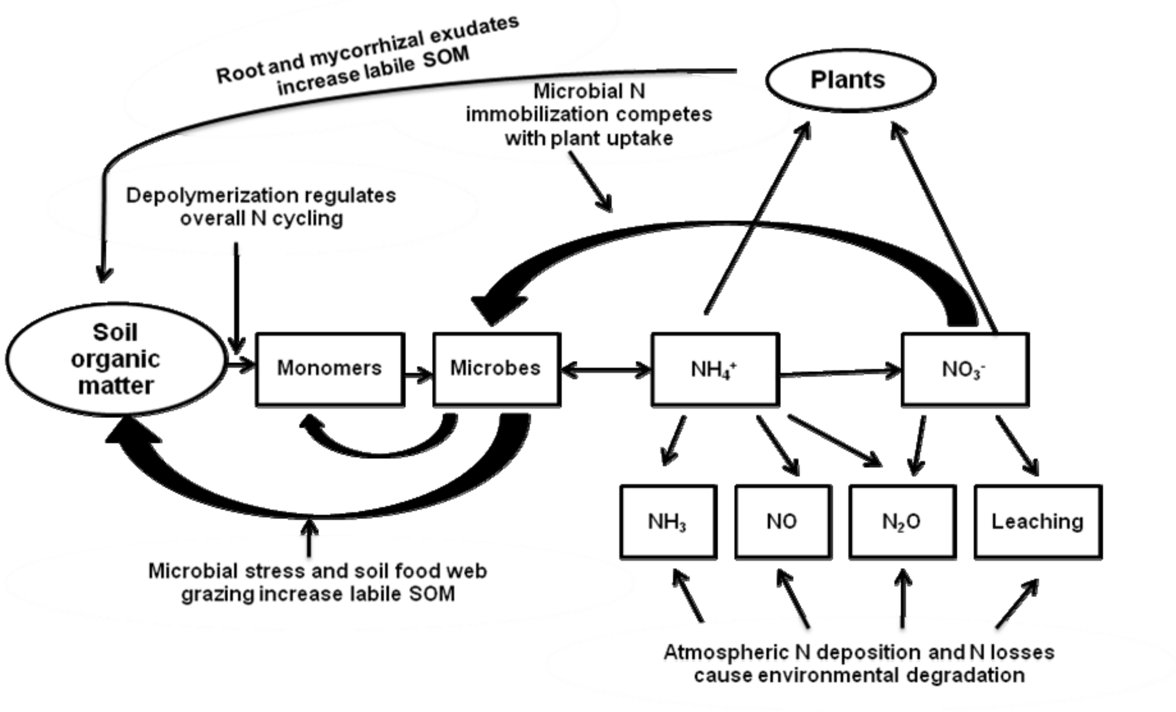


Figure 2. 6 Illustration of N cycles in soil (http://www.extension.org/).

2.5.2. Soil Carbon

Soils hold the largest stock of terrestrial C. It is estimated that forest soils hold 1 100 Pg C, which is about 50% of the total global soil C (Jobbagy and Jackson, 2000). Because of the large areas involved at regional as well as global scale, forest soils play an important role in the global C cycle (Jobbagy and Jackson, 2000; Lal, 2005). C storage in forest ecosystem involves numbers components including biomass C and soil C (Figure 2.7) (Lal, 2005).

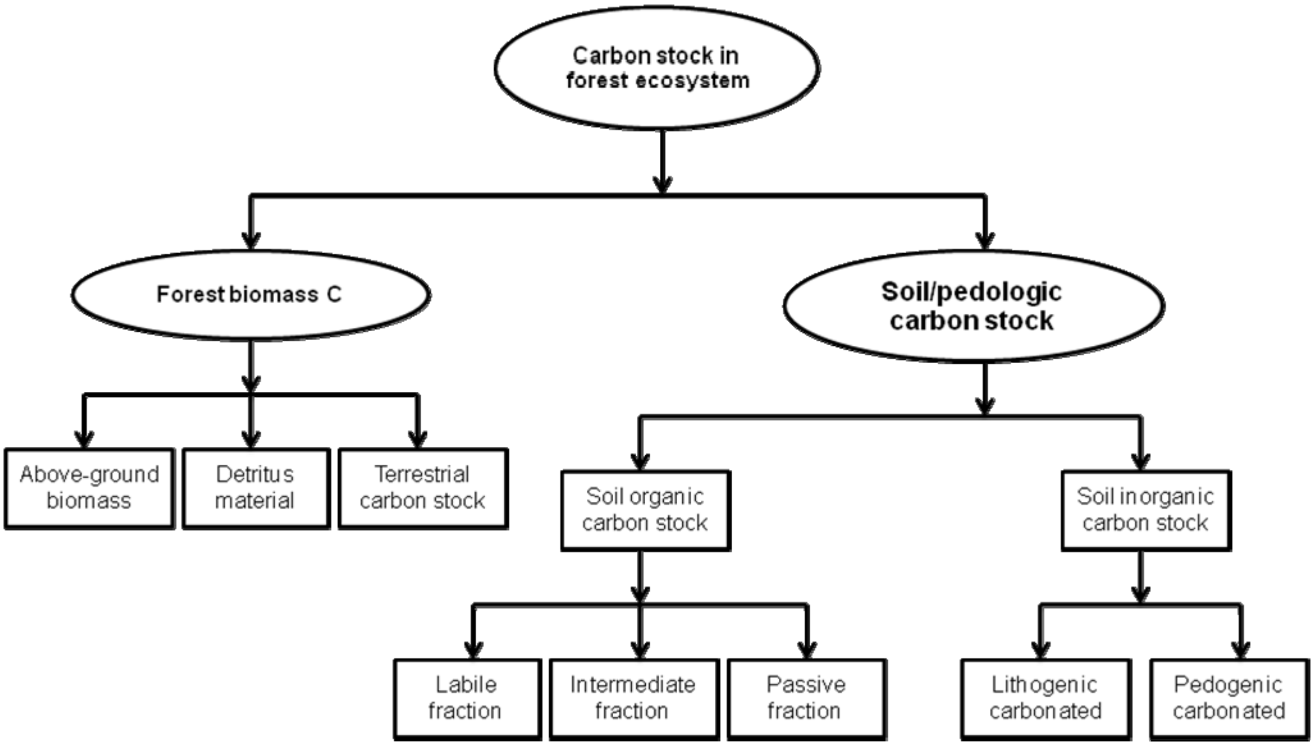


Figure 2. 7 Components of the terrestrial carbon stock (Lal, 2005).

Sequestration of C in soils as organic carbon (OC) may help to slow down the enrichment of CO_2 in the atmosphere. OC increases the nutrient and water storage capacity of soils, which may help to mitigate the adverse effects of increased summer drought on the water and nutrients supply of forest stands. The systematically increasing difference between forest floor OC stock with increasing stand age indicates a consistent dynamics of gradually increasing effects of tree species change (Spielvogel *et al.*, 2006). Soil OC is part of minimum data set for agronomic soils. It is element of pedotranfer functions to calculate CEC, soil bulk density and water retention (Larson and Pierce, 1994). It was reported that soil OC is one of the chemical parameters of nutrient availability with specific scoring functions to be used for plant productivity and environmental components of soil quality.

2.5.3. Exchangeable Cations in Soil

Exchangeable cations refer to the positively charged ions which are loosely attached to the edge of clay particles or organic matter in the soil cations leaving the exchangeable plots enter the soil solution, where they can be taken up by plants, react with other soil constituents or be carried away with drainage water. Increased exchangeable base cations and base saturation in litter and forest floor are crucial factors favouring soil faunal particularly earthworm and microbial activity and mixing, decomposition and mineralization of SOM compounds in the forest floor (Reich *et al.*, 2005). Exchangeable cations could be used to evaluate differences in soil quality between different land management system (Reganold and Palmer, 1995). It was reported that exchangeable K, exchangeable Ca, exchangeable Mg and exchangeable P were used to evaluate differences in soil quality among different land management systems (Reganold and Palmer, 1995).

2.6. Interdependence of Nutrients in Plant and Soil

Potassium (K) is essential for cell expansion, cellular osmoregulation and also is the most dependent nutrient on root reserves for the initial growth of sprouts; Sodium (Na) replaces of K and other cations on the soil exchange complex and can lead to nutrient deficiencies; Calcium (Ca) is an essential part of plant cell wall structure. It provides for normal transport and retention of other elements as well as strength in the plant and counteract the effect of alkali salts and organic acids within a plant; Magnesium (Mg), which helps activate many plant enzymes needed for growth, is part of the chlorophyll in all green plants and essential for photosynthesis; Iron (Fe) is essential for formation of chlorophyll; Manganese (Mn) functions with enzyme systems involves in breakdown of carbohydrates, and N metabolism; Zinc (Zn) is essential for the transformation of carbohydrates (Bryson and Barker, 2002; Teixeira *et al.*, 2002; Ramoliya *et al.*, 2004; Taiz and Zeiger, 2006). K and Ca as macro-nutrient were reported as important indicators of soil quality (Bowersox and Ward, 1972; Doran *et al.*, 1994; Schoenholtz *et al.*, 2000; Zhang and George, 2002; Zhang *et al.*, 2007; Crous *et al.*, 2008). Exchangeable Fe could greatly enhance soil C stock (Lal, 2005). Cation exchange capacity (CEC), which is used as a measure of fertility, nutrient retention capacity and the capacity to protect groundwater from cation contamination, are drawing more attention in scientific study scope of forest and soil sciences (Bennett *et al.*, 1986; Saikh *et al.*, 1998; Regina, 2000; McLaughlin and Phillips, 2006; Yimer *et al.*, 2008; Lu *et al.*, 2010; Milosevic and Milosevic, 2010).

Table 2. 1 Average nutrient contents in different fractions of *Quercus petraea, Fagus sylvatica, Corylus avellana* and *Betula pendula*. Letters indicate authors of individual study (Andre and Ponette, 2003; Berger *et al.*, 2009; Andre *et al.*, 2010). [a] refers Andre and Ponette; [b] refers Berger et al; [c] refers Andre et. al.

	Quercus petraea **wood and bark** (mg g^{-1})	*Quercus petraea* Coppice **foliage** (mg g^{-1})	*Fagus sylvatica* **foliage** (mg g^{-1})	*Corylus avellana* Coppice **foliage** (mg g^{-1})	*Betula pendula* **foliage** (mg g^{-1})
N	1.65[a]	23.0[a]	18.3[b]	36.9[c]	27.0[c]
K	1.00[a]	0.21[a]	0.19[b]	0.27[c]	0.22[c]
Ca	3.03[a]	0.09[a]	0.12[b]	0.13[c]	0.10[c]
Mg	0.10[a]	0.05[a]	0.05[b]	0.11[c]	0.07[c]
P	0.11[a]				
S	0.12[a]				

Several studies (Andre and Ponette, 2003; Berger et al., 2009; Andre et al., 2010) show the nutrient contents in different fractions of *Quercus petraea, Fagus sylvatica, Corylus avellana* and *Betula pendula* (Table 2.1).

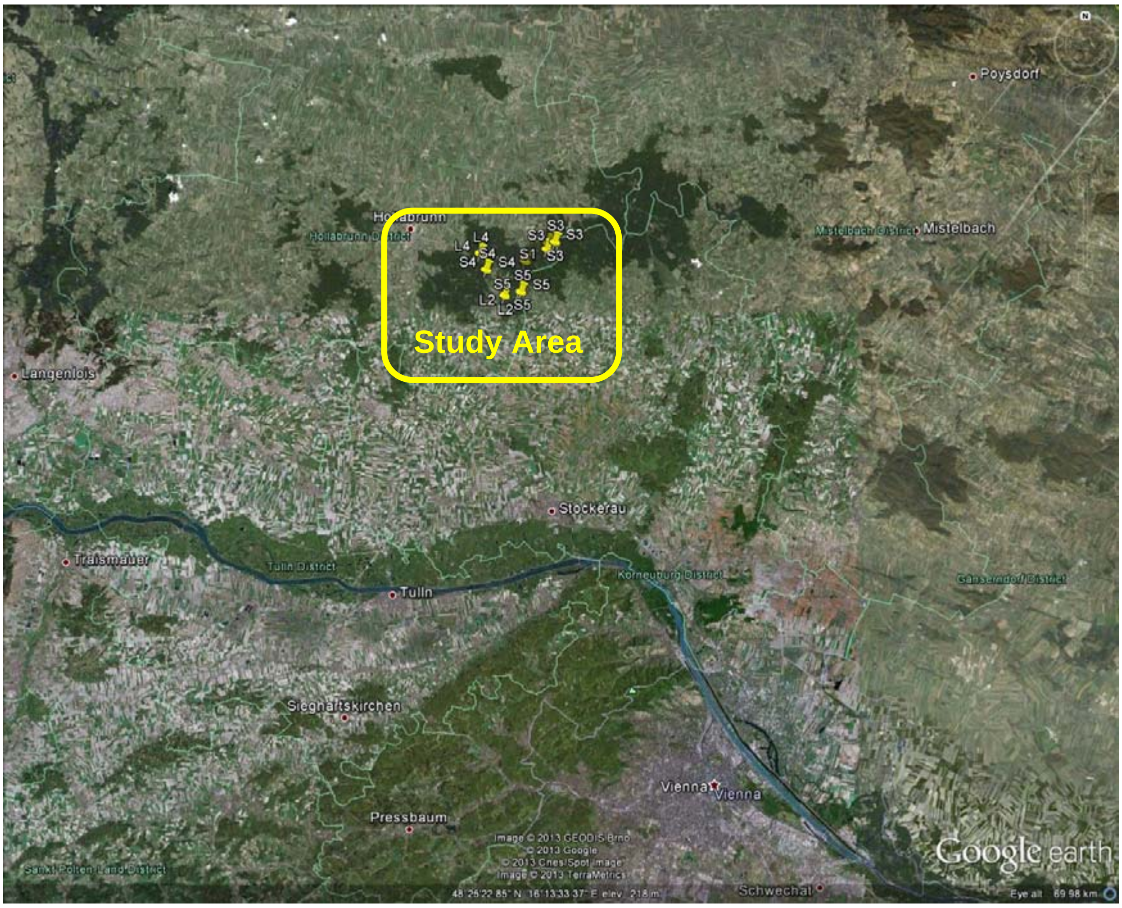
According to recent studies e.g. (Sanchez *et al.*, 2006; Sanchez *et al.*, 2009), removal of SOM or increased soil C and nutrients does not have significant effects on tree foliar nutrients and stand volume. But biomass removal and whole tree harvesting cause the decline of soil nutrients status and low level of exchangeable base cation pools (Olsson, 1996, 1999; Arvidsson and Lundkvist, 2003). Litterfall and decomposition processes can be seen an indicator of efficiency of nutrient cycles (Vitousek, 1982; Proctor *et al.*, 1983; Tang *et al.*, 2010), which are essential process for K recycle in forest ecosystem.

3. Materials and Methods

3.1. Description of the Study Plots

3.1.1. Location of the Study Plots – *Quercus* forest in Schönborn Area

This study area is situated in North-East Austria, approx. at 48°32’ N, 16°10’ E. The name of this area is called Schönborn. All study plots are located in the SE part of Hollabrunn which is a district capital town in the Austrian province of Lower Austria (Figure 3.1). The forest area is about 40 km NNW from Vienna and surrounded by arable land. The owner of this forest is the Forst- und Gutsverwaltung SCHOENBORN KG. Figure 3.1 shows the overview of the study area and the sketch of individual study plot.



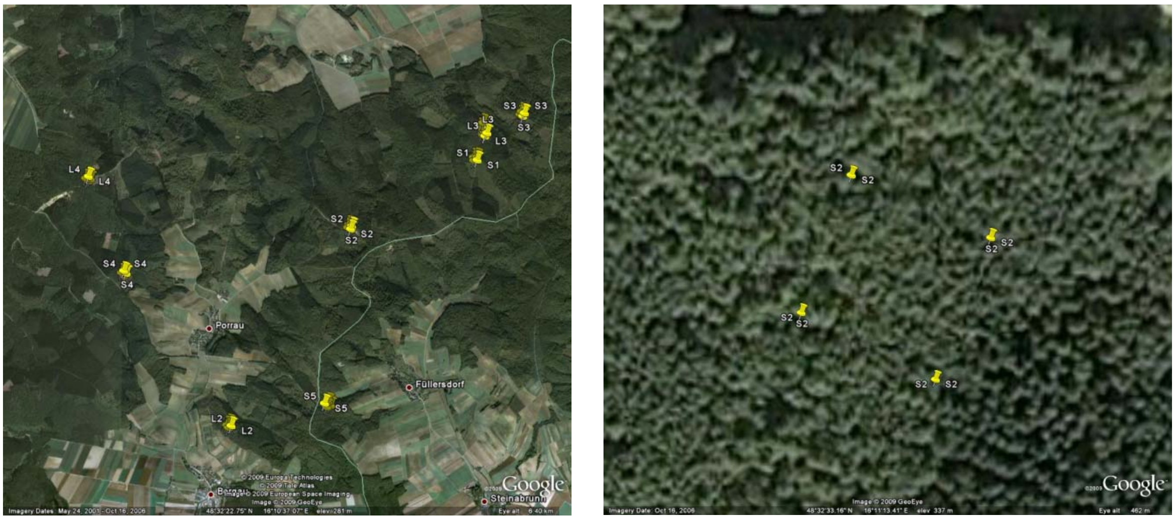


Figure 3. 1 Overview of the study area and the indication of individual study plot in North-East Austrian *Quercus* Forest (Google Earth).

3.1.2. Geology and Geomorphology

The parent material consists of gravel, sand and silt built up during the Pannonium (between 7.2 and 11.6 Ma before present) as a result of the early development of the Göllersbach River (which is also a sub-branch of Danube River) at the Hollabrunn region. The topography is generally rolling hills (< 15°) with some gentle slopes resulting from postglacial erosions (Bruckman *et al.*, 2011). The altitudinal range of the study area is between 300 and 350 m a.s.l.

3.1.3. Climate

The Climate in North-East Austria is a transition from temperate oceanic to temperate continental Pannonian climate zone. The Pannonian climate is noted for cold winters (going down to -20 °C during the night in January and February) and hot and sunny summers (going up to 35 °C during some days in August). The mean temperature is 8.8 °C in study area (ZAMG, 2009). The lowest temperature is in January and February with the monthly mean temperature of -4.2 °C. The coldest record was -30.6 °C. The highest temperature is in July and August with the monthly mean temperature of 25.4 °C. The highest record was 36.7 °C. The mean precipitation is 500 mm annually in Hollabrunn (ZAMG, 2009). The mean snow accumulation is 41.3 cm annually in study area. The mean wind speed is 2.6 $m\ s^{-1}$ annually in this study area. The dominated wind direction is North-West or West (ZAMG, 2009). Above information was from Zentralanstalt für Meteorologie und Geodynamik (ZAMG), which is the Austrian national weather service agency.

3.1.4. Vegetation

Oak-hornbeam forests are the predominant forest vegetation in this region. The dominant tree species is Sessile Oak (*Quercus petraea)* in all of this study plots. Other tree species are found as following: Hornbeam (*Carpinus betulus*), Hazelnut (*Corylus avellana*), Linden (*Tilia platyphyllos*), Norway Spruce (*Picea abies*), Silver Birch (*Betula pendula*), Scots Pine (*Pinus sylvestris*), European Larch (*Larix decidua*), European Beech (*Fagus sylvatica*), Aspen (*Populus tremula*), Field Maple (*Acer campestre*). Component plants in the forest floor and sub canopy vegetation are: Old Man's Beard (*Clematis vitalba*), Wood Bedstraw (*Galium sylvaticum*), Wavy Hair-grass (Deschampsia flexuosa), Small Cow-wheat (*Melampyrum sylvaticum*), Black Berry (*Rubus* fruticosus), Wild privet (*Ligustrum vulgare*), Dogwood (*Cornus sanguinea*), Lily of the valley (*Convallaria majalis*) and Maple Family (Aceraceae). Figure 3.2 shows the profile of nine forest plots which were used for this study in North-East Austria.

S1


S2



S3


S4

S5

L2

L3


L4


L5 

Figure 3. 2 View of the nine forest plots which were used for this study. They are *Quercus* stands in North-East Austria

3.1.5. Soil Classification

The study area has quite fertile soils (Bruckman *et al.*, 2011). According to the international standard taxonomic soil classification system WRB, the soils in this study plots were identified as three soil types: Eutric Cambisol, Calcic Chernozem and Haplic Luvisol (FAO–ISRIC, 2006).

Cambisol conbine soils with at least an incipient subsurface soil formation. Transformation of parent material is evident from structure formation and mostly brownish discoloration, increasing clay percentage and carbonate removal. Eutric represents that soil has a base saturation (by 1 M NH_4OAc) of 50 percent or more in the major part between 20 and 100 cm from the soil surface or between 20 cm and continuous rock or a cemented or indurated layer, or, in leptosols, in a layer, 5 cm or more thick, directly above continuous rock. Chernozems accommodate soils *with a thick black surface layer that is rich in organic matter. Calcic represents that soil has a calcic horizon or concentrations of secondary carbonates starting within 100 cm of the soil surface. Luvisols are soils that have higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes leading to an argic subsoil horizons. Haplic represents soil has a typical expression of certain features (typical in the sense that there is no further or meaningful characterization) and only used if none of the preceding qualifiers applies. Luvisol have high-activity clays throughout the argic horizon and a high base saturation at certain horizons (FAO–ISRIC, 2006).*

Soil profiles were characterized and described in terms of soil horizon, texture, colour, coarse material and surface litter.

3.2. Study Design

This study is part of a biomass project (Untersuchungen zur Dynamik der Biomassen- und Kohlenstoffvorräte in Niederwäldern mit Überhälter, Mittel- und Hochwäldern; Investigations to the dynamics of the biomass and C pools in coppice with reserves stands, coppice with standards stands and high forest) which was supported by Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. Nine permanent *Quercus petraea* dominated forest plots were selected for this study. Stand age, plot size, species composition **%** of *Quercus*, over-storey stand density (no ha^{-1}), over-storey average DBH, over-storey average height, over-storey basal area (m^{-2} ha^{-1}) and soil type are shown in the Tab. 3.1.

Table 3. 1 Description of the selected study plots (study plot code, stand age (years), plot size (m), species composition, % of *Quercus*, over-storey stand density (no ha^{-1}), over-storey average DBH, over-storey average height, over-storey basal area (m^{-2} ha^{-1}) and soil type) in North-East Austrian *Quercus* Forest.

Study plot	**Time since stand initiation (years)**	**Plot size (m)**	**Species composition**	**% of *Quercus***	**Stand density (no. ha^{-1})**	**Mean DBH of overstory (cm)**	**Mean height (m)**	**Basal area (m^2 ha^{-1})**	**Soil type**
S1	11	40x40	*Quercus petraea* with a few *Rubus fruticosus*	99.6	13	28.1	16	0.8	Eutric Cambisol (coarse material <= 40%)
S2	32	40x40	*Quercus petraea* with *Galium sylvaticum* in the understory	92.5	1625	12	13	18.2	
S3	50	40x40	*Quercus petraea* with a few *Corylus avellana*	91.2	575	20.8	18	19.6	
S4	74	40x40	*Quercus petraea* with *Carpinus betuluswith Galium sylvaticum in the understory*	81.4	288	29.1	20	19.1	
S5	91	50x50	*Quercus petraea* with a few *Corylus avellana*	85.8	236	30.2	22	16.9	
L2	31	40x40	*Quercus petraea* with a few *Acer campestre, Betula pendula, Cornus sanguinea*	75.7	1150	15.4	16	21.4	Calcic Chernozem
L3	43	40x40	*Quercus petraea* with a few young *Corylus avellana*	78.1	500	24.6	19	23.8	Haplic Luvisol (coarse material <= 20%)
L4	73	40x40	*Quercus petraea* with a few *Corylus avellana*	76.5	231	32.1	22	18.7	
L5	82	50x50	Quercus petraea with young *Carpinus betulus,* and *Galium sylvaticum* in the understory	72.7	419	22.8	20	17.0	

The chronosequence approach was commonly used to study how ecosystem processes and properties change over time (Covington, 1981; Katzensteiner, 2003; Yanai *et al.*, 2003; Vetter *et al.*, 2005; Walker *et al.*, 2010). This method was applied to get information on how the change of mineral nutrient demand during forest stand growth was reflected in soil nutrient status in this study.

3.3. Sampling and Laboratory Procedure

3.3.1. Field Methods and Soil Sampling

In above-ground: all trees with the DBH > 8 cm, trees seedlings, shrubs and bushes in a radius of 1.4 m were recorded; dead wood and herbaceous ground vegetation were neglected due to the low abundance of biomass in this study.

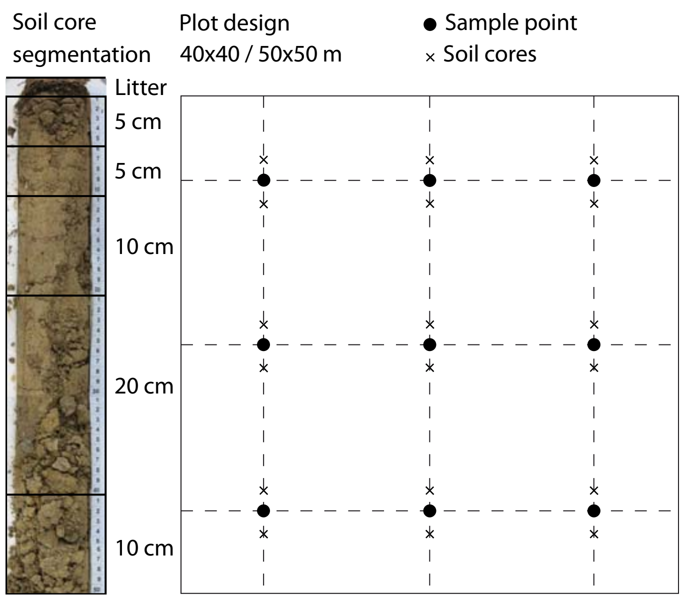


Figure 3. 3 Illustration of soil sampling in this study plots (right) and horizontal differentiation of the soil profile (left) in North-East Austrian *Quercus* Forest.

Eighteen soil cores were collected from each of all nine *Quercus* dominated study plots. A standard sample grid was used in each plot and two soil cores were collected (two meters away from the sample point in north-south direction) (Figure 3.3) by means of a soil corer with 70 mm diameter to a maximum horizon of 60 cm from each sample point (Figure 3.4). Those soil profiles were characterized and described in terms of soil horizon, texture, colour, coarse material and surface litter.

Figure 3. 4 Illustration of soil cores collection

3.3.2. Soil sample preparation

The Zero-Line between ecto-humus and mineral soil was demarcated and the total length of the soil profile was recorded. Soil profiles were separated into O-horizon (Litter layer) and five geometric mineral soil horizons, i.e. 0 to 5 cm, 5 to 10 cm, 10 to 20 cm, 20 to 40 cm and 40-50 cm. The corresponding two soil samples from the same sample point were pooled and passed through a 2 mm sieve for physical and chemical property analysis.

3.3.3. Laboratory Procedures for Soil Physical and Chemical Properties

Soil bulk density, acidity, N, C and exchangeable mineral nutrients i.e. K, Na, Ca, Al, Mg, Fe and Mn were selected for this study.

Commonly soil bulk density was calculated with from oven-dried mineral fine soil < 2mm (Gaudinski *et al.*, 2000; Kulmatiski *et al.*, 2003; Hopmans *et al.*, 2005; Ma *et al.*, 2007; Shuai, 2007; Nilsen and Strand, 2008; Vesterdal *et al.*, 2008; Diochon *et al.*, 2009). Soil bulk density was determined in considering 2.6 g cm^{-3} as rocky coarse material density in this study plots (Bruckman *et al.*, 2011).

Soil bulk density (g cm^{-3}) = (mass of dry soil (g) – mass of coarse soil (g)) / (volume of dry soil (cm^{-3}) – volume of coarse soil (cm^{-3}))

Soil acidity was determined by using pH meter in distilled water (active acidity) and 0.01 M $CaCl_2$ solution (exchangeable acidity). Litter mass was determined from the oven-dried up to constant weight of biomass. Roots were sorted from soil samples and oven-dried. Root dry mass was determined. Total N was determined by Kjeldahl (Kjeltec 2300 Analyzer Unit). Total C was determined in dry combustion by using a LECO SC-444. Scheibler method was used to determine the inorganic C when the pH $CaCl_2$ Value is more than 6.5. Exchangeable K, Na, Ca, Al, Mg, Fe and Mn were determined at different soil horizons by using $BaCl_2$ extraction and subsequent ICP-OES (Inductively Coupled Plasma – Optical

Emission Spectroscopy) analysis. Cation exchange capacity (CEC) was calculated of taking the amount of substance in molar mass (M), as following formula with the unit of (μ mol g^{-1}):

CEC (μ mol g^{-1}) = K ($\mu g\ g^{-1}$) x 1/39.0983 + Ca ($\mu g\ g^{-1}$) x 2/40.078 + Mg ($\mu g\ g^{-1}$) x 2/24.305 + Na ($\mu g\ g^{-1}$) x 1/22.9898 + H ($\mu mol\ g^{-1}$) + Al ($\mu g\ g^{-1}$) x 3/26.9815 + Fe ($\mu g\ g^{-1}$) x 3/55.847+ Mn ($\mu g\ g^{-1}$) x 2/54.38

Base saturation (%) = (K + Ca + Mg + Na)/CEC x 100

Base cations = K + Ca + Mg +Na

Acid cations = Al + Fe + Mn

3.3.4. Determination of Above-ground Biomass and Total Above-ground Nutrient Pools

Calculation of the above-ground standing biomass were based on allometric functions (Hochbichler, 2008) and inventory data (Hochbichler *et al.*, 2009). Biomass data were given in the following fractions of plants: regeneration plant with DBH < 1.3 m; foliage of canopy trees; branch diameter < 2 cm, branch diameter > 2 cm; total wood and bark at the stem diameter < 8 cm; only wood at the stem diameter > 8 cm, bark at the stem diameter > 8 cm. N, P, K, Ca, S, Al, Mg, Fe and Mn in different fractions were determined according to different species in each study plot. Three *Quercus* trees were cut down in study plots S1, S2, S3 and L2 to collect biomass for nutrient analysis. One whole tree analysis was made in those study plots. Three foliage and branch samples were collected in different crown layer. Three foliage and branch samples were collected in study plots S4, S5, L3, L4 and L5 by using shotgun. Three foliage and branch samples were collected for other species in each study plots. Wood and bark of *Quercus* were separated according to different stem diameter (0-1 cm, 1-2 cm, 2-5 cm and >5 cm) in the lab. ICP-OES analysis was used to determine the nutrient content of foliage, branch, wood and bark. Wood: bark ratio of *Quercus* was calculated according to the stimulated model on a basis of our analyzed data. With the support of wood: bark ratio and different nutrient contents in wood and bark, nutrient pools were determined individually in wood and bark of stems and branches.

3.4. Statistical Data Analysis

Microsoft Excel 2007, SPSS 18.0.0 (23.08.2010) and SigmaPlot 12.0 (Build 12.0.0.54) were used as statistical tools. Illustrator CS5 (05.05.2012) was used to improve the figure quality. Effects of stand age and soil type on soil properties, exchangeable cations, base cations, acid cations and CEC at different soil horizons were analyzed by one-way ANOVA in SPSS. *Principal component analysis (PCA) is a mathematical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The number of principal components is less than or equal to the number of original variables. This transformation is defined in such a way that the first principal component has the largest possible variance (that is accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it be orthogonal to (i.e., uncorrelated with) the preceding components (WIKIPEDIA, 2012).* PCA was applied by SPSS to determine the correlation of different parameters. Equamax Rotation Method (ERM) was applied in selected PCA to obtain simple and interpretable factors and to get better understandings of parameter correlations in component 1 and component 2. Kaiser-Meyer-Olkin (KMO) value was used to measure the sampling adequacy. Bivariate correlation was applied to verify the correlation among stand age, soil properties and nutrient pools in above-ground standing biomass. In correlation analysis, stand age was converted into scale levels where: 0 represents rapid growing period (0-40 years); 1 represents stable growing period (40-80 years); 2 represents senescing period (>80 years).

4. Results

4.1. Above-ground Biomass

Above-ground standing biomass, organic C, wood: bark ratio and litter biomass were selected for this study.

4.1.1. Above-ground Standing Biomass

Above-ground standing biomass was calculated in different fractions (foliage of the canopy, regeneration, branch in different diameters, wood and bark). Table 4.1 shows the above-ground biomass was: 12.5 Mg ha^{-1} in S1, 100 Mg ha^{-1} in S2, 129 Mg ha^{-1} in S3, 142 Mg ha^{-1} in S4, 136 Mg ha^{-1} in S5, 130 Mg ha^{-1} in L2, 149 Mg ha^{-1} in L3, 153 Mg ha^{-1} in L4 and 130 Mg ha^{-1} in L5. The biomass was increasing with the stand age until the stable development stage was reached at the study area.

Figure 4.1 shows the study plot L5 had the highest woody biomass. Biomass was mainly contributed by stems and branches. Stands before the senescing period host the highest biomass both in Eutric Cambisol and Haplic Luvisol with the higher biomass in study plots S4 and L4. Biomass in different fractions ranked in following orders: stem > branch > bark > foliage > regeneration. There were exceptions when the stand was very young or has lots of regeneration.

Table 4. 1 Above-ground standing biomass (Mg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austrian. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch of diameter < 2 cm, Bh > 2 cm represents branch of diameter > 2 cm, S+Bk < 8 cm represents total stem and bark when stem diameter < 8 cm, S > 8 cm represents wood of stem diameter > 8 cm, Bk > 8 cm represents bark of stem diameter > 8 cm.

Study plot	Biomass in different fractions (Mg ha^{-1})							Total biomass (Mg ha^{-1})
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	1.56	3.49	1.51	1.01	1.70	2.78	0.47	12.5
S2	7.05	0.30	9.52	10.7	14.8	47.5	10.0	100
S3	3.10	3.21	14.4	22.3	8.22	65.6	12.0	129
S4	2.25	0.01	14.7	35.6	1.57	75.7	12.1	142
S5	2.44	1.25	13.3	37.1	4.35	66.8	10.9	136
L2	4.74	0.03	13.4	19.6	16.5	63.8	12.2	130
L3	3.21	7.28	16.88	26.7	5.80	75.6	13.2	149
L4	2.62	2.52	15.87	35.0	4.80	80.5	11.7	153
L5	2.54	0.02	14.33	29.1	8.10	65.5	10.7	130

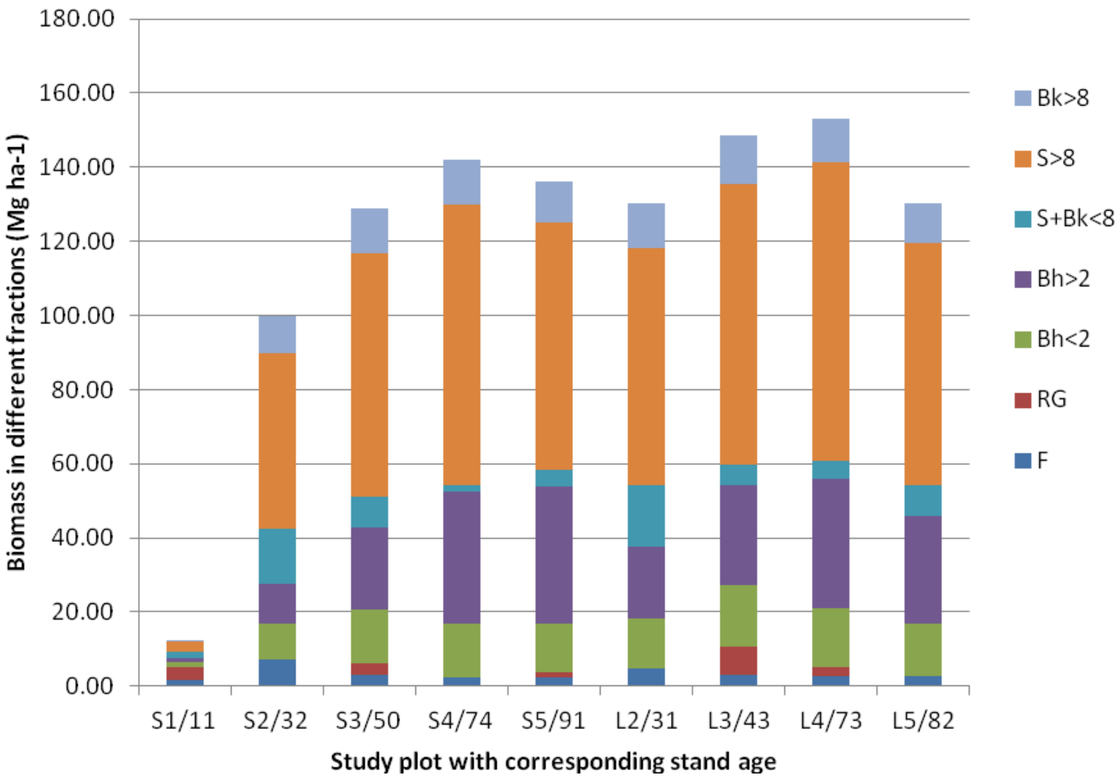


Figure 4. 1 Above-ground standing biomass (Mg ha^{-1}) in different fractions of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, RG represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch of diameter < 2 cm, Bh > 2 cm represents branch of diameter > 2 cm, S+Bk < 8 cm represents total stem and bark when stem diameter < 8 cm, S > 8 cm represents wood of stem diameter > 8 cm, Bk > 8 cm represents bark of stem diameter > 8 cm.

4.1.2. Above-ground Organic C Pools

Above-ground organic C was calculated in different fractions in above-ground as well. Table 4.2 shows the organic C in above-ground were: 6.36 Mg ha^{-1} in S1, 50.5 Mg ha^{-1} in S2, 65.0 Mg ha^{-1} in S3, 71.7 Mg ha^{-1} in S4, 68.9 Mg ha^{-1} in S5, 65.6 Mg ha^{-1} in L2, 75.1 Mg ha^{-1} in L3, 77.5 Mg ha^{-1} in L4 and 65.7 Mg ha^{-1} in L5.

Above-ground organic C was increasing with the stand age until stable growing period at this study area, which was obviously the same trend as with biomass.

Table 4. 2 Above-ground organic C pool (Mg ha^{-1}) in different fractions and total C pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch of diameter < 2 cm, Bh > 2 cm represents branch of diameter > 2 cm, S+Bk < 8 cm represents total stem and bark when stem diameter < 8 cm, S > 8 cm represents wood of stem diameter > 8 cm, Bk > 8 cm represents bark of stem diameter > 8 cm.

Study plot	**Organic C in different fractions (Mg ha^{-1})**							**Total C pool (Mg ha^{-1})**
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	0.79	1.78	0.77	0.51	0.87	1.39	0.24	6.36
S2	3.56	0.15	4.86	5.46	7.52	23.8	5.15	50.5
S3	1.56	1.61	7.33	11.3	4.18	32.9	6.15	65.0
S4	1.13	0.00	7.49	18.1	0.81	37.9	6.20	71.7
S5	1.23	0.64	6.75	18.9	2.20	33.5	5.59	68.8
L2	2.40	0.01	6.75	9.95	8.31	32.0	6.17	65.6
L3	1.61	3.71	8.64	13.6	2.91	37.8	6.79	75.1
L4	1.31	1.28	8.13	17.9	2.41	40.4	6.05	77.5
L5	1.27	0.01	7.32	14.8	4.07	32.7	5.51	65.7

4.1.3. Wood:bark Ratio of *Quercus petraea*

Wood and bark were separated for the *Quercus* branch and stem samples. The model of wood: bark ratio was set up based on our data (Figure 4.2). The wood:bark ratio was increasing with the increasing diameter of stem or branch (Figure 4.2).

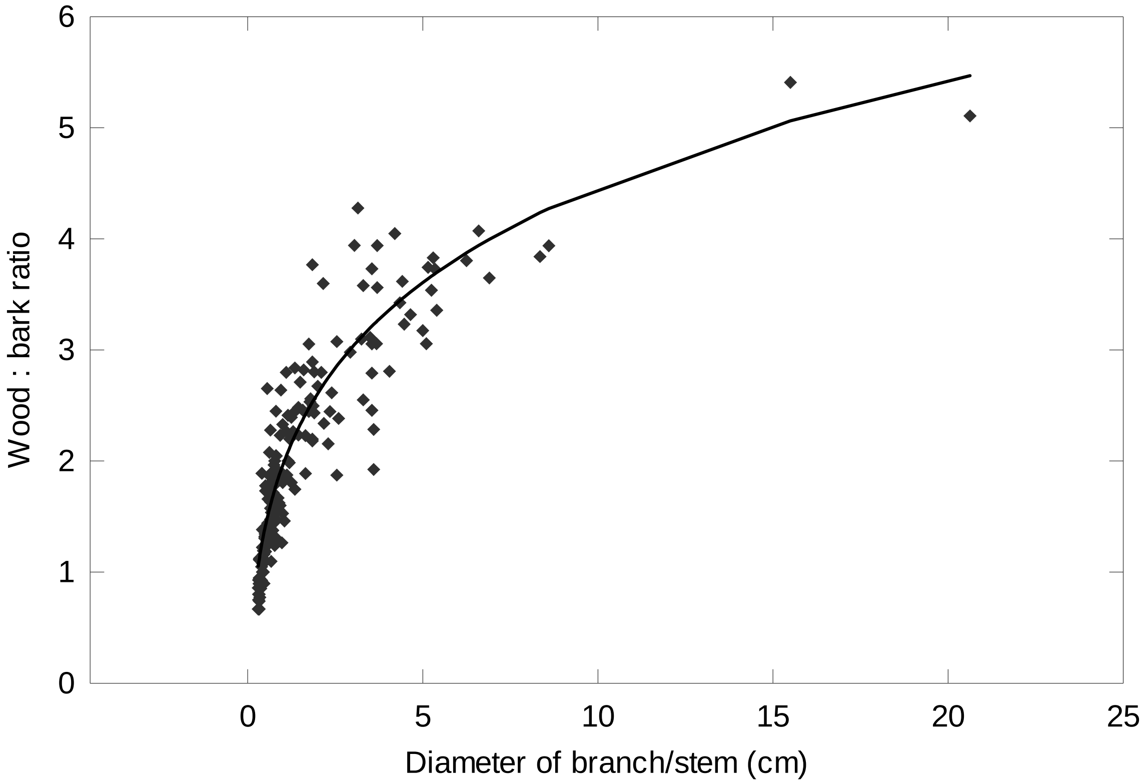


Figure 4. 2 Model of wood:bark ratio for *Quercus petraea* in North-East Austria.

The correlation of wood: bark ratio with branch and stem diameter was:

$Y = (a+b*\ln(x))^2$, (a = 1.399773, b = 0.31010983)

4.1.4. Litter Biomass

Eighteen ecto-humus samples were collected from each plot in this study area. Dry mass was determined after oven drying (80 °C) to constant weight. N and C of ecto-humus were determined after grinding. Table 4.1 shows the dry mass, N and C in Litter in the nine study plots. Mean values in different plots ranged from 9.72 – 17.5 Mg ha^{-1} for dry mass, from 130 – 229 kg ha^{-1} for N and from 3.99 – 6.83 Mg ha^{-}1 for C in litter (Table 4.3).

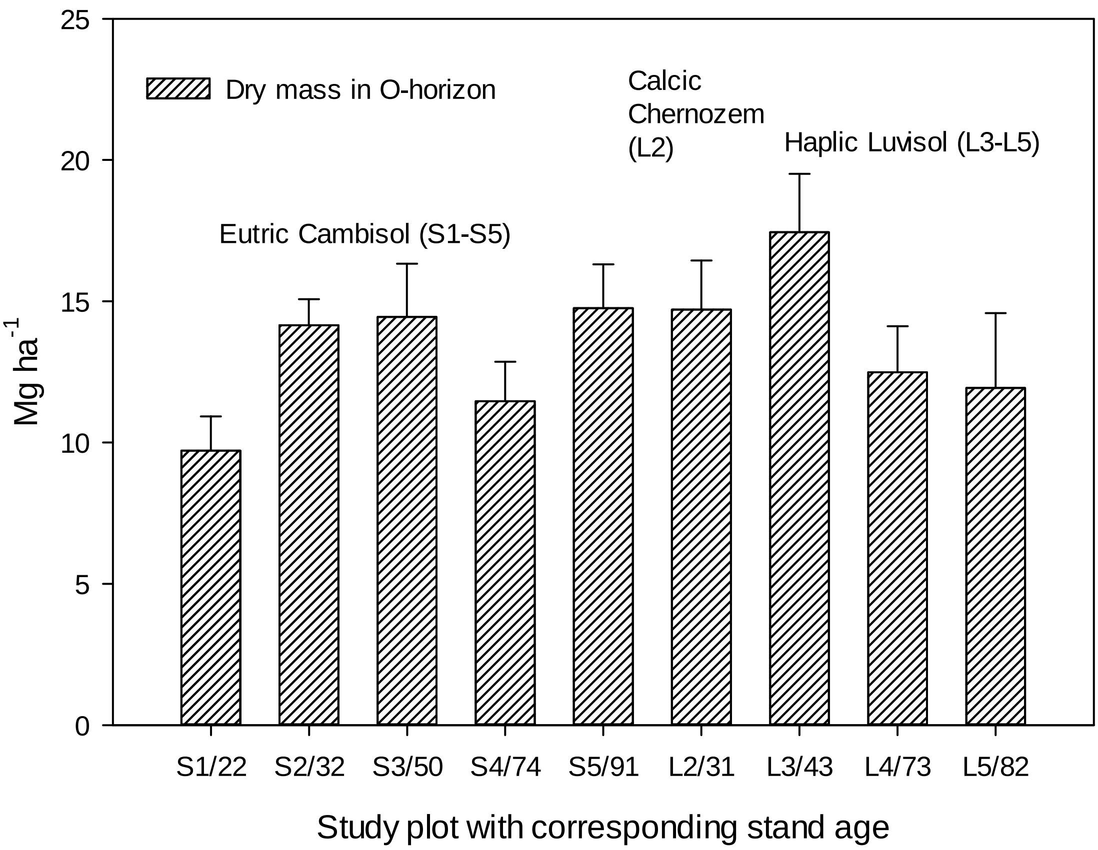
Table 4. 3 Litter dry mass (Mg ha^{-1}) as well as N (kg ha^{-1}) and C (Mg ha^{-1}) in the litter of the nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

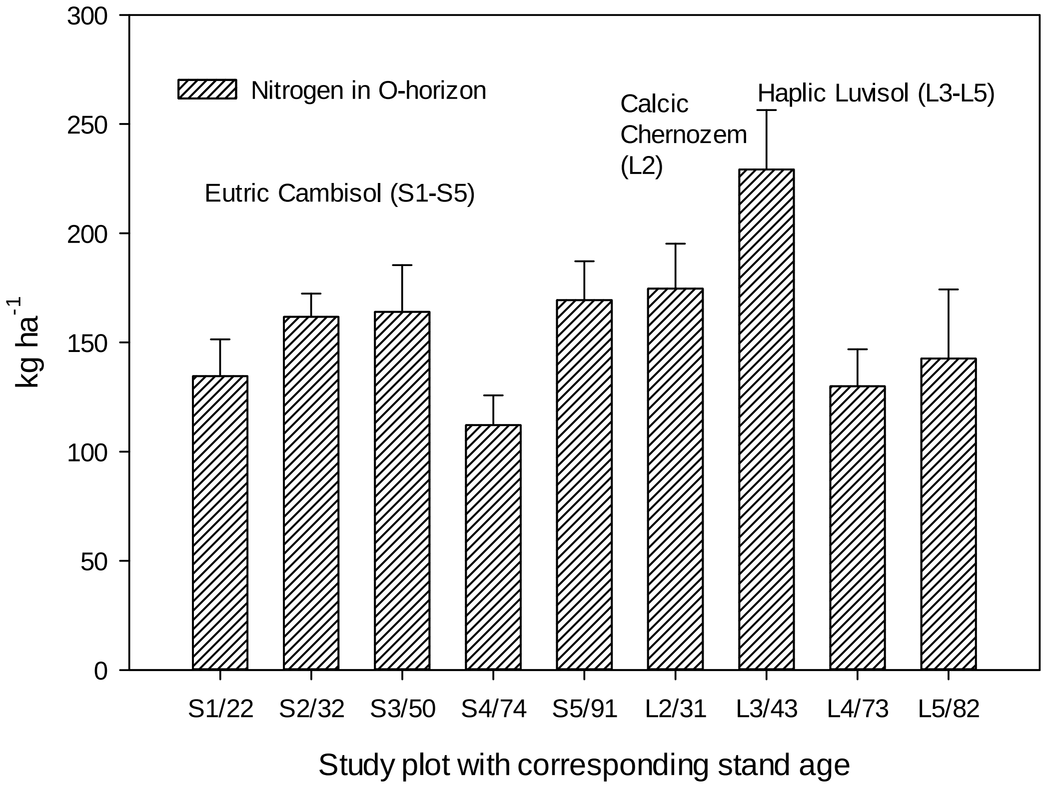
Study plot	Litter dry mass (Mg ha^{-1})	N (kg ha^{-1})	C (Mg ha^{-1})
S1	9.72 ± 1.21^{a}	135 ± 17^{ab}	4.71 ± 0.56^{a}
S2	14.2 ± 0.92	162 ± 11^{ab}	5.43 ± 0.34
S3	14.5 ± 1.88	164 ± 20^{ab}	5.39 ± 0.59
S4	11.5 ± 1.4^{ab}	112 ± 14^{a}	3.99 ± 0.46^{a}
S5	14.8 ± 1.55^{bc}	169 ± 18^{ab}	5.65 ± 0.56
L2	14.7 ± 1.73^{bc}	175 ± 21^{ab}	5.15 ± 0.60
L3	17.5 ± 2.07^{c}	229± 27^{c}	6.83 ± 0.82^{b}
L4	12.5 ± 1.63^{ab}	130± 17^{ab}	4.55 ± 0.58^{a}
L5	11.9 ± 2.65^{ab}	143 ± 32^{ab}	4.44 ± 0.94^{a}

Litter dry mass in study plot S1 was significantly lower than in study plots S5, L2 and L3. Litter dry mass in study plot L3 was significantly higher than in study plots

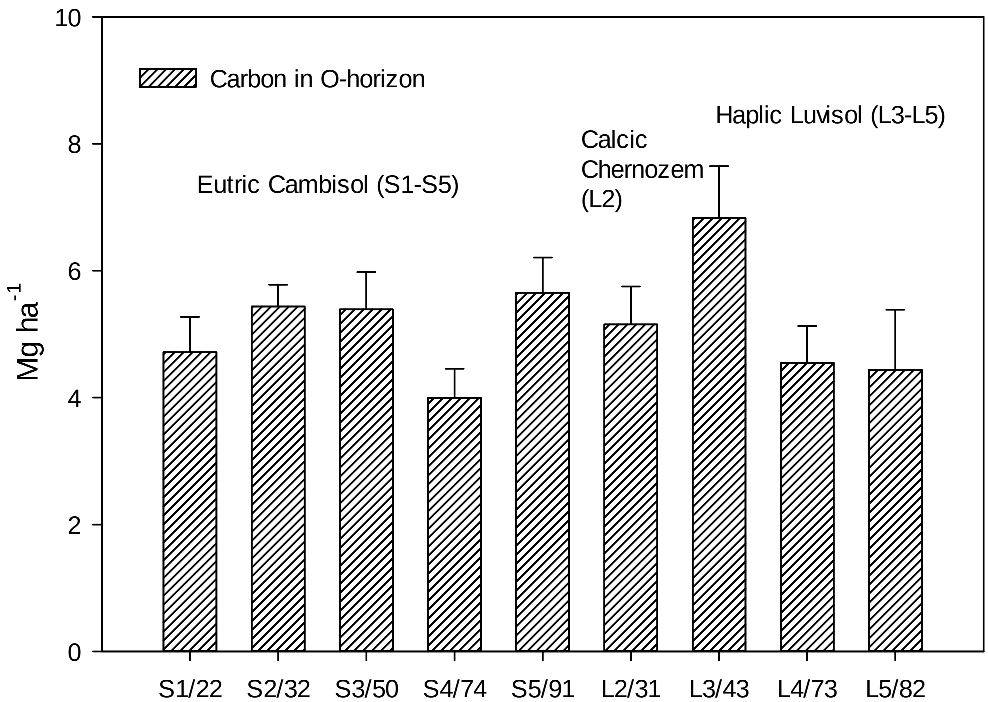
S4, L4 and L5. Study plot L3 had significantly highest Litter N content. C content in study plot L3 was significantly higher than in study plots S1, S4, L4 and L5 (Table 4.3).

Figure 4.3 shows litter dry mass, litter N and litter C were heterogeneously distributed in Eutric Cambisol. S1 had the lowest dry mass and S4 had the lowest C and N in this study plots. Generally L3 had the highest dry mass, N and C among this study plots. Obviously stand age had no decisive influence on litter dry mass, litter C and other mineral nutrients. There the highest litter dry mass, litter N and litter C in Eutric Cambisol were found in the study plot S5 which represents the senescing period of forest. The highest litter dry mass, litter N and litter C in Haplic Luvisol and over all study plots were found in the study plot L3 which represents the stable growing period of forest.





Nitrogen in O-horizon
Calcic
Chernozem
(L2)
Haplic Luvisol (L3-L5)
Eutric Cambisol (S1-S5)
kg ha-1
300
250
200
150
100
50
0
S1/22
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age



Carbon in O-horizon
Haplic Luvisol (L3-L5)
Calcic
Chernozem
(L2)
Eutric Cambisol (S1-S5)
Mg ha-1
10
8
6
4
2
0
S1/22
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age

Figure 4. 3 Pools of litter dry mass (Mg ha^{-1}), litter N (kg ha^{-1}) and litter C (Mg ha^{-1}) in the nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Though there was significant difference of litter dry mass, litter N and litter C in certain different study plots (Table 4.3), ANOVA results show that there was no significant difference of litter dry mass, litter N and litter C within the Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in this study area (Tabel 4.4). The mean values of litter dry mass, litter N and litter C were 13.5 Mg ha^{-1}, 158 kg ha^{-1} and 5.3 Mg ha^{-1} over all study plots (Table 4.4).

Table 4. 4 ANOVA results of litter dry mass (Mg ha^{-1}), litter N (kg ha^{-1}) and litter C (Mg ha^{-1}) in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in North-East Austrian *Quercus* Forest. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. No letters indicate there is no significant difference ($p < 0.05$) between different soil types.

Soil Type	**Dry mass of litter** (Mg ha^{-1})	**Litter N** (kg ha^{-1})	**Litter C** (Mg ha^{-1})
Eutric Cambisol	12.9 ± 0.68	148 ± 8	5.04 ± 0.24
Calcic Chernozem	14.7 ± 1.73	175 ± 20	5.15 ± 0.60
Haplic Luvisol	14.0 ± 1.29	167 ± 17	5.27 ± 0.49
Mean value over all study plots	13.5 ± 0.60	158 ± 7	5.31 ± 0.22

4.2. Root Biomass

Soil root biomass was determined for the different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm) in each study plot. It ranged from 32 to 167 g m^{-2} cm^{-1} at 0-5 cm, from 29 to 82 g m^{-2} cm^{-1} at 5-10 cm, from 20 to 61 g m^{-2} cm^{-1} at 10-20 cm, from 10 to 43 g m^{-2} cm^{-1} at 20-40 cm and from 6 to 81 g m^{-2} cm^{-1} at 40-50 cm (Table 4.5). The mean value of root biomass in total 50 cm of the soil ranged from 27 to 56 g m^{-2} cm^{-1}. In study plot S1 there was highest root biomass in the top of the soil, and the root biomass was decreasing with the increased soil depth. The study plots L3 and L5 shows the same trend as study plot S1. The root biomass was heterogeneously distributed in other study plots.

Table 4. 5 Root biomass (g m^{-2} cm^{-1}) in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	Root biomass (g m^{-2} cm^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	167 ± 13.9^{c}	36 ± 5.4^{a}	20 ± 5.0^{a}	10 ± 2.8^{a}	7 ± 2.6^{a}
S2	78 ± 13.2^{b}	30 ± 5.7^{a}	39 ± 13.5	43 ± 12.0^{b}	32 ± 13.7^{a}
S3	64 ± 9.8^{ab}	45 ± 16.7^{a}	60 ± 12.1^{b}	32 ± 8.3	81± 39^{b}
S4	32 ± 5.9^{a}	56 ± 9.9	61 ± 25.7^{b}	29 ± 9.2	14 ± 6.5^{a}
S5	47 ± 6.3^{ab}	29 ± 3.7^{a}	21 ± 3.7^{a}	19 ± 3.7	21 ± 9.6^{a}
L2	32 ± 3.9^{a}	46 ± 7.4^{a}	30 ± 8.8	25 ± 10.2	22 ± 8.3^{a}
L3	87 ± 34.1^{b}	32 ± 4.6^{a}	25 ± 7.9^{a}	33 ± 8.5	6 ± 1.5^{a}
L4	65 ± 8.2^{ab}	44 ± 9.4^{a}	34 ± 9.0	38 ± 11.0^{b}	26 ± 11.7^{a}
L5	86 ± 7.2^{b}	82 ± 27.4^{b}	36 ± 6.8	26 ± 8.2	24 ± 16.0^{a}

Root biomass in S3 was significantly higher than in other plots, and in S5 was significantly lower than in other plots (Figure 4.4). There was an increasing trend of root biomass in rapid growing period up to 50 years old in Eutric Cambisol. The root biomass was stable or decreasing from the stable period to mature and senescing period of forest.

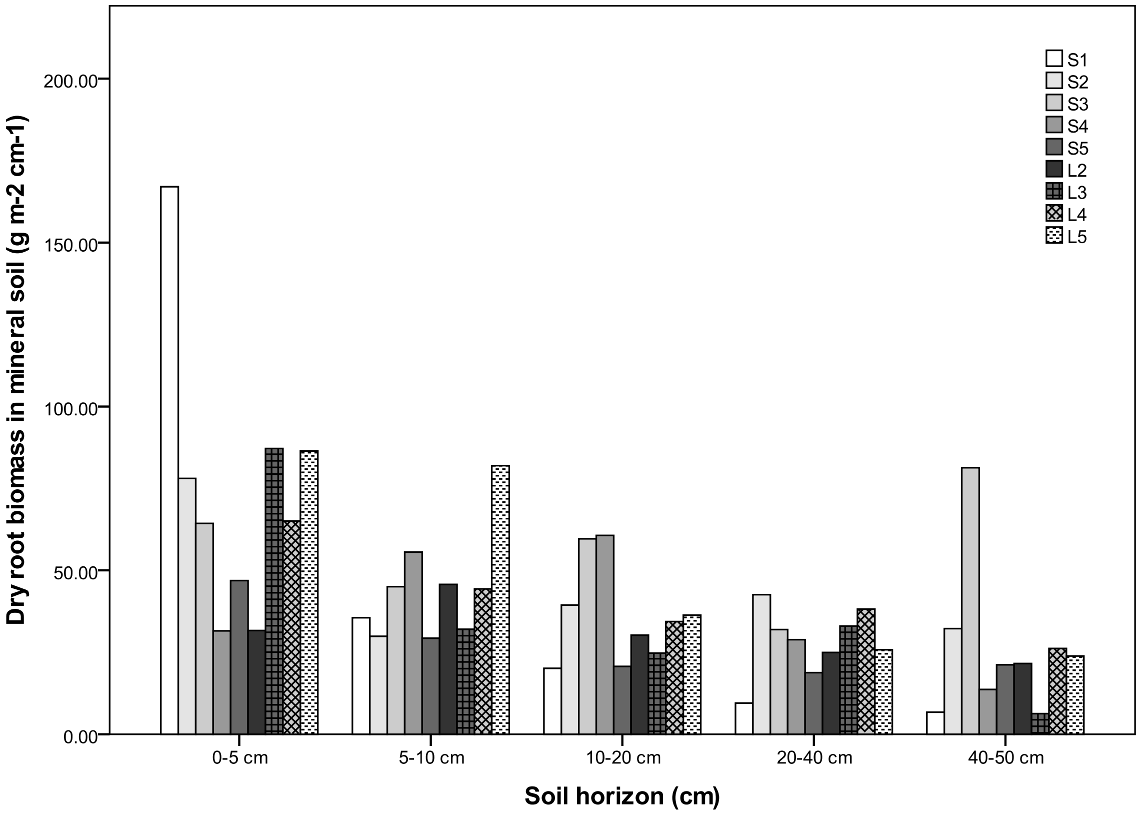


Figure 4. 4 Dry root biomass in mineral soil (g m^{-2} cm^{-1}) of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

In the top of the soil, the root biomass in Calcic Chernozem was significantly lower than in Eutric Cambisol and Haplic Luvisol. There was no significant difference of root biomass in the deep soil horizons and in total 50 cm of the soil among three soil types. Root biomass in different soil horizons were: 73 g m^{-2} cm^{-1} at 0 - 5 cm, 44 g m^{-2} cm^{-1} at 5 - 10 cm, 36 g m^{-2} cm^{-1} at 10 - 20 cm, 29 g m^{-2} cm^{-1} at 20 - 40 cm and 19 g m^{-2} cm^{-1} at 40 – 50 cm over all study plots (Table 4.6). The mean value of root biomass in total of 50 cm soils was 42 g m^{-2} cm^{-1} over all study plots.

Table 4. 6 Root biomass (g m^{-2} cm^{-1}) in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in North-East Austria. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**Root biomass (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	78 ± 8.4[b]	39 ± 4.3	40 ± 6.7	26 ± 3.8	31 ± 9.2
Calcic Chernozem	32 ± 11.7[a]	46 ± 7.4	30 ± 8.8	25 ± 10.2	22 ± 8.3
Haplic Luvisol	80 ± 11.6[b]	53 ± 10.2	32 ± 4.5	32 ± 5.3	19± 6.6
Mean value over all study plots	73 ± 6.3	44 ± 4.3	36 ± 4.1	29 ± 9.2	26 ± 5.6

4.3. Soil Properties

4.3.1. Soil Bulk Density

Soil bulk density was determined from nine study plots according to soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm) (Table 4.7). Soil bulk density in the top 5 cm of the soil was significantly lower than in other horizons. It ranged from 0.74 g cm^{-3} to 0.93 g cm^{-3} at 0-5 cm of the soil, 1.04 g cm^{-3} to 1.66 g cm^{-3} at 5-10 cm of the soil, 1.26 g cm^{-3} to 1.78 g cm^{-3} at 10-20 cm of the soil, 1.27 g cm^{-3} to 1.81 g cm^{-3} at 20-40 cm of the soil and 1.26 g cm^{-3} to 1.79 g cm^{-3} at 40-50 cm of the soil. There was an increase of soil bulk density with increasing soil horizons up to 20 cm and afterwards it became heterogeneous (Figure 4.5). The mean value of soil bulk density in different study plots were: 1.65 g cm^{-3} in S1, 1.48 g cm^{-3} in S2, 1.62 g cm^{-3} in S3, 1.51 g cm^{-3} in S4, 1.56 g cm^{-3} in S5, 1.21 g cm^{-3} in L2, 1.38 g cm^{-3} in L3, 1.26 g cm^{-3} in L4, 1.23 g cm^{-3} in L5 (Table 4.7).

Table 4. 7 Soil bulk density (g cm^{-3}) in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	**Soil bulk density (g cm^{-3}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	0.99 ± 0.11^{b}	1.66 ± 0.10^{c}	1.73 ± 0.13^{b}	1.65 ± 0.19^{bc}	1.78 ± 0.08^{c}
S2	0.74 ± 0.07^{a}	1.31 ± 0.05^{b}	1.67 ± 0.07^{b}	$1.64 \pm 0.07b^{c}$	1.71 ± 0.08^{bc}
S3	0.93 ± 0.21^{b}	1.29 ± 0.05^{b}	1.63 ± 0.09^{b}	1.81 ± 0.09^{c}	1.79 ± 0.18^{c}
S4	0.89 ± 0.13^{ab}	1.30 ± 0.04^{b}	1.46 ± 0.18^{ab}	1.79 ± 0.09^{c}	1.75 ± 0.09^{c}
S5	0.88 ± 0.19^{ab}	1.41 ± 0.06^{bc}	1.78 ± 0.08^{b}	1.79 ± 0.05^{c}	1.75 ± 0.09^{c}
L2	0.86 ± 0.11^{ab}	1.17 ± 0.03^{a}	1.26 ± 0.02^{a}	1.27 ± 0.04^{a}	1.26 ± 0.03^{a}
L3	0.85 ± 0.08^{ab}	1.22 ± 0.03^{ab}	1.44 ± 0.03^{ab}	1.54 ± 0.04^{b}	1.75 ± 0.10^{c}
L4	0.85 ± 0.15^{ab}	1.15 ± 0.04^{a}	1.30 ± 0.03^{a}	1.45 ± 0.01^{ab}	1.57 ± 0.07^{b}
L5	0.86 ± 0.03^{ab}	1.04 ± 0.12^{a}	1.37 ± 0.03^{a}	1.44 ± 0.01^{ab}	1.43 ± 0.03^{b}

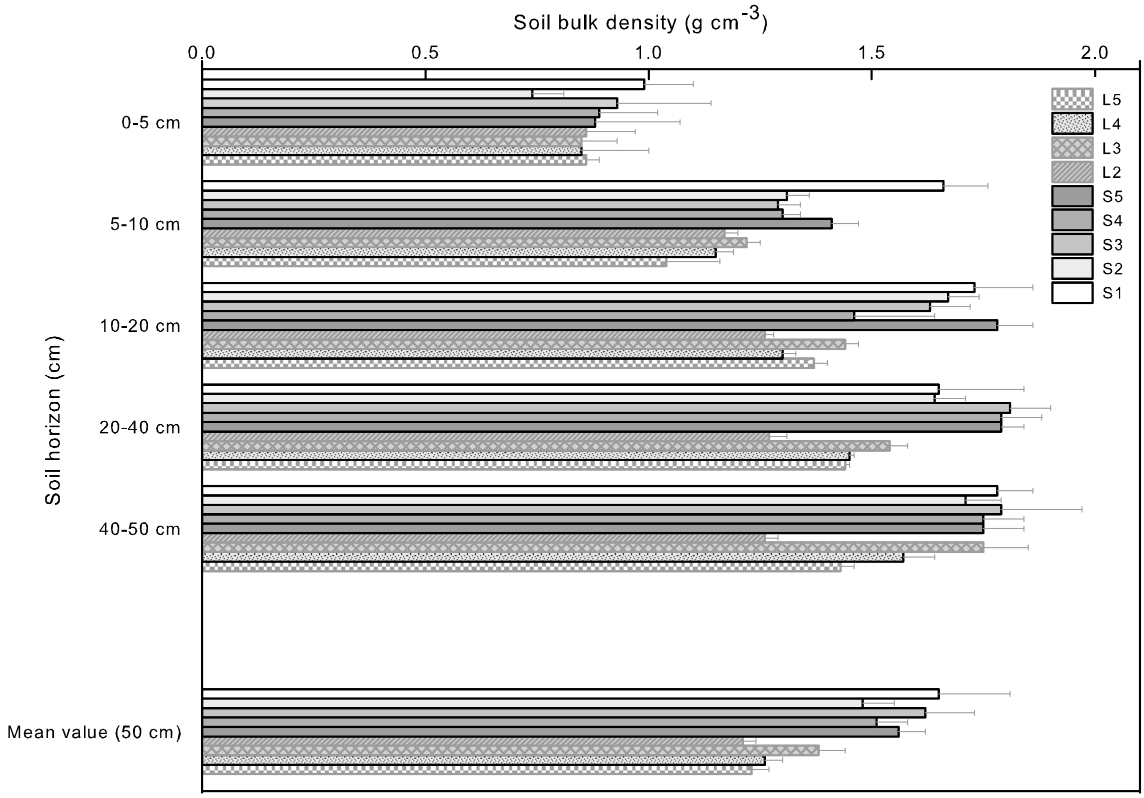


Figure 4. 5 Soil bulk density (g cm^{-3}) in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard errors.

There was no significant difference of soil bulk density in the top 5 cm of the soil among Eutric Cambisol, Calcic Chernozem and Haplic Luvisol (Table 4.8). With the increasing of soil horizons up to 50 cm, the soil bulk density in Eutric Cambisol was significantly higher than in Calcic Chernozem and Haplic Luvisol (Table 4.8). Take the consideration of the top 50 cm of the soil soil: the soil bulk density in Calcic Chernozem was significantly lower than in Eutric Cambisol and Haplic Luvisol; Eutric Cambisol had the significant highest soil bulk density. The mean value of soil bulk density was 0.86 g cm^{-3} at the 0-5 cm soil, 1.21 g cm^{-3} at the 5-10 cm soil, 1.36 g cm^{-3} at the 10-20 cm soil, 1.47 g cm^{-3} at the 20-40 cm soil, 1.67 g cm^{-3} at the 40-50 cm soil and 1.31 g cm^{-3} for the top 50 cm of the soil over all study plots.

Table 4. 8 Soil bulk density (g cm^{-3}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in North-East Austria. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	Soil bulk density (g cm^{-3}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	0.86 ± 0.02	1.27 ± 0.02^b	1.40 ± 0.03^b	1.53 ± 0.01^c	1.76 ± 0.06^c
Calcic Chernozem	0.86 ± 0.11	1.17 ± 0.03	1.26 ± 0.02^a	1.27 ± 0.04^a	1.26 ± 0.03^a
Haplic Luvisol	0.85 ± 0.02	1.13 ± 0.04^a	1.34 ± 0.01	1.43 ± 0.01^b	1.54 ± 0.03^b
Mean value over all study plots	0.86 ± 0.01	1.21 ± 0.02	1.36 ± 0.02	1.47 ± 0.01	1.67 ± 0.04

4.3.2. Soil pH

Active acidity (soil pH H_2O) and exchangeable acidity (soil pH $CaCl_2$) in nine study plots were determined for this study (Table 4.9). Generally there was a decrease of pH value with increasing of soil depth up to 20 cm, and then it turned to an increase of pH value with increasing of soil depth. The pH (H_2O) in the top 50 cm of the soil were: 5.2 in S1, 4.8 in S2, 5.5 in S3, 5.4 in S4, 5.1 in S5, 7.1 in L2, 5.2 in L3, 5.4 in L4 and 5.5 in L5. The pH $CaCl_2$ in the top 50 cm of the soil were: 4.3 in S1, 3.8 in S2, 4.6 in S3, 4.4 in S4, 4.1 in S5, 6.6 in L2, 4.2 in L3, 4.5 in L4 and 4.4 in L5.

Soil active acidity and exchangeable acidity were heterogeneously distributed in Eutric Cambisol and Haplic Luvisol. It shows that the stand age had no decisive effects on soil acidity (Figure 4.6). There were no significant differences of soil acidity among rapid growing period, stable growing period and mature and senescing period of forest. The effect of forest growth on soil acidity was not obvious in *Quercus* stands in North-East Austria.

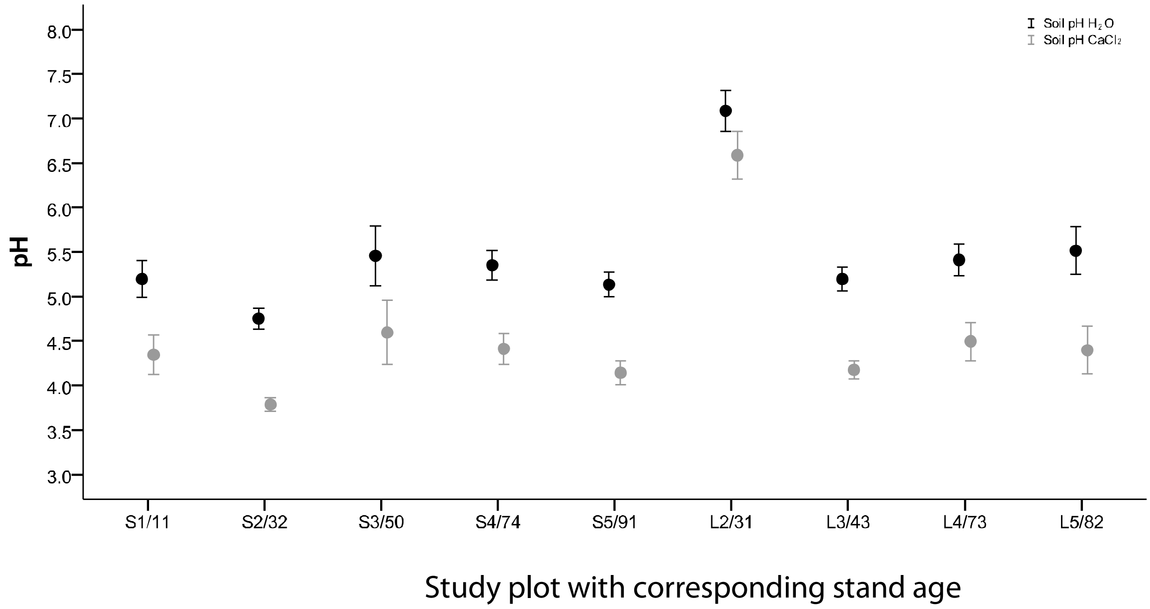


Figure 4. 6 Soil active acidity (pH H_2O) and exchangeable acidity (pH $CaCl_2$) in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Table 4. 9 Soil active acidity (pH H_2O) and exchangeable acidity (pH $CaCl_2$) in different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Study plot	Soil acidity									
	0-5 cm		5-10 cm		10-20 cm		20-40 cm		40-50 cm	
	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$
S1	5.6 ± 0.26^{c}	4.5 ± 0.30^{b}	5.0 ± 0.24^{b}	4.2 ± 0.28^{b}	4.8 ± 0.11^{ab}	4.0 ± 0.10^{ab}	5.0 ± 0.13^{a}	4.1 ± 0.08^{ab}	5.6 ± 0.26^{ab}	4.6 ± 0.30^{b}
S2	4.5 ± 0.07^{a}	4.1 ± 0.06^{a}	4.4 ± 0.06^{a}	3.6 ± 0.05^{a}	4.5 ± 0.05^{a}	3.6 ± 0.04^{a}	5.0 ± 0.07^{a}	3.8 ± 0.04^{a}	5.3 ± 0.07^{a}	4.1 ± 0.06^{a}
S3	5.0 ± 0.19^{b}	5.2 ± 0.53^{c}	5.0 ± 0.28^{b}	4.2 ± 0.28^{b}	5.3 ± 0.36^{b}	4.5 ± 0.41^{b}	5.8 ± 0.41^{b}	4.9 ± 0.47^{c}	6.2 ± 0.06^{bc}	5.2 ± 0.53^{bc}
S4	5.4 ± 0.17^{bc}	4.8 ± 0.26^{bc}	5.0 ± 0.17^{b}	4.2 ± 0.19^{b}	5.1 ± 0.14^{b}	4.1 ± 0.11^{ab}	5.4 ± 0.10^{ab}	4.3 ± 0.08^{b}	5.8 ± 0.21^{b}	4.8 ± 0.26^{b}
S5	5.3 ± 0.13^{b}	4.4 ± 0.11^{ab}	4.8 ± 0.13^{ab}	3.9 ± 0.15^{ab}	4.8 ± 0.08^{ab}	3.8 ± 0.08^{a}	5.2 ± 0.09^{a}	4.1 ± 0.06^{ab}	5.6 ± 0.14^{a}	4.4 ± 0.11^{ab}
L2	6.8 ± 0.20^{d}	7.1 ± 0.23^{d}	6.8 ± 0.27^{c}	6.3 ± 0.34^{c}	6.8 ± 0.26^{c}	6.3 ± 0.34^{c}	7.3 ± 0.23^{c}	6.7 ± 0.30^{d}	7.8 ± 0.19^{d}	7.1 ± 0.23^{d}
L3	4.9 ± 0.08^{b}	4.6 ± 0.03^{bc}	4.7 ± 0.10^{ab}	3.8 ± 0.08^{a}	5.0 ± 0.25^{b}	4.0 ± 0.07^{ab}	5.5 ± 0.04^{b}	4.3 ± 0.04^{b}	5.8 ± 0.04^{b}	4.6 ± 0.03^{b}
L4	5.3 ± 0.20^{b}	4.9 ± 0.25^{c}	5.1 ± 0.24^{b}	4.3 ± 0.30^{b}	5.1 ± 0.18^{b}	4.3 ± 0.25^{b}	5.5 ± 0.05^{b}	4.4 ± 0.03^{b}	6.0 ± 0.16^{b}	4.9 ± 0.25^{b}
L5	5.0 ± 0.14^{b}	5.4 ± 0.40^{c}	4.9 ± 0.12^{b}	3.8 ± 0.08^{a}	5.2 ± 0.13^{b}	4.0 ± 0.08^{ab}	5.9 ± 0.25^{b}	4.7 ± 0.35^{bc}	6.6 ± 0.35^{c}	5.4 ± 0.40^{c}

Table 4. 10 Soil active acidity (pH H_2O) and exchangeable acidity (pH $CaCl_2$) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in North-East Austria. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	pH value in different soil horizons											
	0-5 cm		5-10 cm		10-20 cm		20-40 cm		40-50 cm		Mineral soil 0-50 cm	
	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$	pH H_2O	pH $CaCl_2$
Eutric Cambisol	5.2 ± 0.09[a]	4.4 ± 0.10[a]	4.9 ± 0.09[a]	4.0 ± 0.10[a]	4.9 ± 0.09[a]	4.0 ± 0.10[a]	5.3 ± 0.10[a]	4.2 ± 0.11[a]	5.7 ± 0.12[a]	4.6 ± 0.14[a]	5.2 ± 0.05[a]	4.3 ± 0.05[a]
Calcic Chernozem	6.8 ± 0.20[b]	6.5 ± 0.22[b]	6.8 ± 0.27[b]	6.3 ± 0.34[b]	6.8 ± 0.26[b]	6.3 ± 0.34[b]	7.3 ± 0.23[c]	6.7 ± 0.30[b]	7.8 ± 0.19[c]	7.1 ± 0.23[b]	7.1 ± 0.12[c]	6.6 ± 0.13[b]
Haplic Luvisol	5.1 ± 0.09[a]	4.3 ± 0.10[a]	4.9 ± 0.10[a]	4.0 ± 0.11[a]	5.1 ± 0.08[a]	4.1 ± 0.09[a]	5.7 ± 0.09[b]	4.5 ± 0.10[a]	6.1 ± 0.14[b]	5.0 ± 0.16[a]	5.4 ± 0.06[b]	4.4 ± 0.06[a]
Mean value over all study plots	5.3 ± 0.09	4.6 ± 0.10	5.1 ± 0.09	4.3 ± 0.11	5.2 ± 0.09	4.3 ± 0.11	5.6 ± 0.10	4.6 ± 0.11	6.1 ± 0.11	5.0 ± 0.13	5.5 ± 0.05	4.5 ± 0.05

4.3.3. Soil Nitrogen

Soil N content (g m^{-2} cm^{-1}) was determined in nine study plots according to different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm). There was generally a decrease of N content with soil depth in all study plots. The N content ranged: from 18.2 g m^{-2} cm^{-1} to 29.3 g m^{-2} cm^{-1} in the 0-5 cm of the soil; from 10.7 g m^{-2} cm^{-1} to 25.4 g m^{-2} cm^{-1} in the 5-10 cm of the soil, from 6.1 g m^{-2} cm^{-1} to 18.1 g m^{-2} cm^{-1} in the 10-20 cm of the soil, from 4.5 g m^{-2} cm^{-1} to 9.8 g m^{-2} cm^{-1} in the 20-40 cm of the soil and from 4.5 g m^{-2} cm^{-1} to 8.0 g m^{-2} cm^{-1} in the 40-50 cm of the soil over all study plots (Table 4.11). The difference of N content among different study plots at different soil horizons is shown in Table 4.11.

Table 4. 11 Nitrogen content (g m^{-2} cm^{-1}) at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	Soil nigrogen content (g m^{-2} cm^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	24.0 ± 4.9^{bcd}	10.8 ± 1.4^{a}	6.1 ± 0.6^{a}	4.5 ± 0.6^{a}	5.6 ± 0.8^{ab}
S2	20.6 ± 1.5^{ab}	10.7 ± 0.8^{a}	7.0 ± 0.5^{a}	6.2 ± 0.4^{abcd}	6.5 ± 0.4^{ab}
S3	20.5 ± 3.1^{ab}	13.6 ± 1.5^{ab}	10.4 ± 1.6^{bc}	6.7 ± 0.8^{bcd}	5.0 ± 0.6^{ab}
S4	18.2 ± 1.5^{a}	14.1 ± 1.5^{ab}	7.4 ± 0.9^{ab}	5.0 ± 0.6^{ab}	4.5 ± 0.7^{a}
S5	21.3 ± 1.3^{abc}	14.8 ± 1.1^{ab}	9.3 ± 0.7^{abc}	5.8 ± 0.4^{abc}	8.0 ± 3.0^{b}
L2	29.3 ± 1.2^{e}	25.4 ± 2.1^{c}	18.1 ± 2.6^{d}	9.8 ± 1.1^{f}	6.5 ± 0.5^{ab}
L3	24.9 ± 4.5^{cd}	14.8 ± 1.2^{b}	11.0 ± 1.0^{c}	7.7 ± 0.5^{de}	7.3 ± 0.3^{ab}
L4	27.8 ± 5.9^{de}	15.2 ± 0.6^{b}	10.7 ± 0.6^{bc}	7.5 ± 0.5^{cde}	7.3 ± 0.3^{ab}
L5	24.1 ± 1.5^{bcd}	14.0 ± 2.0^{ab}	12.1 ± 0.8^{c}	9.1 ± 0.3^{ef}	7.4 ± 0.4^{ab}

The mean value of N content in the top 50 cm of the soil was: 10.2 g m^{-2} cm^{-1} in S1, 10.2 g m^{-2} cm^{-1} in S2, 11.3 g m^{-2} cm^{-1} in S3, 9.9 g m^{-2} cm^{-1} in S4, 11.8 g m^{-2} cm^{-1} in S5, 17.8 g m^{-2} cm^{-1} in L2, 13.3 g m^{-2} cm^{-1} in L3, 13.7 g m^{-2} cm^{-1} in L4 and 13.3 g m^{-2} cm^{-1} in L5 (Table 4.11).

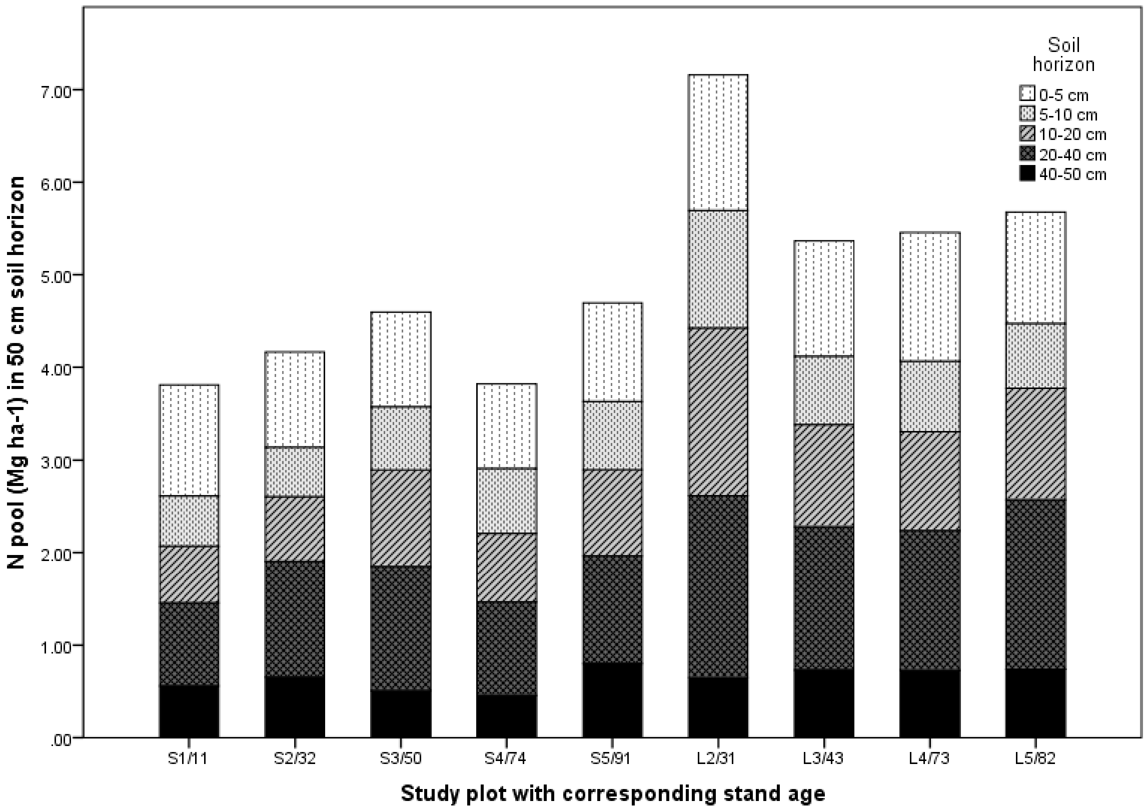


Figure 4. 7 Nitrogen pool (total nitrogen in Mg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

The total N pool in the top 50 cm soil were 3 800 kg ha^{-1} in study plot S1, 4 170 kg ha^{-1} in study plot S2, 4 600 kg ha^{-1} in forest S3, 3 820 kg ha^{-1} in study plot S4, 4 700 kg ha^{-1} in study plot S5, 7 160 kg ha^{-1} in study plot L2, 5 360 kg ha^{-1} in study plot L3, 5 460 kg ha^{-1} in study plots L4 and 5 680 kg ha^{-1} in study plot L5. Soil N content in study plot L2 was significantly higher than in other study plots (Figure 4.7). There was no significant difference of N content among different plots in

Eutric Cambisol and Haplic Luvisol. No matter the forest were in rapid growing period, stable period or mature and senescing period, N pool in the soil were not affected. The stand age had no large influences on soil N pools.

N content in Calcic Chernozem was significantly higher than in Eutric Cambisol and Haplic Luvisol in the top 40 cm of the soil (Table 4.12). There was no significant difference of N content among three soil types in the 40-50 cm soil. N content in Haplic Luvisol was significantly higher than in Eutric Cambisol at the 0-5 and 10-40 cm soil. Calcic Chernozem had significant highest N content in total 50 cm of the soil with the mean value of 17.8 g m^{-2} cm^{-1}. Mean value of N content in Haplic Luvisol was 13.4 g m^{-2} cm^{-1} and significantly higher than in Eutric Cambisol in the top 50 cm of the soil. Mean value of N content in Eutric Cambisol was 10.7 g m^{-2} cm^{-1} in the top 50 cm of the soil (Table 4.12).

Table 4. 12 Nitrogen content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in North-East Austria. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**Soil N content (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	20.9 ± 0.7^{a}	12.8 ± 0.6^{a}	8.1 ± 0.5^{a}	5.7 ± 0.3^{a}	5.9 ± 0.7^{a}
Calcic Chernozem	29.3 ± 1.2^{c}	25.4 ± 2.1^{b}	18.1 ± 2.6^{c}	9.8 ± 1.1^{c}	6.5 ± 0.5^{a}
Haplic Luvisol	25.6 ± 1.0^{b}	14.7 ± 0.8^{a}	11.3 ± 0.5^{b}	8.1 ± 0.3^{b}	7.3 ± 0.2^{a}
Mean value over all study plots	23.4 ± 0.6	14.8 ± 0.6	10.2 ± 0.5	6.9 ± 0.3	6.5 ± 0.4

4.3.4. Soil Carbon

Soil C content (g m^{-2} cm^{-1}) was determined in nine plots according to different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm). There was a decrease of total C content with the increasing of soil horizons up to the 40 cm soil. Then it turned to be heterogeneously distributed. The total C content ranged: from 241 g m^{-2} cm^{-1} to 418 g m^{-2} cm^{-1} in the top 5 cm of the soil; from 187 g m^{-2} cm^{-1} to 322 g m^{-2} cm^{-1} at 5-10 cm of the soil, from 105 g m^{-2} cm^{-1} to 214 g m^{-2} cm^{-1} at 10-20 cm of the soil, from 62 g m^{-2} cm^{-1} to 134 g m^{-2} cm^{-1} at 20-40 cm of the soil and from 50 g m^{-2} cm^{-1} to 156 g m^{-2} cm^{-1} at the 40-50 cm of the soil over all study plots.

Table 4. 13 Carbon content (g m^{-2} cm^{-1}) at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	**Soil C content (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	418 ± 30^{e}	201 ± 19^{ab}	105 ± 9^{a}	62 ± 5^{a}	62 ± 13^{a}
S2	345 ± 28^{bcd}	190 ± 10^{ab}	108 ± 6^{a}	72 ± 5^{ab}	66 ± 4^{a}
S3	362 ± 15^{bcde}	224 ± 18^{b}	156 ± 17^{b}	97 ± 14^{b}	59 ± 11^{a}
S4	241 ± 29^{a}	216 ± 18^{b}	126 ± 18^{ab}	74 ± 12^{ab}	77 ± 24^{a}
S5	298 ± 18^{ab}	187 ± 13^{ab}	114 ± 6^{ab}	70 ± 5^{ab}	50 ± 6^{a}
L2	369 ± 18^{bcde}	322 ± 27^{c}	214 ± 34^{c}	134 ± 21^{c}	156 ± 26^{b}
L3	379 ± 29^{cde}	205 ± 16^{ab}	125 ± 10^{ab}	78 ± 5^{ab}	59 ± 2^{a}
L4	406 ± 28^{de}	217 ± 8^{b}	141 ± 11^{ab}	82 ± 7^{ab}	63 ± 3^{a}
L5	332 ± 30^{bcd}	164 ± 23^{ab}	134 ± 8^{ab}	83 ± 3^{ab}	90 ± 19^{a}

The mean value of C content in the top 50 cm of the soil were: 170 g m^{-2} cm^{-1} in S1, 156 g m^{-2} cm^{-1} in S2, 180 g m^{-2} cm^{-1} in S3, 147 g m^{-2} cm^{-1} in S4, 144 g m^{-2} cm^{-1} in S5, 239 g m^{-2} cm^{-1} in L2, 169 g m^{-2} cm^{-1} in L3, 182 g m^{-2} cm^{-1} in L4 and 160 g m^{-2} cm^{-1} in L5 (Table 4.13). The difference of C content among different study plots at different soil horizons is shown in Table 4.13 as well.

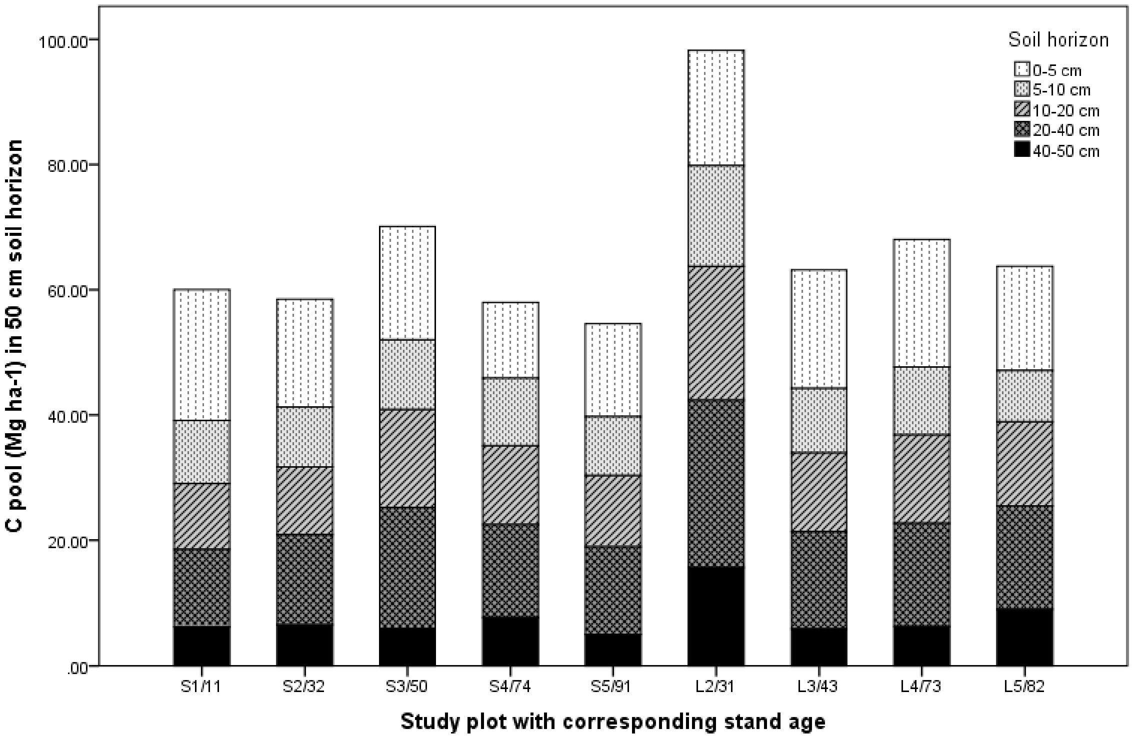


Figure 4. 8 Carbon pool (Mg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

The C pool in the top 50 cm of the soil were 60 Mg ha^{-1} in study plot S1, 58 Mg ha^{-1} in study plot S2, 70 Mg ha^{-1} in forest S3, 58 Mg ha^{-1} in study plot S4, 55 Mg ha^{-1} in study plot S5, 98 Mg ha^{-1} in study plot L2, 63 Mg ha^{-1} in study plot L3, 68 Mg ha^{-1} in forest L4 and 64 Mg ha^{-1} in study plot L5. Soil C content in study plot L2 was significantly higher than in other plots (Figure 4.8). There was no significant difference of C content among Eutric Cambisol plots and Haplic Luvisol plots. C pool in soil was not affected by the forest growing period. The stand age had no large influences on soil C pools.

C content in Calcic Chernozem was significantly higher than in Eutric Cambisol and Haplic Luvisol in 5-50 cm of the soil (Table 4.14). There was no significant difference of C content among three soil types at 0-5 cm of the soil. There was no significant difference of C content between Haplic Luvisol and Eutric Cambisol in all soil horizons. Calcic Chernozem had significant highest C content in 50 cm of the soil with the mean value of 239 g m^{-2} cm^{-1}. Mean value of C content in Eutric Cambisol was 159 g m^{-2} cm^{-1} and in Haplic Luvisol was 13.4 g m^{-2} cm^{-1} in the top 50 cm of the soil (Table 4.14).

Table 4. 14 Carbon content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in North-East Austria. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

	Soil carbon content (g m^{-2} cm^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	332 ± 14^{a}	204 ± 7^{a}	122 ± 6^{a}	75 ± 4^{a}	63 ± 6^{a}
Calcic Chernozem	369 ± 18^{a}	322 ± 27^{b}	214 ± 34^{b}	134 ± 21^{b}	156 ± 26^{b}
Haplic Luvisol	372 ± 17^{a}	195 ± 10^{a}	133 ± 5^{a}	81 ± 3^{a}	71 ± 7^{a}
Mean value over all study plots	350 ± 10	214 ± 7	136 ± 6	83 ± 4	76 ± 6

4.3.5. C:N Ratio

C:N ratio was determined in nine study plots according to different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm). C:N ratio ranged: from 13 to 18 at top 5 cm of the soil; from 12 to 20 at 5-10 cm of the soil, from 11 to 18 at 10-20 cm of the soil, from 9 to 16 at 20-40 cm of the soil and from 8 to 27 at 40-50 cm of the soil over all study plots (Table 4.15). The mean value of C content in the top 50 cm of the soil were: 17 in S1, 15 in S2, 16 in S3, 16 in S4, 12 in S5, 16 in L2, 12 in L3, 13 in L4 and 12 in L5. The difference of C:N ratio among different study plots at different soil horizons is shown in Table 4.15.

Table 4. 15 C:N ratio at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference (p < 0.05) between different study plots.

Study plot	C:N ratio in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	18 ± 0.7^{c}	20 ± 1.5^{d}	18 ± 1.9^{b}	16 ± 2.2^{c}	11 ± 1.3^{ab}
S2	17 ± 0.7^{bc}	18 ± 1.0^{cd}	16 ± 1.2^{b}	12 ± 0.7^{ab}	10 ± 0.2^{ab}
S3	18 ± 0.7^{c}	18 ± 1.8^{cd}	16 ± 1.2^{b}	15 ± 1.1^{bc}	11 ± 1.1^{ab}
S4	15 ± 2.2^{ab}	16 ± 1.2^{bc}	17 ± 1.5^{b}	15 ± 1.5^{bc}	17 ± 2.7^{b}
S5	14 ± 0.3^{ab}	12 ± 0.3^{a}	13 ± 0.5^{a}	13 ± 1.3	10 ± 1.1^{ab}
L2	13 ± 0.4^{ab}	14 ± 1.5^{ab}	12 ± 0.3^{a}	16 ± 3.8^{c}	27 ± 5.6^{c}
L3	15 ± 0.6^{ab}	14 ± 0.5^{ab}	12 ± 0.4^{a}	11 ± 0.6^{ab}	8 ± 0.4^{a}
L4	15 ± 0.6^{ab}	15 ± 0.3^{ab}	13 ± 0.6^{a}	11 ± 0.7^{ab}	9 ± 0.3^{a}
L5	14 ± 0.3^{ab}	12 ± 0.4^{a}	11 ± 0.4^{a}	9 ± 0.4^{a}	13 ± 3.0^{ab}

C:N ratio was heterogeneously distributed at different soil horizons (Figure 4.9). C:N ratio was significantly higher at 40-50 cm of the soil in study plot L2.

C:N ratio in Eutric Cambisol was significantly higher than in Calcic Chernozem and Haplic Luvisol in the top 20 cm of the soil. There was no significant difference of C:N ratio at the top 20 cm of the soil between Calcic Chernozem and Haplic Luvisol. C:N ratio in Haplic Luvisol was significantly lower than in Eutric Cambisol and Calcic Chernozem at 20-40 cm of the soil. There was no significant difference of C:N ratio between Eutric Cambisol and Calcic Chernozem at 20-40 cm of the soil. C:N ratio in Calcic Chernozem was significantly higher than in Eutric Cambisol and Haplic Luvisol at 40-50 cm of the soil. There was no significant difference of C:N ratio between Eutric Cambisol and Haplic Luvisol at 40-50 cm of the soil.

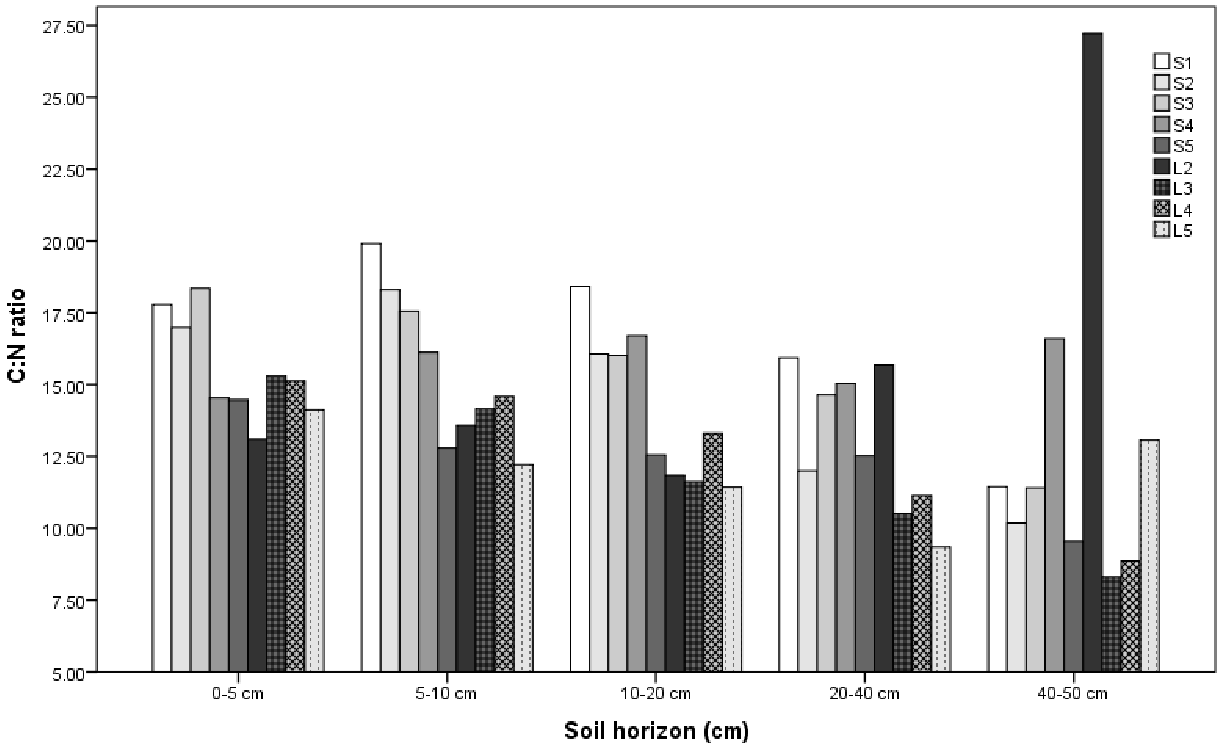


Figure 4. 9 Mean value of C:N ratio at different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm) in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Considering the top 50 cm of the soil: the C:N ratio in Haplic Luvisol was significantly lower than in Eutric Cambisol and Calcic Chernozem; there was no significant difference of C:N ratio between Eutric Cambisol and Calcic Chernozem. Mean value of C:N ratio was: 15 in Eutric Cambisol; 16 in Calcic Chernozem; and 12 in Haplic Luvisol in the top 50 cm of the soil (Table 4.16).

Table 4. 16 C:N ratio at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in North-East Austrian *Quercus* Forest. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**C:N ratio in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	16 ± 0.5^b	17 ± 0.7^b	16 ± 0.6^b	14 ± 0.7^b	12 ± 0.7^a
Calcic Chernozem	13 ± 0.4^a	14 ± 1.5^a	12 ± 0.3^a	16 ± 3.8^b	27 ± 5.6^b
Haplic Luvisol	15 ± 0.3^a	14 ± 0.3^a	12 ± 0.3^a	10 ± 0.4^a	10 ± 1.0^a
Mean value over all study plots	16 ± 0.3	15 ± 0.4	14 ± 0.4	13 ± 0.6	13 ± 1.0

4.3.6. Exchangeable Cations

Exchangeable K, Ca, Mg, Na, Al, Fe and Mn were selected and determined at different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm) in nine study plots for this study.

4.3.6.1. Exchangeable K

The exchangeable K ranged from 2.0 to 3.7 g m^{-2} cm^{-1} at 0-5 cm of the soil, from 1.5 to 3.3 g m^{-2} cm^{-1} at 5-10 cm of the soil, from 1.2 to 3.1 g m^{-2} cm^{-1} at 10-20 cm of the soil, from 1.6 to 3.7 g m^{-2} cm^{-1} at 20-40 cm of the soil and from 2.5 to 4.4 g m^{-2} cm^{-1} at 40 - 50 cm of the soil (Table 4.17). The mean value of exchangeable K in the top 50 cm of the soil were 2.1 g m^{-2} cm^{-1} in study plot S1, 2.4 g m^{-2} cm^{-1} in forest S2, 2.3 g m^{-2} cm^{-1} in forest S3, 2.3 g m^{-2} cm^{-1} in forest S4, 2.3 g m^{-2} cm^{-1} in forest S5, 3.1 g m^{-2} cm^{-1} in forest L2, 2.8 g m^{-2} cm^{-1} in forest L3, 2.6 g m^{-2} cm^{-1} in forest L4 and 3.2 g m^{-2} cm^{-1} in forest L5 (Table 4.17). The exchangeable K in study plots L2, L3 and L5 was significantly higher than in study plots S1, S2, S3, S4 and S5 in the top 50 cm of the soil. The difference of exchangeable K among different study plots at different soil horizons are shown in Table 4.17.

Table 4. 17 Exchangeable K (g m^{-2} cm^{-1}) at different soil horizon in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	**Exchangeable K (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	2.6 ± 0.5^{ab}	1.5 ± 0.4^{a}	1.2 ± 0.3^{a}	1.6 ± 0.3^{a}	3.6 ± 0.8
S2	2.0 ± 0.1^{a}	1.6 ± 0.1^{ab}	1.5 ± 0.2^{ab}	2.4 ± 0.3^{bc}	4.4 ± 0.3^{c}
S3	2.5 ± 0.3^{ab}	2.0 ± 0.3^{ab}	1.9 ± 0.3^{b}	2.2 ± 0.3^{ab}	2.9 ± 0.4^{ab}
S4	2.2 ± 0.2^{ab}	1.9 ± 0.2^{ab}	1.4 ± 0.3^{ab}	2.2 ± 0.4^{ab}	4.0 ± 0.6^{bc}
S5	2.4 ± 0.2^{ab}	1.9 ± 0.2^{ab}	1.7 ± 0.2^{ab}	2.5 ± 0.5^{bc}	3.2 ± 0.7
L2	3.7 ± 0.1^{c}	3.3 ± 0.2^{c}	3.1 ± 0.2^{d}	2.9 ± 0.1^{bcd}	2.5 ± 0.2^{a}
L3	2.7 ± 0.1^{ab}	2.0 ± 0.2^{ab}	2.2 ± 0.2^{bc}	3.1 ± 0.2^{cd}	4.0 ± 0.1^{bc}
L4	2.7 ± 0.1^{b}	1.8 ± 0.1^{ab}	1.8 ± 0.1^{ab}	2.6 ± 0.1^{bc}	3.9 ± 0.2^{bc}
L5	3.5 ± 0.3^{c}	2.3 ± 0.3^{ab}	2.9 ± 0.2^{cd}	3.7 ± 0.1^{d}	3.8 ± 0.3

The total pool of exchangeable K in the top 50 cm of the soil were 1 000 kg ha^{-1} in study plot S1, 1 250 kg ha^{-1} in study plot S2, 1 150 kg ha^{-1} in forest S3, 1 190 kg ha^{-1} in study plot S4, 1 200 kg ha^{-1} in study plot S5, 1 490 kg ha^{-1} in study plot L2, 1 490 kg ha^{-1} in study plot L3, 1 310 kg ha^{-1} in forest L4 and 1 690 kg ha^{-1} in study plot L5 (Figure 4.10). Study plot L5 had the highest exchangeable K pool and study plot S1 had the lowest exchangeable K pool among all study plots.

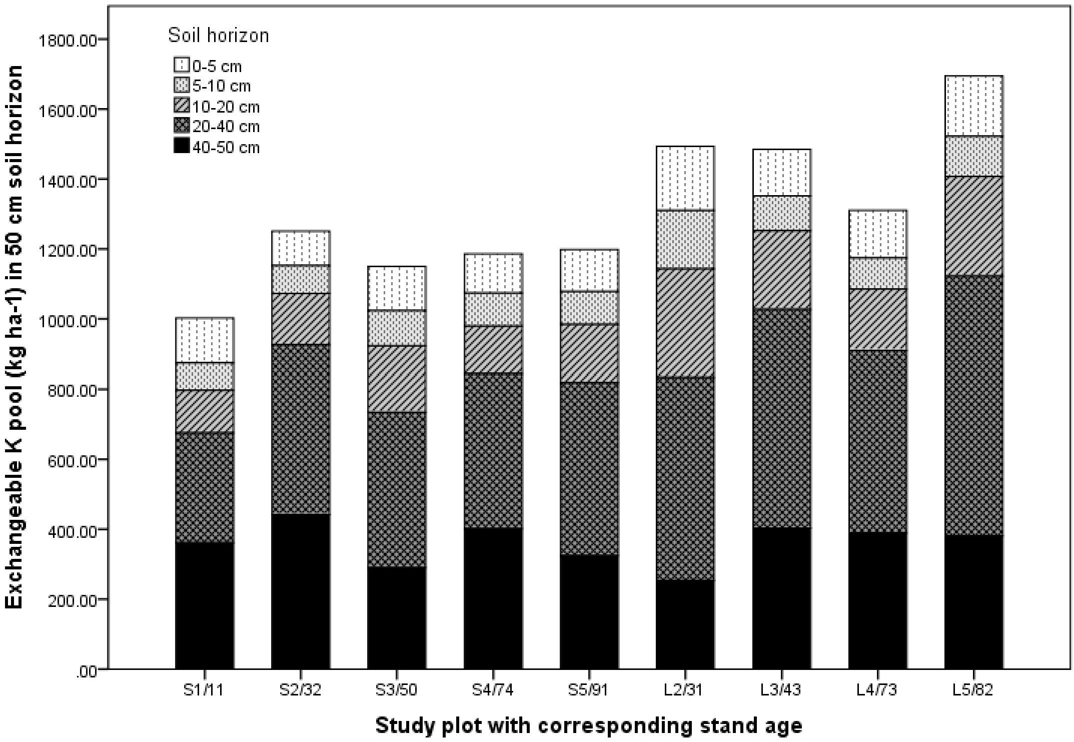


Figure 4. 10 Exchangeable K pool (kg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

The exchangeable K was heterogeneously distributed without any age induced trend in eturic cambisol and Haplic Luvisol. Therefore no decisive influence of the stand age on the exchangeable K pools was detected in this study.

Table 4. 18 Exchangeable K (g m^{-2} cm^{-1}) at different soil horizons in three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in North-East Austria. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**Exchangeable K (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	2.34 ± 0.13^{a}	1.78 ± 0.13^{a}	1.52 ± 0.11^{a}	2.18 ± 0.17^{a}	3.64 ± 0.26^{b}
Calcic Chernozem	3.67 ± 0.09^{c}	3.33 ± 0.17^{b}	3.10 ± 0.24^{c}	2.90 ± 0.14^{b}	2.54 ± 0.16^{a}
Haplic Luvisol	2.95 ± 0.13^{b}	2.03 ± 0.13^{a}	2.28 ± 0.12^{b}	3.14 ± 0.11^{b}	3.91 ± 0.10^{b}
Mean value over all study plots	2.69 ± 0.10	2.03 ± 0.10	1.95 ± 0.10	2.58 ± 0.11	3.61 ± 0.16

Table 4.18 shows the exchangeable K content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol. Calcic Chernozem had the significantly highest exchangeable K in the top 20 cm of the soil in this study area. The exchangeable K in Haplic Luvisol was significantly higher than in Eutric Cambisol at 0-5 cm of the soil. There was no significant difference of exchangeable K between Calcic Chernozem and Haplic Luvisol in the top 50 cm of the soil. The exchangeable K in Eutric Cambisol was significantly lower than in Calcic Chernozem and Haplic Luvisol. The mean value of exchangeable K over all study plots were 2.69 g m^{-2} cm^{-1} at 0-5 cm of the soil, 2.03 g m^{-2} cm^{-1} at 5-10 cm of the soil, 1.95 g m^{-2} cm^{-1} at 10-20 cm of the soil, 2.58 g m^{-2} cm^{-1} at 20-40 cm of the soil and 3.61 g m^{-2} cm^{-1} at 40-50 cm of the soil.

4.3.6.2. Exchangeable Ca

The exchangeable Ca ranged from 3.3 to 29.2 g m^{-2} cm^{-1} at 0-5 cm of the soil, from 1.1 to 33.3 g m^{-2} cm^{-1} at 5-10 cm of the soil, from 1.0 to 36.2 g m^{-2} cm^{-1} at 10-20 cm of the soil, from 4.1 to 32.5 g m^{-2} cm^{-1} at 20-40 cm of the soil and from 11 to 32.9 g m^{-2} cm^{-1} at 40 to 50 cm of the soil (Table 4.19).

Table 4. 19 Exchangeable Ca (g m^{-2} cm^{-1}) at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	**Exchangeable Ca (g m^{-2} cm^{-1}) in differents soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	9.4 ± 1.7^{b}	4.1 ± 1.7^{ab}	1.9 ± 0.7^{ab}	4.1 ± 1.7^{a}	11.0 ± 3.5^{a}
S2	3.3 ± 0.6^{a}	1.1 ± 0.3^{a}	1.0 ± 0.2^{a}	5.6 ± 1.6^{a}	17.0 ± 2.5^{ab}
S3	8.5 ± 1.9^{b}	8.8 ± 3.3^{b}	10.1 ± 4.4^{bc}	12.9 ± 4.5^{b}	15.5 ± 3.8^{ab}
S4	8.1 ± 1.6^{b}	6.4 ± 1.9^{ab}	4.2 ± 1.5^{abc}	11.8 ± 3.1^{b}	27.4 ± 5.2^{cd}
S5	9.3 ± 1.3^{b}	5.3 ± 1.2^{ab}	5.0 ± 1.6^{abc}	13.6 ± 4.1^{b}	22.9 ± 6.3^{bc}
L2	29.2 ± 1.6^{c}	33.3 ± 3.3^{c}	36.2 ± 6.4^{d}	32.5 ± 1.1^{d}	30.2 ± 0.8^{cd}
L3	8.4 ± 1.0^{b}	4.4 ± 1.2^{ab}	6.8 ± 1.4^{abc}	18.7 ± 1.1^{c}	31.5 ± 1.4^{cd}
L4	11.6 ± 1.7^{b}	7.1 ± 2.1^{b}	7.2 ± 2.4^{abc}	12.5 ± 1.1^{b}	24.9 ± 1.4^{bcd}
L5	8.0 ± 1.4^{b}	6.1 ± 1.6^{ab}	10.6 ± 2.2^{c}	24.6 ± 2.5^{c}	32.9 ± 1.1^{d}

The mean value of exchangeable Ca in the top 50 cm of the soil were 6.1 g m^{-2} cm^{-1} in study plot S1, 5.6 g m^{-2} cm^{-1} in study plot S2, 11.2 g m^{-2} cm^{-1} in study plot S3, 11.6 g m^{-2} cm^{-1} in study plot S4, 11.2 g m^{-2} cm^{-1} in study plot S5, 32.3 g m^{-2} cm^{-1} in study plot L2, 13.9 g m^{-2} cm^{-1} in study plot L3, 12.7 g m^{-2} cm^{-1} in forest L4 and 16.5 g m^{-2} cm^{-1} in study plot L5 (Table 4.19). The exchangeable Ca in study plot L2 was the significantly highest among all study plots in the top 50 cm of the soil. The exchangeable Ca in study plots L3, L4 and L5 was significantly higher than study plots L1 and L2 in the top 50 cm of the soil. The difference of exchangeable Ca among different study plots at different soil horizons are shown in Table 4.19.

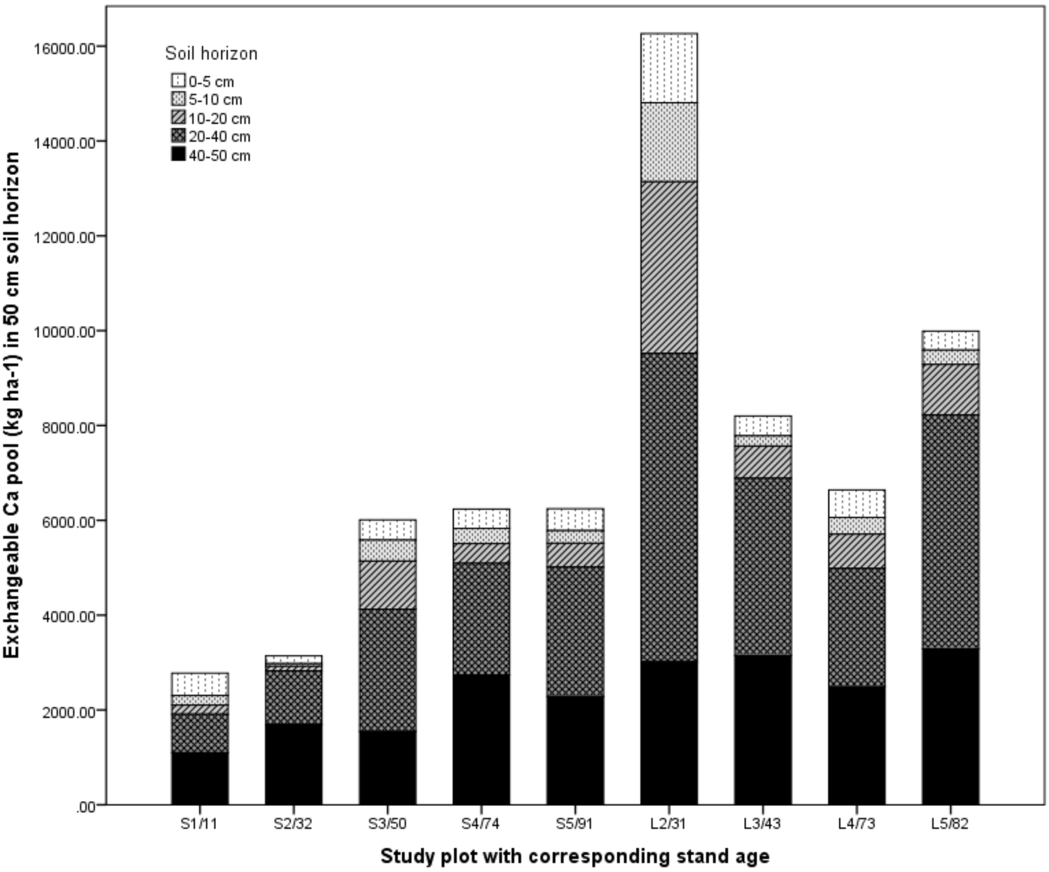


Figure 4. 11 Exchangeable Ca pool (kg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

The total pool of exchangeable Ca in the top 50 cm of the soil were 2 780 kg ha^{-1} in study plot S1, 3 140 kg ha^{-1} in study plot S2, 6 110 kg ha^{-1} in study plot S3, 6 240 kg ha^{-1} in study plot S4, 6 250 kg ha^{-1} in study plot S5, 16 300 kg ha^{-1} in study plot L2, 8 200 kg ha^{-1} in study plot L3, 6 640 kg ha^{-1} in study plot L4 and 9 990 kg ha^{-1} in study plot L5 (Figure 4.11). Study plot L2 had significantly the highest exchangeable Ca pool among all study plots. Exchangeable Ca pool in study plots S1 and S2 was significantly lower than other study plots. Study plot S1 had lowest exchangeable Ca pool among all study plots. The exchangeable Ca was heterogeneously distributed without any age induced trend in Haplic Luvisol. There was no significant difference of exchangeable Ca between stable growing period and senescing period in Eutric Cambisol.

Table 4. 20 Exchangeable Ca (g m^{-2} cm^{-1}) at different soil horizons in three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in North-East Austrian *Quercus* forest. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**Exchangeable Ca (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	7.7 ± 0.73^{a}	5.2 ± 0.9^{a}	4.4 ± 1.1^{a}	9.6 ± 1.5^{a}	18.7 ± 2.1^{a}
Calcic Chernozem	29.2 ± 1.64^{b}	33.3 ± 3.3^{b}	36.2 ± 6.4^{c}	32.5 ± 1.1^{c}	30.2 ± 0.8^{b}
Haplic Luvisol	9.3 ± 0.8^{a}	5.8 ± 0.9^{a}	8.2 ± 2.0^{b}	18.6 ± 1.4^{b}	29.8 ± 1.0^{b}
Mean value over all study plots	10.7 ± 0.9	8.5 ± 1.2	9.2 ± 1.5	15.1 ± 1.3	23.7 ± 1.4

Table 4.20 shows the exchangeable Ca content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol. Calcic Chernozem had the significantly highest exchangeable Ca at 0-40 cm of the soil in this study area. There was no significant difference of exchangeable Ca between

Eutric Cambisol and Haplic Luvisol at 0-10 cm of the soil. The exchangeable Ca in Eutric Cambisol was significantly lower than in Haplic Luvisol at 10-50 cm of the soil. Calcic Chernozem had the significantly highest exchangeable Ca in the top 50 cm of the soil. The exchangeable Ca in Eutric Cambisol was significantly lower than in Haplic Luvisol at the top 50 cm soil. The mean value of exchangeable Ca over all study plots were 10.7 g m^{-2} cm^{-1} at 0-5 cm of the soil, 8.5 g m^{-2} cm^{-1} at 5-10 cm of the soil, 9.2 g m^{-2} cm^{-1} at 10-20 cm of the soil, 15.1 g m^{-2} cm^{-1} at 20-40 cm of the soil and 23.7 g m^{-2} cm^{-1} at 40-50 cm of the soil.

4.3.6.3. Exchangeable Mg

The exchangeable Mg ranged from 0.6 to 3.2 g m^{-2} cm^{-1} at 0-5 cm of the soil, from 0.4 to 3.4 g m^{-2} cm^{-1} at 5-10 cm of the soil, from 0.2 to 3.9 g m^{-2} cm^{-1} at 10-20 cm of the soil, from 0.6 to 4.7 g m^{-2} cm^{-1} at 20-40 cm of the and from 0.6 to 7.6 g m^{-2} cm^{-1} at 40 to 50 cm of the soil (Table 4.21). The mean value of exchangeable Mg at the top 50 cm soil were 0.7 g m^{-2} cm^{-1} in study plot S1, 2.3 g m^{-2} cm^{-1} in study plot S2, 1.4 g m^{-2} cm^{-1} in study plot S3, 1.6 g m^{-2} cm^{-1} in study plot S4, 1.6 g m^{-2} cm^{-1} in study plot S5, 3.2 g m^{-2} cm^{-1} in study plot L2, 2.8 g m^{-2} cm^{-1} in study plot L3, 3.1 g m^{-2} cm^{-1} in study plot L4 and 3.2 g m^{-2} cm^{-1} in study plot L5 (Table 4.21). The exchangeable Mg in study plots L2, L3, L4 and L5 was significantly higher than in study plots S1, S2, S3, S4 and S5 in the top 50 cm of the soil. The difference of exchangeable Mg among different study plots at different soil horizons are shown in Table 4.21.

The total pool of exchangeable Mg in the top 50 cm soil were 351 kg ha^{-1} in study plot S1, 1 325 kg ha^{-1} in study plot S2, 779 kg ha^{-1} in study plot S3, 906 kg ha^{-1} in study plot S4, 951 kg ha^{-1} in study plot S5, 1 579 kg ha^{-1} in study plot L2, 1 672 kg ha^{-1} in study plot L3, 1 755 kg ha^{-1} in study plot L4 and 1 903 kg ha^{-1} in study plot L5 (Figure 4.12). Study plot L5 had the significantly highest exchangeable Mg pool and study plot S1 had the significantly lowest exchangeable Mg pool among all study plots. Study plot S2 had the significantly highest Mg pool in the top 20 cm soil among all study plots. The exchangeable Mg pool in study plot S2 was significantly higher than other study plots in Eutric Cambisol due to the large contribution from 40-50 cm of the soil. The exchangeable Mg pool was increasing with the increase of stand age in Eutric Cambisol and Haplic Luvisol the large amount of exchange Mg (the reason could be the difference of parent material) at 40-50 cm of the soil in study plot S2 was not considered.

Table 4. 21 Exchangeable Mg (g m^{-2} cm^{-1}) at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	**Exchangeable Mg (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	0.7 ± 0.1^{ab}	0.4 ± 0.2^{a}	0.2 ± 0.1^{a}	0.6 ± 0.2^{a}	1.6 ± 0.4^{a}
S2	0.6 ± 0.1^{a}	0.4 ± 0.1^{a}	0.4 ± 0.1^{ab}	2.0 ± 0.4^{b}	8.3 ± 5.3^{c}
S3	1.0 ± 0.2^{ab}	0.9 ± 0.2^{ab}	0.9 ± 0.3^{ab}	1.6 ± 0.4^{ab}	2.9 ± 0.8^{a}
S4	1.0 ± 0.2^{ab}	0.9 ± 0.2^{ab}	0.7 ± 0.2^{ab}	1.9 ± 0.4^{b}	3.7 ± 0.5^{a}
S5	1.0 ± 0.1^{ab}	0.8 ± 0.2^{ab}	0.9 ± 0.2^{ab}	2.2 ± 0.4^{bc}	3.4 ± 0.9^{a}
L2	3.2 ± 0.5^{c}	3.4 ± 0.6^{c}	3.9 ± 1.1^{d}	3.2 ± 0.5^{cd}	2.2 ± 0.2^{a}
L3	1.2 ± 0.1^{b}	1.0 ± 0.2^{ab}	1.6 ± 0.2^{bc}	3.8 ± 0.2^{de}	6.6 ± 0.7^{b}
L4	1.5 ± 0.1^{b}	1.1 ± 0.1^{b}	1.5 ± 0.2^{bc}	3.6 ± 0.4^{de}	7.6 ± 0.6^{b}
L5	1.5 ± 0.2^{b}	1.4 ± 0.3^{b}	2.3 ± 0.4^{c}	4.7 ± 0.5^{e}	5.9 ± 0.7^{b}

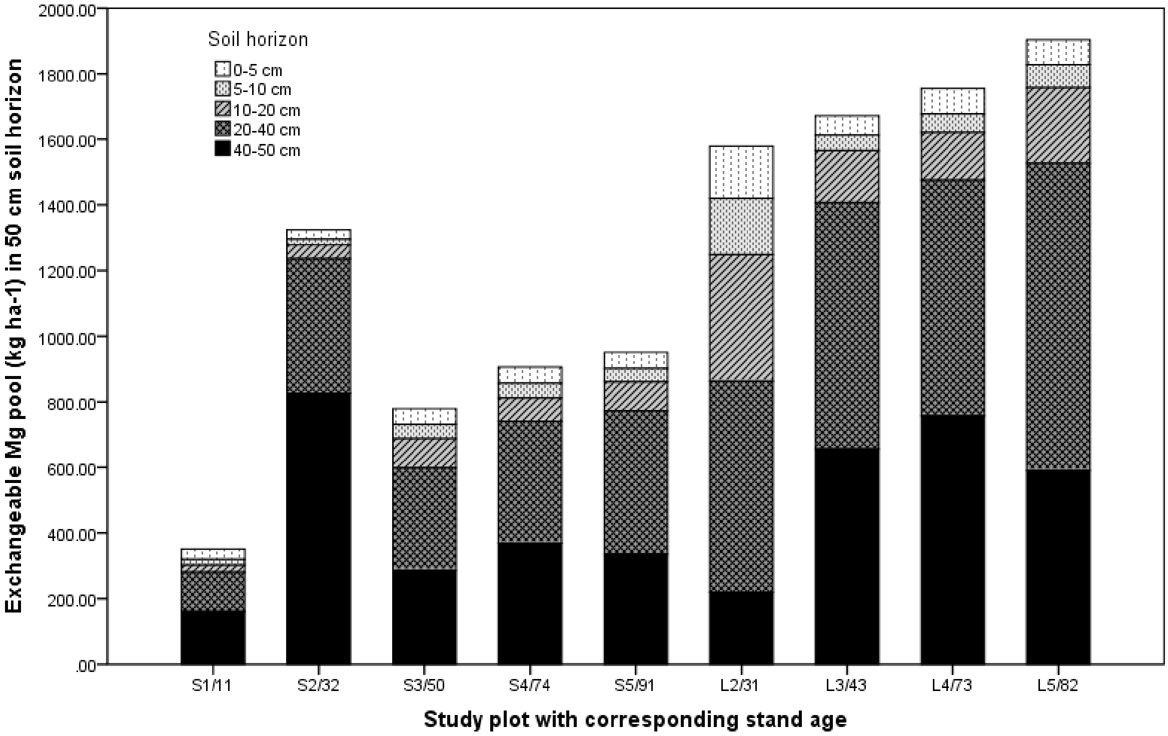


Figure 4. 12 Exchangeable Mg pool (kg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Table 4.22 shows the exchangeable Mg content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol. Calcic Chernozem had the significantly highest exchangeable Mg in the top 0-20 cm soil in this study area. The exchangeable Mg in Haplic Luvisol was significantly higher than in Eutric Cambisol at 0-50 cm soil. There was no significant difference of exchangeable Mg between Calcic Chernozem and Haplic Luvisol in 20-40 cm of the soil. The exchangeable Mg in Calcic Chernozem was significantly lower than in Eutric Cambisol and Haplic Luvisol at 40-50 cm of the soil. There was no significant difference of exchangeable Mg between Calcic Chernozem and haplic luvisol in the top 50 cm of the soil. The exchangeable Mg in Eutric Cambisol was significantly lower than in Calcic Chernozem and Haplic Luvisol in the top 50 cm of the soil. The mean value of exchangeable Mg over all study plots were 1.28 g m^{-2} cm^{-1} in the top 5 cm soil, 1.13 g m^{-2} cm^{-1} at 5-10 cm of the soil, 1.37 g m^{-2} cm^{-1} at

10-20 cm of the soil, 2.61 g m^{-2} cm^{-1} at 20-40 cm of the soil and 4.67 g m^{-2} cm^{-1} at 40-50 cm of the soil.

Table 4. 22 Exchangeable Mg (g m^{-2} cm^{-1}) at different soil horizon in three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in North-East Austria. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**Exchangeable Mg (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	0.83 ± 0.07^{a}	0.65 ± 0.08^{a}	0.63 ± 0.09^{a}	1.65 ± 0.18^{a}	3.96 ± 0.50^{b}
Calcic Chernozem	3.19 ± 0.48^{c}	3.43 ± 0.58^{c}	3.85 ± 1.12^{c}	3.22 ± 0.46^{b}	2.19 ± 0.15^{a}
Haplic Luvisol	1.41 ± 0.09^{b}	1.16 ± 0.12^{b}	1.78 ± 0.16^{b}	4.01 ± 0.24^{b}	6.68 ± 0.40^{c}
Mean value over all study plots	1.28 ± 0.11	1.13 ± 0.13	1.37 ± 0.18	2.61 ± 0.18	4.67 ± 0.35

4.3.6.4. Exchangeable Na

The exchangeable Na ranged from 0.09 to 0.15 g m^{-2} cm^{-1} at 0-5 cm of the soil, from 0.14 to 0.20 g m^{-2} cm^{-1} at 5-10 cm of the soil, from 0.15 to 0.32 g m^{-2} cm^{-1} at 10-20 cm of the soil, from 0.17 to 0.37 g m^{-2} cm^{-1} at 20-40 cm of the soil and from 0.25 to 0.46 g m^{-2} cm^{-1} at 40 to 50 cm of the soil (Table 4.23). The mean value of exchangeable Na in the top 50 cm soil were 0.18 g m^{-2} cm^{-1} in study plot S1, 0.22 g m^{-2} cm^{-1} in study plot S2, 0.18 g m^{-2} cm^{-1} in study plot S3, 0.21 g m^{-2} cm^{-1} in study plot S4, 0.23 g m^{-2} cm^{-1} in study plot S5, 0.22 g m^{-2} cm^{-1} in study plot L2, 0.27 g m^{-2} cm^{-1} in study plot L3, 0.28 g m^{-2} cm^{-1} in study plot L4 and 0.28 g m^{-2} cm^{-1} in study plot L5 (Table 4.23). The exchangeable Na in study plots L3, L4 and L5 was significantly higher than in study plots S1, S2, S3, S4 and L2 in the top 50 cm of the soil. The difference of exchangeable Na among different study plots at different soil horizons are shown in Table 4.23.

The total pool of exchangeable Na in the top 50 cm of the soil were 95 kg ha^{-1} in study plot S1, 125 kg ha^{-1} in study plot S2, 98 kg ha^{-1} in study plot S3, 115 kg ha^{-1} in study plot S4, 128 kg ha^{-1} in study plot S5, 118 kg ha^{-1} in study plot L2, 156 kg ha^{-1} in study plot L3, 158 kg ha^{-1} in study plot L4 and 162 kg ha^{-1} in study plot L5 (Figure 4.13). Study plot L5 had the highest exchangeable Na pool and study plot S1 had the lowest exchangeable Na pool among all study plots. The exchangeable Na pool in study plots L3, L4 and L5 (Haplic Luvisol) was significantly higher than other study plots. The exchangeable Na pool was heterogeneously distributed without any age induced trend in Eutric Cambisol. There was no significant difference of exchangeable Na pool among faster growing period, stable growing period and senescing period in Eutric Cambisol and Haplic Luvisol. Stand age had no decisive influences on exchangeable Na pools in this study area.

Table 4. 23 Exchangeable Na (g m^{-2} cm^{-1}) at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	Exchangealbe Na (g m^{-2} cm^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	0.10 ± 0.01^{a}	0.14 ± 0.02^{a}	0.15 ± 0.02^{a}	0.17 ± 0.02^{a}	0.32 ± 0.06^{ab}
S2	0.09 ± 0.01^{a}	0.17 ± 0.01	0.19 ± 0.03^{ab}	0.25 ± 0.02^{bc}	0.43 ± 0.04^{c}
S3	0.11 ± 0.01^{a}	0.14 ± 0.01^{a}	0.16 ± 0.02^{a}	0.21 ± 0.02^{ab}	0.28 ± 0.05^{ab}
S4	0.11 ± 0.02^{a}	0.18 ± 0.03	0.17 ± 0.02^{a}	0.24 ± 0.03^{ab}	0.37 ± 0.04^{b}
S5	0.12 ± 0.02^{ab}	0.16 ± 0.01	0.19 ± 0.01^{ab}	0.29 ± 0.05^{cd}	0.37 ± 0.04^{b}
L2	0.12 ± 0.01^{ab}	0.18 ± 0.01	0.28 ± 0.04^{cd}	0.25 ± 0.02^{bc}	0.25 ± 0.04^{a}
L3	0.13 ± 0.01^{bc}	0.18 ± 0.01	0.24 ± 0.01^{bc}	0.35 ± 0.02^{de}	0.46 ± 0.03^{c}
L4	0.15 ± 0.02^{c}	0.20 ± 0.01^{b}	0.25 ± 0.01^{bc}	0.35 ± 0.02^{de}	0.45 ± 0.04^{c}
L5	0.14 ± 0.01^{bc}	0.19 ± 0.02	0.32 ± 0.04^{d}	0.37 ± 0.02^{e}	0.40 ± 0.03^{bc}

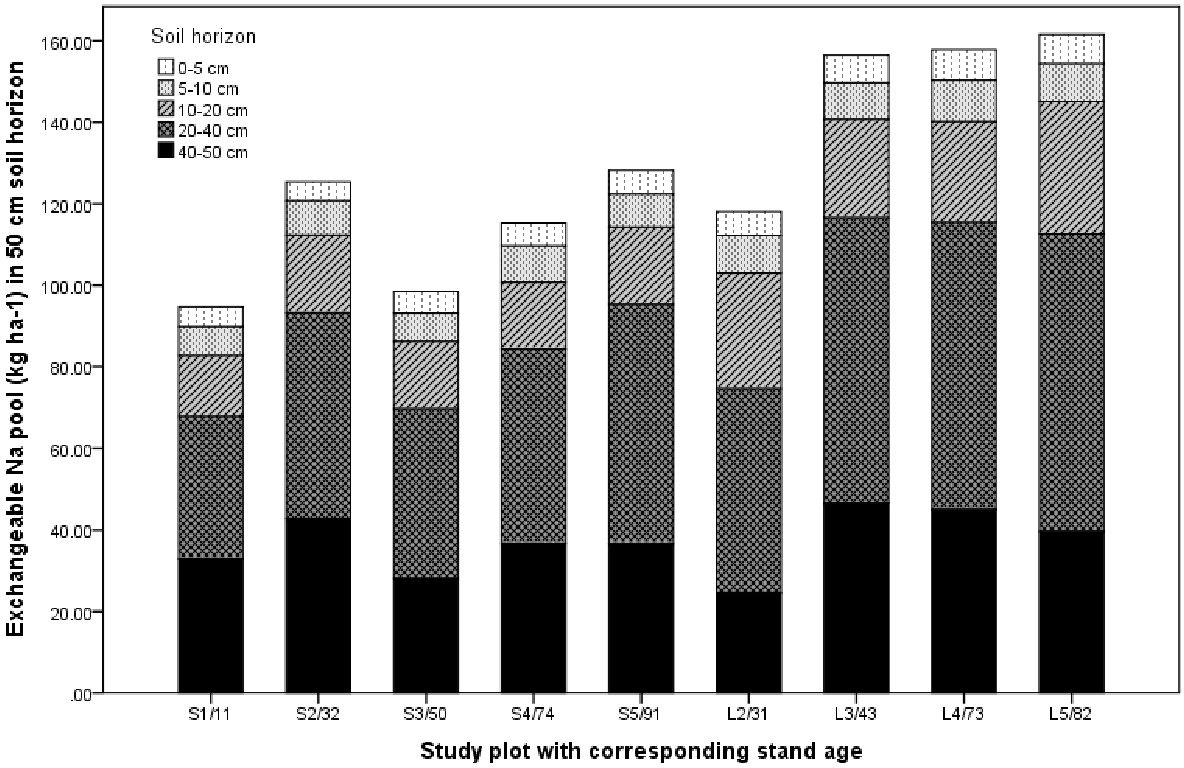


Figure 4. 13 Exchangeable Na pool (kg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Table 4.24 shows the exchangeable Na content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol. The exchangeable Ca in Haplic Luvisol was significantly higher than in Eutric Cambisol in the top 50 cm of the soil in this study area. There was no significant difference of exchangeable Na between Calcic Chernozem and Haplic Luvisol at 0-20 cm of the soil. The exchangeable Na in Calcic Chernozem was significantly lower than in Haplic Luvisol at 20-50 cm of the soil. Haplic Luvisol had the significantly highest exchangeable Na in the top 50 cm of the soil. There was no significant difference of exchangeable Na between Eutric Cambisol and Haplic Luvisol in the top 50 cm of the soil. The mean value of exchangeable Na over all study plots were 0.12 g m^{-2} cm^{-1} at 0-5 cm of the soil, 0.17 g m^{-2} cm^{-1} at 5-10 cm of the soil, 0.22 g m^{-2} cm^{-1}

at 10-20 cm of the soil, 0.28 g m^{-2} cm^{-1} at 20-40 cm of the soil and 0.37 g m^{-2} cm^{-1} at 40-50 cm of the soil.

Table 4. 24 Exchangeable Na (g m^{-2} cm^{-1}) at different soil horizons in three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in North-East Austrian *Quercus* Forest. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**Exchangeable Na (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	0.11 ± 0.01^{a}	0.16 ± 0.01^{a}	0.17 ± 0.01^{a}	0.23 ± 0.01^{a}	0.35 ± 0.02^{b}
Calcic Chernozem	0.12 ± 0.01	0.18 ± 0.01	0.28 ± 0.04^{b}	0.25 ± 0.02^{a}	0.25 ± 0.04^{a}
Haplic Luvisol	0.14 ± 0.01^{b}	0.19 ± 0.01^{b}	0.27 ± 0.02^{b}	0.36 ± 0.01^{b}	0.44 ± 0.02^{c}
Mean value over all study plots	0.12 ± 0.00	0.17 ± 0.01	0.22 ± 0.01	0.28 ± 0.01	0.37 ± 0.02

4.3.6.5. Exchangeable Al

The exchangeable Al ranged from 0.02 to 2.39 g m^{-2} cm^{-1} at 0-5 cm of the soil, from 0.23 to 3.85 g m^{-2} cm^{-1} at 5-10 cm of the soil, from 0.27 to 4.65 g m^{-2} cm^{-1} at 10-20 cm of the soil, from 0.10 to 3.78 g m^{-2} cm^{-1} at 20-40 cm of the soil and from 0.03 to 2.70 g m^{-2} cm^{-1} at 40 to 50 cm of the soil (Table 4.25). The mean value of exchangeable Al in the top 50 cm of the soil were 1.5 g m^{-2} cm^{-1} in study plot S1, 3.3 g m^{-2} cm^{-1} in study plot S2, 2.1 g m^{-2} cm^{-1} in study plot S3, 1.1 g m^{-2} cm^{-1} in study plot S4, 1.6 g m^{-2} cm^{-1} in study plot S5, 0.13 g m^{-2} cm^{-1} in study plot L2, 2.9 g m^{-2} cm^{-1} in study plot L3, 2.1 g m^{-2} cm^{-1} in study plot L4 and 2.4 g m^{-2} cm^{-1} in study plot L5 (Table 4.25). The exchangeable Al in study plots L2 was the significantly lowest among all study plots in the top 50 cm of the soil. The exchangeable Al in study plot S2 was the significantly highest among all study plots in the top 50 cm soil. The exchangeable Al in study plots L3 and L5 was significantly higher than in study plots S1, S4 and S5 in the top 50 cm of the soil. The difference of exchangeable Al among different study plots at different soil horizons are shown in Table 4.25.

Table 4. 25 Exchangeable Al (g m^{-2} cm^{-1}) at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	Exchangeable Al (g m^{-2} cm^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	0.37 ± 0.11^{ab}	1.77 ± 0.38^{bc}	1.76 ± 0.31^{bc}	1.66 ± 0.27^{b}	2.05 ± 0.58^{d}
S2	1.79 ± 0.28^{c}	4.10 ± 0.50^{cd}	4.38 ± 0.58^{d}	3.78 ± 0.40^{d}	2.70 ± 0.29^{e}
S3	1.28 ± 0.36^{b}	2.28 ± 0.51^{bc}	2.70 ± 0.73^{bc}	2.45 ± 0.70^{c}	1.76 ± 0.55^{d}
S4	0.42 ± 0.14^{ab}	1.55 ± 0.38^{b}	1.64 ± 0.38^{bc}	1.24 ± 0.15^{b}	0.83 ± 0.19^{bc}
S5	0.50 ± 0.12^{ab}	2.26 ± 0.43^{bc}	2.77 ± 0.35^{bc}	1.73 ± 0.19^{bc}	0.78 ± 0.21^{bc}
L2	0.02 ± 0.00^{a}	0.23 ± 0.21^{a}	0.27 ± 0.19^{a}	0.10 ± 0.08^{a}	0.03 ± 0.00^{a}
L3	2.04 ± 0.38^{c}	4.60 ± 0.58^{d}	4.65 ± 0.58^{d}	2.16 ± 0.20^{bc}	1.16 ± 0.04^{c}
L4	0.98 ± 0.24^{b}	2.95 ± 0.58^{c}	3.62 ± 0.66^{cd}	2.23 ± 0.20^{c}	0.82 ± 0.13^{bc}
L5	2.39 ± 0.46^{c}	3.85 ± 0.52^{cd}	3.96 ± 0.62^{cd}	1.41 ± 0.34^{bc}	0.33 ± 0.09^{ab}

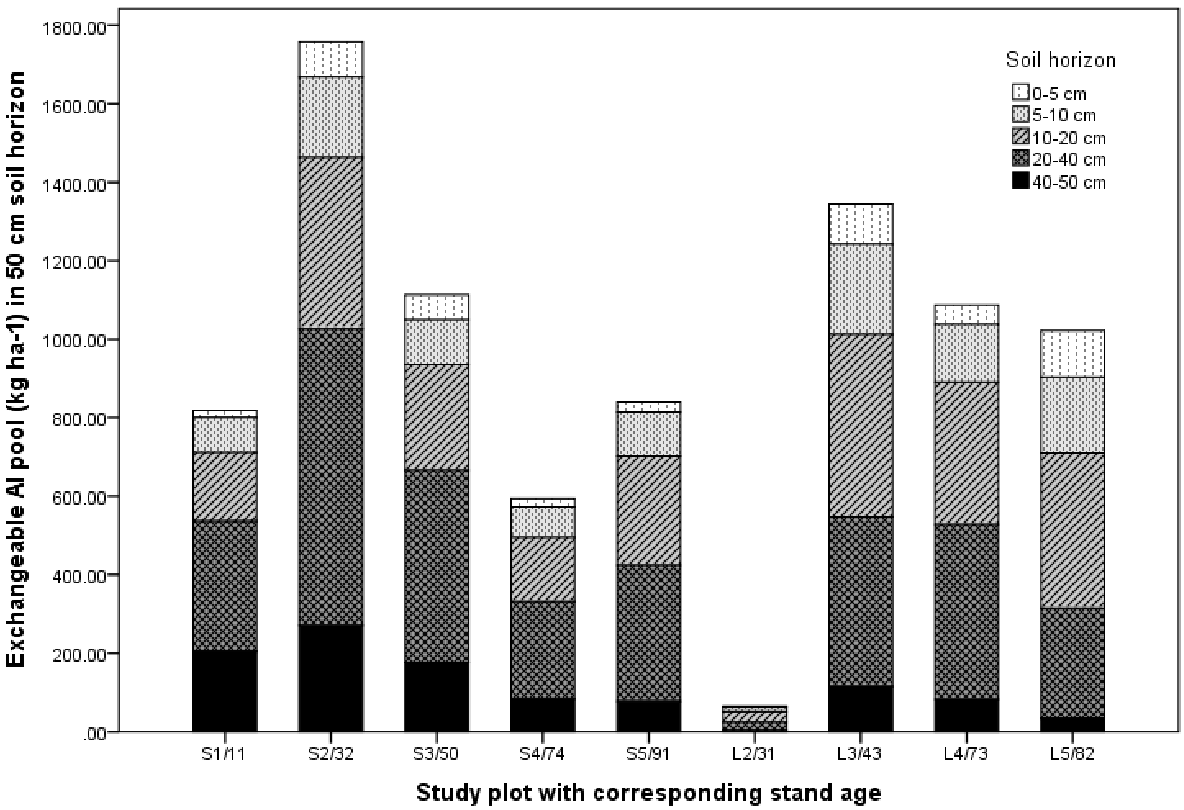


Figure 4. 14 Exchangeable Al pool (kg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

The total pool of exchangeable Al in the top 50 cm of the soil were 819 kg ha^{-1} in study plot S1, 1 758 kg ha^{-1} in study plot S2, 1 113 kg ha^{-1} in study plot S3, 594 kg ha^{-1} in study plot S4, 839 kg ha^{-1} in study plot S5, 64 kg ha^{-1} in study plot L2, 1 344 kg ha^{-1} in study plot L3, 1 087 kg ha^{-1} in study plot L4 and 1 022 kg ha^{-1} in study plot L5 (Figure 4.14). Study plot S2 had the significantly highest exchangeable Al pool and study plot L2 had the significantly lowest exchangeable Al pool among all study plots. The exchangeable Al pool in study plots S2 was significantly higher than other study plots in Eutric Cambisol. The exchangeable Al was heterogeneously distributed without any age induced trend in Eutric Cambisol. The exchangeable Al was decreasing with the increase of stand age in Haplic Luvisol.

There was no significant difference of exchangeable Al pool among faster growing period, stable growing period and senescing period in Eutric Cambisol.

Table 4. 26 Exchangeable Al (g m^{-2} cm^{-1}) at different soil horizons in three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in North-East Austrian *Quercus* Forest. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference (p < 0.05) between different soil types.

Soil type	**Exchangeable Al (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	0.87 ± 0.13^{b}	2.39 ± 0.23^{b}	2.65 ± 0.26^{b}	2.17 ± 0.21^{b}	1.62 ± 0.20^{c}
Calcic Chernozem	0.02 ± 0.01^{a}	0.23 ± 0.21^{a}	0.27 ± 0.19^{a}	0.10 ± 0.08^{a}	0.03 ± 0.00^{a}
Haplic Luvisol	1.80 ± 0.24^{c}	3.80 ± 0.34^{c}	4.08 ± 0.35^{c}	1.93 ± 0.16^{b}	0.77 ± 0.09^{b}
Mean value over all study plots	1.09 ± 0.12	2.62 ± 0.21	2.86 ± 0.22	1.86 ± 0.15	1.16 ± 0.03

Table 4.26 shows the exchangeable Al content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in this study area. Calcic Chernozem had the significantly lowest exchangeable Al in the top 0-50 cm of the soil. Haplic Luvisol had the significantly highest exchangeable Al at 0-20 cm of the soil. There was no significant difference of exchangeable Al between Eutric Cambisol and Haplic Luvisol at 20-40 cm of the soil. The exchangeable Al in Eutric Cambisol was significantly higher than in Haplic Luvisol at 40-50 cm of the soil. Calcic Chernozem had the significantly lowest exchangeable Al in the top 50 cm of the soil. The exchangeable Al in Eutric Cambisol was significantly lower than in Haplic Luvisol in the top 50 cm of the soil. The mean value of exchangeable Al over all study plots were 1.09 g m^{-2} cm^{-1} at 0-5 cm of the soil, 2.62 g m^{-2} cm^{-1} at 5-

10 cm of the soil, 2.86 g m^{-2} cm^{-1} at 10-20 cm of the soil, 1.86 g m^{-2} cm^{-1} at 20-40 cm of the soil and 1.16 g m^{-2} cm^{-1} at 40-50 cm of the soil.

4.3.6.6. Exchangeable Fe

The exchangeable Fe ranged from undetectable to 0.069 g m^{-2} cm^{-1} at 0-5 cm of the soil, from 0.030 to 0.152 g m^{-2} cm^{-1} at 5-10 cm of the soil, from 0.016 to 0.110 g m^{-2} cm^{-1} at 10-20 cm of the soil, from undetectable to 0.019 g m^{-2} cm^{-1} at 20-40 cm of the soil and from undetectable to 0.003 g m^{-2} cm^{-1} at 40 to 50 cm of the soil (Table 4.27).

Table 4. 27 Exchangeable Fe (g m^{-2} cm^{-1}) at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	Exchangeable Fe (g m^{-2} cm^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	0.001 ± 0.000	0.031 ± 0.020^{a}	0.016 ± 0.010^{a}	0.002 ± 0.002^{a}	0.003 ± 0.003
S2	0.059 ± 0.048	0.089 ± 0.055	0.041 ±0.027^{a}	0.012 ± 0.011^{a}	0.000 ± 0.000
S3	0.059 ± 0.044	0.152 ± 0.074^{b}	0.110 ± 0.049^{b}	0.019 ± 0.014^{a}	0.000 ± 0.000
S4	0.057 ± .0.019	0.193 ± 0.043^{b}	0.057 ± 0.022	0.003 ± 0.002^{a}	0.000 ± 0.000
S5	0.000 ± .0.000^{a}	0.030 ± 0.023^{a}	0.016 ± 0.010^{a}	0.009 ± 0.007^{b}	0.000 ± 0.000
L2	0.002 ± 0.001	0.042 ± 0.027	0.031 ± 0.022^{a}	0.001 ± 0.001^{a}	0.000 ± 0.000
L3	0.024 ± 0.001	0.059 ± 0.027	0.029 ± 0.012^{a}	0.008 ± 0.006^{b}	0.000 ± 0.000
L4	0.017 ± 0.006	0.111 ± 0.037	0.026 ± 0.011^{a}	0.001 ± 0.001^{a}	0.000 ± 0.000
L5	0.069 ± 0.021^{b}	0.061 ± 0.018	0.017 ± 0.011^{a}	0.000 ± 0.000^{a}	0.000 ± 0.000

The mean value of exchangeable Fe in the top 50 cm of the soil were 0.011 g m^{-2} cm^{-1} in study plot S1, 0.04 g m^{-2} cm^{-1} in study plot S2, 0.068 g m^{-2} cm^{-1} in study plot S3, 0.062 g m^{-2} cm^{-1} in study plot S4, 0.013 g m^{-2} cm^{-1} in study plot S5, 0.015 g m^{-2} cm^{-1} in study plot L2, 0.024 g m^{-2} cm^{-1} in study plot L3, 0.031 g m^{-2} cm^{-1} in study plot L4 and 0.029 g m^{-2} cm^{-1} in study plot L5 (Table 4.27). The exchangeable Fe in study plots S3 and S4 was significantly higher than in study plots S1, S2, L2, L3 and L5 in the top 50 cm of the soil. The difference of exchangeable Fe among different study plots at different soil horizons are shown in Table 4.27.

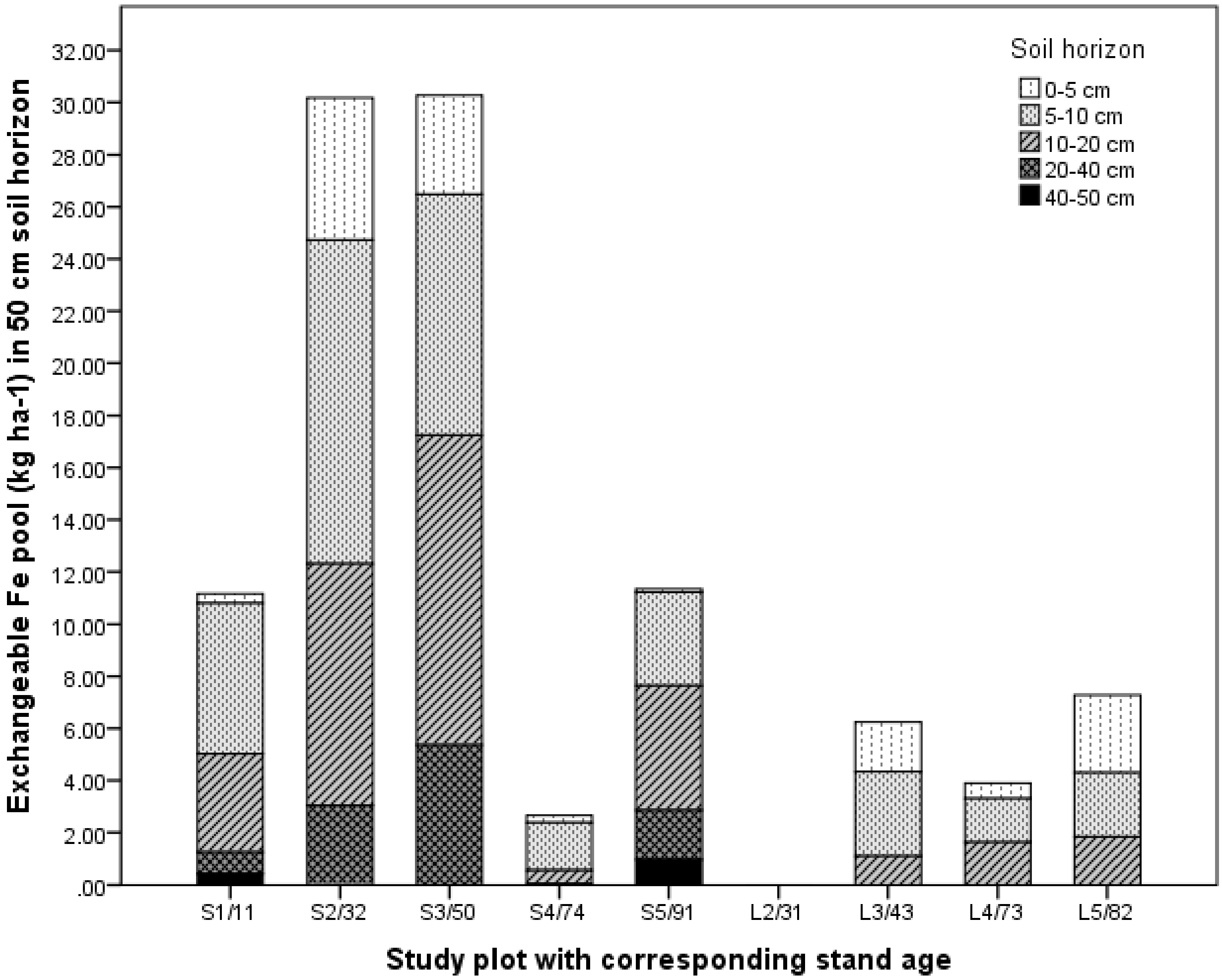


Figure 4. 15 Exchangeable Fe pool (kg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

The total pool of exchangeable Fe in the top 50 cm of the soil were 11 kg ha^{-1} in study plot S1, 30 kg ha^{-1} in study plot S2, 30 kg ha^{-1} in study plot S3, 3 kg ha^{-1} in study plot S4, 11 kg ha^{-1} in study plot S5, a little bit (less than 0.1 kg ha^{-1}) in study plot L2, 6 kg ha^{-1} in study plot L3, 4 kg ha^{-1} in study plot L4 and 7 kg ha^{-1} in study plot L5 (Figure 4.15). Forest L2 had the significantly lowest exchangeable Fe pool among all study plots. The exchangeable Fe pool in study plots S2 and S3 was significantly higher than other study plots in this study area. The exchangeable Fe pool was heterogeneously distributed without any age induced trend in Eutric Cambisol and Haplic Luvisol. Stand age had no decisive influence on exchangeable Fe pool in Eutric Cambisol and Haplic Luvisol.

Table 4. 28 Exchangeable Fe (g m^{-2} cm^{-1}) at different soil horizons in three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in North-East Austrian *Quercus* Forest. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**Exchangeable Fe (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	0.035 ± 0.014^{b}	0.099 ± 0.023^{b}	0.048 ± 0.013^{b}	0.009 ± 0.04^{b}	0.002 ± 0.001^{a}
Calcic Chernozem	0.002 ± 0.001^{a}	0.042 ± 0.027^{a}	0.031 ± 0.022	0.001 ± 0.001^{a}	0.000 ± 0.000^{a}
Haplic Luvisol	0.037 ± 0.009^{b}	0.077 ± 0.017^{b}	0.024 ± 0.006^{a}	0.003 ± 0.002^{a}	0.000 ± 0.000^{a}
Mean value over all study plots	0.032 ± 0.008	0.085 ± 0.014	0.038 ± 0.008	0.006 ± 0.002	0.001 ± 0.001

Table 4.28 shows the exchangeable Fe content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in this study

area. Calcic Chernozem had the significantly lowest exchangeable Fe at 0-10 cm of the soil. There was no significant difference of exchangeable Fe between Eutric Cambisol and Haplic Luvisol at 0-10 cm of the soil. The exchangeable Fe in Eutric Cambisol was significantly higher than in Haplic Luvisol at 10-40 cm of the soil. There was no significant difference of exchangeable Fe among Eutric Cambisol, Haplic Luvisol and Calcic Chernozem at 40-50 cm and in the top 50 cm of the soil. The mean value of exchangeable Fe over all study plots were 0.032 g m^{-2} cm^{-1} at 0-5 cm of the soil, 0.085 g m^{-2} cm^{-1} at 5-10 cm of the soil, 0.038 g m^{-2} cm^{-1} at 10-20 cm of the soil, 0.006 g m^{-2} cm^{-1} at 20-40 cm of the soil and 0.001 g m^{-2} cm^{-1} at 40-50 cm of the soil.

4.3.6.7. Exchangeable Mn

The exchangeable Mn ranged from 0.38 to 1.92 g m^{-2} cm^{-1} at 0-5 cm of the soil, from 0.36 to 1.13 g m^{-2} cm^{-1} at 5-10 cm of the soil, from 0.22 to 0.83 g m^{-2} cm^{-1} at 10-20 cm of the soil, from 0.10 to 0.68 g m^{-2} cm^{-1} at 20-40 cm of the soil and from 0.05 to 0.60 g m^{-2} cm^{-1} at 40 to 50 cm of the soil (Table 4.29).

Table 4. 29 Exchangeable Mn (g m^{-2} cm^{-1}) at different soil horizons in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	Exchangeable Mn (g m^{-2} cm^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	1.05 ± 0.15^{b}	0.38 ± 0.08^{a}	0.34 ± 0.07^{ab}	0.37 ± 0.08^{bc}	0.53 ± 0.18^{bc}
S2	1.28 ± 0.51^{bc}	0.36 ± 0.09^{a}	0.34 ± 0.10^{ab}	0.44 ± 0.12^{cd}	0.59 ± 0.09^{c}
S3	1.19 ± 0.16^{bc}	0.76 ± 0.25	0.30 ± 0.09^{ab}	0.16 ± 0.05^{ab}	0.39 ± 0.15^{b}
S4	1.34 ± 0.11^{bc}	1.13 ± 0.12^{b}	0.83 ± 0.10^{d}	0.68 ± 0.07^{e}	0.60 ± 0.13^{c}
S5	1.26 ± 0.08^{bc}	0.87 ± 0.08^{b}	0.56 ± 0.06^{bc}	0.48 ± 0.07^{cde}	0.53 ± 0.13^{bc}
L2	0.38 ± 0.10^{a}	0.38 ± 0.14^{a}	0.22 ± 0.08^{a}	0.10 ± 0.06^{a}	0.05 ± 0.05^{a}
L3	1.45 ± 0.10^{c}	0.96 ± 0.15^{b}	0.78 ± 0.08^{cd}	0.56 ± 0.04^{cde}	0.53 ± 0.03^{bc}
L4	1.92 ± 0.22^{d}	1.04 ± 0.15^{b}	0.80 ± 0.14^{cd}	0.63 ± 0.06^{de}	0.43 ± 0.05^{bc}
L5	1.23 ± 0.11^{bc}	0.72 ± 0.12	0.67 ± 0.03^{cd}	0.50 ± 0.06^{cde}	0.32 ± 0.06^{b}

The mean value of exchangeable Mn in the top 50 cm of the soil were 0.54 g m^{-2} cm^{-1} in study plot S1, 0.60 g m^{-2} cm^{-1} in study plot S2, 0.56 g m^{-2} cm^{-1} in study plot S3, 0.92 g m^{-2} cm^{-1} in study plot S4, 0.74 g m^{-2} cm^{-1} in study plot S5, 0.23 g m^{-2} cm^{-1} in study plot L2, 0.86 g m^{-2} cm^{-1} in study plot L3, 0.97 g m^{-2} cm^{-1} in study plot L4 and 0.69 g m^{-2} cm^{-1} in study plot L5 (Table 4.29). The exchangeable Mn in study plot L4 was the significant highest among all study plots. The exchangeable Mn in study plots S4, S5 and L3 was significantly higher than in study plots S1, L2 and L5 in the top 50 cm of the soil. The difference of exchangeable Mn among different study plots at different soil horizons are shown in Table 4.29.

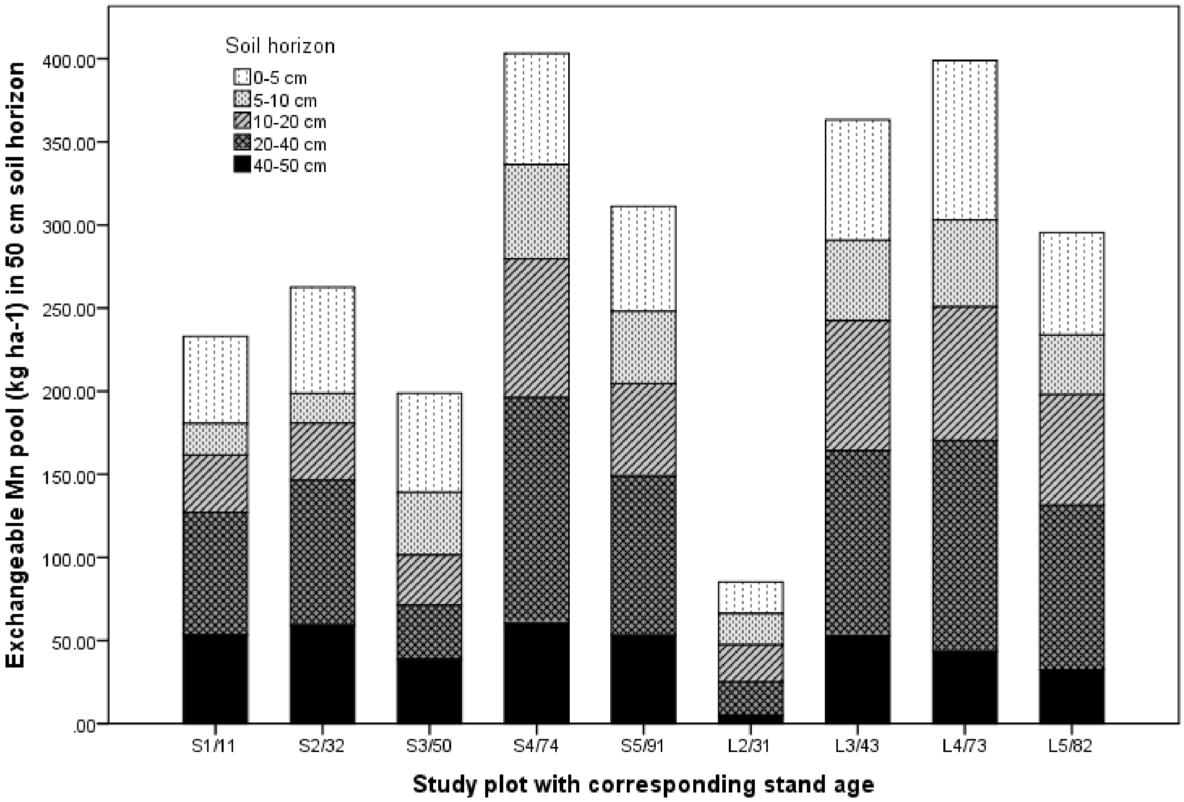


Figure 4. 16 Exchangeable Mn pool (kg ha^{-1}) in the top 50 cm of the soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

The total pool of exchangeable Mn in the top 50 cm of the soil were 233 kg ha^{-1} in study plot S1, 263 kg ha^{-1} in study plot S2, 199 kg ha^{-1} in study plot S3, 403 kg ha^{-1} in study plot S4, 311 kg ha^{-1} in study plot S5, 85 kg ha^{-1} in study plot L2, 363 kg ha^{-1} in study plot L3, 399 kg ha^{-1} in study plot L4 and 295 kg ha^{-1} in study plot L5 (Figure 4.16). Study plot L2 had the significantly lowest exchangeable Mn pool among all study plots. The exchangeable Mn pool in study plots S4 was significantly higher than other study plots in Eutric Cambisol. The exchangeable Mn pool was heterogeneously distributed without any age induced trend in Eutric Cambisol and Haplic Luvisol. Stand age had no decisive influences on exchangeable Mn pools in this study area.

Table 4. 30 Exchangeable Mn (g m^{-2} cm^{-1}) at different soil horizons in three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in North-East Austrian *Quercus* Forest. Mean values (n = 90 for Eutric Cambisol, n = 18 for Calcic Chernozem, n = 54 for Haplic Luvisol, n = 162 for total) and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**Exchangeable Mn (g m^{-2} cm^{-1}) in different soil horizons**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	1.22 ± 0.06^{b}	0.70 ± 0.07	0.47 ± 0.05^{b}	0.42 ± 0.04^{b}	0.53 ± 0.06^{b}
Calcic Chernozem	0.38 ± 0.10^{a}	0.38 ± 0.14^{a}	0.22 ± 0.08^{a}	0.10 ± 0.06^{a}	0.05 ± 0.05^{a}
Haplic Luvisol	1.53 ± 0.10^{c}	0.91 ± 0.08^{b}	0.75 ± 0.05^{c}	0.56 ± 0.03^{c}	0.43 ± 0.03^{b}
Mean value over all study plots	1.23 ± 0.06	0.73 ± 0.05	0.54 ± 0.04	0.43 ± 0.03	0.44 ± 0.04

Table 4.30 shows the exchangeable Mn content (g m^{-2} cm^{-1}) at different soil horizons in Eutric Cambisol, Calcic Chernozem and Haplic Luvisol in this study area. Haplic Luvisol had the significantly highest exchangeable Mn at 0-5 cm of the soil. The exchangeable Mn in Eutric Cambisol was significantly higher than in Calcic Chernozem at 0-5 cm of the soil. There was no significant difference of exchangeable Mn between Eutric Cambisol and Calcic Chernozem at 5-10 cm of the soil. The exchangeable Mn in Haplic Luvisol was significantly higher than in Eutric Cambisol and Calcic Chernozem at 10-40 cm of the soil. The exchangeable Mn in Eutric Cambisol was significantly higher than in Calcic Chernozem at 10-50 cm of the soil. There was no significant difference of exchangeable Mn between Eutric Cambisol and Haplic Luvisol at 40-50 cm of the soil.

Calcic Chernozem had the significantly lowest exchangeable Mn in the top 50 cm of the soil. The exchangeable Mn in Eutric Cambisol was significantly lower than in Haplic Luvisol in the top 50 cm of the soil. The mean value of exchangeable Mn over all study plots were 1.23 g m^{-2} cm^{-1} at 0-5 cm of the soil, 0.73 g m^{-2} cm^{-1} at 5-

10 cm of the soil, 0.54 g m^{-2} cm^{-1} at 10-20 cm of the soil, 0.43 g m^{-2} cm^{-1} at 20-40 cm of the soil and 0.44 g m^{-2} cm^{-1} at 40-50 cm of the soil.

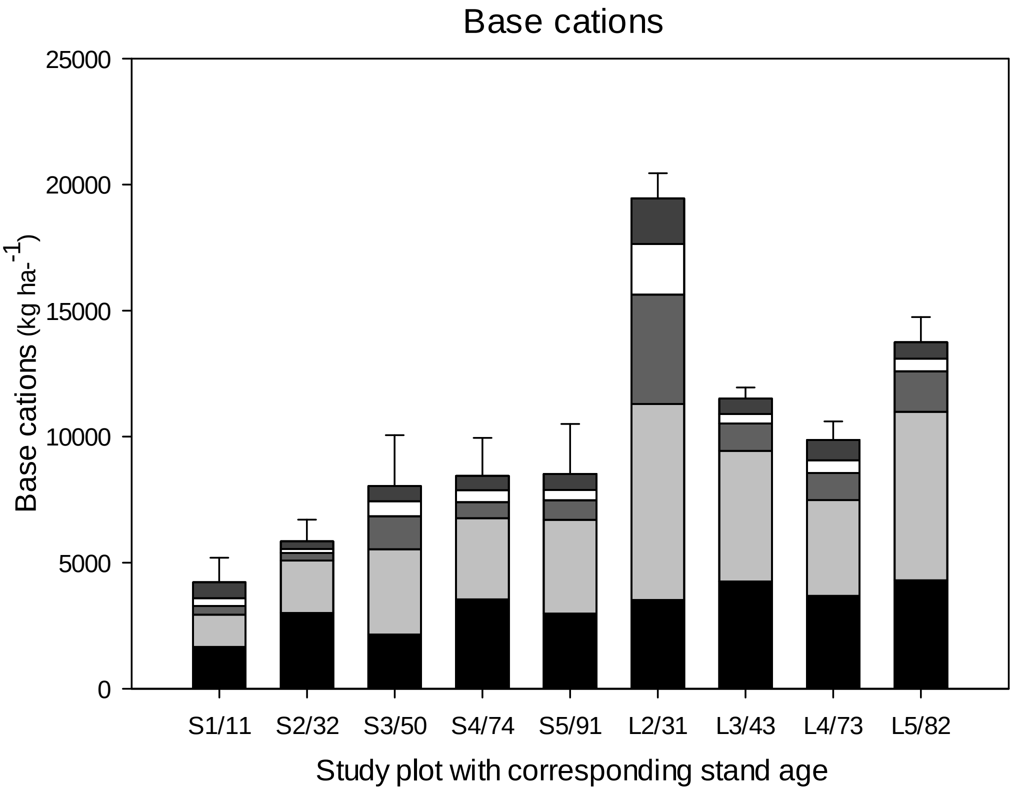
4.3.7. Base Cations (K, Na, Ca, Mg) and Acid Cations (Al, Fe, Mn)

Base cations and acid cations at different soil horizons in different study plots are shown in Table 4.31. Base cations over all study plots ranged: from 298 to 1 810 kg ha^{-1} at 0-5 cm of the soil; from 162 to 2 010 kg ha^{-1} at 5-10 cm of the soil; from 306 to 4 343 kg ha^{-1} at 10-20 cm of the soil; from 1 280 to 7 780 kg ha^{-1} at 20-40 cm of the soil; from 1 540 to 3 850 kg ha^{-1} at 40-50 cm of the soil. The base cations in study plot L2 were significantly higher than in other study plots in the top 40 cm of the soil. There was a decrease of base cations with the increase of soil horizon up to 10 cm in all study plots except L2. Base cations was increasing after 10 cm with increase of soil horizons up to 40 cm. Base cations in L2 was always increasing with the increase of soil horizon up to 40 cm.

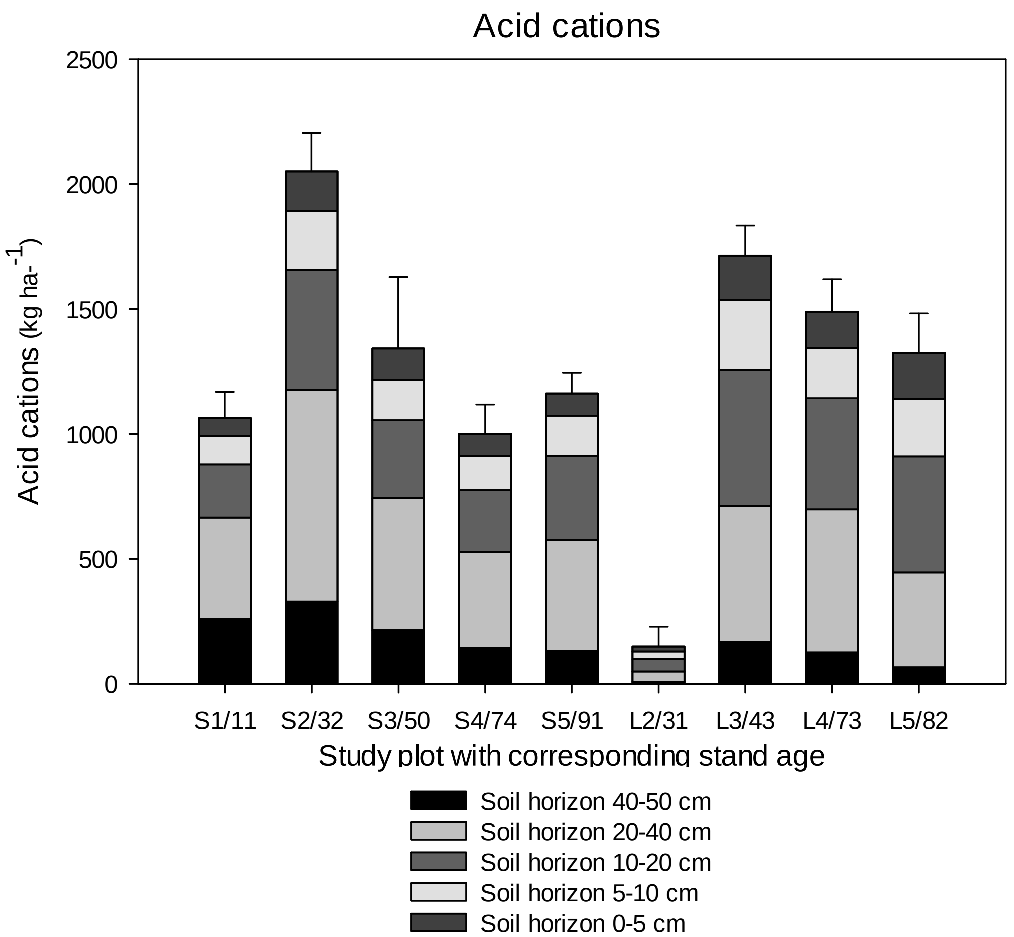
Acid cations over all study plots ranged: from 20 to 184 kg ha^{-1} at 0-5 cm of the soil; from 31 to 281 kg ha^{-1} at 5-10 cm of the soil; from 49 to 545 kg ha^{-1} at 10-20 cm of the soil; from 41 to 846 kg ha^{-1} at 20-40 cm of the soil; from 9 to 231 kg ha^{-1} at 40-50 cm of the soil. Acid cations in Calcic Chernozem were significantly lower than in Eutric Cambisol and Haplic Luvisol in the top 50 cm of the soil (Table 4.31).

Table 4. 31 Mean value ± standard deviation, ANOVA results for the base cations (K, Na, Ca, Mg) (kg ha^{-1}) and acid cations (Al, Fe, Mn) (kg ha^{-1}) at different soil horizons (0 to 5 cm, 5 to 10 cm, 10 to 20 cm, 20 to 40 cm, 40-50 cm) in the nine *Quercus* dominated study plots (S1 - S5 and L2 - L5) in North-East Austria. Letters indicate significant difference ($p < 0.05$) between different study plots.

Study plot	Base cations (kg ha^{-1}) in different soil horizons					Acid cations (kg ha^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	635 ± 116^{b}	306 ± 114^{ab}	351 ± 103^{ab}	1280 ± 411^{bc}	1540 ± 612^{bc}	71 ± 12^{b}	113 ± 20^{bc}	214 ± 31^{e}	406 ± 56^{gh}	142 ± 37^{cd}
S2	298 ± 40^{a}	162 ± 19^{a}	306 ± 47^{ab}	2070 ± 454^{cd}	2110 ± 360^{cd}	159 ± 14^{cd}	236 ± 25^{ef}	481 ± 58^{h}	846 ± 64^{j}	231 ± 25^{ef}
S3	606 ± 113^{b}	593 ± 190^{b}	1310 ± 490^{bc}	3380 ± 959^{ef}	2240 ± 571^{cd}	127 ± 21^{c}	161 ± 27^{cd}	312 ± 74f^{g}	528 ± 147^{hi}	129 ± 45^{c}
S4	573 ± 95^{b}	470 ± 119^{ab}	640 ± 189^{bc}	3210 ± 784^{ef}	2920 ± 532de	88 ± 12^{b}	136 ± 17^{c}	248 ± 43e^{f}	384 ± 39^{gh}	110 ± 17^{bc}
S5	640 ± 79^{b}	408 ± 74^{ab}	776 ± 204^{bc}	3720 ± 981^{ef}	2220 ± 604^{cd}	88 ± 8^{b}	160 ± 21^{cd}	338 ± 33f^{g}	444 ± 35^{h}	88 ± 13^{b}
L2	1810 ± 87^{c}	2010 ± 176^{cd}	4340 ± 757^{ef}	7780 ± 246^{h}	3800 ± 217^{ef}	20 ± 5^{a}	31 ± 16^{a}	49 ± 27^{a}	41 ± 28^{a}	9 ± 5^{a}
L3	617 ± 59^{b}	374 ± 78^{ab}	1080 ± 165^{bc}	5180 ± 280^{fg}	2870 ± 266de	176 ± 16^{d}	281 ± 23^{f}	545 ± 52^{hi}	543 ± 37^{hi}	110 ± 9^{bc}
L4	803 ± 89^{b}	508 ± 111^{ab}	1070 ± 260^{bc}	3800 ± 290^{ef}	3640 ± 212^{ef}	145 ± 22^{cd}	202 ± 33^{e}	444 ± 66^{h}	573 ± 39^{i}	124 ± 19^{c}
L5	655 ± 83^{b}	499 ± 103^{ab}	1610 ± 268^{cd}	6680 ± 584^{gh}	3850 ± 330^{ef}	184 ± 23^{d}	231 ± 29e^{f}	464 ± 62^{h}	380 ± 76^{gh}	56 ± 11^{ab}



Base cations
Base cations (kg ha-[-1])
25000
20000
15000
10000
5000
0
S1/11
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age



Acid cations
Acid cations (kg ha-[-1])
2500
2000
1500
1000
500
0
S1/11
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age
Soil horizon 40-50 cm
Soil horizon 20-40 cm
Soil horizon 10-20 cm
Soil horizon 5-10 cm
Soil horizon 0-5 cm

Figure 4. 17 Pools of base cations and acid cations (kg ha^{-1}) in the top 50 cm of the forest soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error.

There was an increase of base cations with the increasing of stand age in Eutric Cambisol (Figure 4.17). Base cations in study plot L2 was significantly higher than in other study plots. Acid cations in study plot L2 was significantly lower than in other study plots. There was a heterogeneous trend of base cations in Haplic Luvisol. There was a decrease of acid cations with the increasing of stand age in Haplic Luvisol. There was a heterogeneous trend of acid cations in Eutric Cambisol.

Mean value of base cations were 7 010 kg ha^{-1} in Eutric Cambisol, 11 700 kg ha^{-1} in Haplic Luvisol and 19 500 kg ha^{-1} in Calcic Chernozem and were significantly different among three different soil types (Table 4.17). Mean value of acid cations were 1 320 kg ha^{-1} in Eutric Cambisol, 1 510 kg ha^{-1} in Haplic Luvisol and 149 kg ha^{-1} in Calcic Chernozem. Acid cations in Calcic Chernozem were significantly lower than in Eutric Cambisol and Haplic Luvisol. There was no significant difference of acid cations between Eutric Cambisol and Haplic Luvisol.

Table 4. 32 Base cation and acid cation (kg ha $^{-1}$) of three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in *Quercus* study plots in North-East Austria. Mean values and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil Type	Base Cations	Acid Cations
Eutric Cambisol	7 010 ± 708^{a}	1 320 ± 611^{b}
Calcic Chernozem	19 500 ± 996^{c}	149 ± 79^{a}
Haplic Luvisol	11 700 ± 524^{b}	1510 ± 82 ^{b}

4.3.8. CEC and Base Saturation

Cation exchangeable capacity (CEC) was determined in nine study plots according to different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm). Mean value of CEC ranged from 34 to 190 μmol g^{-1} over the whole range of study plots (Table 4.33).

Table 4. 33 CEC (μmol g^{-1}) at different soil horizons (0 to 5 cm, 5 to 10 cm, 10 to 20 cm, 20 to 40 cm, 40 to 50 cm) in the nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. Mean values (n=18) and standard error. Letters indicate significant difference ($p < 0.05$) among different study plots.

Study plot	CEC (μmol g^{-1}) in different soil horizons				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
S1	92 ± 9.8^{a}	45 ± 5.9^{a}	34 ± 2.8^{a}	38 ± 6.0^{a}	57 ± 10.0^{a}
S2	90 ± 4.9^{a}	59 ± 4.0^{ab}	53 ± 5.8^{b}	63 ± 7.3^{b}	77 ± 7.2^{a}
S3	107 ± 9.3^{ab}	86 ± 12.7^{c}	81 ± 13.9^{c}	80 ± 13.3^{bcd}	78 ± 12.6^{ab}
S4	88 ± 10.4^{a}	62 ± 7.9^{b}	52 ± 6.5^{b}	66 ± 11.4^{b}	95 ± 15.4^{abc}
S5	95 ± 8.5^{a}	61 ± 6.3^{b}	55 ± 7.1^{b}	69 ± 13.9^{bc}	83 ± 19.1^{abc}
L2	189 ± 12.7^{c}	157 ± 13.1^{d}	153 ± 21.5^{d}	136 ± 3.8^{e}	126 ± 2.5^{c}
L3	112 ± 4.1^{ab}	82 ± 2.3^{c}	78 ± 2.4^{c}	97 ± 2.7^{cd}	116 ± 2.4^{c}
L4	120 ± 4.8^{b}	77 ± 2.4^{c}	73 ± 4.4^{c}	75 ± 2.9^{bc}	98 ± 3.1^{bc}
L5	105 ± 4.0^{ab}	86 ± 2.8^{c}	84 ± 3.3^{c}	107 ± 5.7^{d}	126 ± 3.4^{c}

CEC in different soil horizons were: from 88 to 189 μmol g^{-1} at top 5 cm; from 45 to 157 μmol g^{-1} at 5-10 cm, from 34 to 153 μmol g^{-1} at 10-20 cm, from 38 to 136 μmol g^{-1} at 20-40 cm and from 57 to 126 μmol g^{-1} at 40-50 cm over all study plots. The mean value of CEC in the top 50 cm of the soil were: 53 μmol g^{-1} in S1, 68 µmol g $^{-1}$ in S2, 86 µmol g $^{-1}$ in S3, 72 µmol g $^{-1}$ in S4, 73 µmol g $^{-1}$ in S5, 152 µmol g $^{-1}$ in L2, 97 µmol g $^{-1}$ in L3, 89 µmol g $^{-1}$ in L4 and 101 µmol g $^{-1}$ in L5. CEC in study plot L2 was significantly higher than in other study plots in the top 50 cm of the soil. Study plot S1 had the significantly lowest CEC at 10-40 cm of the soil and lowest CEC in the top 50 cm of the soil among all study plots.

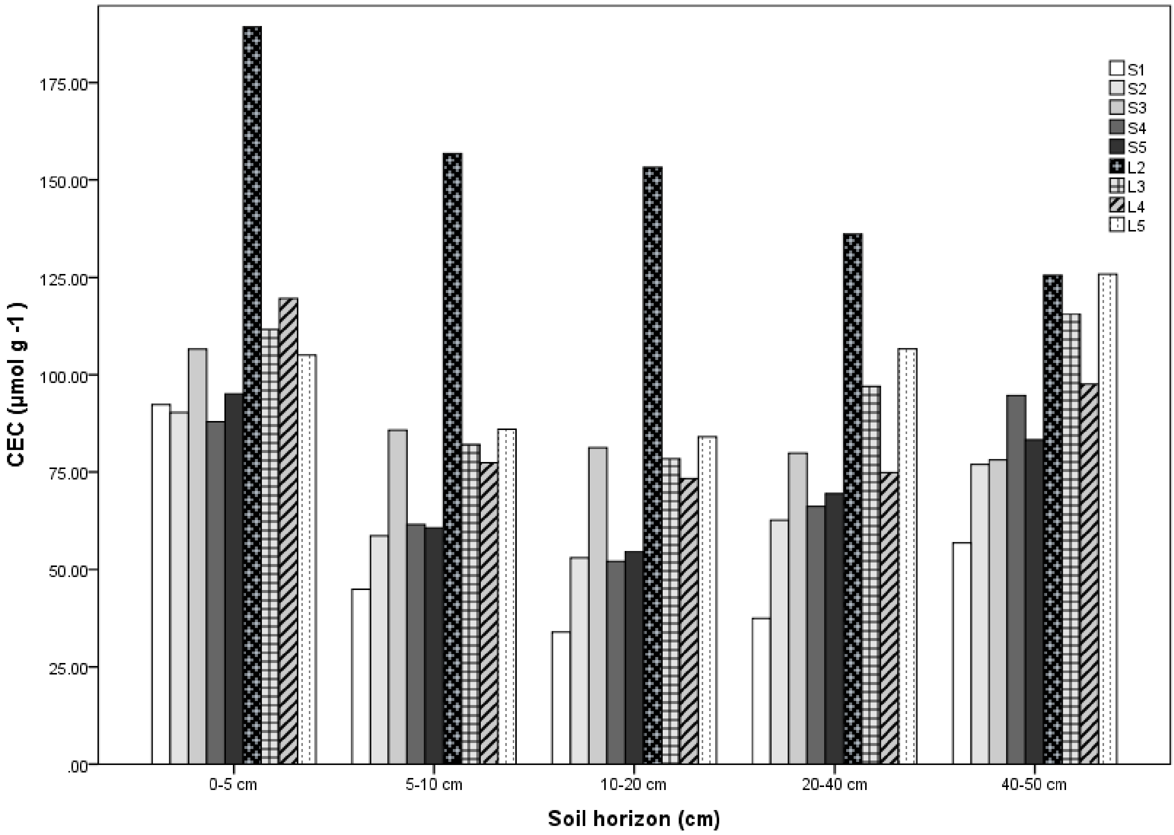


Figure 4. 18 Mean value of CEC (µmol g $^{-1}$) at different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm) in nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Figure 4.18 shows CEC (µmol g $^{-1}$) distribution at different soil horizons (0-5, 5-10, 10-20, 20-40 and 40-50 cm) over the whole range of study plots. CEC decreased steadily with the increasing of soil horizons in study plot L2. CEC decreased to minimum value with the increasing of soil horizon up to 20 cm, and then increased with soil horizon up to 50 cm in study plots S1-S5 and L3-L5. The highest CEC over our whole study was 189 µmol g $^{-1}$ in the top 5 cm of the soil in study plot L2.

Mean value of CEC were 71 µmol g $^{-1}$ in Eutric Cambisol, 152 µmol g $^{-1}$ in Haplic Luvisol and 96 µmol g $^{-1}$ in Calcic Chernozem (Table 4.34). Calcic Chernozem had the significantly highest CEC at 0-40 cm of the soil. There were significant difference of CEC at 0-40 cm of the soil and in the top 50 cm of the soil among three different soil types. CEC ranged following orders: Calcic Chernozem > Haplic Luvisol > Eutric Cambisol. There was no significant difference of CEC between Calcic Chernozem and Haplic Luvisol at 40-50 cm of the soil.

Table 4. 34 Cation exchangeable capacity (µmol g $^{-1}$) in three different soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in *Quercus* study plots in North-East Austria. Mean values and standard error. Letters indicate significant difference ($p < 0.05$) between different soil types.

Soil type	**CEC (µmol g $^{-1}$) in different soil horizon**				
	0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm
Eutric Cambisol	94 ± 3.9^{a}	62 ± 3.9^{a}	54 ± 4.1^{a}	63 ± 5.1^{a}	78 ± 6.0^{a}
Calcic Chernozem	189 ± 12.7^{c}	157 ± 13^{c}	153 ± 22^{c}	136 ± 3.8^{c}	126 ± 2.5^{b}
Haplic Luvisol	112 ± 2.7^{b}	82 ± 1.6^{b}	79 ± 2.1^{b}	93 ± 3.4^{b}	113 ± 2.8^{b}
Mean value over all study plots	111 ± 4.2	79 ± 4.2	74 ± 4.7	81 ± 4.0	95 ± 4.1

In this study CEC was significantly positively correlated (Pearson correlation coefficient 0.661, $P<0.01$) with the pH (H_2O) of the soil. Base saturation and pH (H_2O) at different soil horizons were shown in Figure 4.19. It was indicated that base saturation were positively correlated with soil pH (H_2O). There was a decrease of base saturation and soil pH (H_2O) with the increase of soil horizon up to 20 cm and an increase of base saturation and soil pH (H_2O) with the continues increase of soil horizon up to 50 cm. Base saturation and pH value were lowest at 5-20 cm of the soil and significantly higher ($p<0.05$) in Calcic Chernozem.

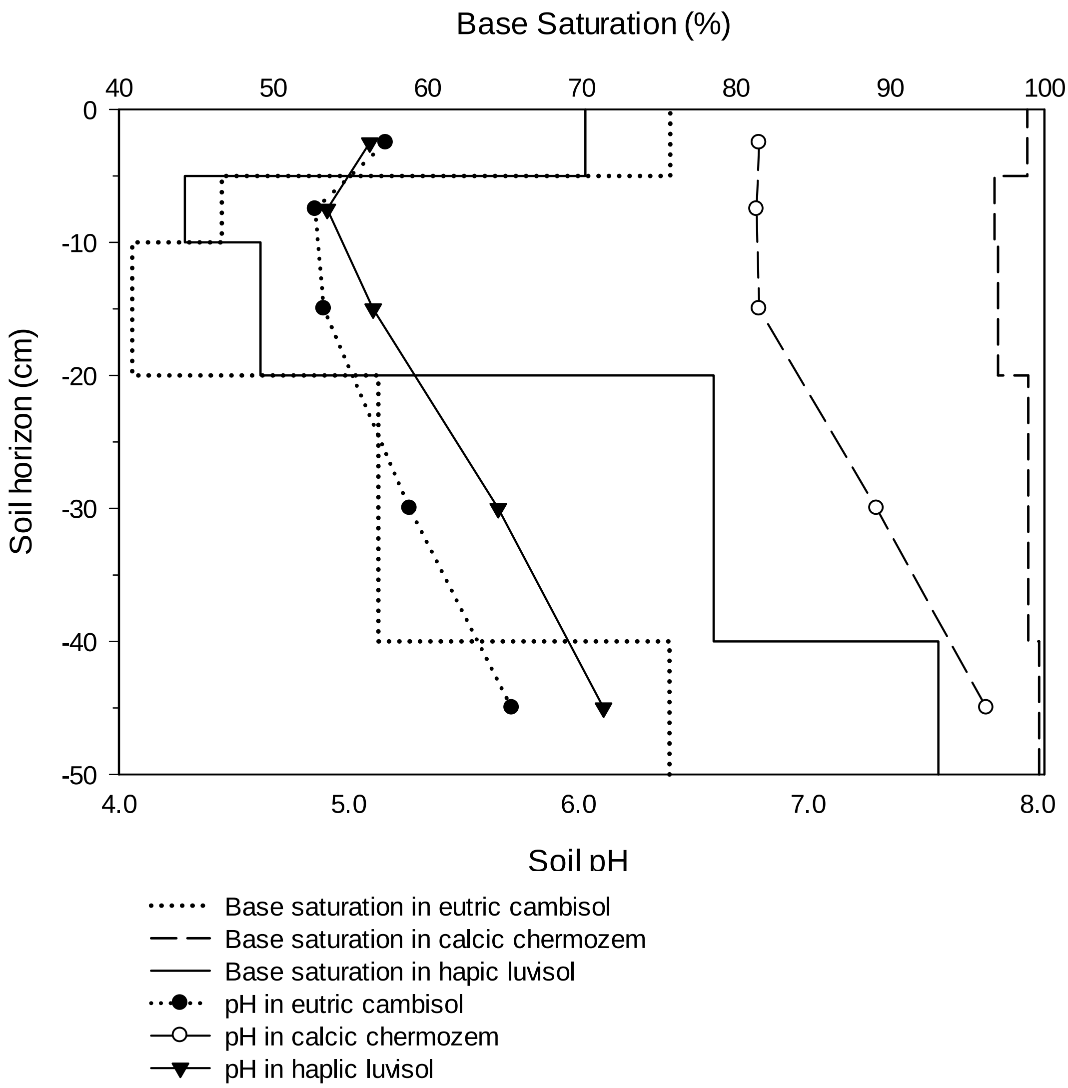


Figure 4. 19 Base saturation (%) and soil pH (H_2O). (mean value interpolated) at different soil horizons in three soil types (Eutric Cambisol, Calcic Chernozem and Hapic Luvisol) in North-East Austrian *Quercus* Forest.

4.4. Above-ground Nutrient Pools

Nutrient pools of N, K, Ca, Na, Al, Fe, Mn, P and S in different fractions (foliage, regeneration, branches of different diameters, wood and bark) of above-ground standing biomass were determined in this study.

4.4.1. Above-ground N Pool

The total above-ground N pool standing biomass were: 88.7 kg ha^{-1} in study plot S1, 532 kg ha^{-1} in study plot S2, 582 kg ha^{-1} in study plot S3, 612 kg ha^{-1} in study plot S4, 609 kg ha^{-1} in study plot S5, 635 kg ha^{-1} in study plot L2, 757 kg ha^{-1} in study plot L3, 742 kg ha^{-1} in study plot L4 and 680 kg ha^{-1} in study plot L5. Regeneration in study plots S2, S4, L2 and L5 were very less.

Table 4. 35 Above-ground N (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	**N content in different fractions (kg ha^{-1})**							**Total N pool (kg ha^{-1})**
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	33.2	21.0	9.1	5.8	9.8	6.9	2.9	88.7
S2	146	2.2	57.5	61.4	84.5	119	60.7	532
S3	63.5	23.2	88.0	127	44.0	163	72.6	582
S4	46.0	0.1	89.7	203	7.3	193	72.9	612
S5	49.9	9.62	80.6	212	22.4	169	65.7	609
L2	101	0.2	89.5	111	96.5	159	77.3	635
L3	67.0	56.7	117	148	36.8	246	85.9	757
L4	55.1	19.6	110	193	30.3	258	75.7	742
L5	53.8	0.17	101	160	44.6	250	70.4	680

4.4.2. Above-ground K Pool

The total K pool in above-ground standing biomass were: 47.6 kg ha^{-1} in study plot S1, 276.8 kg ha^{-1} in study plot S2, 329.3 kg ha^{-1} in study plot S3, 340.9 kg ha^{-1} in study plot S4, 345 kg ha^{-1} in study plot S5, 302.1 kg ha^{-1} in study plot L2, 445.4 kg ha^{-1} in study plot L3, 417.8 kg ha^{-1} in study plot L4 and 365.8 kg ha^{-1} in study plot L5.

Table 4. 36 Above-ground K (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) stands in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	K content in different fractions (kg ha^{-1})							Total K pool (kg ha^{-1})
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	13.4	13.8	6.0	3.4	5.7	4.2	1.2	47.6
S2	55.8	1.7	37.7	36.0	49.6	71.0	25.2	277
S3	24.5	17.8	58.5	74.6	26.0	97.8	30.1	329
S4	20.3	0.04	57.6	117	3.4	113	30.0	341
S5	19.9	7.3	53.1	124	12.6	101	27.3	345
L2	39.6	0.11	47.5	55.3	52.1	83.3	24.3	302
L3	25.2	43.5	79.3	88.8	19.0	151	38.5	445
L4	21.1	15.0	72.8	108	15.5	152	33.1	418
L5	20.7	0.09	64.9	93.7	19.3	136	31.2	366

4.4.3. Above-ground Ca Pool

The total Ca pool in above-ground standing biomass were: 94.7 kg ha^{-1} in study plot S1, 567 kg ha^{-1} in study plot S2, 700 kg ha^{-1} in study plot S3, 722 kg ha^{-1} in study plot S4, 724 kg ha^{-1} in study plot S5, 962 kg ha^{-1} in study plot L2, 837 kg ha^{-1} in study plot L3, 790 kg ha^{-1} in study plot L4 and 929 kg ha^{-1} in study plot L5.

Table 4. 37 Above-ground Ca (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	Ca content in different fractions (kg ha^{-1})							Total Ca pool (kg ha^{-1})
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	16.1	33.5	14.6	7.3	12.4	3.3	7.6	94.7
S2	68.0	3.7	91.9	78.0	108	56.2	161	567
S3	35.0	38.8	141	162	53.3	76.8	193	700
S4	24.7	0.1	142	258	7.6	97.2	192	722
S5	27.5	14.1	129	269	26.1	84.3	174	724
L2	60.6	0.4	157	190	141	87.4	327	962
L3	42.2	83.0	165	216	35.2	111	186	837
L4	34.2	28.7	154	270	29.0	113	162	790
L5	32.0	0.4	158	231	48.6	302	158	929

4.4.4. Above-ground Mg Pool

The total Mg pool in above-ground standing biomass were: 10.9 kg ha^{-1} in study plot S1, 58.2 kg ha^{-1} in study plot S2, 71.9 kg ha^{-1} in study plot S3, 74.8 kg ha^{-1} in study plot S4, 74.2 kg ha^{-1} in study plot S5, 80.2 kg ha^{-1} in study plot L2, 93.1 kg ha^{-1} in study plot L3, 91.1 kg ha^{-1} in study plot L4 and 83.4 kg ha^{-1} in study plot L5.

Table 4. 38 Above-ground Mg (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	**Mg content in different fractions (kg ha^{-1})**							**Total Mg pool (kg ha^{-1})**
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	3.3	3.3	1.4	0.6	1.1	0.78	0.39	10.9
S2	10.7	0.4	9.1	6.8	9.3	13.4	8.4	58.2
S3	5.6	4.4	14.1	14.0	5.4	18.4	10.0	71.9
S4	4.3	0.01	13.9	22.5	1.0	22.9	10.1	74.8
S5	4.5	1.7	12.9	23.5	2.9	19.5	9.2	74.2
L2	10.4	0.02	11.3	16.3	14.1	18.7	9.5	80.2
L3	7.0	9.9	16.4	18.3	5.6	24.9	11.0	93.1
L4	5.8	3.4	15.2	23.4	4.6	29.1	9.7	91.1
L5	5.5	0.03	14.5	19.9	6.5	28.0	9.1	83.4

4.4.5. Above-ground Na Pool

The total Na pool in above-ground standing biomass were: 2.1 kg ha^{-1} in study plot S1, 10.7 kg ha^{-1} in study plot S2, 14.9 kg ha^{-1} in study plot S3, 14.9 kg ha^{-1} in study plot S4, 14.0 kg ha^{-1} in study plot S5, 11.3 kg ha^{-1} in study plot L2, 14.5 kg ha^{-1} in study plot L3, 14.7 kg ha^{-1} in study plot L4 and 14.1 kg ha^{-1} in study plot L5.

Table 4. 39 Above-ground Na (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	**Na content in different fractions (kg ha^{-1})**							**Total Na pool (kg ha^{-1})**
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	1.08	0.33	0.14	0.06	0.10	0.33	0.08	2.13
S2	0.81	0.12	0.91	0.65	0.89	5.61	1.74	10.7
S3	0.36	1.23	1.65	1.35	0.48	7.78	2.08	14.9
S4	0.26	0.00	1.49	2.13	0.06	8.90	2.08	14.9
S5	0.28	0.11	1.47	2.24	0.25	7.79	1.87	14.0
L2	0.65	0.00	1.30	1.26	1.27	5.19	1.64	11.3
L3	0.50	0.64	1.39	1.65	0.48	7.82	2.03	14.5
L4	0.40	0.22	1.33	2.04	0.39	8.51	1.81	14.7
L5	0.41	0.00	1.22	1.81	0.60	8.29	1.73	14.1

4.4.6. Above-ground Al Pool

The total Al pool in above-ground standing biomass were: 1.45 kg ha^{-1} in study plot S1, 4.52 kg ha^{-1} in study plot S2, 5.84 kg ha^{-1} in study plot S3, 5.95 kg ha^{-1} in study plot S4, 5.86kg ha^{-1} in study plot S5, 2.99 kg ha^{-1} in study plot L2, 3.85 kg ha^{-1} in study plot L3, 3.55 kg ha^{-1} in study plot L4 and 4.43 kg ha^{-1} in study plot L5.

Table 4. 40 Above-ground Al (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	**Al content in different fractions (kg ha^{-1})**							**Total Al pool (kg ha^{-1})**
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	1.01	0.14	0.06	0.03	0.05	0.14	0.02	1.45
S2	0.50	0.02	0.38	0.32	0.44	2.36	0.50	4.52
S3	0.25	0.22	0.60	0.67	0.22	3.28	0.60	5.84
S4	0.17	0.00	0.60	1.06	0.04	3.48	0.60	5.95
S5	0.21	0.09	0.55	1.11	0.11	3.26	0.54	5.86
L2	0.45	0.00	0.63	0.57	0.46	0.03	0.85	2.99
L3	0.30	0.51	0.59	1.06	0.12	0.76	0.53	3.85
L4	0.24	0.18	0.57	1.34	0.10	0.66	0.47	3.55
L5	0.35	0.00	0.60	1.12	0.18	1.69	0.48	4.43

4.4.7. Above-ground Fe Pool

The total Fe pool in above-ground standing biomass were: 2.32 kg ha^{-1} in study plot S1, 7.65 kg ha^{-1} in study plot S2, 9.41 kg ha^{-1} in study plot S3, 9.60 kg ha^{-1} in study plot S4, 9.53 kg ha^{-1} in study plot S5, 8.79 kg ha^{-1} in study plot L2, 9.61 kg ha^{-1} in study plot L3, 8.98 kg ha^{-1} in study plot L4 and 10.33 kg ha^{-1} in study plot L5.

Table 4. 41 Above-ground Fe (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	Fe content in different fractions (kg ha^{-1})							Total Fe pool (kg ha^{-1})
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	1.17	0.55	0.24	0.06	0.11	0.15	0.03	2.32
S2	1.19	0.03	1.52	0.69	0.94	2.63	0.66	7.65
S3	0.54	0.33	2.24	1.41	0.46	3.64	0.79	9.41
S4	0.36	0.00	2.23	2.22	0.05	3.95	0.78	9.60
S5	0.42	0.08	2.05	2.36	0.25	3.65	0.71	9.53
L2	1.50	0.01	1.94	0.97	1.01	2.32	1.05	8.79
L3	1.13	0.45	0.60	2.21	0.49	4.07	0.66	9.61
L4	0.87	0.16	0.56	2.64	0.40	3.76	0.58	8.98
L5	1.00	0.00	0.73	2.42	0.71	4.83	0.63	10.3

4.4.8. Above-ground Mn Pool

The total Mn pool in above-ground standing biomass were: 14.4 kg ha^{-1} in study plot S1, 64 kg ha^{-1} in study plot S2, 72.9 kg ha^{-1} in study plot S3, 76.7 kg ha^{-1} in study plot S4, 75.9 kg ha^{-1} in study plot S5, 31.5 kg ha^{-1} in study plot L2, 76.8 kg ha^{-1} in study plot L3, 76.7 kg ha^{-1} in study plot L4 and 77.1 kg ha^{-1} in study plot L5.

Table 4. 42 Above-ground Mn (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	Mn content in different fractions (kg ha^{-1})							Total Mn pool (kg ha^{-1})
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	3.70	5.5	2.4	0.7	1.3	0.4	0.48	14.4
S2	12.8	0.2	14.9	7.9	10.8	7.1	10.3	64.0
S3	5.4	2.3	21.8	16.3	5.0	9.8	12.3	72.9
S4	3.6	0.01	22.2	25.8	0.7	12.2	12.2	76.7
S5	4.2	1.4	19.8	27.0	2.5	10.0	11.1	75.9
L2	4.0	0.02	9.0	5.3	5.3	3.6	4.4	31.5
L3	6.3	8.0	18.1	20.9	2.6	11.0	9.9	76.8
L4	5.1	2.8	16.9	26.7	2.2	14.3	8.8	76.7
L5	5.8	0.02	15.6	22.7	5.3	19.3	8.4	77.1

4.4.9. Above-ground P Pool

The total P pool in above-ground standing biomass were: 8.67 kg ha^{-1} in study plot S1, 45.9 kg ha^{-1} in study plot S2, 53.4 kg ha^{-1} in study plot S3, 59.1 kg ha^{-1} in study plot S4, 56.3 kg ha^{-1} in study plot S5, 66.8 kg ha^{-1} in study plot L2, 107 kg ha^{-1} in study plot L3, 108 kg ha^{-1} in study plot L4 and 87.6 kg ha^{-1} in study plot L5.

Table 4. 43 Above-ground P (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	P content in different fractions (kg ha^{-1})							Total P pool (kg ha^{-1})
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	3.22	2.19	0.95	0.53	0.90	0.70	0.18	8.67
S2	10.5	0.25	6.00	5.68	7.82	11.9	3.81	45.9
S3	4.47	2.56	9.23	11.8	4.36	16.4	4.55	53.4
S4	3.23	0.01	9.60	19.1	0.93	21.7	4.58	59.1
S5	3.50	1.45	8.43	19.6	2.33	16.9	4.13	56.3
L2	7.67	0.02	10.9	13.0	12.5	18.0	4.75	66.8
L3	6.47	8.66	17.7	17.5	5.51	44.6	6.20	107
L4	5.14	3.00	16.7	23.4	4.53	50.1	5.42	108
L5	5.24	0.02	14.7	18.9	5.78	38.0	5.08	87.6

4.4.10. Above-ground S Pool

The total S pool in above-ground standing biomass were: 8.4 kg ha^{-1} in study plot S1, 42.8 kg ha^{-1} in study plot S2, 49.2 kg ha^{-1} in study plot S3, 51.0 kg ha^{-1} in study plot S4, 51.1 kg ha^{-1} in study plot S5, 57.1 kg ha^{-1} in study plot L2, 75.5 kg ha^{-1} in study plot L3, 71.0 kg ha^{-1} in study plot L4 and 75.1 kg ha^{-1} in study plot L5.

Table 4. 44 Above-ground S (kg ha^{-1}) in different fractions and total pools of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria. F represents foliage of canopy trees, Rg represents tree regeneration which also means total biomass of plants with DBH < 1.3 m, Bh < 2 cm represents branch < 2 cm, Bh > 2 cm represents branch > 2 cm, S+Bk < 8 cm represents total stem and bark when stem < 8 cm, S > 8 cm represents stem > 8 cm, Bk > 8 cm represents bark biomass when stem > 8 cm.

Study plot	S content in different fractions (kg ha^{-1})							Total S pool (kg ha^{-1})
	F	Rg	Bh < 2	Bh > 2	S+Bk<8	S>8	Bk > 8	
S1	3.05	2.32	1.01	0.48	0.82	0.45	0.31	8.44
S2	9.72	0.23	6.37	5.14	7.08	7.63	6.61	42.8
S3	4.44	2.39	9.71	10.7	3.58	10.5	7.90	49.2
S4	3.11	0.01	9.86	16.9	0.50	12.7	7.92	51.0
S5	3.48	1.13	8.86	17.7	1.87	10.9	7.14	51.1
L2	7.29	0.02	9.54	11.1	9.45	9.43	10.3	57.1
L3	4.77	6.70	14.6	13.4	3.19	22.7	10.2	75.5
L4	3.90	2.32	13.6	16.8	2.61	23.0	8.81	71.0
L5	3.71	0.03	13.7	14.6	4.37	30.0	8.70	75.1

5. Discussions

5.1. Above-ground Standing Biomass

Forests act as major sinks for atmospheric CO_2 (Myneni *et al.*, 2001; Schimel *et al.*, 2001; Wang *et al.*, 2008) and major sources for bio-energy (Bringezu *et al.*, 2009; Verkerk *et al.*, 2011). Stable growing forests have the highest above-ground standing biomass both in Eutric Cambisol and Haplic Luvisol in this study. The biomass harvesting should be in stable growing period to have the high biomass productivity. Several studies reported that organic C is 50% of total above-ground biomass (Lamlom and Savidge, 2003; Liski *et al.*, 2003; Kaipainen *et al.*, 2004; Bruckman *et al.*, 2011).

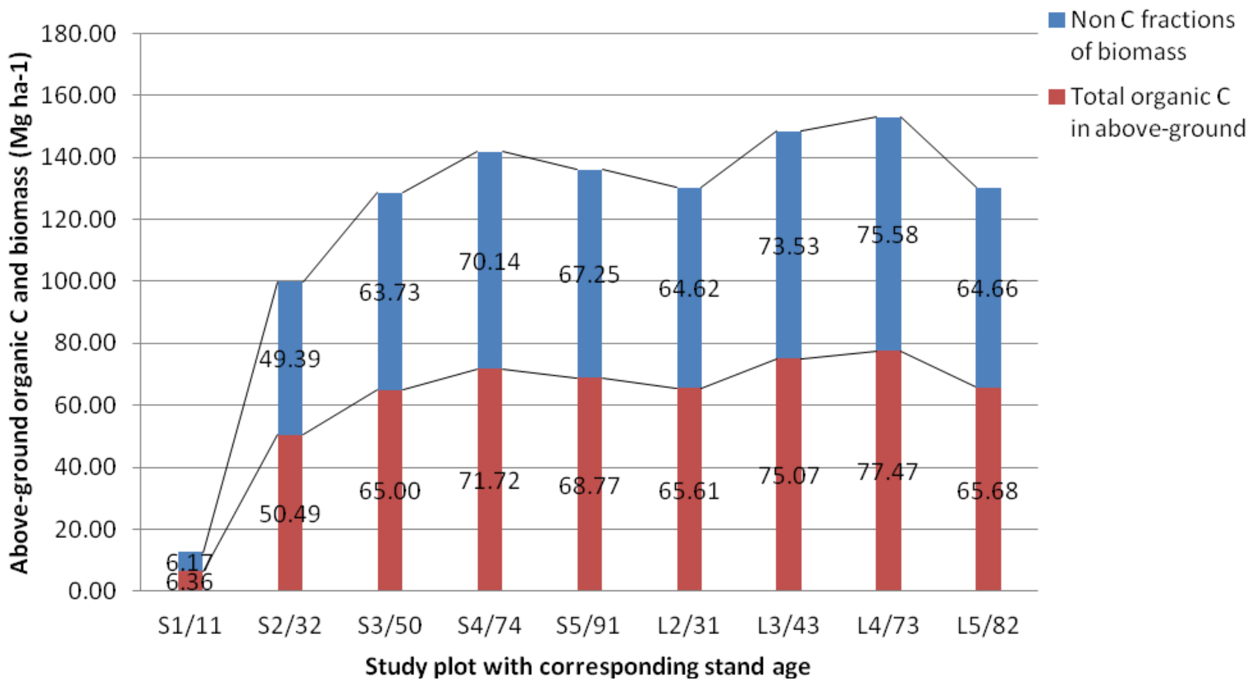


Figure 5. 1 Above-ground organic C pool (Mg ha^{-1}) and non C fractions of biomass of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

This study shows that organic C was slightly higher than 50% of total biomass in all study plots (Figure 5.1). It gave the hints that organic C content in biomass is practically in the same in fast growing, stable growing and senescing period. There was no significant difference of C sequestration with the same increment of forest in fast growing, stable growing and senescing period. The average C density in vegetation ranges from 53 Mg ha^{-1} to 96 Mg ha^{-1} in boreal and temperate forests (Lal, 2005). It is obvious that the stand age, climate conditions and soil properties have influences on above-ground organic C stocks. The organic C stocks in this study ranged from 6.4 Mg ha^{-1} to 77.5 Mg ha^{-1}. The results of this study show that soil is relatively fertile in the study area. The limiting factor for organic C stock are likely the climate conditions since the annual precipitation is about 500 mm.

The forests in study area were managed for high quality timber production as well. There were no wood and bark samples collected from study plots S4, S5, L3, L4 and L5. There was a big difference of nutrient contents between wood and bark (Andre and Ponette, 2003; Andre *et al.*, 2010). Therefore the main reason to determine the wood: bark ratio was to have better understanding and precise evaluation of nutrient pools of branches and stems. Further study should consider enriching the model (Figure 4.2) of wood: bark ratio by adding more large diameter samples data on *Quercus petraea*.

5.2. Litter, N and C at the Forest Floor

Our hypotheses is based on the general assumption that stand age and harvesting affect the soil properties due to incorporation of nutrients in plant biomass. The results of this study of heterogeneously distributed dry mass, N and C in forest floor and no significant different of dry mass, N and C among three different soil types have supported our general assumption by proofing that there was no effect of forest floor either on nutrients pools in plant biomass or mineral soil properties. Figure 5.2 shows the PCA of litter, C and N in forest floor. KMO value (0.694) confirmed that the sampling adequacy is feasible for this study. Component 1 explains 58% of total variances and component 2 explains 32% of the total variances in PCA of study plots, soil types, litter, C and N in forest ground. Three soil types were not correlated in either component 1 or component 2 in this study. PCA explained that the soil type was the main reason causing differences in soil properties (Fig 5.2).

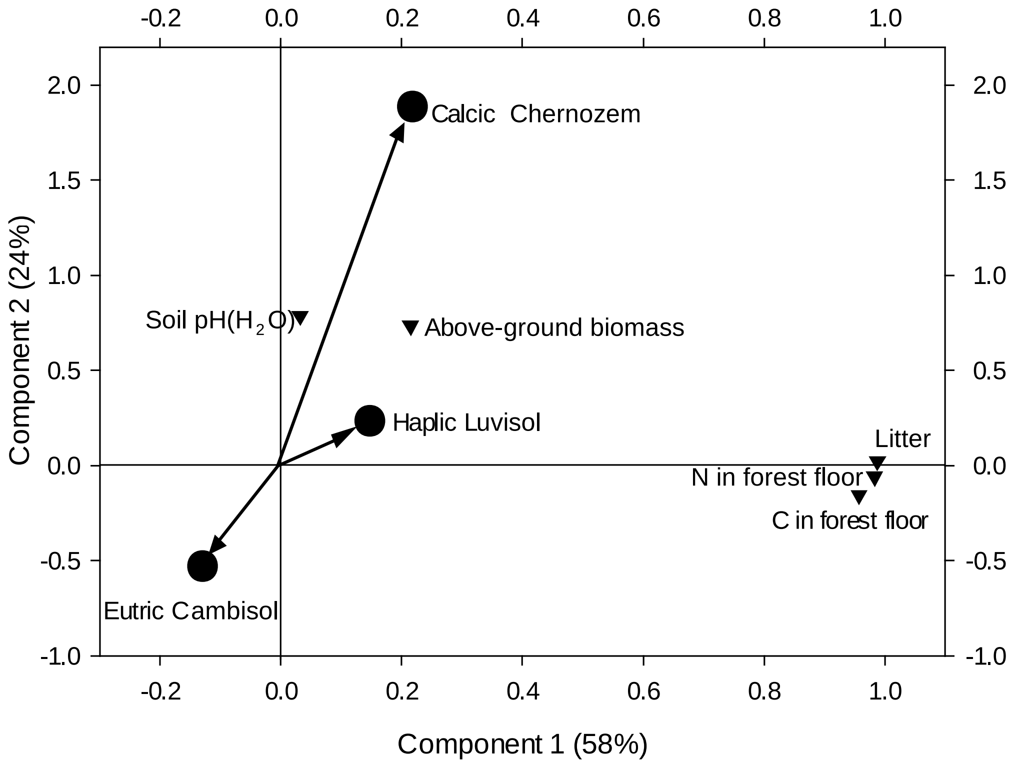


Figure 5. 2 Principal component analysis for the variables Litter, N, and C in forest floor, above-ground standing biomass and soil pH (H_2O) of nine *Quercus* study plots in North-East Austria.

Figure 5.3 shows the total litter C in forest floor was less than 50% of total litter biomass in all study plots. The reason could be the rapid transformation of litter C into organic soil C. It might also because the litter samples had some minerals (sands and small particle stones) due to sample collection procedure which could decrease the % of C ratio. Accelerated litter decomposition could cause the decreasing of C ratio in litter. It has been proofed that this is not the case for this study here (Bruckman *et al.*, 2011). Climatic condition such as low precipitation was not favorable factors for litter decomposition in study area. Open area in some study plots (for instance in study plots S5) could accelerate litter decomposition and mineralization. Mycorrhizal activities in forest soil could also accelerate the decomposition and mineralization of litter (Fisher and Fule, 2004; Allen *et al.*, 2005). This could be another reason of low N and C content in forest floor of this study area.

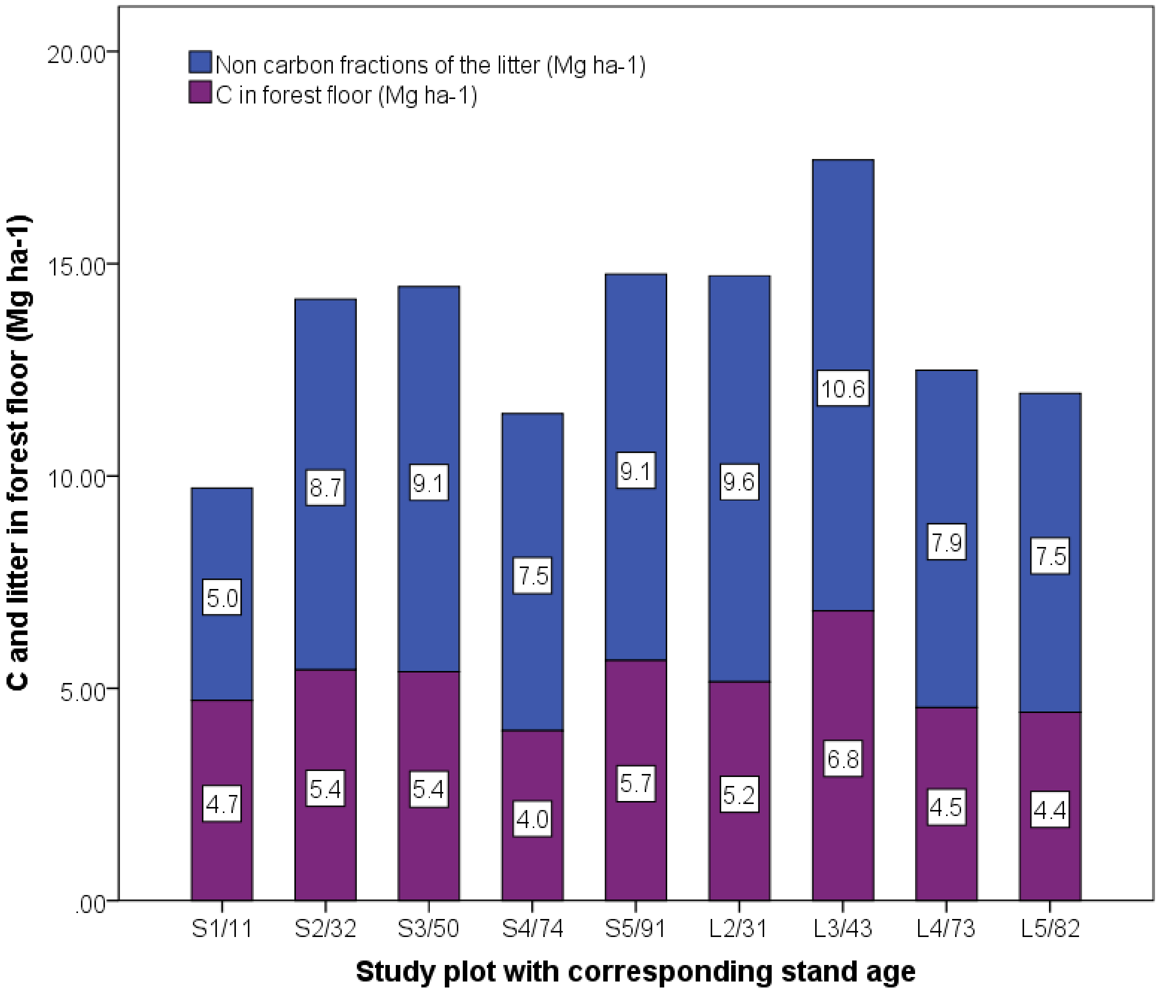


Figure 5. 3 Organic C (Mg ha^{-1}) pool in forest floor and non carbon fractions of litter of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

The litter dry mass, litter N and litter C were linear positively correlated with each other in different stand age and soil types (Figure 5.4). Forest floor retains moisture in the soil as well as improves soil textures for better aeration and drainage (Shuai, 2007). It could also provide favourable conditions for soil organisms and consequently increase the nutrients availability for plants. Many studies have shown that relatively large amount of nutrients are stored in the forest floor (Covington, 1981; Alifragis *et al.*, 2001; Arvidsson and Lundkvist, 2003; Yanai *et al.*, 2003; De Schrijver *et al.*, 2009).

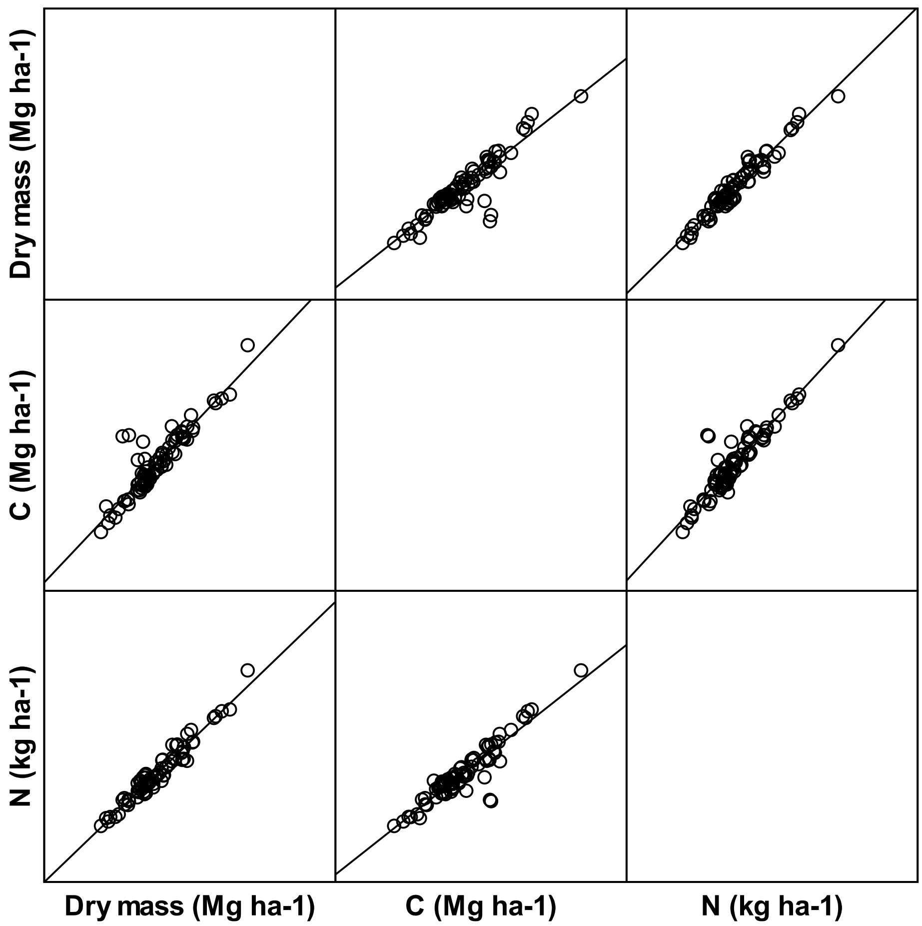


Figure 5. 4 Correlation among litter dry mass, N and C in forest floor of nine *Quercus* study plots in North-East Austria.

In this study the N and C storage in forest floor were significantly lower than in above-ground standing biomass and in mineral soil of top 50 cm horizon. That could be due to accelerated decomposition rate and forest management such as thinning etc. It is confirmed that nutrients and C in forest floor did not reflect the nutrient and C in mineral soil and above-ground standing biomass. The extreme data from Figure 5.4 were found in study plot S1. It could be the disturbance causing the C accumulating in certain area and it was collected for one or two of our samples. This was corresponding with Figure 5.3 that the % of litter C in study plot S1 was higher than other study plots.

5.3. Root Biomass

This study shows that study plot S3 had the highest root biomass and study plot S5 had the lowest root biomass (Table 4.5). There was no significant difference of root biomass in total 50 cm of the soil among three different soil types. Soil characteristics, such as nutrient availability and texture were reported to have significant influence on root biomass (Gower, 1987; Cairns *et al.*, 1997; Carter *et al.*, 2004). The reason for higher root biomass in S3 and lower root biomass in S5 might be the difference of stand density. Figure 5.5 shows the PCA of root biomass, C, N, soil types, soil bulk density, pH H_2O, exchangeable K, exchangeable Ca and exchangeable Mg in nine study plots. KMO value (0.686) confirmed that the sampling adequacy is feasible for this study. Component 1 explains 39% of total variances and component 2 explains 32% of the total variances in PCA. Soil bulk density in forest soil is closely and inversely related to the organic fraction of the soil (Adams, 1973). This study supported this conclusion by showing that soil bulk density was negatively correlated with other parameters in component 2. It is obvious study plots under the same soil type were closely correlated with each other. But the distance of study plots on different soil type was rather larger. This was caused mainly by soil acidity and base cations.

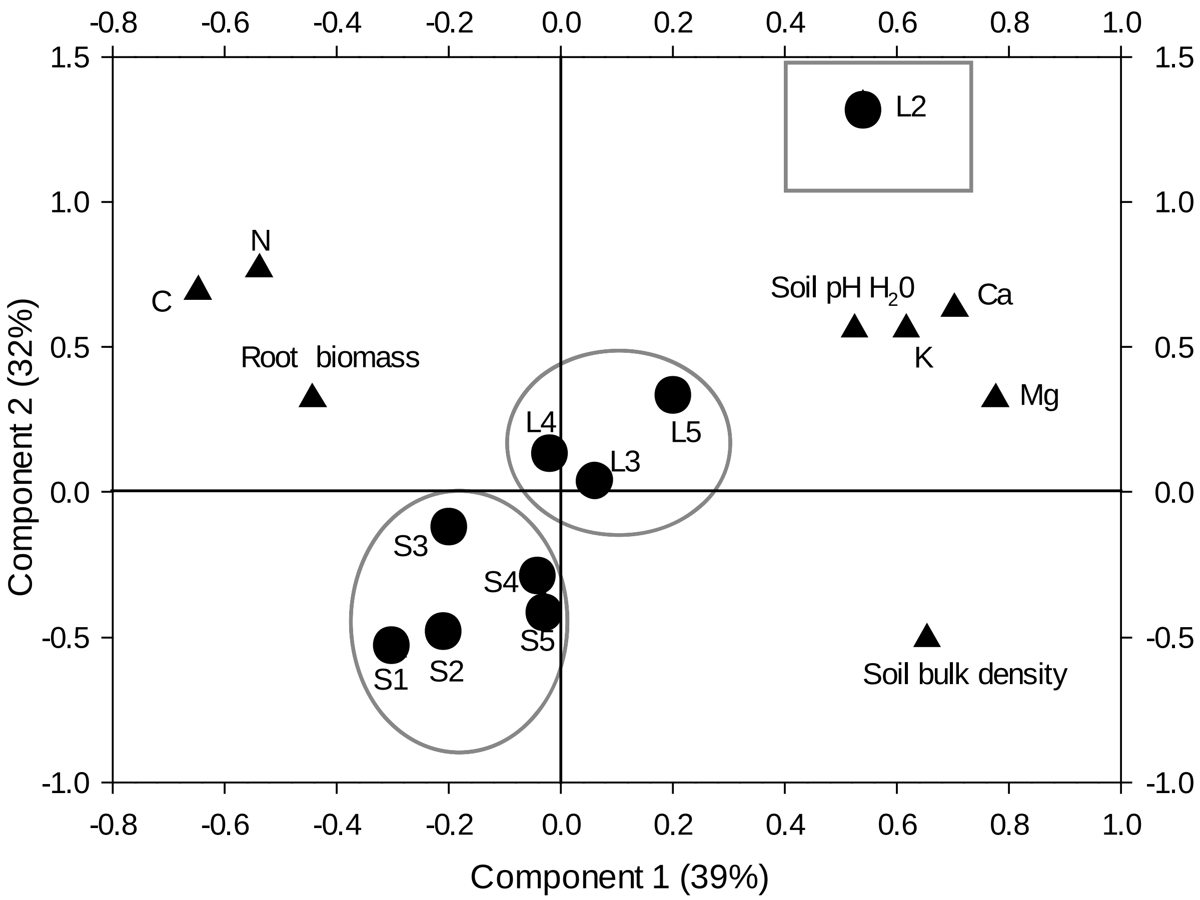


Figure 5. 5 Principal component analysis of soil properties (root biomass, C, N, soil types, soil bulk density, pH (H_2O), exchangeable K, exchangeable Ca and exchangeable Mg) in nine *Quercus* study plots in North-East Austria.

Plants with a higher proportion of roots can compete more effectively for soil nutrients. Plants with a higher proportion of shoots can collect more light energy. Root: shoot ratio changed with climatic, biotic factors and soil nutrient statues (Mokany *et al.*, 2006; Paul *et al.*, 2006; Wang *et al.*, 2008; Bi *et al.*, 2010; Zhang *et al.*, 2010). Plants respond to N availability by changing their root: shoot ratios (Agren and Franklin, 2003). Study plot S1 had significantly higher root: shoot ratio due to the less above-ground biomass. The nutrient pools in mineral soil were generally higher with the correlation of lower root: shoot ratio (Figure 5.6) in this study area.

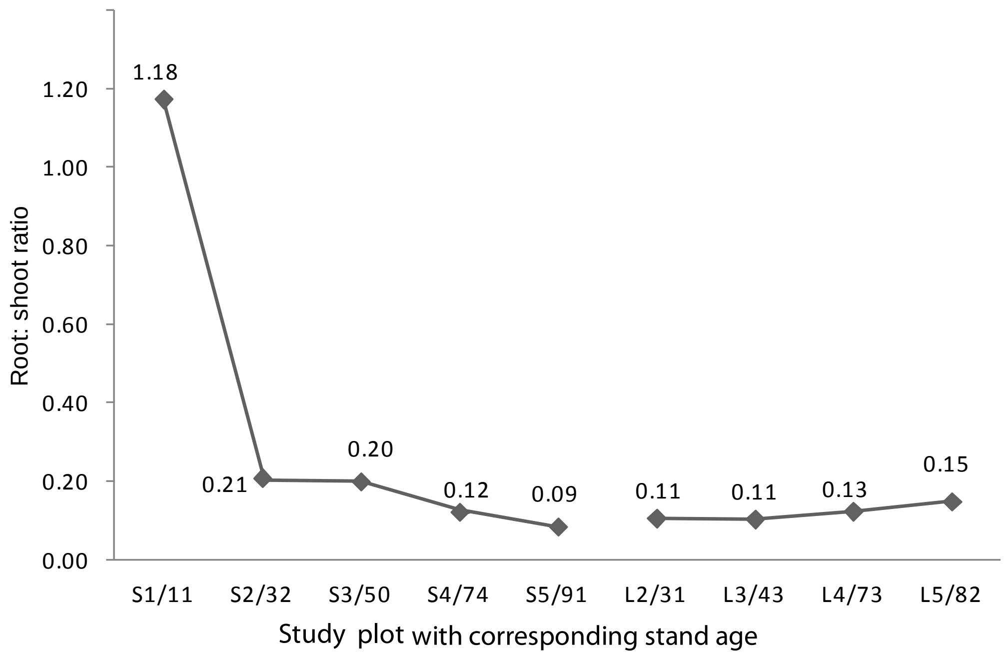


Figure 5. 6 Root: shoot ratio in nine *Quercus* study plots in North-East Austria.

5.4. Soil Properties

5.4.1. Soil Bulk Density against other selected soil properties

There was significant difference of soil bulk density among three different soil types in this study. The stand age and soil pH had no decisive influence on soil bulk density in this study. Soil types and soil horizons were most important factors to affect soil bulk density. Eutric Cambisol had significantly highest soil bulk density. Calcic Chernozem had the significantly lowest soil bulk density. Soil bulk density was not correlated with soil pH (H_2O), exchangeable K and exchangeable

Ca, but slightly negatively correlated with soil N (Figure 5.7). The reason could be high SOM content corresponding with lower soil bulk density. This conclusion is supported by many studies (Barton *et al.*, 1999; Berger and Hager, 2000; Morisada *et al.*, 2004; Tan and Chang, 2007; Sanchez *et al.*, 2009). The large soil N content with low soil bulk density indicates the samples from the top soil horizon. The large bulk density with low soil N content indicated the samples from the deep soil horizon (Figure 5.7). The soil bulk density ranged mainly between 1.25 g m^{-3} to 1.6 g m^{-3}.

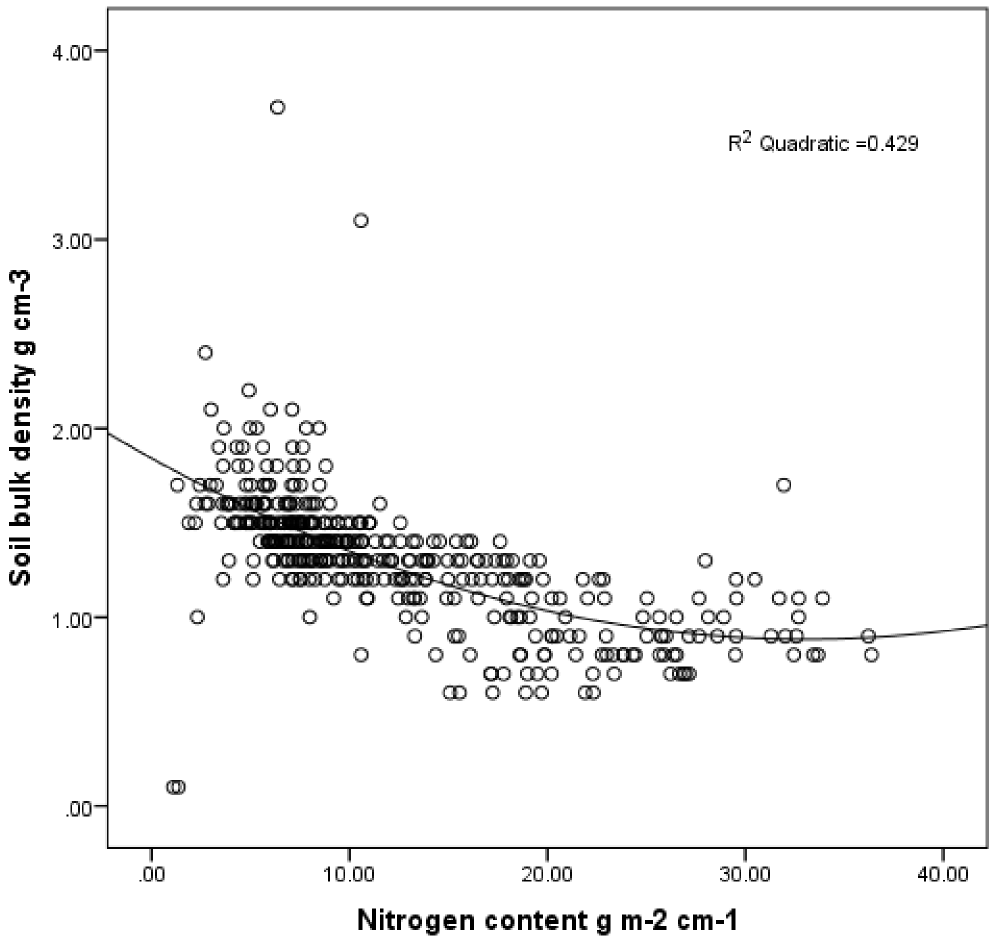


Figure 5. 7 Correlation of soil bulk density with soil nitrogen in *Quercus* study plots in North-East Austria.

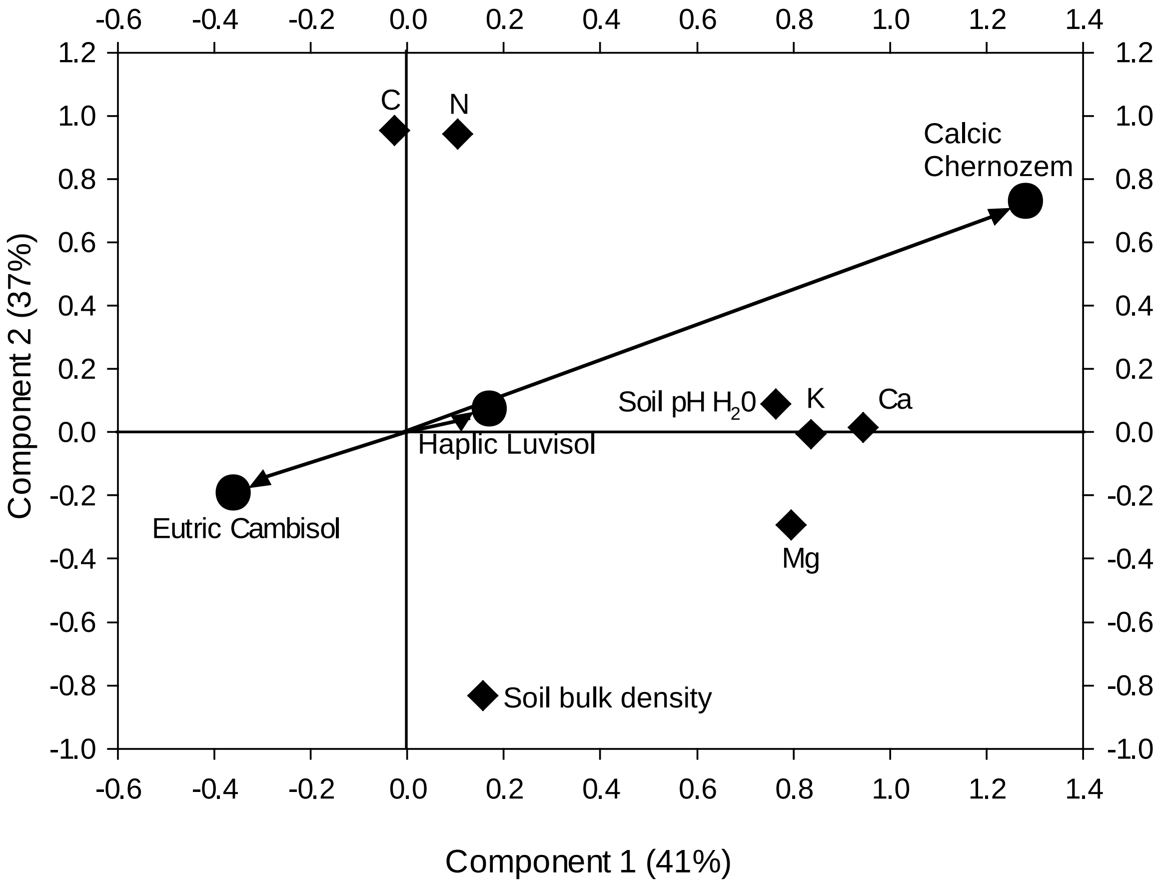


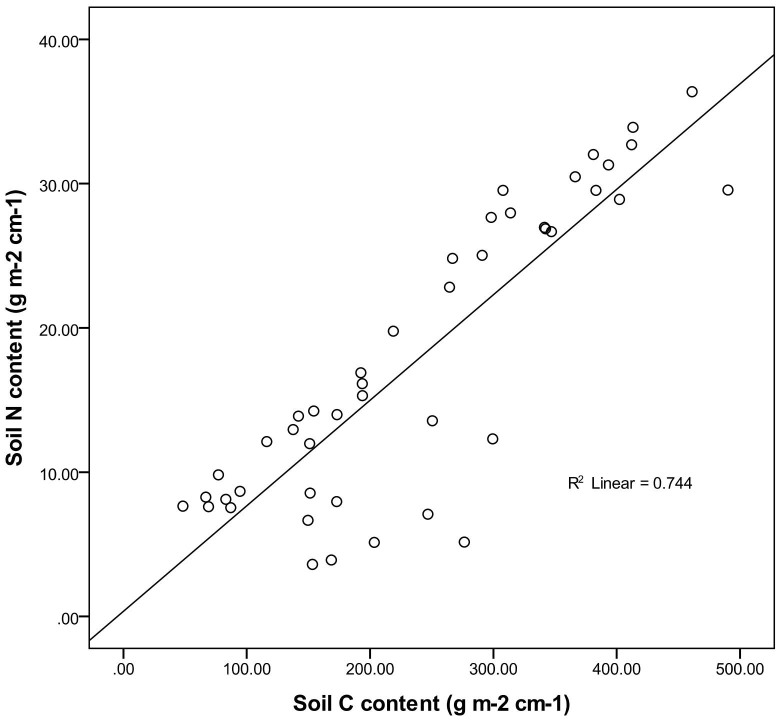
Figure 5. 8 Principal component analysis of soil properties (soil bulk density, C, N, soil types, pH (H_2O), exchangeable K, exchangeable Ca and exchangeable Mg) in nine *Quercus* study plots in North-East Austria.

Figure 5.8 shows the PCA of soil bulk density, C, N, soil types, pH (H_2O), exchangeable K, exchangeable Ca and exchangeable Mg in nine study plots. Soil bulk density was positively correlated with soil types, soil pH (H_2O) exchangeable K, exchangeable Ca and Exchangeable Mn in component 1. KMO value (0.670) confirmed that the sampling adequacy is feasible for this study. Soil bulk density was negatively correlated with soil N and C in component 2. The reason has been discussed in Figure 5.2. Component 1 explains 41% of total variances and component 2 explains 37% of the total variances in PCA. Equamax Rotation Method was applied in this analysis in order to obtain simple and interpretable factors. It could help to get better understanding of correlations in component 1 and component 2. Soil C, N and soil bulk density were correlated in component 2. But three soil types were correlated with soil pH (H_2O), exchangeable K, exchangeable Ca and Exchangeable Mg in component 1. It is obvious that Calcic Chernozem, Haplic Luvisol and Eutric Cambisol are in different positions with large distance to each other. This indicates the difference of soil properties were caused by different base saturation (Figure 4.19)

5.4.2. Nitrogen, Carbon and C:N Ratio

N is one of the most important elements for plant development in the soil. There is a large demand of N by plants and microorganisms uptake. Meanwhile the plants and microorganisms have competition for getting N and other nutrients. It was reported that most temperate and boreal forest ecosystems are still N limited (Nilsson, 1995; Michel, 2002; Michel and Matzner, 2002). Soil pH and N supply are the key distribution drivers for some broad-leaved species (Marage and Gegout, 2009). Soil acidity might affect the availability of N uptake by affecting the activity of microorganisms involved in ammonification, nitrification, denitrification, immobilization and non-symbiotic N fixation (Robson and Abbott, 1989). It was reported that N mineralization is negatively correlated with litter lignin: N ratio (Van Cleve *et al.*, 1993; Scott and Binkley, 1997; Joshi *et al.*, 2003), soil C:N ratio (Janssen, 1996; Cote *et al.*, 2000) and soil pH (H_2O) (Falkengren-Grerup *et al.*, 1998; Pietri and Brookes, 2008). In this study, soil N was not correlated with soil pH (H_2O) (Figure 5.8). It was reported that 90% of soil N existing as organic matter and the distribution of N and C are usually closely correlated (Sowden *et al.*, 1977). Results of this study (Figure 5.9) shows that soil N and C were positively correlated with each other, which supported the conclusion from Sowden (Sowden *et al.*, 1977). It was proofed that stand age had no large influence on soil N pools (Table 4.11 and Figure 4.7). Soil type was the most important factor to determine soil N pools.

Correlation of soil N with C in study plot L2 (Calcic Chernozem)



Correlation of soil N with C over all study plots including plot L2

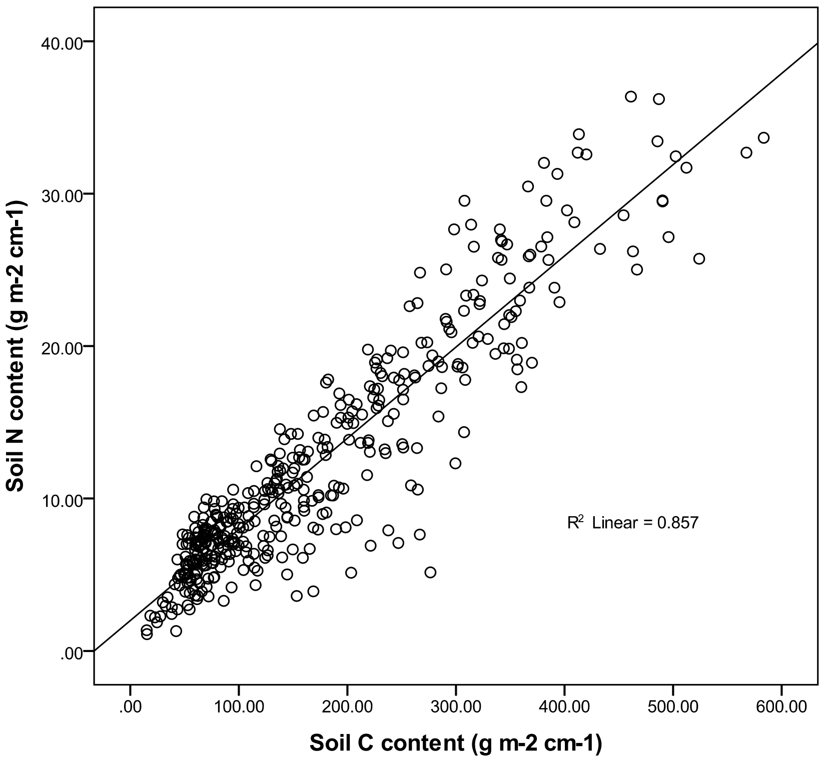


Figure 5. 9 Correlation of soil N with soil C in *Quercus* study plots in North-East Austria.

Due to the rich organic matter content in particular organic C (Table 4.13) in Calcic Chernozem, there are some extreme values of soil C content in the Figure 5.9. This is one of the evidences that Calcic Chernozem had lots of wood decays or debris with diameter smaller than 2 mm. Some mechanisms, for instance climate conditions of less windy and physical and chemical protections of micro aggregates, are likely going on to stabilize the carbon.

Figure 5.10 shows the N pool in mineral soil was significantly higher than in above-ground standing biomass. In this study area, the low precipitation may minimize the amount of N leaching into the deep soil horizons. Therefore, high amount of N accumulated in the shallow soil horizons.

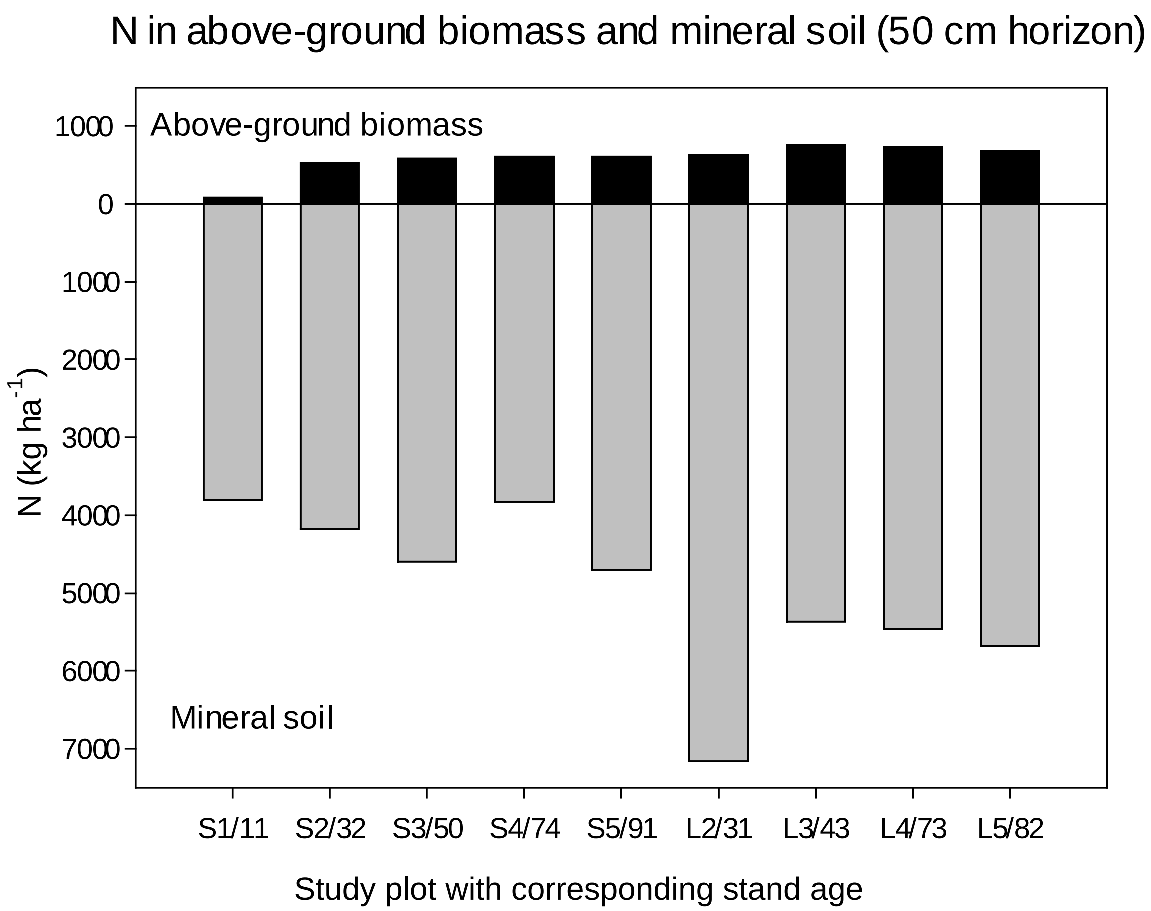


Figure 5. 10 N pools (kg ha^{-1}) in above-ground standing biomass and in the top 50 cm mineral soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Table 2.1 shows the N content in *Quercus* study plots was 1.65 mg g^{-1} in wood and bark and 23 mg g^{-1} in foliage from other studies (Andre and Ponette, 2003; Berger et al., 2009; Andre et al., 2010). This study has discovered that the average N content in *Quercus* study plots was 3.2 mg g^{-1} in wood, 7.1 mg g^{-1} in bark and 21 mg g^{-1} in foliage. This study determined more precise data of nutrients for above-ground standing biomass as the biomass amount from wood and bark were separated by using wood: bark ratio.

N: P ratio in foliage has been used as diagnostic indicators of N saturation (Fenn *et al.*, 1996; Morillas *et al.*, 2012) and to identify the thresholds of nutrient limitation (Kroetsch and Meuleman, 1996; Aerts and Chapin, 2000; Gusewell and Koerselman, 2002; Morillas *et al.*, 2012). It is reported that the thresholds of foliar N: P ratio were found to be < 14 for N limitation and > 16 for P limitation. Therefore the N: P ratios can be used for management and monitoring purposes in evaluating the nutrient status of upland ecosystems (Morillas *et al.*, 2012). Nutrient uptake by plants, microbial immobilization and nitrification could be the causes of reduction in NH_4-N availability in the medium term (Duran *et al.*, 2008, 2009). Leaching could also reduce the quantity of NH_4-N present in the soil, contributing to reduce N availability in terrestrial ecosystems (Debano and Conard, 1987). The N is lost from the plot, and the nitrate anion is also accompanied by cation nutrients, such as exchangeable K and exchangeable Ca. This sequence also generated H and may acidify the soil (Binkley, 1986). The N: P ratio of foliage in this study was from 11 to 14. It has been confirmed that at least P was not limited in this study forest. The N: P ratio was about 11 in study plot S1. It is the evidence that though the total N pool was large (Figure 5.10) in study plot S1, the N availability for plants was still low and N was limited in study plot S1. The reason for limited N availability of trees in study plot S1 could be: competition of herbaceous plants in forest floor (since this plot is in rapid growing period and under regeneration development, there were lots of herbaceous plants with strong N uptake ability in forest floor); silvicultural operations in the past has caused excessive N extraction in forest; climatic conditions limited the N availability particularly for study plot S1, which had the highest nutrients demand from mineral soil and the low precipitation limited the plants N uptake.

The role of soil C pools for mitigating of greenhouse gases (GHG) has highlighted the need for more knowledge on forest management effects (Jandl *et al.*, 2007). There are many factors affecting the amount and concentration of soil C in forest soils. They were divided into natural and anthropogenic factors (Larionova *et al.*, 2002). A natural disturbance can be a destructive event with drastic perturbation of an ecosystem, such as wind, fire, drought, insects and disease. Anthropogenic factors, which may affect SOC in forests, include forest management activities, deforestation, afforestation of agricultural soils and subsequent management of forest plantations. It was reported that in temperate forest, the C density ranges from 59 Mg ha^{-1} to 96 Mg ha^{-1} and from 96 Mg ha^{-1} to 122 Mg ha^{-1} in mineral soil (Schimel *et al.*, 2001; Lal, 2005).

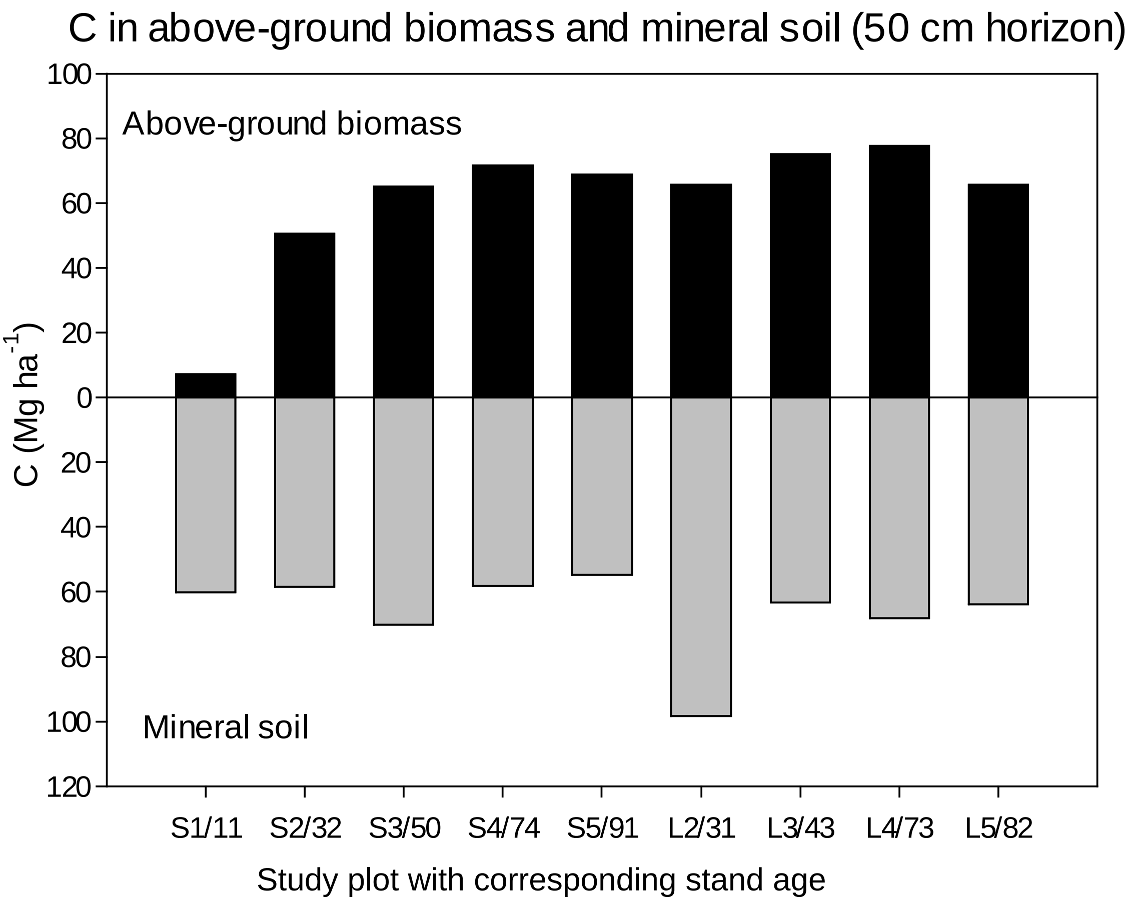
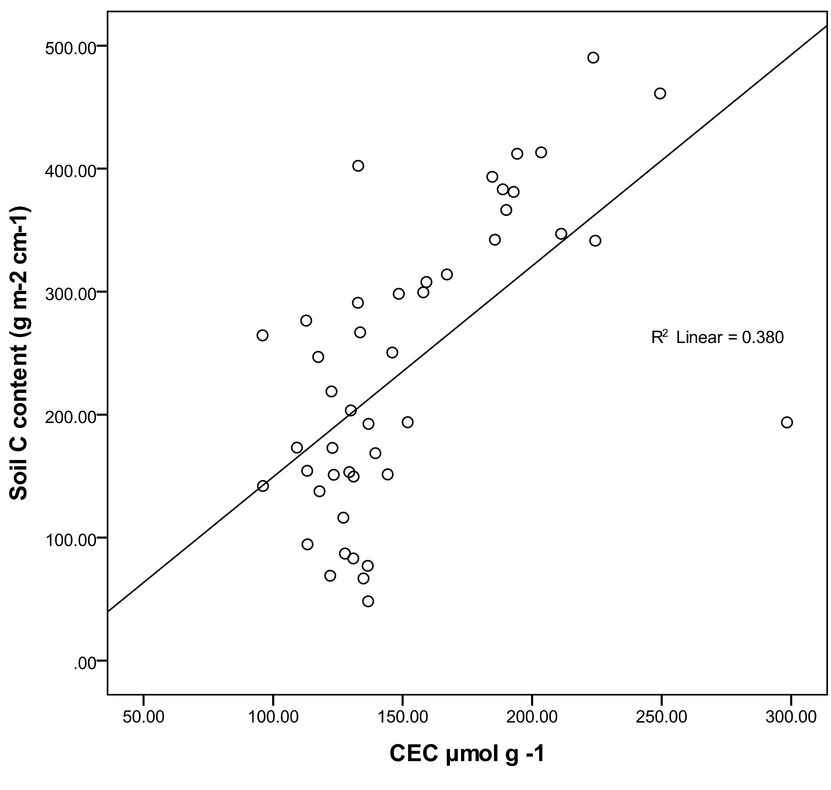


Figure 5. 11 C pools (kg ha^{-1}) in above-ground standing biomass and in the top 50 cm mineral soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

Figure 5.11 shows the C pool in above-ground standing biomass and in the top 50 cm of the soil. The lower C pool of above-ground standing biomass in study plot S1 was because of young stand age and less amount of biomass. C pool in above-ground standing biomass is more or less close to the C pool in the top 50 cm of the soil. Stand age had no decisive influence on C storage in mineral soil.

Figure 5.12 shows soil C was not correlated with CEC over all study plots but slightly positively correlated in study plot L2. It seems that organic matter is not correlated with exchangeable cations. It gave the evidence that pool of exchangeable cations is very much depending on soil types but not on the influence of decomposition of forest floor. The extreme value of highest CEC was from study plot L2. This was caused by extrem higher content of Ca. The extreme values of C were from study plots S1 as discussed reasons of disturbance (Figure 5.12). It is obvious that soil type was the most important factor to influence the soil quality and properties.

Correlation of soil C with CEC in study plot L2 (Calcic Chernozem)



Correlation of soil C with CEC over all study plots including plot L2

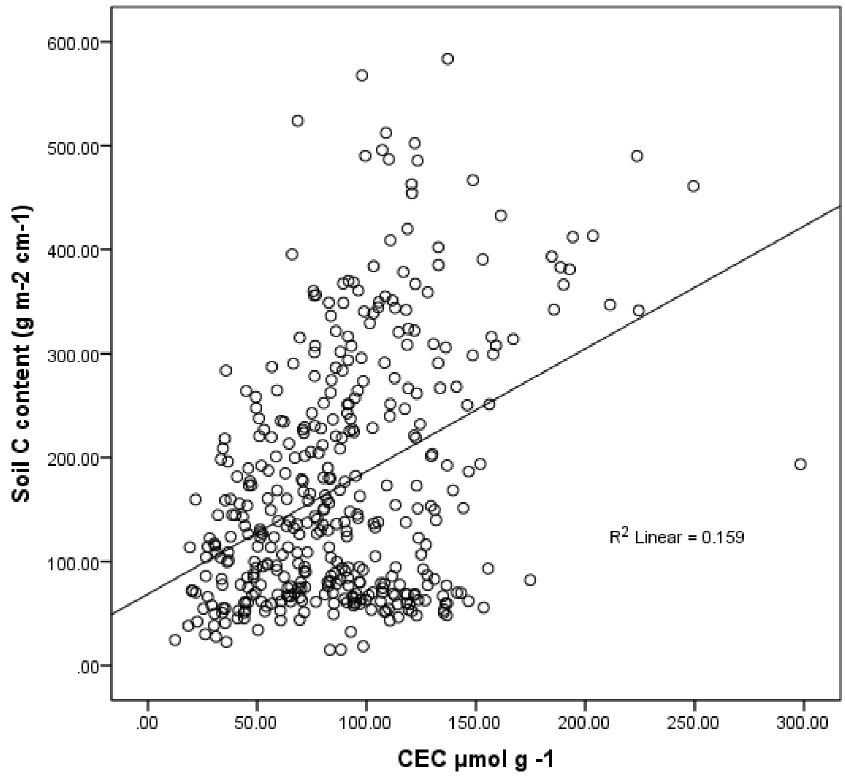


Figure 5. 12 Correlation of soil C with CEC in *Quercus* study plots in North-East Austria.

Figure 5.13 shows the PCA of soil N, soil C, exchangeable Na, exchangeable Al, exchangeable Fe and exchangeable Mn in nine study plots. Soil N and C was positively correlated with Exchangeable Mn and negatively correlated with exchangeable Na in component 1. Soil N and soil N was not correlated with any parameters in Component 2. KMO value (0.681) confirmed that the sampling adequacy is feasible for this study. Component 1 explains 46% of total variances and component 2 explains 20% of the total variances in PCA. Exchangeable Al was positively correlated with exchangeable Fe but not correlated with exchangeable Mn in component 2 in this study. Study plot L2 was positively correlated with exchangeable Al and exchangeable Fe in component 2. Study plots S1, S2, S3, S4, S5, L3, L4 and L5 were distributed very close to each other and not correlated with each other either in component 1 or in component 2. The reason was the component 1 represents of exchangeable Mn, soil C and N which had no significant difference of total pools between them (Figure 4.7, Figure 4.8 and Figure 4.16. There was significant difference of exchangeable Na between Eutric Cambisol and Haplic Luvisol (Figure 4.13). The difference of exchangeable Na is shown in component 2. The distanc of study plots under Eutric Cambisol and Haplic Luvisol was not very large. But the distance between study plot L2 and other study plots was quite large and in different parts of components (Figure 5.13). This could be the influence of exchangeable Al and other acidic cations. It is clear that base cations could differ in the study plots under Eutric Cambisol and Haplic Luvisol, while the acidic cations would not.

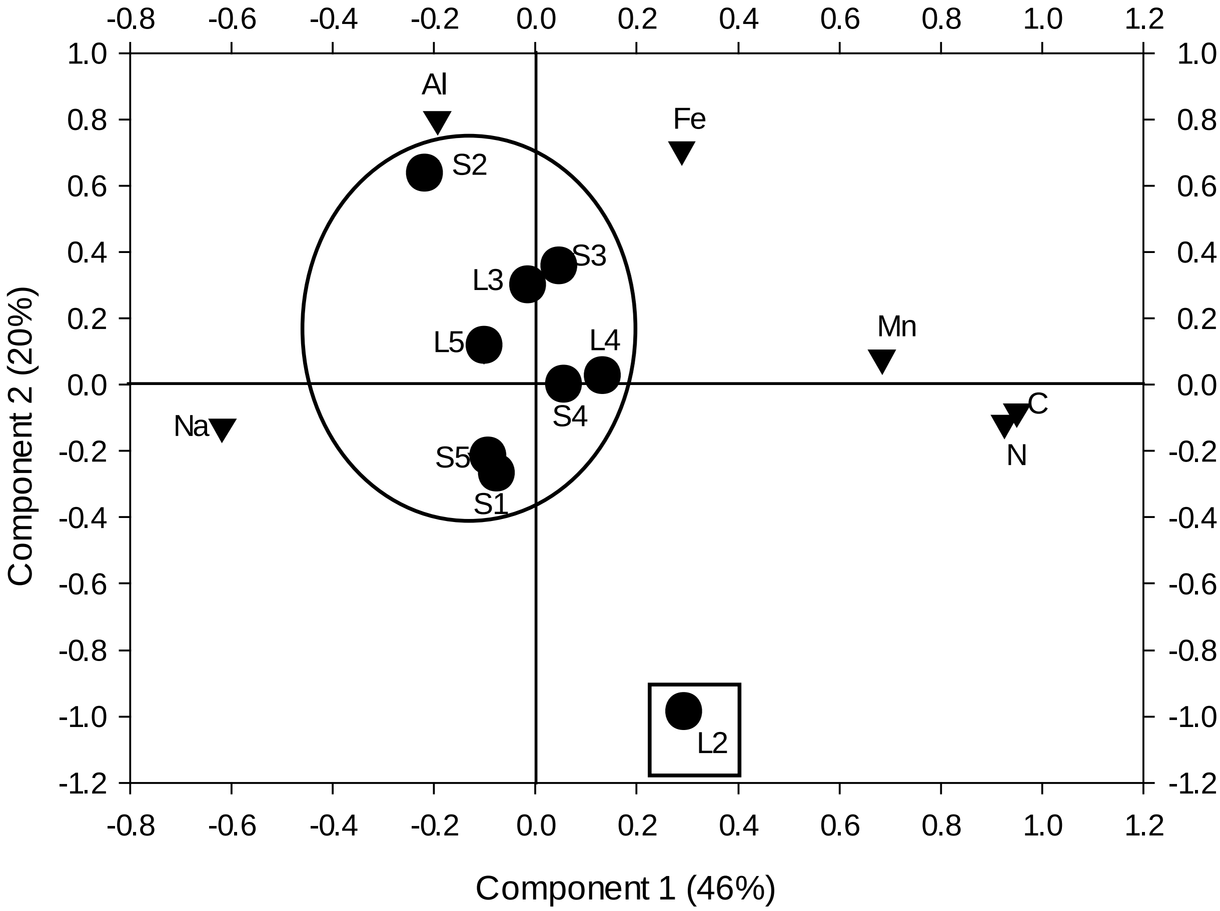


Figure 5. 13 Principal component analysis of soil N, soil C, exchangeable Na, exchangeable Al, exchangeable Fe and exchangeable Mn in nine *Quercus* study plots in North-East Austria.

Soil C:N ratio is important parameters for assessment of tree species effects on ecosystems functioning (Vesterdal *et al.*, 2008). Soil C:N ratio is recognized as good indicator of ecosystem N saturation and consequently nitrates leaching to ground and surface waters (Dise *et al.*, 1998; Gundersen *et al.*, 1998; Vesterdal *et al.*, 2008). Readiness of N mineralization from organic compounds is a function of C:N ratio. When the C:N ratio is less than 15:1, the N concentration is relatively high and the microorganisms rapidly release N when they decompose the material. When the C:N ratio is more than 30:1, it indicated low N concentration. In order for the organism to break down a high C:N material, then inorganic material is removed from the soil solution (Camberato, 2001; Shuai, 2007). The C:N ratio in this study was from 12 to 16, which was indicating high N concentration and availability. For surface soils, and for the top layer of lake and marine sediments, the ratio generally falls within well-defined limits, usually from about10 to 12. In most soils, the C:N ratio decreases with the increasing of soil horizons, often attaining values less than 5.0. Native humus would be expected to have a lower C:N ratio than most undecayed plant residues for following reasons. The decay of organic residues by soil organisms leads to incorporation of part of the C into microbial tissue with the remainder being liberated as CO_2. As a general rule, about one-third of the applied C in fresh residues will remain in the soil after the first few months of decomposition. The decay process is accompanied by conversion of organic form of N to NH_3 and NO_3^- and soil microorganisms utilize part of this N for synthesis of new cells. The gradual transformation of plant raw material into stable organic matter (humus) leads to the establishment of reasonably consistent relationship between C and N. Other factors which may be involved in narrowing of the C:N ratio include chemical fixation of NH_3 or amines by lignin like substances. The C:N ratio of virgin soils formed under grass vegetation is normally lower than for soils formed under forest vegetation, and for the latter, the C:N ratio of the humus layers is usually higher than for the mineral soil proper. Also the C:N ratio of a well-decomposed muck soil is lower than for a fibrous peat. As a general rule it can be said that conditions which encourage decomposition of organic matter result in narrowing of the C:N ratio. The ratio nearly always narrows sharply with the soil horizons in the profile; for certain subsurface soils C:N ratios lower than 5 are not uncommon.

Figure 5.14 shows the PCA of soil N, soil C, C:N ratio, soil bulk density exchangeable K, exchangeable Ca, exchangeable Mg and CEC in nine study plots. Soil N and C was not correlated with exchangeable K exchangeable Ca, Exchangeable Mn and CEC in component 1. Soil N and soil was negatively correlated with soil bulk density in component 2. C:N ratio was slightly negatively correlated with exchangeable K exchangeable Ca, Exchangeable Mn and CEC in component 1. C:N ratio was slightly negatively correlated with soil bulk density in component 2. KMO value (0.624) confirmed that the sampling adequacy is feasible for this study. Component 1 explains 39% of total variances and component 2 explains 36% of the total variances in PCA. Soil types are shown in different position with large distance to each other. Soil types more or less correlated together with exchangeable K, exchangeable Ca, exchangeable Mg and CEC with component 1. Soil N, C, C:N ratio and soil bulk density were more or less correlated in component 2.

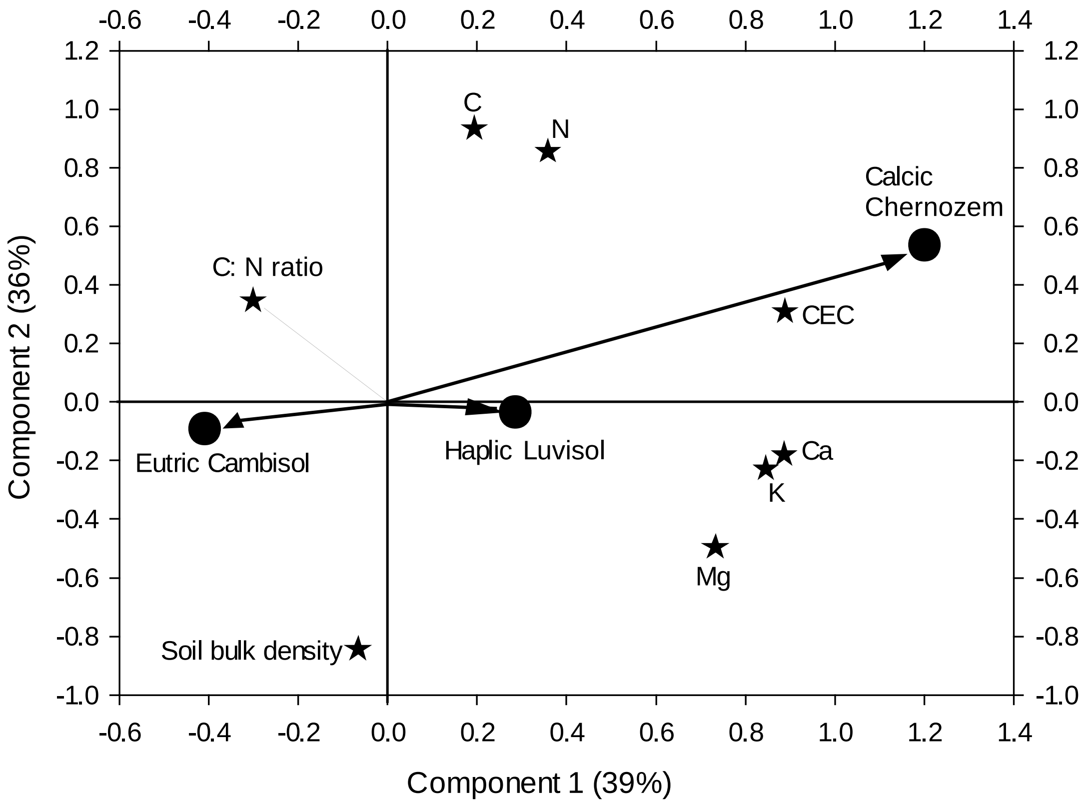


Figure 5. 14 Principal component analysis of soil N, soil C, C:N ratio, soil bulk density, exchangeable K, exchangeable Ca and exchangeable Mg in *Quercus* study plots in North-East Austria.

This study hypotheses were: (1) plant uptake causing N depletion during the rapid in contrast to the stable growing period; (2) forest in the mature and senescing period hold the highest soil N pool due to decreased plant uptake and increased forest litter decomposition; (3) due to large amount of N absorption by fine roots in the shallow soil horizons, stand age may have influence of the soil N pool in the top soil horizon (soil depth < 20 cm), but not in the deep soil horizon (soil depth > 20 cm). The results of this study show that there were high N concentration in the soil and lower C:N ratio indicating high N supply potentials. The results of this study do not support our hypotheses as forest growth and plant uptake did not cause any N deficiency and stand age had no decisive influence on soil N pools both in the top and deep soil horizons. The hypotheses of nutrient contents were: in the forest soil it differs among diverse soil types; it ranks in following order (Eutric Cambisol < Haplic Luvisol < Calcic Chernozem). The results of this study supported this hypothesis by showing the soil N pools as following order: Eutric Cambisol < Haplic Luvisol < Calcic Chernozem. There was no evidence that the changing mineral nutrient demand during forest stand growth is reflected in soil N and C pools.

5.4.3. Exchangeable Cations

Based on the chronosequence approach in this study, it was found that forest age was not significantly reflected in the exchangeable K, Na, Ca, Al, Mg, Fe and Mn content of the Eutric Cambisol and Haplic Luvisol. K concentration is very much dependent on mineralization conditions (Falkengren-Grerup, 1995). Exchangeable K was positively correlated with CEC (Figure 5.15). The extreme value of K content in Figure 5.15 is 9.45 g m^{-2} cm^{-1}, which is from one sample point of study plot S1. The reason for K accumulation at this single sample point could be disturbance by humans, e.g. ashes from a campfire.

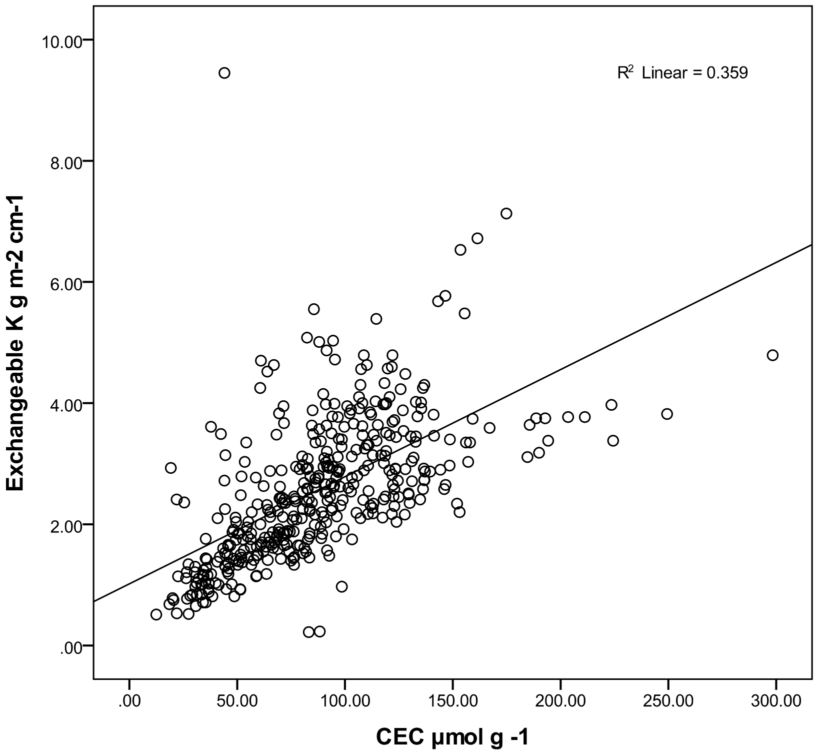


Figure 5. 15 Correlation of exchangeable K with CEC in *Quercus* study plots in North-East Austria.

Ca is usually positively correlated with pH (H_2O) and abundant in the alkali soils (Nakos, 1989; Fisher and Binkley, 1999; Schoenholtz *et al.*, 2000). This study shows that exchangeable Ca was positively correlated with soil pH (H_2O) and soil pH $CaCl_2$ (Figure 5.9) and gave support to the above conclusion. Several studies showed that Ca is sometimes related to other mineral nutrients (Crooke *et al.*, 1964; Smith *et al.*, 2007; De Schrijver *et al.*, 2009) and important to the prediction of plot quality on these soils (Bowersox and Ward, 1972). Extremely high exchangeable Ca in Calcic Chernozem might be helpful for nutrients retention. But over all study plots, there was no correlation of exchangeable Ca with N and C.

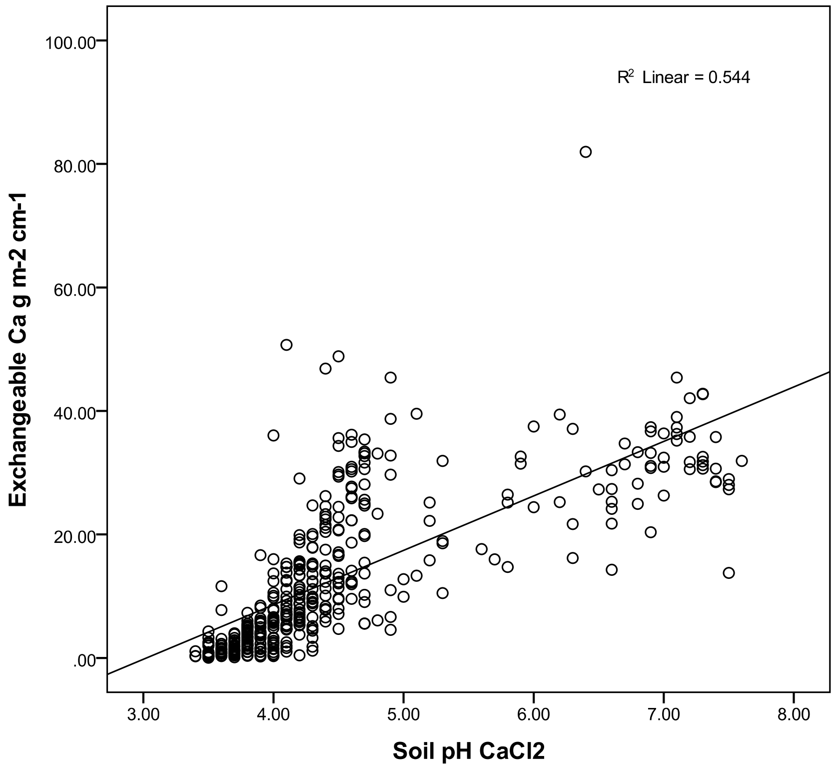


Figure 5. 16 Correlation of exchangeable Ca with soil pH $CaCl_2$, in *Quercus* study plots in North-East Austria.

Exchangeable Mg plays a crucial role in improving nutrient quality of the soil (Xue, 1996) in their study area. In this study high exchangeable Mg went along with higher N content in Haplic Luvisol and Calcic Chernozem than in Eutric Cambisol (Figure 4.7 and Figure 4.12). Exchangeable Mg was positively correlated with exchangeable Na (Figure 5.17). It gave the hints that base cations shows the same trend of contents in mineral soil.

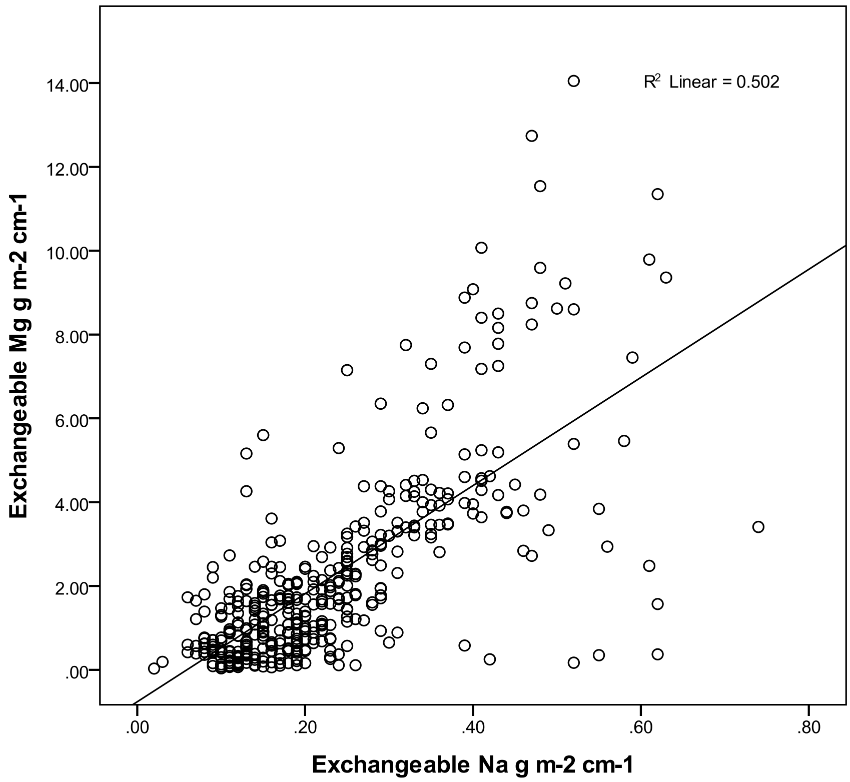


Figure 5. 17 Correlation of exchangeable Mg with exchangeable Na in *Quercus* study plots in North-East Austria.

Exchangeable Na could replace K and other cations on the soil exchange complex and can lead to nutrient deficiencies. Levels and trends of exchangeable Al are controlled mainly by soil pH (H_2O) (Nakos, 1989). Fisher and Binkely (Fisher and Binkley, 1999) claimed that in soil where aluminum dominates the exchange complex, pH (H_2O) values range between 4.0 and 4.5 and when the exchange complex was dominated by base cations (e.g. Ca^2+, Mg^2+, K+), pH (H_2O) values commonly range between 5.0 to 6.5, while soil with high carbonate content may have pH (H_2O) values higher than 6.5. This study confirmed that 32 years old *Quercus* stand on Eutric Cambisol had the lowest pH (H_2O) value corresponding to the highest Al content (Figure 4.6 and Figure 4.14). This study gave support to this conclusion by finding significantly lower Al content at high pH (H_2O) in Calcic Chernozem (Figure 4.6 and Figure 4.14). Exchangeable Al was negatively correlated with soil pH (H_2O) and soil pH $CaCl_2$ in this study. Exchangeable Fe together with N could greatly enhance soil C stock (Lal, 2005) by promoting the forest growth. There was no correlation of exchangeable Fe with soil pH (H_2O) and soil pH $CaCl_2$ in this study area. Exchangeable Mn in response of pH change controlled the Mn in soil solution (Khanna and Mishra, 1977). This study supported this conclusion with slightly negative correlation of exchangeable Mn with soil pH (H_2O) and soil pH ($CaCl_2$).

Figure 5.18 shows the PCA of soil type, soil pH (H_2O), exchangeable K, exchangeable Ca, exchangeable Mg, exchangeable Na and exchangeable Al in nine study plots. KMO value (0.752) confirmed that the sampling adequacy is feasible for this study. Component 1 explains 58% of total variances and component 2 explains 24% of the total variances in PCA. Exchangeable Al was negatively correlated with base cations (exchangeable K, exchangeable Ca, exchangeable Mg and exchangeable Na) (Figure 5.18). The closest distance (Figure 5.18) between exchangeable Al and study plot S2 indicated the highest exchangeable Al in study plot S2. This is corresponding with the results of this study Figure 4.14 and Table 4.25. Study plot L2 was positively correlated with other study plots both in component 1 and in component 2 in Figure 5.18. Exchangeable Na, exchangeable Mg and exchangeable K were close to study plots L2, L3 and L5, which were also corresponding to The results of this study Figure 4.10, Figure 4.12, Figure 4.13, Table 4.17, Table 4.21 and Table 4.23. Base cations and acidic cations were both used in our PCA (Figure 5.18). The study plots were more or less correlated with each other under the same soil type but separated in different positions with large distance under different soil types. This is the evidence that CEC could differ the study plots under Eutric Cambisol and Haplic Luvisol. It shows the same trend as base cations.

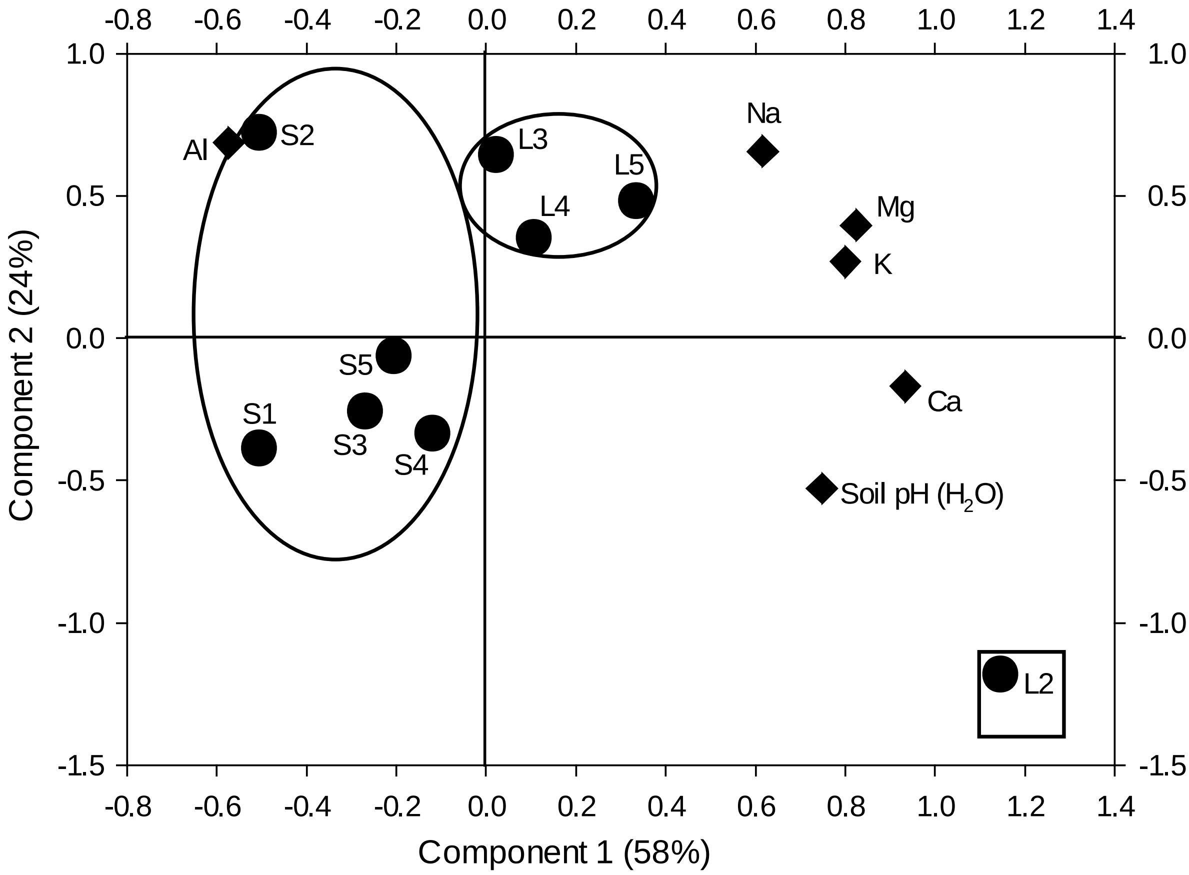


Figure 5. 18 Principal component analysis of soil type, soil pH (H_2O), exchangeable K, exchangeable Ca, exchangeable Mg, exchangeable Na and exchangeable Al in nine *Quercus* study plots in North-East Austria.

Figure 5.19 shows the PCA of soil type, soil bulk density, soil N, exchangeable K, exchangeable Ca, exchangeable Mg, exchangeable Fe, exchangeable Mn and CEC in nine study plots. KMO value (0.634) confirmed that the sampling adequacy is feasible for this study. Component 1 explains 38% of total variances and component 2 explains 29% of the total variances in PCA. Due to the high CEC and high Ca pool in Calcic Chernozem, Figure 5.19 shows the closest distance of Ca and CEC with Calcic Chernozem. It was negatively correlated with Eutric Cambisol in component 1. Calcic Chernozem, Haplic Luvisol and Eutric Cambisol are in different positions with large distance among each other. This is caused mainly by CEC and exchangeable K and exchangeable Ca (Figure 5.19).

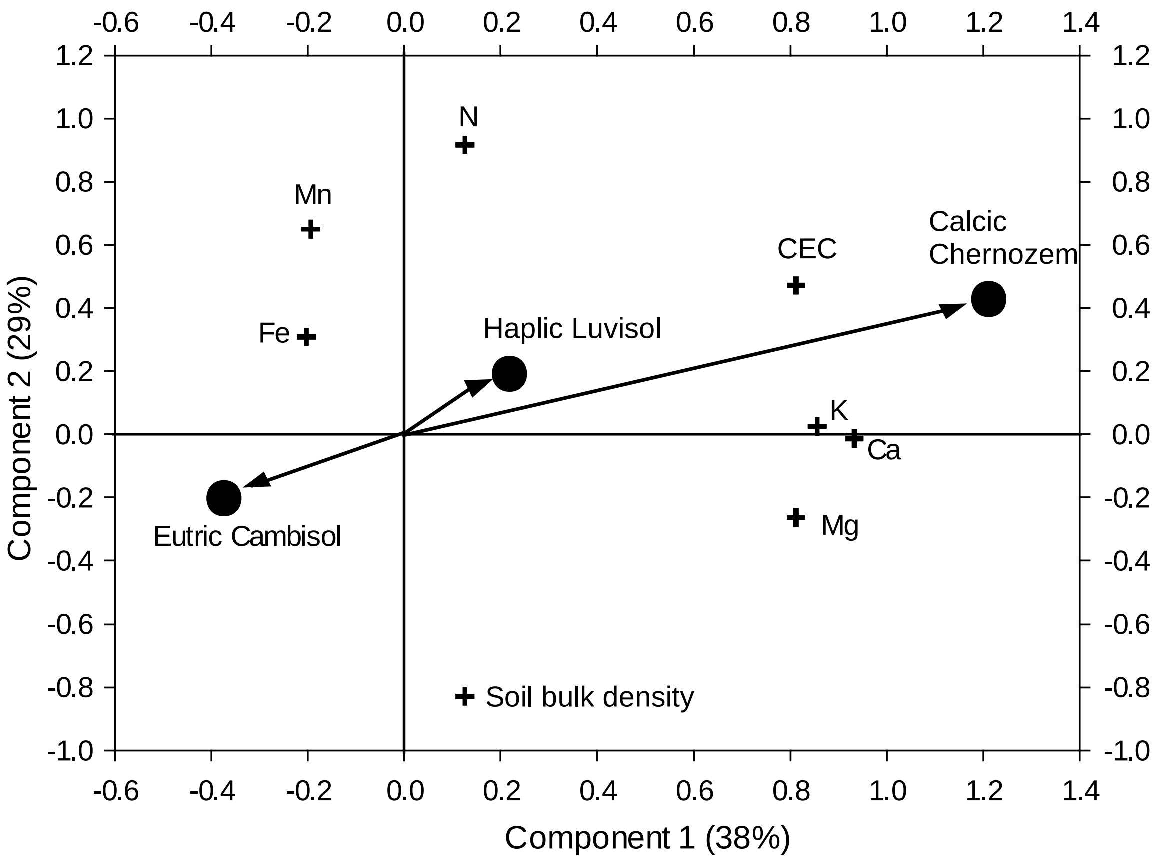


Figure 5. 19 Principal component analysis of soil type, soil bulk density, soil N, exchangeable K, exchangeable Ca, exchangeable Mg, exchangeable Fe, exchangeable Mn and CEC in nine *Quercus* study plots in North-East Austria.

The hypotheses that plant uptake causes exchangeable cations depletion during the rapid growing period (up to 40 years) in contrast to the stable growing period (41-80 years) in the upper (soil depth 0-20 cm) soil horizons and stand age may not have strong influence of the exchangeable cations in the deep (> 20 cm) soil horizons. The results of this study supported to this hypotheses regarding to nonexistent influence of the exchangeable cations in the deep soil horizons but not for plant uptake causing nutrient depletion during growing period in the upper soil horizons. The hypotheses of nutrient contents were: in the forest soil it differs among diverse soil types; it ranks in following order (Eutric Cambisol < Haplic

Luvisol < Calcic Chernozem). The results of this study supported this hypothesis by showing the pools of exchangeable K, exchangeable Ca and exchangeable Mg as following order: Eutric Cambisol < Haplic Luvisol < Calcic Chernozem. But the pool of exchangeable Na was shown as order: Eutric Cambisol < Calcic Chernozem < Haplic Luvisol. The pools of exchangeable Al and exchangeable Mn were shown as order: Calcic Chernozem < Eutric Cambisol < Haplic Luvisol. The pool of exchangeable Fe was shown as order: Calcic Chernozem < Haplic Luvisol < Eutric Cambisol.

5.4.4. Cation Exchange Capacity

Following Richter *et al*., 1999 and subsequently Diochon *et al*., 2009, standard errors indicated the spatial variation of CEC among the nine study plots in this study (Table 4.16). CEC is correlated to soil texture and pH in mineral soil. CEC was significantly positively correlated (Pearson correlation coefficient 0.661, $P<0.01$) with the pH (H_2O) and pH ($CaCl_2$) of the soil as well as in Figure 5.20.

As expected, Calcic Chernozem had the highest CEC in comparison to Eutric Cambisol and Haplic Luvisol. In Eutric Cambisol and Haplic Luvisol, CEC had a minimum in the 20 cm of the soil and then increased with the soil horizon up to 50 cm. CEC decreased steadily with the soil horizons in Calcic Chernozems, but still significantly higher than other soil types or study plots (Figure 4.18, Table 4.33). It showed the same trend as exchangeable Ca in different soil horizons in nine study plots (Table 4.19).The reason could be high exchangeable Ca and other cations at the same soil horizon (Figure 4.11). Recent studies (Eshetu *et al.*, 2004; Yimer *et al.*, 2008) found that high CEC values in the forest soils are consistent, showing a strong relationship between CEC and concentrations of SOM. This is consistent with results from our plots, showing that soil organic C and N were significantly higher in Calcic Chernozems (Table 4.12 and Table 4.14).

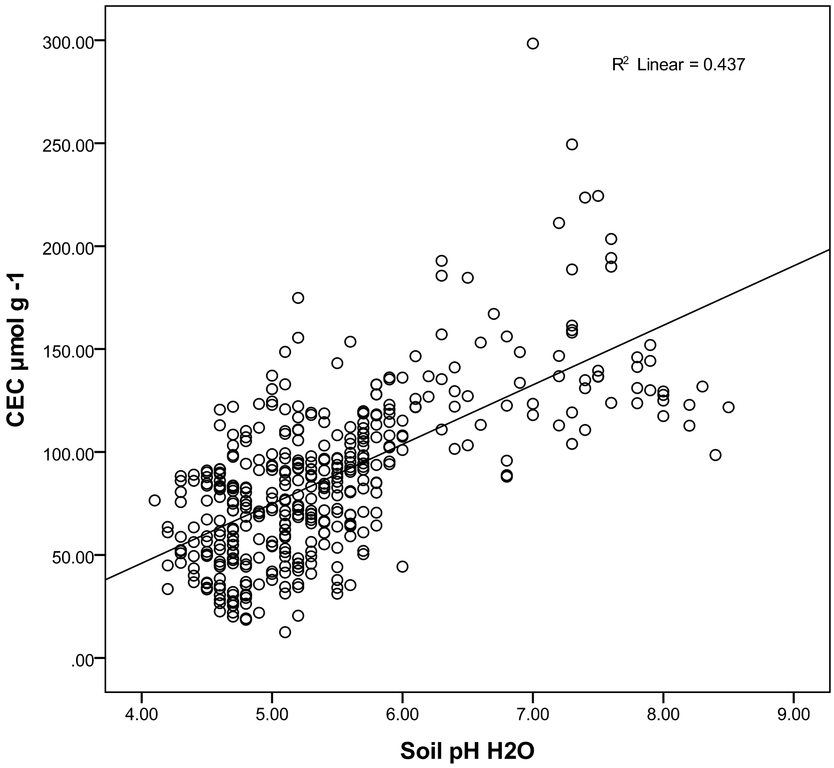


Figure 5. 20 Correlation of CEC with soil pH (H_2O) in *Quercus* study plots in North-East Austria.

CEC was correlated with exchangeable K, exchangeable Ca and exchangeable Mg. The hypotheses of nutrient contents were: in the forest soil it differs among diverse soil types; it ranks in following order (Eutric Cambisol < Haplic Luvisol < Calcic Chernozem). The results of this study supported this hypothesis by showing the CEC as following order: Eutric Cambisol < Haplic Luvisol < Calcic Chernozem. Stand age had no large influence on soil CEC. Soil type, soil pH and soil horizons were the most important factors influencing soil CEC.

Table 5. 1 Bivariate correlation coefficients of CEC (µmol g^{-1}) and base saturation (%) against soil pH (H_2O), soil pH $CaCl_2$, exchangeable K, exchangeable Na, exchangeable Ca, exchangeable Al, exchangeable Mg, exchangeable Fe and exchangeable Mn at different soil horizons in the nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

		Cation exchange capacity									Base saturation								
		S1	**S2**	**S3**	**S4**	**S5**	**L2**	**L3**	**L4**	**L5**	**S1**	**S2**	**S3**	**S4**	**S5**	**L2**	**L3**	**L4**	**L5**
pH H_2O		0.866**	0.37	0.725*	0.65	0.28	0.65	0.31	0.894**	0.09	0.833**	0.928**	0.895**	0.935**	0.810**	0.950**	0.926**	0.899**	0.981**
pH $CaCl_2$		0.864**	0.30	0.790*	0.61	0.38	0.677*	0.35	0.905**	0.17	0.830**	0.983**	0.915**	0.925**	0.830**	0.972**	0.933**	0.888**	0.974**
K		0.917**	0.881**	0.709*	0.772*	0.56	-0.26	0.51	-0.38	0.20	0.61	0.20	0.51	0.21	0.28	-0.29	0.679*	-0.28	0.45
Na		-0.32	0.59	0.41	-0.34	-0.07	-0.771*	-0.29	-0.26	-0.33	-0.42	-0.19	-0.01	-0.08	0.12	-0.753*	-0.42	-0.17	0.57
Ca	**0-5 cm**	0.870**	0.734*	0.963**	0.920**	0.798**	0.805**	0.66	0.782*	0.31	0.778*	0.814**	0.847**	0.751*	0.704*	0.59	0.925**	0.911**	0.969**
Al		-0.53	0.04	-0.710*	-0.41	-0.30	-0.63	-0.45	-0.66	-0.19	-0.900**	-0.890**	-0.907**	-.954**	-0.917**	-0.820**	-0.978**	-0.951**	-0.984**
Mg		0.927**	0.825**	0.815**	0.792*	0.726*	-0.03	0.51	0.24	0.16	0.60	0.64	0.685*	0.692*	0.48	-0.38	0.860**	0.64	0.893**
Fe		-0.32	-0.40	-0.62	-0.39	-0.21	.a	-0.25	-0.35	-0.10	-0.751*	-0.831**	-0.804**	-.908**	-0.782*	.a	-0.921**	-0.884**	-0.797*
Mn		-0.50	0.821**	0.51	-0.21	0.23	-0.49	0.33	-0.59	0.41	-0.63	0.64	0.26	-0.50	-0.13	-0.957**	0.882**	-0.65	0.33
pH H_2O		0.955**	-0.44	0.810**	0.749*	0.18	0.796*	0.40	0.56	0.00	0.911**	0.830**	0.914**	0.975**	0.862**	0.808**	0.931**	0.924**	0.952**
pH $CaCl_2$		0.940**	-0.62	0.43**	0.789*	0.19	0.761*	0.43	0.58	0.22	0.894**	0.866**	0.897**	0.949**	0.895**	0.853**	0.944**	0.868**	0.975**
K		0.956**	0.780*	0.963**	0.970**	0.752*	0.842**	0.801**	0.13	-0.23	0.870**	-0.25	0.912**	0.792*	0.16	0.42	.711*	0.65	0.740*
Na		-0.20	-0.06	0.64	0.08	-0.13	-0.42	0.53	-0.12	-0.09	-0.57	-0.23	0.45	-0.18	-0.53	-0.20	0.25	-0.49	0.63
Ca	**5-10 cm**	0.948**	0.13	0.957**	0.954**	0.833**	0.944**	0.700*	0.60	0.46	0.933**	0.821**	0.975**	0.829**	0.793*	0.767*	0.984**	0.931**	0.967**
Al		-0.49	0.894**	-0.686*	-0.44	0.22	-0.59	-0.46	-0.38	-0.24	-0.878**	-0.719*	-0.841**	-0.881**	-0.810**	-0.996**	-0.961**	-0.981**	-0.06
Mg		0.958**	0.58	0.976**	0.861**	0.915**	0.04	0.742*	0.37	0.41	0.841**	0.36	0.894**	0.783*	0.58	0.22	0.939**	0.876**	0.958**
Fe		-0.49	0.50	-0.827**	-0.33	-0.14	.a	-0.04	-0.49	0.11	-0.61	-0.834**	-0.805**	-0.764*	-0.764*	.a	-0.66	-0.818**	-0.45
Mn		0.11	-0.02	0.708*	0.47	0.37	-0.59	0.52	-0.23	0.19	0.32	0.709*	0.57	0.778*	0.720*	-0.799**	0.948**	-0.34	0.59
pH H_2O		0.58	-0.21	0.888**	0.54	0.24	0.52	0.22	0.749*	0.48	0.963**	0.759*	0.982**	0.948**	0.796*	0.840**	0.935**	0.911**	0.983**
pH $CaCl_2$		0.34	-0.60	0.799**	0.48	0.00	0.44	0.33	0.806**	0.56	0.977**	0.856**	0.959**	0.957**	0.64	0.882**	0.954**	0.882**	0.991**
K		0.39	0.860**	0.932**	0.28	0.904**	0.883**	0.890**	0.30	0.10	0.792*	0.10	0.747*	0.36	0.38	0.10	0.51	0.35	0.56
Na		0.23	0.18	0.54	-0.05	0.789*	0.23	-0.26	0.39	0.19	0.02	-0.24	0.26	-0.14	0.759*	-0.64	0.39	0.12	-0.09
Ca	**10-20 cm**	0.63	0.62	0.961**	0.50	0.935**	0.983**	0.47	0.808**	0.731*	0.978**	0.62	0.900**	0.711*	0.765*	0.46	0.988**	0.936**	0.947**
Al		0.24	0.945**	-0.62	-0.31	0.45	-0.41	-0.07	-0.39	-0.43	-0.688*	-0.45	-0.825**	-0.833**	-0.50	-0.999**	-0.935**	-0.929**	-0.989**
Mg		0.51	0.743*	0.874**	0.40	0.919**	0.800**	0.57	0.66	0.710*	0.871**	0.42	0.700*	0.62	0.699*	0.15	0.869**	0.928**	0.949**
Fe		-0.710*	0.63	-0.705*	-0.18	-0.03	.a	0.04	-0.01	-0.12	-0.39	-0.63	-0.738*	-0.742*	-0.61	.a	-0.34	-0.699*	-0.840**
Mn		0.828**	-0.01	0.56	-0.32	0.18	-0.54	0.31	-0.19	-0.35	0.40	0.880**	0.53	-0.10	0.715*	-0.945**	0.871**	0.07	0.49
pH H_2O		0.915**	0.33	0.886**	0.65	0.55	0.941**	0.62	0.48	0.911**	0.980**	0.968**	0.946**	0.885**	0.882**	0.837**	0.875**	0.814**	0.712*
pH $CaCl_2$		0.693*	0.08	0.819**	0.54	0.46	0.909**	0.63	0.46	0.860**	0.934**	0.891**	0.920**	0.798*	0.772*	0.909**	0.985**	0.64	0.63
K		0.687*	0.841**	0.61	0.948**	0.979**	-0.803**	0.855**	0.909**	0.19	0.66	0.668*	0.54	0.846**	0.791*	-0.57	0.682*	0.49	0.19
Na		0.907**	0.39	0.24	0.735*	0.07	-0.877**	-0.04	0.33	0.08	0.719*	0.60	0.10	0.841**	-0.29	-0.60	0.63	-0.01	0.45
Ca	**20-40 cm**	0.914**	0.890**	0.954**	0.966**	0.986**	0.56	0.869**	0.880**	0.973**	0.953**	0.725*	0.962**	0.892**	0.853**	0.729*	0.907**	0.853**	0.921**
Al		0.20	0.789*	-0.60	-0.07	0.12	-0.747*	-0.50	-0.08	-0.842**	-0.25	-0.20	-0.810**	-0.32	-0.40	-0.997**	-0.962**	-0.860**	-0.996**
Mg		0.896**	0.788*	0.38	0.908**	0.754*	-0.54	0.66	0.832**	0.54	0.732*	0.862**	0.240	0.954**	0.817**	-0.12	0.506	0.56	0.53
Fe		-0.44	0.33	-0.32	.a	0.772*	.a	.a	.a	.a	-0.49	-0.39	-0.60	.a	0.37	.a	.a	.a	.a
Mn		0.874**	-0.36	-0.50	0.60	-0.59	-0.857**	0.03	-0.19	-0.759*	0.867**	0.54	-0.46	0.43	-0.57	-0.951**	0.35	-0.03	-0.56
pH H_2O		0.897**	0.41	0.799**	0.50	0.14	-0.14	0.48	0.711*	0.09	0.808**	0.922**	0.843**	0.62	0.725*	0.934**	0.805**	0.890**	0.798*
pH $CaCl_2$		0.804**	0.39	0.778*	0.37	0.25	0.02	0.50	0.62	0.06	0.65	0.947**	0.801**	0.45	0.718*	0.984**	0.888**	0.796*	0.776*
K		0.725*	0.863**	0.701*	0.869**	0.991**	0.42	-0.03	0.10	0.26	0.763*	0.44	0.57	0.877**	0.65	-0.62	0.63	-0.11	-0.15
Na		0.56	0.842**	0.48	0.782*	0.56	0.19	0.35	-0.08	0.08	0.57	0.669*	0.32	0.815**	0.739*	-0.896**	0.63	-0.45	-0.29
Ca	**40-50 cm**	0.865**	0.923**	0.942**	0.930**	0.975**	0.718*	0.20	0.802**	0.54	0.65	0.63	0.855**	0.815**	0.686*	0.01	0.693*	0.727*	0.546
Al		-0.50	0.28	-0.31	-0.44	0.47	0.26	0.05	-0.65	-0.32	-0.50	-0.46	-0.40	-0.29	-0.10	-0.719*	-0.50	-0.908**	-0.868**
Mg		0.60	.914**	0.25	0.61	0.55	0.63	0.48	-0.23	0.10	0.706*	0.810**	0.25	0.837**	0.62	-0.40	0.44	-0.39	-0.26
Fe		-0.39	.a	.a	0.00	0.60	.a	.a	.a	.a	-0.60	.a	.a	0.10	0.12	.a	.a	.a	.a
Mn		-0.06	-0.18	-0.10	0.65	-0.18	-0.18	-0.19	-0.49	0.10	0.02	-0.01	-0.11	0.50	-0.30	-0.994**	0.42	-0.54	-0.50

* . Significantly correlated ($P \leq 0.05$)

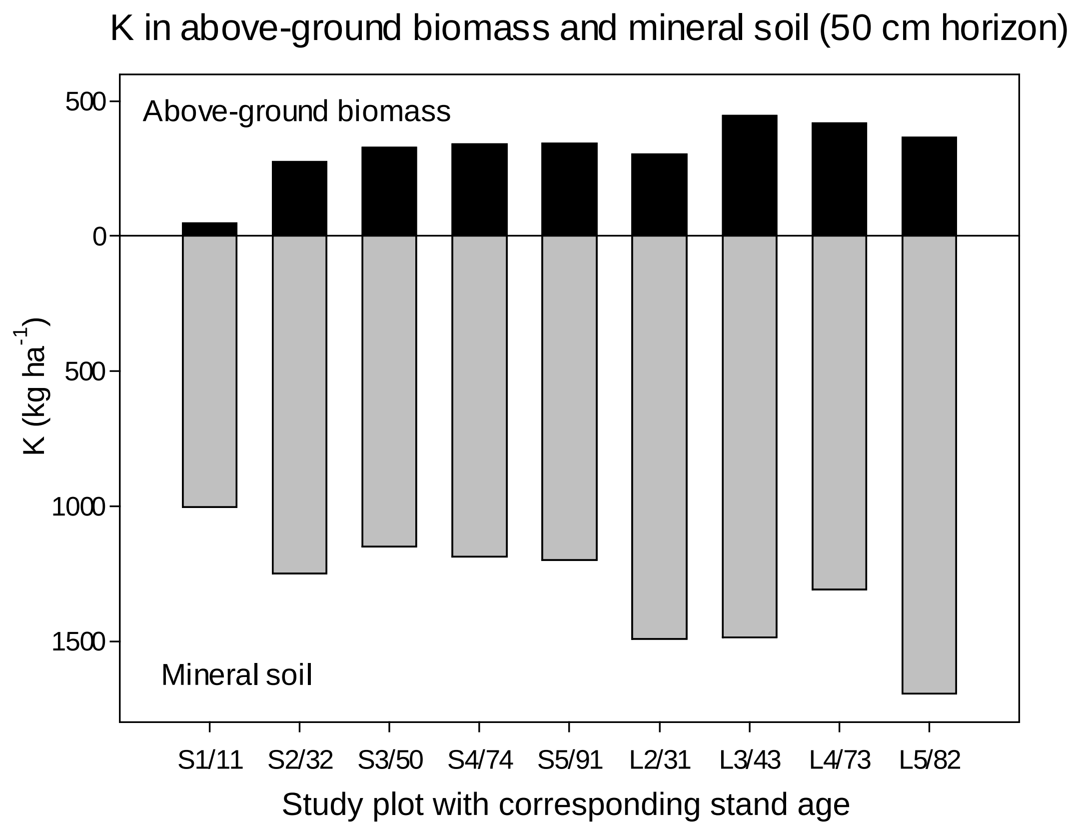
** . Strongly significantly correlated ($P \leq 0.01$)

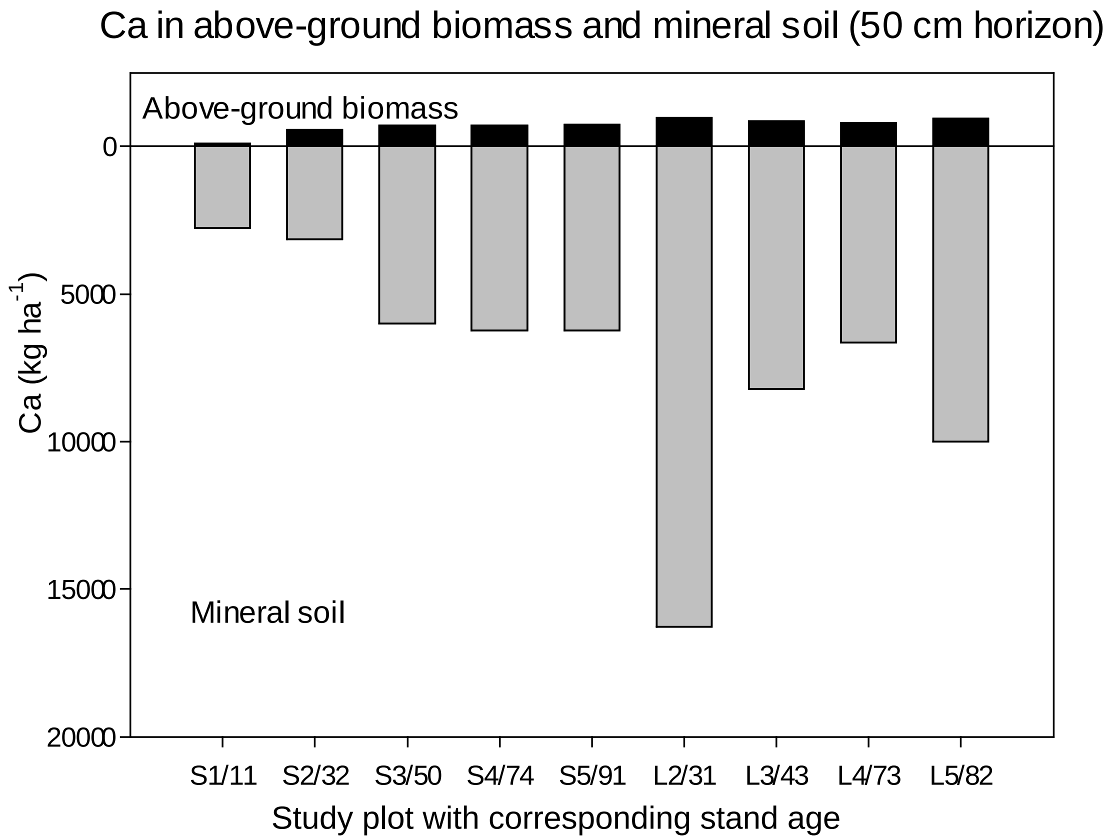
a. No correlation since an undetected value existing

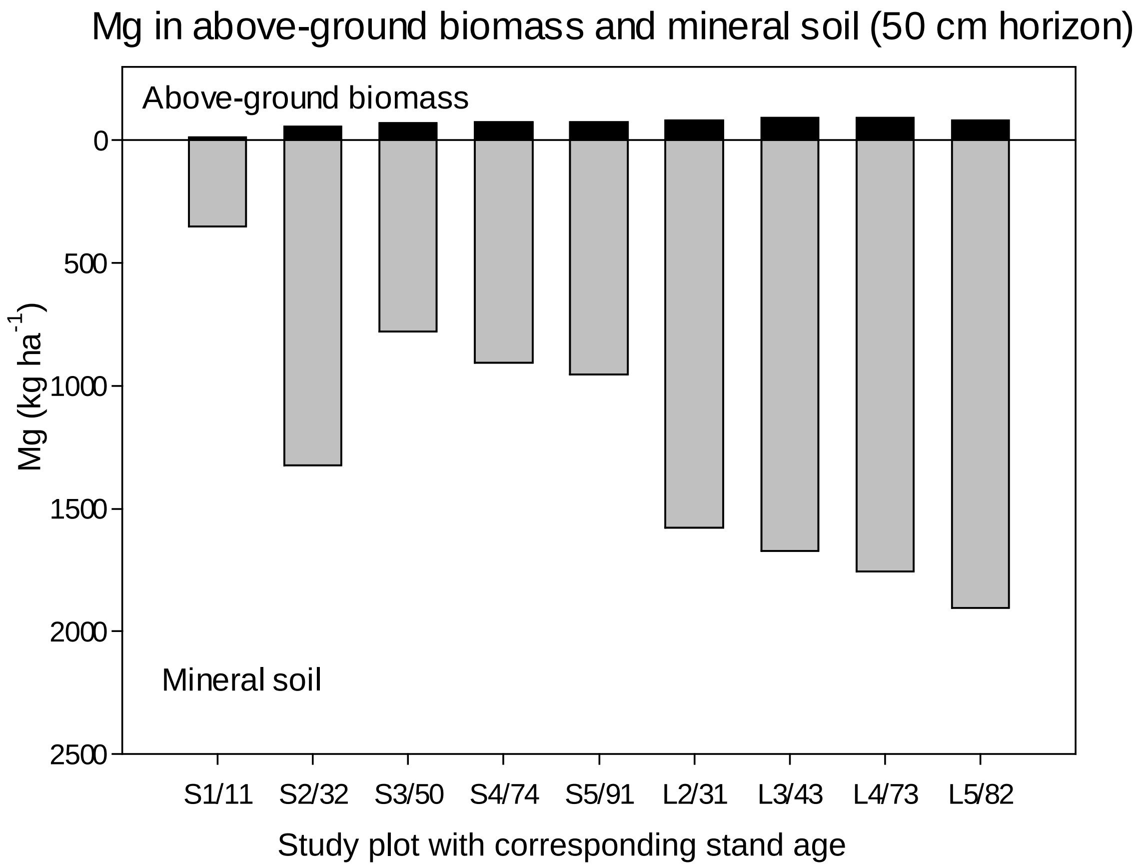
Table 5.1 gives more detail information on effects of soil pH, soil horizon and exchangeable cations on soil CEC and base saturation in each study plots. Generally base saturation was positively correlated with soil pH (H_2O) and soil pH ($CaCl_2$) in all study plots in the top 50 cm of the soil. There were positive correlation of base saturation with exchangeable Ca and occasionally with exchangeable K, and occasionally negative correlation with exchangeable Al. Lower base saturation indicates acidic soil (Van Miegroet *et al.*, 2007). The results of this study supported this conclusion (Figure 4.19 and Table 5.1).

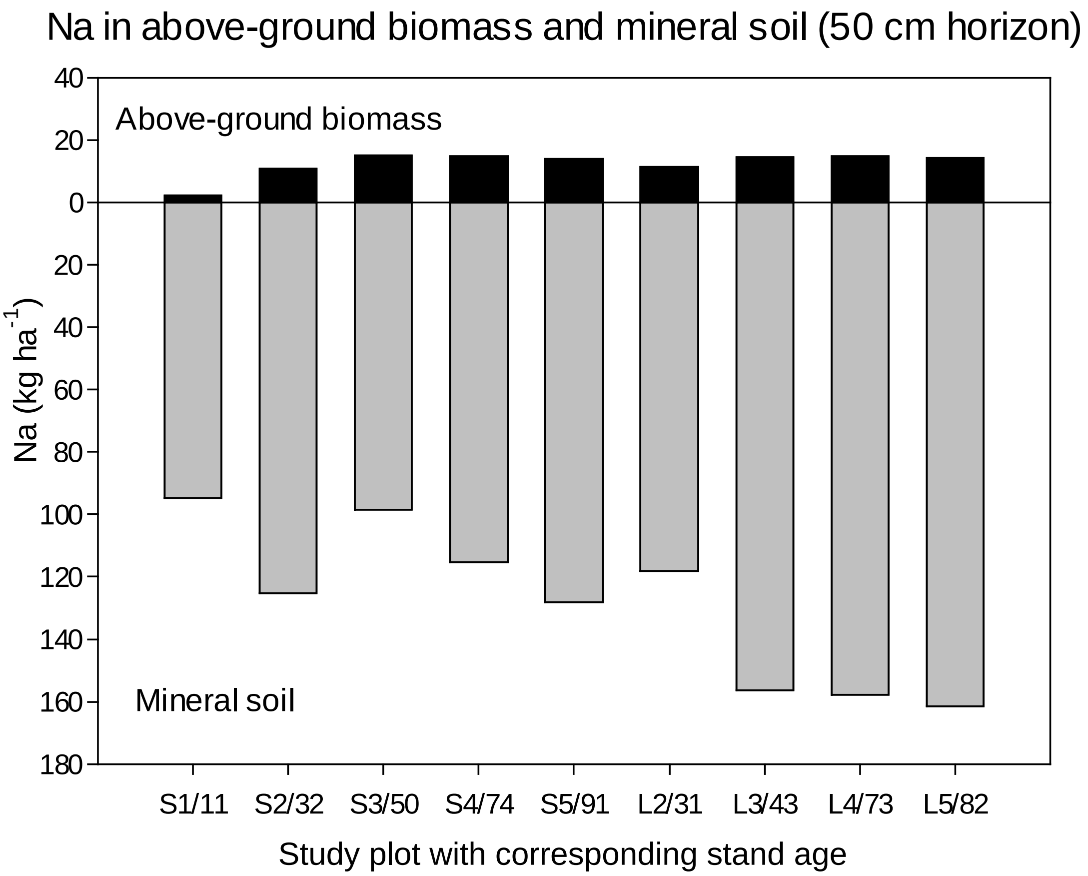
5.5. Reflects of Forest Growth on Soil Properties and Above-ground Nutrient Pools

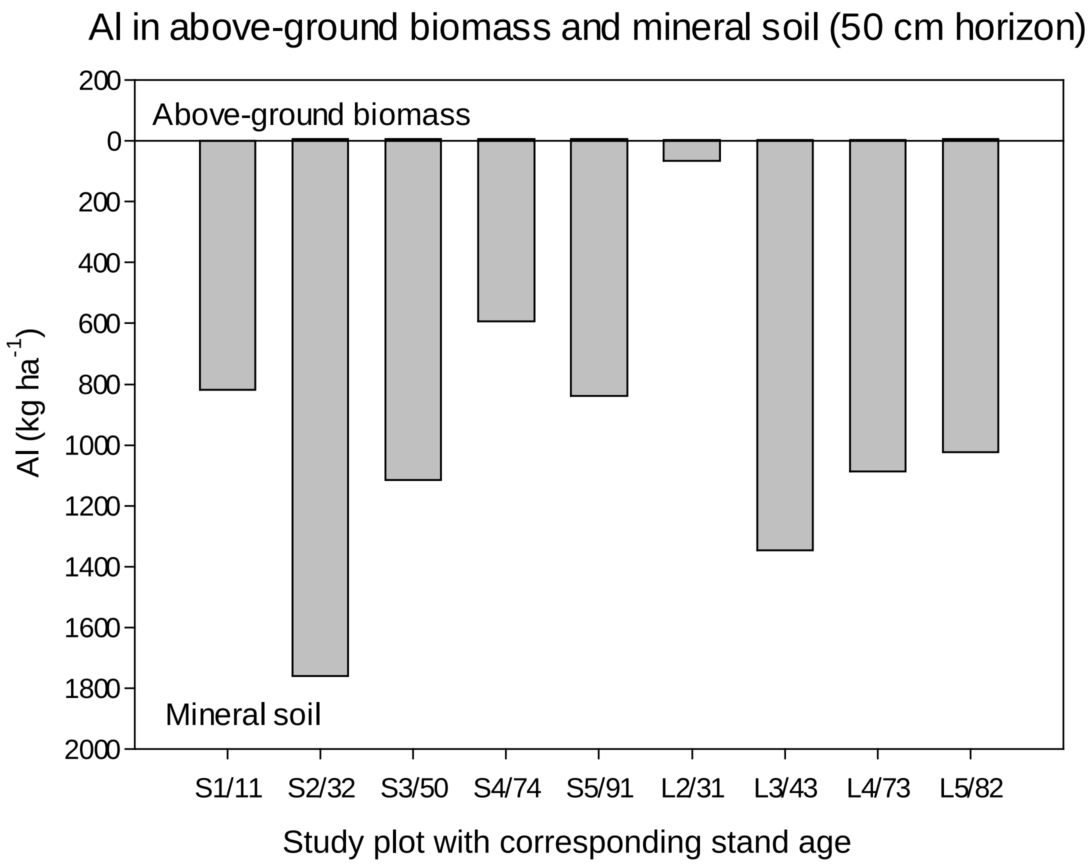
Figure 5.21 shows the nutrient pools of K, Ca, Mg, Na, Al, Fe and Mn in above-ground standing biomass and pools of exchangeable K, exchangeable Ca, exchangeable Mg, exchangeable Na, exchangeable Al, exchangeable Fe and exchangeable Mn in the top 50 cm of the soil. Exchangeable K, exchangeable Ca, exchangeable Mg, exchangeable Na, exchangeable Al and exchangeable Mn in mineral soil were significantly higher than pools of K, Ca, Mg, Na, Al and Mn in above-ground standing biomass. Table 2.1 shows nutrient content in wood and bark was: 1.0 mg g^{-1} for K, 3.0 mg g^{-1} for Ca, 0.1 mg g^{-1} for Mg, 0.1 mg g^{-1} for P and 0.1 mg g^{-1} for S in *Quercus* study plots. This study has determined that the nutrient content in wood was: 1.36 mg g^{-1} for K, 1.1 mg g^{-1} for Ca, 0.4 mg g^{-1} for Mg, 0.4 mg g^{-1} for P and 0.2 mg g^{-1} for S. This study has determined that the nutrient content in bark was 2.7 mg g^{-1} for K, 15.3 mg g^{-1} for Ca, 1.0 mg g^{-1} for Mg, 0.4 mg g^{-1} for P and 0.8 mg g^{-1} for S. It is confirmed that nutrient in bark was much higher than in wood. Wood: bark ratio should be considered for *Quercus* study plots with large DBH.

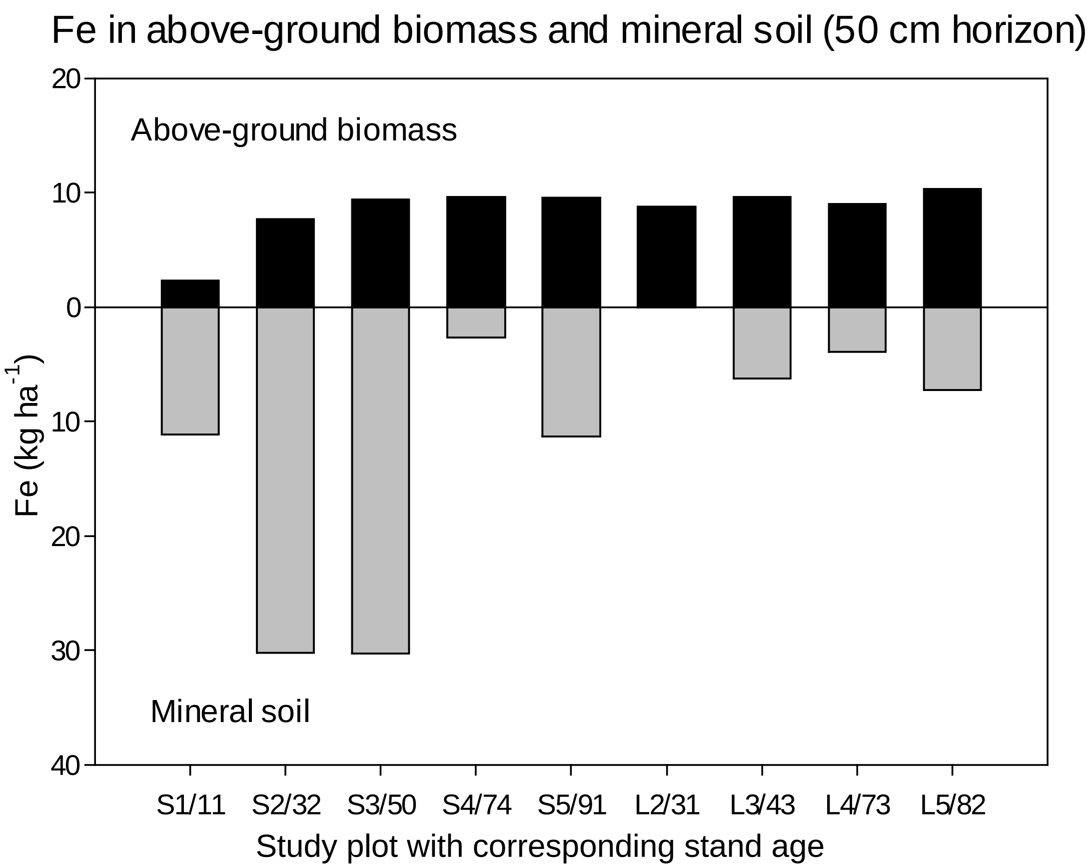

K in above-ground biomass and mineral soil (50 cm horizon)
Above-ground biomass
Mineral soil
K (kg ha-1)
500
0
500
1000
1500
S1/11
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age


Ca in above-ground biomass and mineral soil (50 cm horizon)
Above-ground biomass
Mineral soil
Ca (kg ha-1)
0
5000
10000
15000
20000
S1/11
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age


Mg in above-ground biomass and mineral soil (50 cm horizon)
Above-ground biomass
Mineral soil
Mg (kg ha-1)
0
500
1000
1500
2000
2500
S1/11
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age


Na in above-ground biomass and mineral soil (50 cm horizon)
Above-ground biomass
Mineral soil
Na (kg ha-1)
40
20
0
20
40
60
80
100
120
140
160
180
S1/11
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age


Al in above-ground biomass and mineral soil (50 cm horizon)
Above-ground biomass
Mineral soil
Al (kg ha-1)
200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
S1/11
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age


Fe in above-ground biomass and mineral soil (50 cm horizon)
Above-ground biomass
Mineral soil
Fe (kg ha-1)
20
10
0
10
20
30
40
S1/11
S2/32
S3/50
S4/74
S5/91
L2/31
L3/43
L4/73
L5/82
Study plot with corresponding stand age

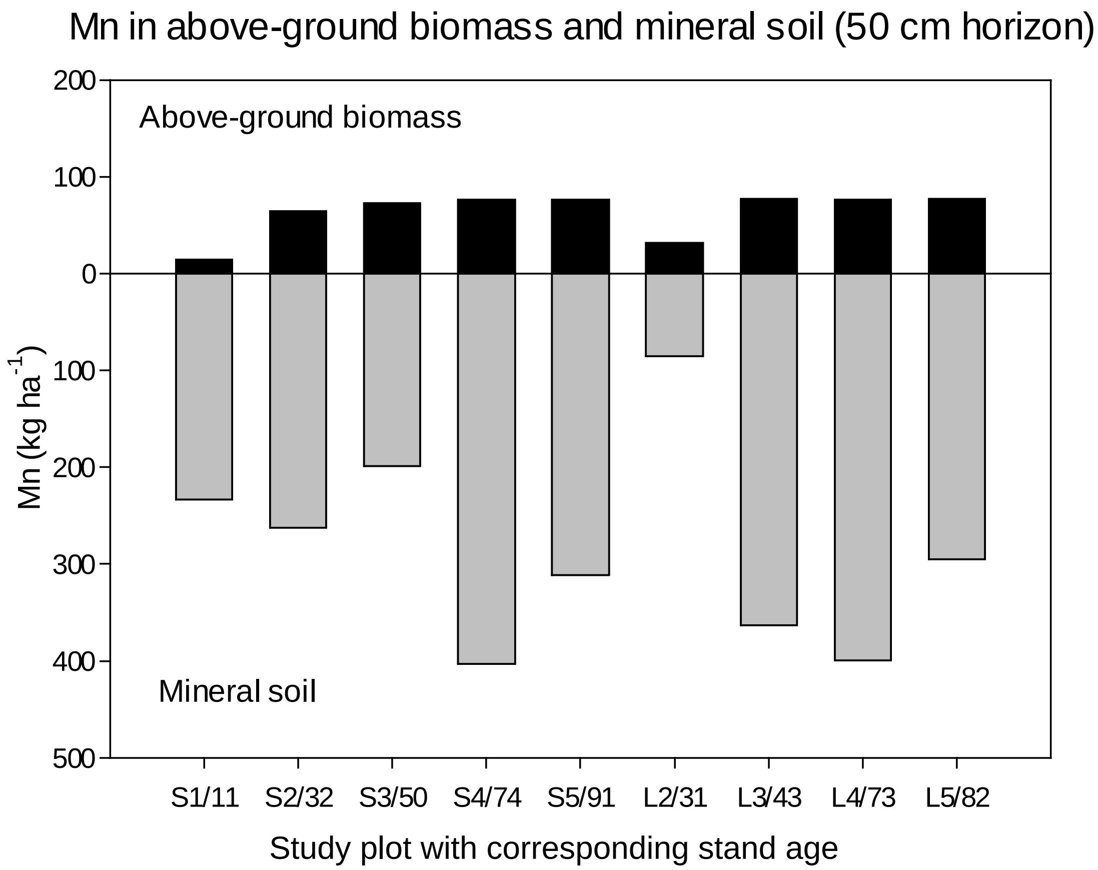


Figure 5. 21 Pools of K, Ca, Mg, Na, Al, Fe and Mn (kg ha^{-1}) in above-ground standing biomass and pools of exchangeable K, exchangeable Ca, exchangeable Mg, exchangeable Na, exchangeable Al, exchangeable Fe and exchangeable Mn in the top 50 cm mineral soil of nine *Quercus* study plots (S1 - S5 and L2 - L5) in North-East Austria.

It is confirmed that nutrient pool of Al in above-ground standing biomass was very low in all study plots. Study plot L2 was dominated by base cations as the soil property of Calcic Chernozem. It explained well that significantly lower exchangeable Al and Fe in study plot L2. Soil mineralization could in the future increase the content of Al and Fe. Since exchangeable Fe could greatly enhance soil C stock (Lal, 2005) and the low content of exchangeable Fe in study plots S1, S4, S5, L3, L4, L5 and practically in study plot L2, fertilizer with high Fe could considered to be applied in this study area to promote the net primary production

(NPP). It is confirmed that changing mineral nutrient demand during forest stand growth is not reflected in soil nutrient status.

In the following the hypotheses that the changing mineral nutrient demand during forest stand growth is reflected in soil nutrient status will be discussed. A bivariate correlation analysis was carried out in order to test whether stand age affecting soil properties and above-ground standing biomass in Eutric Cambisol stands. Nutrient pools of K and Ca in above-ground standing biomass were highly significantly positively correlated with stand age with Person Coefficients of 0.521 ($P<0.01$) and 0.607 ($P<0.01$) (Table 5.2). This is consistent with our hypotheses that incorporation of nutrients in the plant biomass was accumulated with the stand age. Nutrient pools of K and Ca in above-ground standing biomass were not correlated with exchangeable K but significantly positively correlated with exchangeable Ca in mineral soil (Table 5.2). Exchangeable Ca was positively significantly correlated with stand age (Table 5.2) in Eutric Cambisol which was not consistent with our hypotheses. The reason could be the historical land use management and the large Ca pools with accelerated mineralization rate in study plots S4 and S5.

There was no correlation of stand age with exchangeable K, soil N and C. Stand age was significantly positively correlated with soil pH and CEC with Person Coefficients of 0.135 ($P<0.05$) and 0.170 ($P<0.05$).

Table 5. 2 Bivariate correlation Person Coefficients of exchangeable K and exchangeable Ca and stand age with soil N, soil C, soil pH (H_2O), CEC, nutrient pools of K and Ca in above-ground standing biomass and stand age in Eutric Cambisol (Study plots S1-S5) *Quercus* study plots in North-East Austria. Age class: rapid growing period (0-40 years); stable growing period (40-80 years); senescing period (>80 years). **. P<0.01; *. P<0.05.

	Exchangeable K	**Exchangeable Ca**	**Stand age**
Stand age	0.054	**0.192****	
Soil N	**0.360****	**0.338****	0.12
Soil C	**0.152***	**0.209****	-0.02
Soil pH	**0.382****	**0.643****	**0.135***
CEC	**0.404****	**0.607****	**0.170***
Above-ground standing biomass K	0.104	**0.134***	**0.521****
Above-ground standing biomass Ca	0.103	**0.154***	**0.607****

The results of this study (Figure 4.7, Figure 4.10, Figure 4.11, Figure 4.12, Figure 4.13 and Figure 4.14) show that mineral soil has huge nutrient pools to support potential growth of above-ground standing biomass. Above-ground standing biomass nutrients constantly accumulated with forest growth unless there are thinning management or harvesting (Ranger *et al.*, 1995; Alifragis *et al.*, 2001). K and Ca were interpolated in above-ground standing biomass and mineral soil corresponding with stand age (Figure 5.13). The trends of K and Ca in above-ground standing biomass were corresponding with our correlation results. Accelerated Ca mineralization could be the reason of significant positive correlation between stand age and exchangeable Ca. Likewise there is significant positive correlation between stand age and soil pH and CEC. Several studies showed that Ca is sometimes related to other mineral nutrients (Crooke *et al.*, 1964; Smith *et al.*, 2007; De Schrijver *et al.*, 2009). Results from Table 5.2 together with independent exchangeable K and Ca (Figure 5.22) have proved that stand age had no decisive influence on mineral nutrient levels in the soil, indicating that no nutritional bottleneck results from incorporation of nutrients into the biomass. In comparison with several studies (Nakos, 1989; Olsson, 1996; Xue, 1996; Olsson, 1999; Eshetu *et al.*, 2004; Lemenih *et al.*, 2004; McLaughlin and Phillips, 2006; Yimer *et al.*, 2008; Ritter, 2009), the levels of nutrients in particular N, exchangeable K, exchangeable Ca and exchangeable Mg in this study areas were reasonably high and do not indicate the necessity for additional fertilization under current silvicultural goal and biomass extraction.

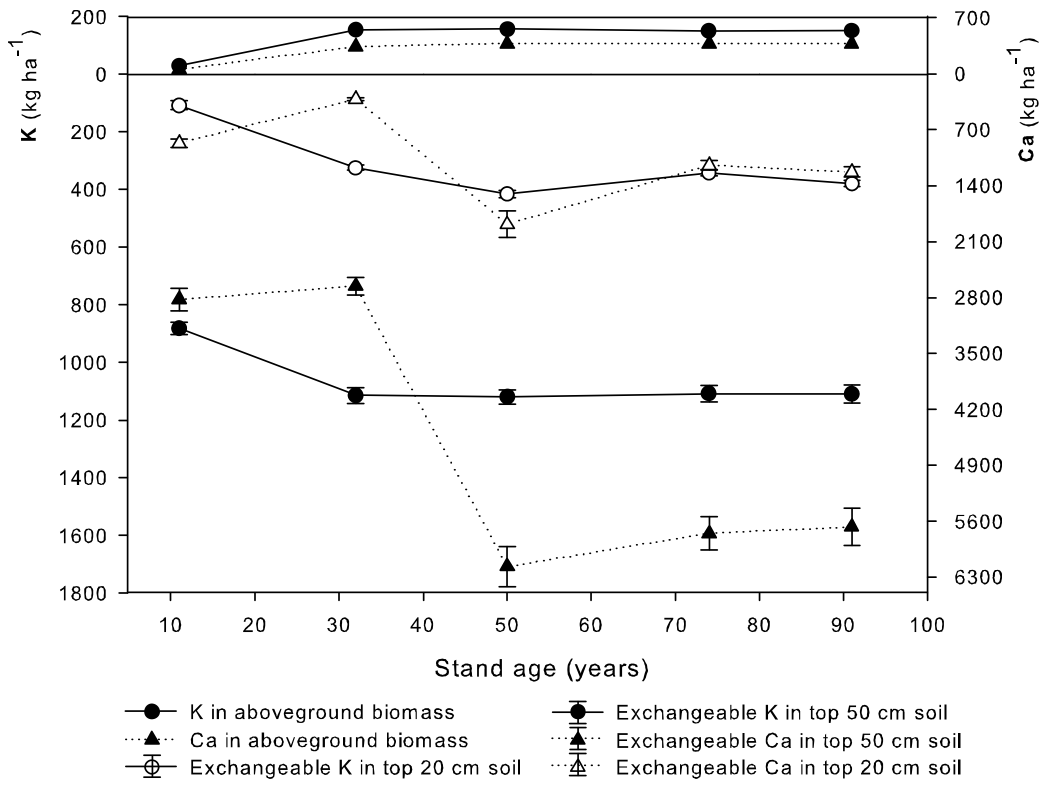


Figure 5. 22 Dynamic K and Ca pools corresponding with stand age in Eutric Cambisol study plots (Study plots S1-S5).

5.6. Plant Nutrient Availability

Nutrient contents and exchangeable cations in the forest soil differ among diverse soil types and ranks in following order: cambisol < luvisol < chernozem. Independence of exchangeable K and Ca on stand age were observed in Eutric Cambisol and Haplic Luvisol. K and Ca concentration is very much dependent on mineralization conditions (Falkengren-Grerup, 1995). According to this study, dynamic mineralization rate in chernozem and luvisol is higher than in cambisol. As the most prevalent exchangeable cations in the soil, base cations are key factors controlling N retention and release of forest ecosystem (Berger *et al.*, 2002). The depletion of available base cations pools in soils would impair forest health and productivity (Watmough and Dillon, 2003). Generally high acid cations corresponded to low base cations and vice versa. They could be adjusted by soil fertilization. Soil acidity might affect the availability of nutrient uptake by affecting the activity of microorganisms involved in ammonification, nitrification, denitrification, immobilization and non-symbiotic N fixation (Robson and Abbott, 1989). It was reported that pH and N supply are the key distribution drivers for some broad-leaved species (Marage and Gegout, 2009). This is consistent with results from our plots, showing that soil organic C and N were significantly higher in Calcic Chernozems.

Since the precipitation is very low in North-East Austrian *Quercus* Forest, the nutrients leaching and running off will not happen. Plant uptake and biomass removal are the main reasons causing nutrient and exchangeable cations depletion. This study hypothesized that: trees in rapid growing period demands more nutrients and cause significant N and exchangeable cations depletion; senescing forests hold the highest nutrient pools. Our ANOVA results (Table 4.16) did not fully support this hypothesis by showing that there is no significant decreasing of CEC with stand age in Eutric Cambisol and Haplic Luvisol. CEC was not significant higher in mature and senescing study plots S5 and L5. The hypotheses stand age may have influence of the nutrients and exchangeable cations in the top soil horizons (soil horizon < 20 cm) due to large amount of nutrient absorption by fine roots in the shallow soil horizons. The results of this study did not support to this hypotheses regarding to nonexistent trends of the exchangeable cations in the all soil horizons and no plant uptake causing significant nutrient depletion during growing period in the upper soil horizons. It answered the question that the changing mineral nutrient demand during forest stand growth is not reflected in soil nutrient status.

5.7. Open Discussion on Further Studies

Beside the climatic influences and the geographic particularities another thing has much impact on soil properties and processes: the way how agricultural land is systematically farmed has a big impact on the stability and fertility for the harvest and the possibilities to use it for in the future again. Land use related processes of soil erosion, organic matter depletion, salinization, nutrient imbalance, compaction and hard-setting are causing soil regression and degradation. In Central Europe, former agricultural land has been rapidly transferred into forest area since the 19th century (Koerner *et al.*, 1997; Dupouey *et al.*, 2002; Jussy *et al.*, 2002). Many studies showed that changes in soil properties caused by different land use management had a long lasting effect on changing the soil fertility as well as the site index (Zinke, 1962; Andersson *et al.*, 2000; Wall and Hytonen, 2005; Falkengren-Grerup *et al.*, 2006; Shuai, 2007; le Mellec and Michalzik, 2008; Boley *et al.*, 2009). It would be interesting to conduct further studies on impact of the land use history on nutrients cycles together with phosphorus (P) and sulfur (S) dynamics in this study area.

Research on C sequestration potential and ecological functions should be carried out in order to get complete information and a better understanding of managing deciduous forests in a sensitive, dynamic and sustainable way. One of the Kyoto-Protocol's market-based mechanisms, clean development mechanism (CDM), has encouraged and supported a dramatic world-wide establishment of artificial forest plantations. According to this international forests development trend and increasing of deforestation (Elbakidze and Angelstam, 2007; Peterson *et al.*, 2009), this study would recommend that the forest land in North-East Austria should be maintained not only for sustainable biomass utilization but also for C sequestration and other ecological functions. To compensate of soil C loss due to forest harvesting and to enhance the capacity of soil C stock, micronutrients Fe as fertilizer could be applied. Logging residues such as leaves and branches and litter should be remained in the field as soil nutrients depletion and soil acidification are the major concerns associated with removal of litters and logging residues (Olsson, 1996, 1999; Arvidsson and Lundkvist, 2003).

6. Conclusions

This study examined three soil types (Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) in *Ouercus* dominated deciduous forest in North-East Austria.

This study has determined the above-ground standing biomass and above-ground nutrients pools of N, K, Ca, Mg, Na, Al, Fe, Mn, P and S. The total biomass in this study area ranged from 12.5 Mg ha^{-1} to 153 Mg ha^{-1}. Stands before senescing period host the highest biomass. Biomass in different fractions ranked in following orders: stem > branch > bark > foliage > regeneration. The C in above-ground standing biomass ranged from 6.36 Mg ha^{-1} to 77.5 Mg ha^{-1}.

This study determined the dry mass of litter, N and C in litter, root biomass, soil pH, soil N, soil C, C:N ration in soil, exchangeable cations K, Na, Ca, Al, Mg, Fe and Mn in mineral soil, base cations and acid cations and CEC at different soil horizons of nine study plots. This study supplemented the information of mineral nutrients and exchangeable cations in soils of *Quercus* dominated stands in central Europe. As this study expected, SOM and nutrients pools differed among diverse soil types and ranked in the following order: Eutric Cambisol < Haplic Luvisol < Calcic Chernozem. It is confirmed that Calcic Chernozem is the most fertile soil in our study area.

The effects of stand age, soil type, soil horizons on soil dry mass in Litter, soil pH, soil bulk density, soil N, soil C, exchangeable cations and CEC in deciduous forests in North-East Austria were studies. Based on the chronosequence approach, it is found that stand age had no decisive influence on soil properties and mineral nutrient levels in the soil, indicating that no nutritional bottleneck results from incorporation of nutrients into the biomass. Soil type, soil horizons and soil pH are the most important factors determining the mineral nutrient content and the CEC of deciduous forests in these study areas. The spatial distribution of mineral element contents in different aged stands was heterogeneous. It is confirmed that the changing mineral nutrient demand during forest growth was not reflected in soil nutrient status.

The results show that mineral soil contains substantial nutrient pools to support potential growth of above-ground standing biomass. There is considerable potential for making greater use of forest land as a bio-energy feedstock. Soil fertilization is currently not necessary in traditional forest management. At current biomass extraction levels the investigated deciduous forests in North-East Austria can be managed both for timber or, if the market permits, for biomass used as energy.

This study has determined the amount of nutrients immobilized which would be prime importance for deciding the harvest intensity that will ensure the sustainability of forest management practices. This study would recommend that the forest land in North-East Austria should be maintained not only for sustainable biomass utilization but also for C sequestration and other ecological functions. To compensate of soil C loss due to forest harvesting and to enhance the capacity of soil C stock, micronutrients Fe as fertilizer could be applied. In this study, to retain and recycle the logging residues such as leaves and branches and litter in the field are at present not necessary due to the large nutrient pools in the mineral soil, but the author would not recommend the removal of foliage and fine branches in order to avoid some problems caused by soil nutrients depletion and soil acidification in a long period.

Wood: bark ratio could be used to have better understanding and evaluation of stems and branches nutrient pools without felling the valuable trees in the future. As important indicator of N and P limitation, N: P ratio of foliage should be considered for nutrient evaluation and forest management in the future. The author would recommend that further studies on impact of the land use history on nutrients cycles together with dynamic soil P and S in the same area should be carried out if there is enough founds.

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Acronyms:

AFFL	**Austrian Federal Forest Law**
Al	**Aluminum**
ANOVA	**Anaysis of Variance**
BOKU	**University of Natural Resources and Life Sciences, Vienna**
C	**Carbon**
Ca	**Calcium**
CO_2	**Carbon Dioxide**
CEC	**Cation Exchangeable Capacity**
DBH	**Diameter of Brest height**
EC	**Exchangeable Cations**
ERM	**Equamax Rotation Method**
FAO	**Food and Agriculture Organization of the United Nations**
Fe	**Iron**
GHG	**Greenhouse Gases**
ICP-OES	**Inductively Coupled Plasma – Optical Emission Spectroscopy**
K	**Potassium**
KMO	**Kaiser-Meyer-Olkin**
M	**Molar mass**
MDG	**Millennium Development Goals**
Mg	**Magnesium**
Mn	**Manganese**
N	**Nitrogen**
Na	**Sodium**
NPP	**Net primary production**
OC	**Organic Carbon**
P	**Phosphorus**

PCA	**Principal Component Analysis**
RSG	**Reference Soil Groups**
S	**Sulfur**
SOM	**Soil Organic Matter**
UCS	**Union of Concerned Scientists**
UN	**United Nations**
USDA	**United States Department of Agriculture**
WRB	**The World Reference Base for Soil Resources**
ZAMG	**Zentralanstalt für Meteorologie und Geodynamik in Austria**
Zn	**Zinc**

List of Conference Proceedings

1. **Yan, Shuai**; Bruckman, Viktor J.; Glatzel, Gerhard; (2010) Exchangeable Cations in the Soils of Quercus Dominated Forests in North-East Austria. European Geosciences Union Generally Assembly. April 2010, Vienna, Austria.
2. **Yan, Shuai**; Bruckman, Viktor J.; (2010) Soil nitrogen and carbon pools under high and coppice forest in the Vienna Woods. Proceedings of the IUFRO World Conference. August 2010, Seoul, Korea.
3. **Yan, Shuai**; Bruckman, Viktor J.; Glatzel, Gerhard; Eduard Hochbichler (2011) Nutrient Pools in Oak Forests as a decision support for harvesting intensities (Biomass potential). Central European Biomass Conference. January, 2011, Graz, Austria.
4. **Yan, Shuai**; Bruckman, Viktor J.; Glatzel, Gerhard; Eduard Hochbichler (2011) A chronosequence approach to study stand age effects on total nitrogen as well as exchangeable K, Ca and Mg in the soils in view of increased energetic utilization of Quercus dominated forests in North-East Austria. European Geosciences Union Generally Assembly. April 2011, Vienna, Austria.
5. **Yan, Shuai**; Bruckman, Viktor J.; Glatzel, Gerhard; Eduard Hochbichler (2011) Study of soil nutrient pools by chronosequence approach in view of aboveground biomass potentials in *Quercus* dominated forests. ESF-COST High-Level Research Conference: FUTURE ROLE OF BIO-ENERGY FROM TREE BIOMASS IN EUROPE. November 2011 Vienna, Austria.
6. **Yan, Shuai**; Bruckman, Viktor J.; Glatzel, Gerhard; Hochbichler, Eduard (2012) Assesment of Forest Nutrients in view of biomass potential – A Case Study from Austria Oak Stands European Geosciences Union Generally Assembly. April 2012, Vienna, Austria.
7. **Yan, Shuai**; Bruckman, Viktor J. (2012) Is the changing mineral nutrient demand of forest stand growth reflected in the potassium and calcium status of the soil? 4th International Conference Euro Soil. July 2012, Bari, Italy.

8. Bruckman, Viktor J.; **Yan, Shuai**; Glatzel, Gerhard (2010) Determinants of soil organic carbon pools in oak stands in North-East Austria. European Geosciences Union Generally Assembly. April 2010, Vienna, Austria.
9. Bruckman, Viktor J.; **Yan, Shuai**; Hochbichler, Eduard; Glatzel, Gerhard (2011) Impact of forest stand management on temporal dynamics of soil carbon and nitrogen. European Geosciences Union Generally Assembly. April 2011, Vienna, Austria.
10. Bruckman, Viktor J.; **Yan, Shuai**; Hochbichler, Eduard; Glatzel, Gerhard (2012) Carbon pools and temporal dynamics along a rotation period in sessile oak dominated high forest and coppice with standards stands . European Geosciences Union Generally Assembly. April 2012, Vienna, Austria.

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Exchangeable Cations in the Soils of Quercus Dominated Forests in Northeastern Austria

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In northeastern Austria there is a growing interest in increased utilisation of forest biomass for energy. This study focuses on soil properties and nutrient pool characteristics in deciduous forests in order to provide advice for forest management. We (i) quantified selected exchangeable cations in the soils of our study area and (ii) identified the effects of stand age, soil type, soil depth and soil pH on exchangeable cations and cation exchange capacity (CEC). Nine permanent Quercus petraea dominated plots on sandy, clayey cambisols and calcic chernozem were selected for our study. From each plot 18 soil samples were collected in a systematic grid by means of a soil corer with 70 mm diameter to a maximum depth of 60 cm. Soil pH, exchangeable mineral elements K, Ca, Mg, Na, Mn, Al, and Fe were determined in five geometric soil horizons. Statistical analysis showed that (i) forest age did not influence the exchangeable K content of the sandy soils; (ii) the exchangeable K content decreased with increasing standage in clayey cambisols; (iii) exchangeable K, Na and Mg were higher in calcic chernozems and clayey cambisols (iv) exchangeable Fe was significantly higher in sandy forest soils except in the 60-80 years old stand; (v) exchangeable Fe was below detection limit in calcic chernozem soils. A comparison of exchangeable cations revealed that (i) Ca is the key element of base cations (ii) the content of base cations is strongly significant higher in calcic chernozem soils (iii) calcic chernozem soils have the highest CEC. CEC ranged from 38 to 190 µmol/g in the entire research area. Base cations, acid cations and CEC differ with soil depth as followed (i) in sandy and clayey cambisols, CEC had a minimum in 20 cm depth and then increased with soil depth to 50 cm; (ii) CEC decreased stadily with soil depth in calcic chernozems. As expected, CEC is significantly positively correlated (Pearson correlation coefficient 0.661, $P<0.01$) with the pH of the soil. The contents of plants and above ground biomass nutrients, the rate of mineral nutrients accumulation or loss from soil and the correlation of mineral nutrients with nitrogen and carbon pools will be analyzed from samples collected in this study if funded. Our results show that the spatial distribution of mineral element pools is heterogeneous in this study area. On the whole the study suggests thatsoil fertilization is currently not necessary in deciduous forest in northeastern Austria. Stand age has no large influence on mineral nutrients, indication that no nutritional bottleneck results from incorporation of nutrients into the biomass. Soil type, soil depth and soil pH are the most important factors to influence the mineral nutrients and CEC of deciduous forests in northeastern Austria.

Key words: Oak stands; Austria; soil properties; exchangeable cations; CEC; base saturation

Exchangeable Cations in the Soils of Quercus Dominated Forests in Northeastern Austria

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Introduction and Methods

In northeastern Austria there is a growing interest in increased utilisation of forest biomass for energy. This study focuses on soil properties and nutrient pool characteristics in deciduous forests in order to provide advice for forest management. We are (i) quantifying selected exchangeable cations in the soils of our study area and (ii) identifying the effects of stand age, soil type, soil depth and soil pH on exchangeable cations and cation exchange capacity (CEC).

Nine permanent *Quercus petraea* dominated plots on eutric cambisols with high sand content, calcic chernozem and haplic luvisol with low sand content were selected for our study. From each plot 18 soil samples were collected in a systematic grid by means of a soil corer with 70 mm diameter to a maximum depth of 60 cm. Soil pH, exchangeable mineral elements K, Ca, Mg, Na, Mn, Al, and Fe were determined in five geometric soil horizons.

Table 1. Description of the selected study plots

Plot Number	*Quercus* Stand Age (year)	Plot Size (m)	Species Composition	Soil Types
S1	11	40*40	*Quercus petraea* with few *Rubus occidentalis*	eutric cambisol (high sand content)
S2	32	40*40	*Quercus petraea* with *Galium sylvaticum*	
S3	50	40*40	*Quercus petraea* with few *Corylus avellana*	
S4	74	40*40	*Quercus petraea* with *Carpinus betulus* and *Galium sylvaticum*	
S5	91	50*50	*Quercus petraea* with few *Corylus avellana*	
L2	31	40*40	*Quercus petraea* with few *Acer campestre*, *Betula pendula*, *Cornus sanguinea*	calcic chernozem
L3	43	40*40	*Quercus petraea* with few young *Corylus avellana*	haplic luvisol (low sand content)
L4	73	40*40	*Quercus petraea* with few *Corylus avellana*	
L5	82	50*50	*Quercus petraea* with young *Carpinus betulus*, ground *Galium sylvaticum*	

Results

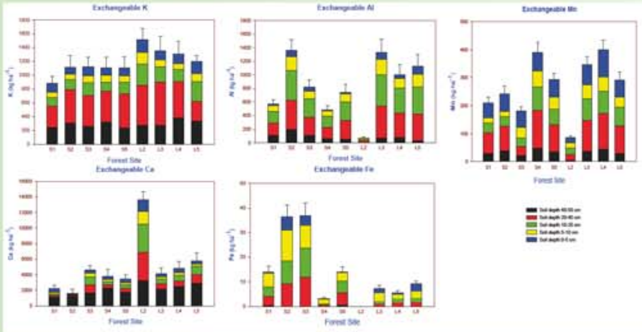

Fig. 1. Pools of exchangeable cations (K, Ca, Al, Fe, Mn) (kg ha-1) in the top 50 cm of the forest soil of nine study plots (S1 - S5 and L2 - L5) in *Quercus* forests in northeastern Austria. (Mean values (n=9) and standard deviation bars)

Statistical analysis showed that (i) forest age did not influence the exchangeable K content of the eutric cambisols with high sand content; (ii) the exchangeable K content decreased with increasing stand age in haplic luvisols with low sand content; (iii) exchangeable K, Na and Mg were higher in calcic chernozems and haplic luvisols with low sand content; (iv) exchangeable Fe was significantly higher in eutric cambisols with high sand content except in the 74 years old stand; (v) exchangeable Fe was below detection limit in calcic chernozem.

A comparison of exchangeable cations revealed that (i) Ca is the key element of base cations (ii) the content of base cations is strongly significant higher in calcic chernozems; (iii) calcic chernozem has the highest CEC. CEC ranged from 38 to 190 µmol/g in the entire research area. Base cations, acid cations and CEC differ with soil depth as followed (i) in eutric cambisols with high sand content and haplic luvisols with low sand content, CEC had a minimum in 20 cm depth and then increased with soil depth to 50 cm; (ii) CEC decreased steadily with soil depth in calcic chernozems. As expected, CEC is significantly positively correlated (Pearson correlation coefficient 0.661, $P<0.01$) with the pH of the soil.

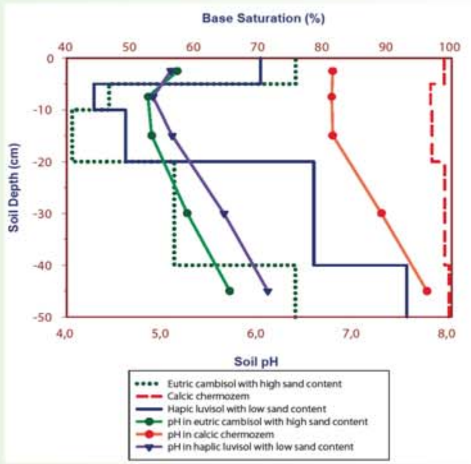

Fig. 2. Base saturation (%) and soil pH (H_2O). (mean value ± standard error) at different soil depths in three soil types in *Quercus* forests in northeastern Austria.

Conclusion

We studied the effects of stand age, soil type, soil depth and soil pH on exchangeable cations and CEC in deciduous forests in northeastern Austria. In our study stand age had no decisive influence on mineral nutrient levels in the soil, indicating that no nutritional bottleneck results from incorporation of nutrients into the biomass. Soil type, soil depth and soil pH are the most important factors determining the mineral nutrient content and the CEC of deciduous forests in these study areas. Calcic chernozem had the highest base cations pool and CEC. At current biomass extraction levels the investigated deciduous forests in northeastern Austria can be managed both for timber or, if the market permits, for biomass used as energy.

A comparison of selected soil properties under high and coppice forest in the Vienna Woods

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In this study soil properties of a high forest and a coppice forest in the Vienna Woods were compared. 15 soil samples were randomly collected from each forest patch at 80 m interval grid along the plots by means of a soil core with 70 mm diameter to a maximum soil horizon of 60 cm. Soil samples were classified using the FAO- WRB classification system. Each soil profile was divided into ectohumus (O-horizon) as well as into vertical geometric mineral soil horizons of 0 to 5, 5 to 10, 10 to 20, 20 to 40 and 40+ cm depths. Dry mass of ectohumus, coarse and fine mineral soil, of roots, soil bulk density, soil pH, total nitrogen and total and organic carbon of each sample were determined. Statistical analysis revealed differences of ectohumus dry mass, root dry mass, soil bulk density, soil pH, total nitrogen and total and organic carbon at different soil horizons under coppice and high forest. As expected, correlation analysis showed that nitrogen and organic carbon are highly positively correlated in high and coppice forest. Possible reasons are discussed.

Soil Nitrogen and Carbon Pools under High and Coppice Forests in the Vienna Woods

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Introduction

As a favorite outdoor destination for the densely populated area around the city, Vienna woods is also an important source of supplying renewable , sustainable woody biomass for energy. Therefore this study focuses on soil properties which have fundamental impacts on forest productivity. It aims to (i) quantify selected soil properties and soil organic matter stores in high and coppice deciduous forest; (ii) identify nitrogen and carbon distributions across different forests and soil horizons; (iii) identify the effects of historical forest management on soil nutrient pools.

Methods

Fifteen soil samples were systematically collected from high forest (*Fagus sylvatica* dominated) and coppice forest (*Quercus petraea* dominated) at 80 m interval grid along the plots by means of a soil corer with 70 mm diameter to a maximum soil depth of 60 cm. Soil pH, dry mass of ectohumus, soil bulk density, total nitrogen and organic carbon were determined in five geometric soil horizons at each soil sample.

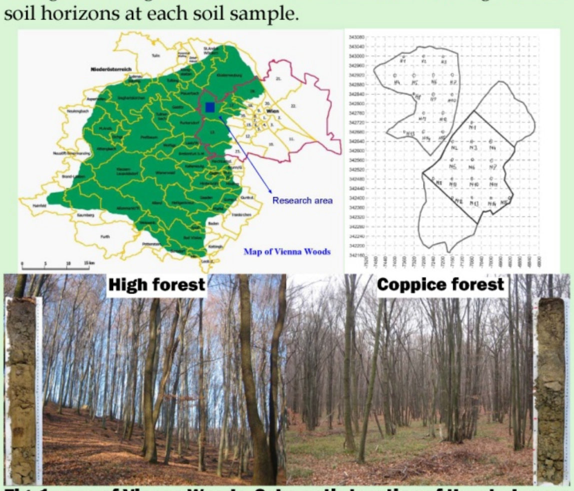

Fig. 1. map of Vienna Woods, Schematic location of the study area (Gauss-Krüger M34 coordinates system, H represents high forest, N represents coppice forest), landscape of forest stands and examples of soil profiles

Results

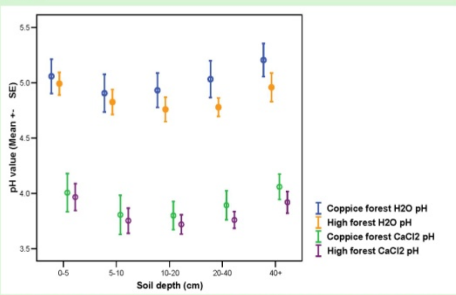

Fig. 2. Soil pH value (mean ± SE) at different soil depths in the high and coppice forest in the Vienna Woods (n=15)

Soil acidity was determined by the active acidity (soil pH H_2O) and the exchanged acidity (soil pH $CaCl_2$) (Fig. 2). Soil pH in the coppice forest is higher than in the high forest in all depth strata.

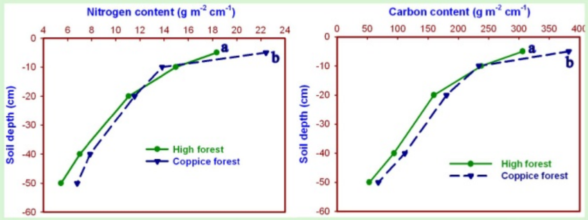

Fig. 3. Mean value of soil nitrogen and carbon content (g m^{-2} cm^{-1}) standardized to 1 cm at different soil depths in high and coppice forest in the Vienna Woods (n=15). Letters indicate significant differences according to horizons between two forests (p<0.05)

The nitrogen content ranged from 5.46 g m^{-2} cm^{-1} to 18.35 g m^{-2} cm^{-1} in the high forest and from 6.79 g m^{-2} cm^{-1} to 22.43 g m^{-2} cm^{-1} in the coppice forest. The carbon content ranged from 53.15 g m^{-2} cm^{-1} to 305.06 g m^{-2} cm^{-1} in the high forest and from 67.93 g m^{-2} cm^{-1} to 381.94 g m^{-2} cm^{-1} in the coppice forest. Soil nitrogen and carbon content is decreasing with the increase of soil depth both in the high and coppice forest (Fig. 3). There is no significant difference in soil nitrogen and carbon content in the subsoil horizons (5-40cm) for the two forest patches. The soil nitrogen and carbon content in the coppice forest was significantly higher than in the high forest at soil depth 0 to 5 cm.

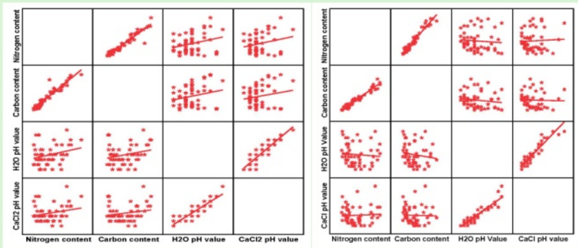

Fig. 4. Correlation among nitrogen, carbon, H_2O pH value and $CaCl_2$ pH value in the coppice and high forest in the Vienna Woods

There is a high positive correlation of the total nitrogen and carbon content both in the high and coppice forests (Fig.4). It is evident that nitrogen and carbon stores in the soil are not or possibly only very weakly correlated with soil acidity under the conditions encountered in the investigated stands.

Conclusion

This study has confirmed that the entire study area has moderately acidic soils. Intensive biomass extraction from coppice forest in the past centuries probably closed the gap of pH value in top 20 cm soil, which was significantly different in sub soil in two forests. Reasons for high nitrogen and carbon pools in coppice forest at top 5 cm soils are: (i) organic matter was translocated from high forest with steep terrain to coppice forest with flat terrain; (ii) decomposition rates of litter and branch residues in coppice forest is higher than in high forest. Lower N and C contents in coppice forest in the 5-10 cm soil stratum were witnesses of high biomass extraction rates in the past.

Nutrient Pools in Oak Forests as a decision support for harvesting intensities (Biomass potential)

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There is growing interest in exploring the potential of woody biomass as a source of renewable, sustainable energy for this region in North-East Austria's forests. A fundamental question is how mineral nutrition is affected by harvesting biomass. Losses of plant nutrients exceeding the natural replenishment due to deposition and weathering will ultimately lead to declining growth rates. This study focused on mineral nutrient pool characteristics in deciduous forests in order to investigate the effects of stand age and soil type on exchangeable cations as a basis for sustainable forest management in *Quercus* dominated forests in North-East Austria. We (i) quantified selected exchangeable cations in the soils of our study area and (ii) identified the effects of stand age, soil type, soil depth and pH on exchangeable cations and cation exchange capacity (CEC). Three soil types (according to WRB system: Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) were considered representative for the area and sampled. Nine permanent *Quercus petraea* dominated plots were selected for our study. Soil pH, nitrogen and the exchangeable mineral elements K, Ca, Mg, Na, Mn, Al, and Fe were determined in five geometric soil horizons. Inventory of aboveground biomass was performed. In our study area, nutrient pools at soil depth 0-50 cm were (kg.ha^{-1}): N 3640 – 7210, K 883 - 1510, Ca 1630 – 13630 and Mg 320 - 1850. A comparison of exchangeable cations revealed that (i) Ca was the key element of base cations, (ii)

base cations were strongly significantly higher in Calcic Chernozem, (iii) Calcic Chernozem had the highest CEC (cation exchange capacity). CEC ranged from 34 to 189 $\mu mol.g^{-1}$ in the entire research area. As expected, CEC was significantly positively correlated (Pearson correlation coefficient 0.661, $P<0.01$) with the pH (H_2O) of the soil. Stand age had no pronounced influence on mineral nutrient contents in the soil. Taken together with the contents of aboveground biomass nutrients in several compartments (stem wood, stem bark, foliage, branches) the data indicates that no nutritional bottleneck results from incorporation of nutrients into the biomass under the present traditional harvest regime. Literature review suggests, however, that phosphorus is a limiting factor at higher biomass extractions (e.g. in case of full tree harvests). Stand age has no large influence on nutrient pools. Soil type, soil depth and soil pH were the most important factors to influence the nutrients and CEC.

Nutrient pools in Oak forests as a decision support for harvesting intensities (Biomass potential)

Yan Shuai [a,d], Viktor J. Bruckman [a,b], Gerhard Glatzel [a,b], Eduard Hochbichler [c]

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Introduction

There is growing interest in exploring the potential of woody biomass as a source of renewable, sustainable energy in Northeastern Austria's forests. A fundamental question is how mineral nutrition is affected by harvesting biomass. Losses of plant nutrients exceeding the natural replenishment due to deposition and weathering will ultimately lead to declining growth rates. This study focused on mineral nutrient pool characteristics in deciduous forests in order to investigate the effects of stand age and soil type on exchangeable cations as a basis for sustainable forest management in *Quercus* dominated forests in northeastern Austria.

Methods

Nine permanent *Quercus petraea* dominated plots (Fig 1, Tab 1) were selected for our study. Soil pH, nitrogen and the exchangeable mineral elements K, Ca, Mg, Na, Mn, Al, and Fe were determined in five (0-5 cm, 5-10 cm, 10-20 cm, 20-40cm, 40-50cm) geometric soil horizons. Inventory of aboveground biomass was performed.

Fig 1 Landscape of study area

Table 1 Description of the selected study plots

Plot number	Quercus Stand age (year)	Plot size (m)	Species composition	Soil types
S1	11	40*40	*Quercus petraea* with few *Rubus fruticosus*	Eutric cambisol (coarse material ≤ 40%)
S2	32	40*40	*Quercus petraea* with *Galium sylvaticum* in the understory	
S3	50	40*40	*Quercus petraea* with few *Corylus avellana*	
S4	74	40*40	*Quercus petraea* and *Carpinus betulus* with *Galium sylvaticum* in the understory	
S5	91	50*50	*Quercus petraea* with few *Corylus avellana*	
L2	31	40*40	*Quercus petraea* with few *Acer campestre*, *Betula pendula*, *Cornus sanguinea*	Calcic chernozem
L3	43	40*40	*Quercus petraea* with few young *Corylus avellana*	Haplic luvisol (coarse material ≤ 20%)
L4	73	40*40	*Quercus petraea* with few *Corylus avellana*	
L5	82	50*50	*Quercus petraea* with young *Carpinus betulus* and *Galium sylvaticum* in the understory	

Results

In our study area, nutrient pools at soil depth 0-50 cm were (kg/ha): N 3640 – 7210, K 883 - 1510, Ca 1630 – 13630, Al 66 - 1656, Mg 322 - 1848, Fe 0 - 30 and Mn 85 - 399. Base cations are key factors controlling nitrogen retention and release of forest ecosystems. Generally high acid cation content corresponded to low base cations and vice versa (Fig 2). CEC ranged from 34 to 189 µmol/g in the entire research area and was significantly positively correlated (Pearson correlation coefficient 0.661, $P<0.01$) with the soil pH (H_2O). Fig 3 shows that mineral soil has sufficient nutrient pools to support potential by increased harvesting of aboveground biomass.

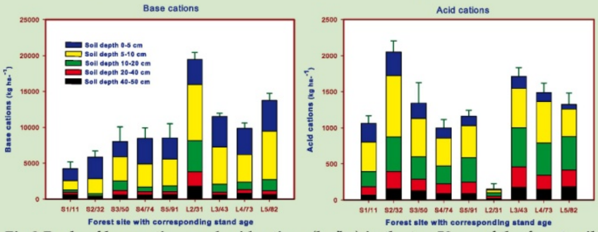

Fig 2 Pools of base cations and acid cations (kg/ha) in the top 50 cm of the forest soil in our study area. Mean values (n=9) and standard error bars.

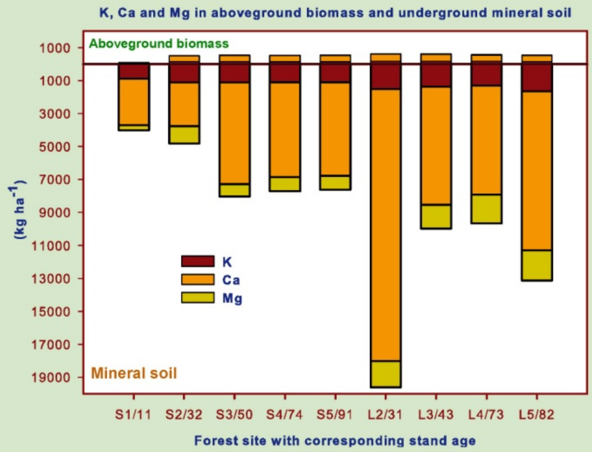

Fig 3 Comparison of estimated nutrients pools of K, Ca and Mg (kg/ha) in aboveground biomass and exchangeable K, Ca and Mg in underground 50 cm mineral soils.

Conclusion

In our study stand age has no large influence on nutrient pools. Soil type, soil depth and soil pH were the most important factors to influence the nutrients and CEC. At current biomass extraction levels the investigated deciduous forests in northeastern Austria can be managed both for timber or, if the market permits, for biomass used as energy source.

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A chronosequence approach to study stand age effects on total nitrogen as well as exchangeable K, Ca and Mg in the soils in view of increased energetic utilization of *Quercus* dominated forests in northeastern Austria

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The recent IUFRO World Congress Seoul Resolution of August 2010 lists bio-energy as one of the six key thematic areas of scientific research and international collaboration. In view of growing interest in woody biomass as a source of renewable and sustainable energy in northeastern Austria, a better understanding of soil properties is needed to assess the capacity of the soils for sustainable forest productivity for this region. This study focuses on exchangeable K, Ca and Mg pools of soils in order to learn more on the temporal dynamics of plant nutrients as a basis for sustainable biomass harvesting in *Quercus* dominated forests in northeastern Austria. We (i) quantified nitrogen and the exchangeable cations K, Ca, Mg as well as CEC in the soils of our study area, (ii) identified the effects of stand age on exchangeable cations and (iii) estimated macronutrients pool of N, K, Ca, and Mg in aboveground biomass. Three soil types (according to WRB: eutric cambisol, calcic chernozem and haplic luvisol) were considered representative for the area and sampled. Nine permanent *Quercus petraea* dominated plots were selected for our study. Soil pH, nitrogen and exchangeable K, Ca and Mg, were determined in five geometric soil horizons. Aboveground biomass was sampled by harvesting. In our study area, the nutrient pools in the top 50 cm of the soil were (kg.ha^{-1}): N 3640 – 7210, K 883 - 1510, Ca 1630 – 13630 and Mg 320 - 1850. The chronosequence approach was used to study how stand age influences the pools of exchangeable cations in cambisols and luvisols of *Quercus* dominated stands. Our study showed that the nutrient pools in the mineral soil are sufficient to support the tree growth; stand age had no significant influence on mineral nutrient levels in the soil. The levels of nutrients in particular exchangeable cations in our study areas are reasonably high and do not indicate the necessity for additional fertilization under current silvicultural practices and biomass extraction rates.

Key words: *Quercus*; biomass; chronosequence approach; soil properties; exchangeable cations

A Chronosequence Approach to Study Stand Age Effects on Exchangeable K and Ca in the Soils in View of Increased Energetic Utilization of *Quercus* Dominated Forests in Northeastern Austria

Shuai Yan [a, d], Viktor J. Bruckman [a, b], Gerhard Glatzel [a, b], Eduard Hochbichler [c]

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Introduction

The recent IUFRO World Congress Seoul Resolution listed bio-energy as a key thematic areas of scientific research and international collaboration. In view of growing interest in woody biomass as a source of renewable and sustainable energy, a better understanding of soil properties is needed to assess the capacity of the soils for sustainable forest productivity. This study focuses on exchangeable K and Ca pools of soils in order to learn more on the temporal dynamics of plant nutrients as a basis for increased biomass harvesting in northeastern Austria.

Materials and methods

Five permanent *Quercus* dominated sites (Tab 1) were selected for our study. Soil pH, N, C, exchangeable mineral elements K, Ca, Mg, Na, Mn, Al, and Fe were determined in five (0-5 cm, 5-10 cm, 10-20 cm, 20-40cm, 40-50cm) geometric soil horizons.

Table 1 Description of the selected study plots

Plot number	Stand age (year)	Plot size (m)	Species composition	Soil types
S1	11	40*40	*Quercus petraea* with few *Rubus fruticosus*	Eutric cambisol (coarse material ≤ 40%)
S2	32	40*40	*Quercus petraea* with *Galium sylvaticum* in the understory	
S3	50	40*40	*Quercus petraea* with few *Corylus avellana*	
S4	74	40*40	*Quercus petraea* and *Carpinus betulus* with *Galium sylvaticum* in the understory	
S5	91	50*50	*Quercus petraea* with few *Corylus avellana*	

Results

The total pools of exchangeable Mg and Ca in the top 50 cm of the soil range from 882 to 1.652 kg ha^{-1} and 2.661 to 16.510 kg ha^{-1}. Mean value of CEC in different plots ranges from 34 to 107 μmol g^{-1}.

Table 2 CEC (μmol g^{-1}) at different soil depths. Mean values (n=9) and standard error. Letters indicate significant difference (p < 0.05).

Forest Site	CEC (μmol g^{-1}) in Different Soil Depth 0-5 cm	5-10 cm	10-20 cm	20-40 cm	40-50 cm	0-50 cm
S1	92 ± 9.8a	45 ± 5.9a	34 ± 2.8a	38 ± 6.0a	57 ± 10.0a	53±4.5a
S2	90 ± 4.9a	59 ± 4.0ab	53 ± 5.8b	63 ± 7.3b	77 ± 7.2a	68±3.3ab
S3	107 ± 9.3ab	86 ± 12.7c	81 ± 13.9c	80 ± 13.3bcd	78 ± 12.6ab	86±5.6bcd
S4	88 ± 10.4a	62 ± 7.9b	52 ± 6.5b	66 ± 11.4b	95 ± 15.4abc	72±5.2abc
S5	95 ± 8.5a	61 ± 6.3b	55 ± 7.1b	69 ± 13.9bc	83 ± 19.1abc	73±5.6abc

Nutrient pools in above ground biomass were calculated by using data from several recent studies and reports.

Table 3 Bivariate correlation Person Coefficients between exchangeable K and Ca, stand age and soil N, C, pH, CEC, K and Ca in aboveground biomass. Age class: rapid growing period (0-40 years); stable growing period (40-80 years); degrading period (>80 years). (**. P<0.01; *. P<0.05)

	Exchangeable K	Exchangeable Ca	Age class
Stand age	0.054	0.192**	
Soil N	0.360**	0.338**	0.12
Soil C	0.152*	0.209**	-0.02
Soil pH	0.382**	0.643**	0.135*
CEC	0.404**	0.607**	0.170*
Aboveground biomass K	0.104	0.134*	0.521**
Aboveground biomass Ca	0.103	0.154*	0.607**

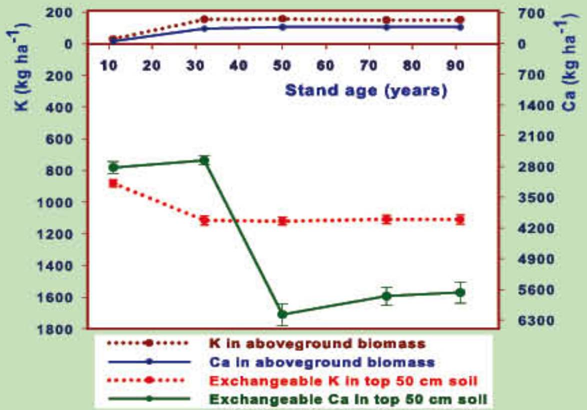

Fig 1 Dynamic K and Ca pools corresponding with stand age. Mean values (n=9) and standard error bar for mineral soil.

There is no correlation between stand age and exchangeable K, soil N and C. The changing mineral nutrient demand during forest stand growth is not reflected in soil nutrient status.

Conclusions

►Soil type, depth and pH are the most important factors to influence the mineral nutrients and CEC.

►Stand age had no significant influence on mineral nutrient levels in the soil.

►The levels of mineral soil nutrients in particular of exchangeable cations are reasonably high and sufficient to support the tree growth under current silvicultural practices and biomass extraction rates.

Study of soil nutrient pools by chronosequence approach in view of aboveground biomass potentials in *Quercus* dominated forests

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As one of the six key thematic areas of scientific research and international collaboration, Bio-energy was pointed out at the recent IUFRO (Internal Union of Forest Research Organizations) World Congress Seoul Resolution in August 2010. Concomitant information on soil nutrient pools in North-East Austria and possible effects of increasing biomass extraction are lacking. Based on the general assumption that stand age and harvesting affect the soil properties due to incorporation of nutrients in the plant biomass, this study focuses on mineral nutrient pool characteristics in deciduous forests in order to identify these impact factors as a basis for sustainable forest management in *Quercus* dominated forests in North-East Austria. We (i) identified three soil types according to WRB in our study area, (ii) selected nine permanent *Quercus petraea* dominated plots, (iii) quantified N and selected exchangeable cations as well as CEC in the soils, (iv) identified the effects of stand age on nutrient statues in the soil (v) estimated macronutrients pool of N, K, Ca, and Mg in aboveground biomass. We found (i) nutrients pools (kg.ha^{-1}) at soil depth 0-50 cm in our study area were: N 3640 – 7210, exchangeable K 883 - 1652, exchangeable Ca 2661 – 16510, exchangeable

Mg 322 - 1848, (ii) base cations were strongly significantly higher in Calcic Chernozem (iii) Calcic Chernozem had the highest CEC. CEC ranged from 34 to 189 μmol g^{-1} in the entire research area. Our study showed that soil type, depth and pH are the most important factors to influence the mineral nutrients and CEC. The levels of mineral soil nutrients are reasonably high and sufficient to support the tree growth with the current silvicultural goal of biomass extraction.

Study of soil nutrient pools in view of aboveground biomass potentials in *Quercus* dominated forests

Yan Shuai [a, d], Viktor J. Bruckman [a, b], Gerhard Glatzel [a, b], Eduard Hochbichler [c]
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Introduction

As one of the six key thematic areas of scientific research and international collaboration, Bio-energy was pointed out at the recent IUFRO World Congress Seoul Resolution in August 2010. Concomitant information on soil nutrient pools in northeastern Austria and possible effects of increasing biomass extraction are lacking. Based on the general assumption that stand age and harvesting affect the soil properties due to incorporation of nutrients in the plant biomass, this study focuses on mineral nutrient pool characteristics in *Quercus* dominated forests in northeastern Austria.

Methods

Nine permanent *Quercus petraea* dominated plots (Fig 1, Tab 1) were selected for our study. Soil pH, nitrogen and exchangeable mineral elements K, Ca, Mg, Na, Mn, Al, and Fe were determined in five (0-5 cm, 5-10 cm, 10-20 cm, 20-40cm, 40-50cm) geometric soil horizons. Inventory of aboveground biomass was performed.

Fig 1 Landscape of study area

Table 1 Description of the selected study plots

Plot number	Quercus Stand age (year)	Plot size (m)	Species composition	Soil types
S1	11	40*40	*Quercus petraea* with few *Rubus fruticosus*	Eutric cambisol (coarse material ≤ 40%)
S2	32	40*40	*Quercus petraea* with *Galium sylvaticum* in the understory	
S3	50	40*40	*Quercus petraea* with few *Corylus avellana*	
S4	74	40*40	*Quercus petraea* and *Carpinus betulus* with *Galium sylvaticum* in the understory	
S5	91	50*50	*Quercus petraea* with few *Corylus avellana*	
L2	31	40*40	*Quercus petraea* with few *Acer campestre*, *Betula pendula*, *Cornus sanguinea*	Calcic chernozem
L3	43	40*40	*Quercus petraea* with few young *Corylus avellana*	Haplic luvisol (coarse material ≤ 20%)
L4	73	40*40	*Quercus petraea* with few *Corylus avellana*	
L5	82	50*50	*Quercus petraea* with young *Carpinus betulus* and *Galium sylvaticum* in the understory	

Results

In our study area, nutrient pools at soil depth 0-50 cm were (kg ha^{-1}): N 3.640 – 7.210, K 883 - 1.510, Ca 2.661 – 16.510, Mg 322 –1.847. The total pool in aboveground biomass ranged from 29 to 181 kg ha^{-1} for K, from 56 to 426 kg ha^{-1} for Ca and from 5 to 25 kg ha^{-1} for Mg. K and Ca in the aboveground biomass were highly significantly positively correlated with stand age with Person coefficients of 0.521 (P<0.01) and 0.607 (P<0.01).

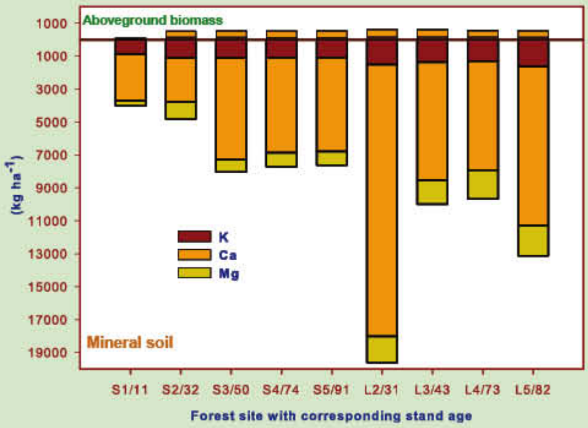

Fig 2 Comparison of estimated nutrients pools of K, Ca and Mg (kg/ha) in above-ground biomass and exchangeable K, Ca and Mg in mineral soils (0-50 cm).

Table 2 Bivariate correlation coefficients between exchangeable K and Ca, stand age and soil N, C, pH, CEC, K and Ca in aboveground biomass. Age class: rapid growing period (0-40 years); stable growing period (40-80 years); degrading period (>80 years). (**. P<0.01; *. P<0.05)

	Exchangeable K	Exchangeable Ca	Age class
Stand age	0.054	0.192**	
Soil N	0.360**	0.338**	0.12
Soil C	0.152*	0.209**	-0.02
Soil pH	0.382**	0.643**	0.135*
CEC	0.404**	0.607**	0.170*
Aboveground biomass K	0.104	0.134*	0.521**
Aboveground biomass Ca	0.103	0.154*	0.607**

Conclusion

Our study showed that soil type, depth and pH are the most important factors to influence the mineral nutrients and CEC. The levels of mineral soil nutrients are reasonably high and sufficient to support the tree growth with the current silvicultural goal of biomass extraction.

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Assessment of forest nutrient pools in view of biomass potentials - a case study from Austria oak stands

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As one of the renewable energy forms, bio-energy could help to relieve the pressure which is caused by growing global energy demand. In Austria, large area of forests, traditional utilization of biomass and people's desire to live in a sound environment have supported the positive development of bio-energy. Soil nutrient status is in principle linked with the productivity of the aboveground biomass. This study focuses on K, Ca and Mg pools in soils and aboveground biomass in order to learn more on the temporal dynamics of plant nutrients as indicators for biomass potentials in Quercus dominated forests in northeastern Austria. Three soil types (according to WRB: eutric cambisol, calcic chernozem and haplic luvisol) were considered representative for the area and sampled. We selected nine Quercus petraea dominated permanent plots for this study. Exchangeable cations K, Ca and Mg in the soils were quantified in our study plots. Macronutrients pools of K, Ca and Mg in aboveground biomass were calculated according to inventory data and literature review. The exchangeable cations pool in the top 50 cm of the soil were 882 – 1,652 kg ha-1 for K, 2,661 to 16,510 kg ha-1 for Ca and 320 – 1,850 kg ha-1 for Mg. The nutrient pool in aboveground biomass ranged from 29 to 181 kg ha-1 for K, from 56 to 426 kg ha-1 for Ca and from 4 to 26 kg ha-1 for Mg. The underground exchangeable pools of K, Ca and Mg are generally 10, 22 and 58 times higher than aboveground biomass nutrient pools. Our results showed that the nutrient pools in the mineral soil are sufficient to support the tree growth. The levels of soil nutrients in particular K, Ca and Mg in our study areas are reasonably high and do not indicate the necessity for additional fertilization under current silvicultural practices and biomass extraction rate. The forest in our study areas is in favorable condition to supply biomass as raw material for energy utilization.

Assessment of forest nutrient pools in view of biomass potentials - a case study from Austrian oak stands

Shuai Yan [a, c] and Viktor J. Bruckman [a, b]

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Introduction

In Austria, large area of forests, traditional utilization of biomass and people's desire to live in a sound environment have supported the positive development of bio-energy. Soil nutrient status is in principle linked with the productivity of the aboveground biomass. This study focuses on K, Ca and Mg pools in soils and aboveground biomass in order to learn more on the temporal dynamics of plant nutrients as indicators for biomass potentials in broadleaf forests in north-eastern Austria.

Materials and methods

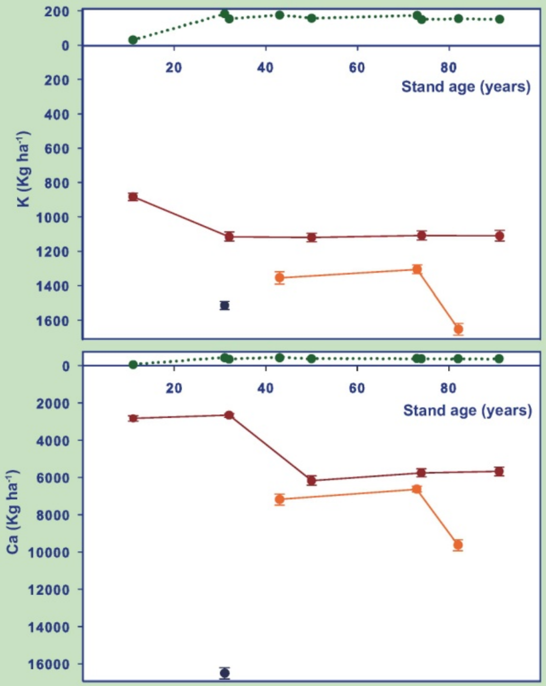
Nine *Quercus petraea* dominated permanent plots (Tab 1) were selected for this study. Nutrient pools of K, Ca and Mg in aboveground biomass and exchangeable cations K, Ca and Mg in the soils were quantified.

Tab 1 Description of the selected study plots.

Plot	Stand age (years)	Plot size (m^2)	Species composition	Soil types
E1	11	40x40	*Quercus petraea* with a few *Rubus fruticosus*	Eutric cambisol (coarse material ≤ 40%)
E2	32	40x40	*Quercus petraea* with *Galium sylvaticum* in the understory	
E3	50	40x40	*Quercus petraea* with a few *Corylus avellana*	
E4	74	40x40	*Quercus petraea* and *Carpinus betulus* with *Galium sylvaticum* in the understory	
E5	91	50x50	*Quercus petraea* with a few *Corylus avellana*	
C1	31	40x40	*Quercus petraea* with a few *Acer campestre*, *Betula pendula*, *Cornus sanguinea*	Calcic chernozem
L1	43	40x40	*Quercus petraea* with a few young *Corylus avellana*	Haplic luvisol (coarse material ≤ 20%)
L2	73	40x40	*Quercus petraea* with a few *Corylus avellana*	
L3	82	50x50	*Quercus petraea* with young *Carpinus betulus* and *Galium sylvaticum* in the understory	

Results

The exchangeable cation pools in top 50 cm soil horizons were 882 – 1,652 kg ha^{-1} for K, 2,661 – 16,510 kg ha^{-1} for Ca and 320 – 1,850 kg ha^{-1} for Mg. As Fig 1 shows, the exchangeable pools of K, Ca and Mg with significant difference between different soil types were generally 10, 22 and 58 times higher than the corresponding aboveground biomass nutrient pools.



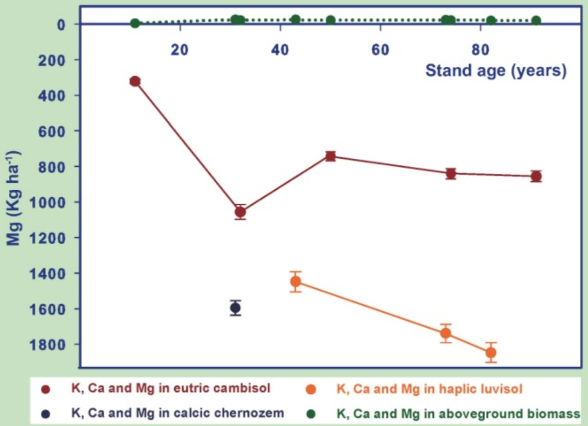


Fig 1 Pools of K, Ca and Mg in different soil types corresponding with stand age. Mean values (n=18) and SE for mineral soil. E1-E5 eutric cambisol, C1 calcic chernozem, L1-L3 haplic luvisol.

The exchangeable K, Ca and Mg in mineral soil were significantly positively correlated with soil N, soil C and soil pH. Certain trends of exchangeable cation pools were observed with stand age.

Conclusions

The changing mineral nutrient demand during forest growth was not reflected in soil nutrient status. The levels of mineral soil nutrients in particular of exchangeable cations are reasonably high in our study area. There is huge potential for making greater use of forest biomass as bio-energy feedstock, which could help to locally relieve the pressure of growing energy demand.

Is the changing mineral nutrient demand of forest stand growth reflected in the potassium and calcium status of the soil?

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The nutrient demand of tree growth is predominantly met by uptake from the nutrient pool of the mineral soil. This study focuses on K and Ca pools in order to learn more on the temporal dynamics of plant nutrients in *Quercus* dominated forests in North-East Austria. Three soil types (according to WRB: Eutric Cambisol, Calcic Chernozem and Haplic Luvisol) were considered representative for the area and sampled. Nine permanent, *Quercus petraea* dominated, plots were selected for our study. We (i) quantified exchangeable cations K, Ca as well as CEC in the soils of our study area, (ii) calculated macronutrients pool of K and Ca in aboveground biomass and (iii) identified the effects of stand age on exchangeable cations. The exchangeable cations pool in the top 50 cm of the soil were 882 – 1,652 kg ha^{-1} for K and 2,661 to 16,510 kg ha^{-1} for Ca. CEC in different plots ranged from 34 to 190 µmol g $^{-1}$. The nutrient pool in aboveground biomass ranged from 29 to 181 kg ha^{-1} for K and from 56 to 426 kg ha^{-1} for Ca. Our study showed that the nutrient pools in the mineral soil are sufficient to support the tree growth. Stand age had no significant influence on mineral nutrient levels in the soil. The levels of nutrients in particular K and Ca in our study areas are reasonably high and do not indicate the necessity for additional fertilization under current silvicultural practices.

Is the changing mineral nutrient demand of forest stand growth reflected in the potassium and calcium status of the soil?

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[b] Northwest A&F University, Yangling, China
[c] Commission for Interdisciplinary Ecological Studies (KIOES) of the Austrian Academy of Sciences

Introduction

The nutrient demand of tree growth is predominantly met by uptake from the nutrient pool of the mineral soil. This study focuses on K and Ca pools in order to learn more on the temporal dynamics of plant nutrients in Quercus dominated forests in northeastern Austria.

Methods

Three soil types (according to WRB: eutric cambisol, calcic chernozem and haplic luvisol) were considered representative for the area and sampled. Nine permanent *Quercus petraea* dominated plots (Fig 1, Tab 1) were selected for our study. Inventory of aboveground biomass and mineral soil was performed.

Fig 1 View of forest sites in our study area.

Table 1 Description of the selected study plots.

Forest site	Quercus Stand age (year)	Site size (m)	Species composition	Soil types
S1	11	40x40	*Quercus petraea* with a few *Rubus fruticosus*	Eutric cambisol (coarse material ≤ 40%)
S2	32	40x40	*Quercus petraea* with *Galium sylvaticum* in the understory	
S3	50	40x40	*Quercus petraea* with a few *Corylus avellana*	
S4	74	40x40	*Quercus petraea* and *Carpinus betulus* with *Galium sylvaticum* in the understory	
S5	91	50x50	*Quercus petraea* with a few *Corylus avellana*	
L2	31	40x40	*Quercus petraea* with a few *Acer campestre, Betula pendula, Cornus sanguinea*	Calcic chernozem
L3	43	40x40	*Quercus petraea* with a few young *Corylus avellana*	Haplic luvisol (coarse material ≤ 20%)
L4	73	40x40	*Quercus petraea* with a few *Corylus avellana*	
L5	82	50x50	*Quercus petraea* with young *Carpinus betulus* and *Galium sylvaticum* in the understory	

Results

The exchangeable cation pools in top 50 cm soil horizons were 882 – 1,652 kg ha^{-1} for K and 2,661 – 16,510 kg ha^{-1} for Ca. The exchangeable pools of K and Ca were generally 10 and 22 times higher than the corresponding aboveground biomass nutrient pools.

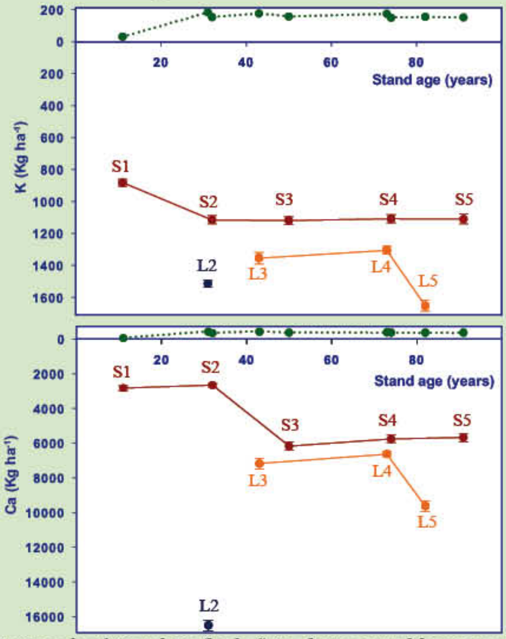

Fig 2 pools of K and Ca (kg ha^{-1}) in above-ground biomass and exchangeable K and Ca in the top 50 cm mineral soil of nine study sites in Quercus stands in north-eastern Austrian Schönborn Forest.

Table 2 shows the correlation of soil properties and nutrient pools of K and Ca in above-gorund bioamss.

Table 2 Bivariate correlation coefficients between exchangeable K and Ca, stand age and soil N, C, pH, CEC, K and Ca in aboveground biomass. Age class: rapid growing period (0-40 years); stable growing period (40-80 years); degrading period (>80 years). (. P<0.01; *. P<0.05).**

	Exchangeable K	Exchangeable Ca	Age class
Stand age	0.054	0.192**	
Soil N	0.360**	0.338**	0.12
Soil C	0.152*	0.209**	-0.02
Soil pH	0.382**	0.643**	0.135*
CEC	0.404**	0.607**	0.170*
Aboveground biomass K	0.104	0.134*	0.521**
Aboveground biomass Ca	0.103	0.154*	0.607**

Conclusion

Our study showed that the nutrient pools in the mineral soil are sufficient to support the tree growth. Stand age had no significant influence on mineral nutrient levels in the soil. The levels of nutrients in particular K and Ca in our study areas are reasonably high and do not indicate the necessity for additional fertilization under current silvicultural practices.

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Determinants of soil organic carbon pools in oak stands in northeastern Austria

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Recently deciduous forests in northeastern Austria received increased attention as potential sources of biomass for energetic utilisation. There are still substantial deficits in the knowledge on carbon pools, -sequestration and -dynamics at these forest sites. The aim of our study was therefore to identify the main determinants which control soil organic carbon (SOC) pools in differently managed Quercus petraea dominated stands. We used the chronosequence approach to test the influence of stand age and management on the SOC pool. Soil samples were systematically collected from 14 plots by means of a 70mm hand auger to a depth of max. 60cm and separated into five geometric horizons. Narrow O-layers and signs of active bioturbation on most sites suggest rapid carbon mineralisation. Carbon pools of the aboveground biomass, the O horizon as well as fine and coarse roots and decay were determined. Soils in our study are cambisols derived from fossil alluvial deposits and loess and calcic chernozems derived from loess. Total soil carbon was determined by means of dry combustion and subtraction of soil inorganic carbon (SIC, by means of the Scheibler-method) if present. Mean SOC contents ranged from 5.3 kg.m-2 to10.4 kg.m-2 in the entire study area. The highest contents were found in calcic chernozem sites (7.2-10.4 kg.m-2) followed by loamy cambisol (6.1-6.8 kg.m-2) and sandy cambisol sites (5.3-6.9 kg.m-2). Among three chronosequence sets, we found strong positive correlations with total nitrogen (Pearson correlation coefficients of +0.91 to +0.93, $p<0.01$) and medium strong positive correlations with fine root content (+0.27 to +0.42, $p<0.01$). In both cases, stronger correlations were observed at cambisol sites. Further medium correlations were found between SOC and decay (+0.23 to +0.42, $p<0.01$), but no influence of the soil type was observed. As expected, SOC contents decreased significantly with increasing soil depth. Tighter C/N ratios in deeper horizons suggest ongoing decomposition of soil organic matter (SOM). Total carbon pools analysis revealed a decline of the share of SOC on total carbon pool with increasing stand age and an increase in aboveground carbon in the vegetation (r^2=0.88). SOC accounted for 34-66 percent of the total carbon pool. In our study, the main determinants of SOC are soil type, soil depth and fine root content. Our results suggest that forest management (coppice with standards vs. high forest system) in deciduous forests in the northeastern lowlands of Austria has no decisive influence on soil carbon pools.

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Impact of forest stand management on temporal dynamics of soil carbon and nitrogen

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The quantity and quality of soil organic matter (SOM) strongly influence the biomass production capacity of forest ecosystems. At present, increased biomass harvesting for energetic utilisation is a hot topic. The extraction of logging residues, which are left on site in traditional forest management in Austria, and shortening of rotation periods will potentially alter carbon (C) and nitrogen (N) mineralization rates and turnover. This study focuses on i) assessing the influence of different forest management systems for deciduous species on soil C- and N stores and mineralization potential along a full rotation period and ii) testing whether silvicultural systems can be used to manage N retention and release. The chronosequence approach was used to study temporal dynamics of C and N on differently managed, *Quercus petraea* dominated forest sites (high forest on eutric cambisol, 11-91years as well as coppice with standards system on haplic chernozem, 1-50years). Above- and belowground biomass pools as well as belowground organic C- and total N pools (in five geometric horizons, up to 50cm depth) were estimated by means of systematic sampling of the soil and use of allometric functions for biomass pools. C was determined by dry combustion (soil organic carbon (SOC) and N by Kieldahl digestion (soil total N). SOC pools ranged from 5.3 to 6.9kg.m^{-2} on eutric cambisol, representing 43% of total site C stores and from 7.2 to 10.4kg.m^{-2} on haplic chernozem, representing 42% respectively. Total N stores in the mineral soil compartment ranged from 0.36 to 0.45kg.m^{-2} and from 0.65 to 0.94kg.m^{-2} for the two soil types. No significant correlation with stand age was observed for C and N pools in both study areas. However, C/N ratios as a measure for nitrogen availability show distinct temporal trends along the chronosequence in differently managed stands. The high forest system shows a gradual decrease of C/N ratio with increasing stand age in all horizons while the coppice with standards system shows a decrease until about half of the rotation period after which it increases again to the end of the rotation period. Wide C/N ratios at the beginning of rotation periods indicate rapid mineralization rates after harvesting. In the high forest on eutric cambisol sites, the C/N ratio is predominantly correlated with C (Pearson correlation coefficient of $R=+0.70$, $p<0.01$) in contrast to N ($R=+0.17$, $p<0.01$). Conversely, the C/N ratio in the coppice with standards on haplic chernozem is predominantly correlated with N ($R=-0.33$, $p<0.01$) in contrast to C ($R=+0.20$, $p<0.01$). A general trend of higher C/N ratios in the high forest indicates higher accumulation rates for C than for N. C/N ratios around 30-35 (<20 in mineral soil) indicate rapid litter decomposition under both silviculture regimes. The ratio between aboveground (living biomass, litter) and belowground carbon pools (SOC, roots, decay) generally increases with rising age and is always higher in coppice with standards system due to remaining standards after harvesting. This effect offsets nearly 10 years of stand development in the high forest system. We were able to identify clear patterns of C- and N dynamics resulting from different management regimes in different soil types on our study sites. The retention and release of nitrogen could be regulated by appropriate silvicultural systems, which should be considered when increased biomass extraction for energetic use becomes the management goal.

Keywords: SOC, C/N ratio, mineralization, forest management, *Quercus*.

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Carbon pools and temporal dynamics along a rotation period in sessile oak dominated high forest and coppice with standards stands

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Carbon pools in two *Quercus petraea* (sessile oak) dominated chronosequences under different forest management (high forest and coppice with standards) were investigated. The objective was to study temporal carbon dynamics, in particular carbon sequestration in the soil and woody biomass production, in common forest management systems in eastern Austria along with stand development. The chronosequence approach was used to substitute time-for-space to enable coverage of a full rotation period in each system. Carbon content was determined in the following compartments: aboveground biomass, litter, soil to a depth of 50 cm, living root biomass and decomposing residues in the mineral soil horizons. Biomass carbon pools, except fine roots and residues, were estimated using species-specific allometric functions. Total carbon pools were on average 143 Mg ha^{-1} in the high forest stand (HF) and 213 Mg ha^{-1} in the coppice with standards stand (CS). The mean share of the total organic carbon pool (TOC) which is soil organic carbon (SOC) differs only marginally between HF (43.4%) and CS (42.1%), indicating the dominance of site factors, particularly climate, in controlling this ratio. While there was no significant change in O-layer and SOC stores over stand development, we found clear relationships between living biomass (aboveground and belowground) pools and C:N ratio in topsoil horizons with stand age. SOC pools seem to be very stable and an impact of silvicultural interventions was not detected with the applied method. Rapid decomposition and mineralization of litter, indicated by low O-horizon pools with wide C:N ratios of residual woody debris at the end of the vegetation period, suggests high rates of turnover in this fraction. CS, in contrast to HF benefits from rapid resprouting after coppicing and hence seems less vulnerable to conditions of low rainfall and drying topsoil.

Keywords: carbon dynamics; soil carbon; chronosequence; *Quercus petraea*; coppice; high forest

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