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Soil change after 50 years of converting Norway spruce dominated age class forests into single tree selection forests

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ABSTRACT

Intensive forest management is known to influence soil structure and composition. Homogenous age class forests managed in a clear cut system reduce soil carbon and nutrients. Continuous cover forests (including plenter/single tree selection forests) on the other hand are considered to be a sustainable alternative, but little is known about their influence on soil carbon and soil nitrogen stocks. In this study, we investigated the recovery of soil carbon and nitrogen stocks after converting Norway spruce dominated age class forests (AC) into single tree selection/plenter forests (PL) at the Koralpe in the Austrian province of Styria. These forests originated from previous age class forests and the PL evolved after a decision from the early 1960s to change management from an age class system to a plenter system. Ten pairs of each a typical age class Norway spruce forest and a plenter forest adjacent to one another were obtained. The two stands of a pair are characterised by the same site conditions, and had the same stand history prior to the transition of one of the two stands. Differences in the stand and soil parameters by management regime are apparent. On the PL sites mineral soil in 0–20 cm depth contains 9 Mg C ha^{-1} or 11% more carbon and 0.4 Mg N ha^{-1} or 11% more nitrogen compared to the AC sites. Differences in total soil carbon (litter plus mineral soil) are not significant, whereas higher total soil nitrogen at PL are evident. These results suggest that soil conditions responded to changes in forest management practices.

1. Introduction

For centuries overexploitation of forest resources have resulted in forest and soil degradation and a shortage of timber supply across Europe (Glatzel, 1999). Large clear cuttings were continuously applied to address the emerging demand of timber mainly driven by the growing industrialization and population increase. Fast growing coniferous tree species such as Norway spruce (*Picea abies* [L.] Karst) were promoted in areas of mixed species stands but also on typical broadleaved sites (Spiecker et al., 2004).

Today, researchers suggest that these conifer-dominated age class forests are highly susceptible to biotic and abiotic disturbances, including storm, snow, drought, insects, fungi and soil degradation (Pommerening and Murphy, 2004; Spiecker et al., 2004). Thus a transformation of such even-aged plantations into diverse, uneven-aged single tree selection or so called plenter forests is currently pursued to address the sustainability requirements of forest management, including forest soils (Pommerening and Murphy, 2004).

Forest soils fulfil important ecosystem functions such as the storage of water and nutrients to sustain forest growth as well as providing a habitat for soil microorganisms important for mineralisation and nutrient fixation processes (Blum, 2005). In recent years, forest soils have become a main focus in the context of carbon sequestration for mitigating climate change effects (Liski et al., 2002; Schulze and Freibauer, 2005). In temperate forests, average soil carbon stock is estimated to be 60% of the terrestrial carbon stock (Lal, 2005). Weiss et al. (2000) calculated the carbon stocks in Austrian forest soils at 0–50 cm depth to be 106 Mg C ha^{-1}.

Tree species, climate and bedrock fundamentally influence the development of soil structure and composition. Forest stand structure and succession dynamics alter light, temperature and moisture conditions as well as the input of dead organic material and drive soil processes. Forest management strongly affects such processes, particularly if the natural species composition has been changed and large forest clear cuttings are applied (Berger et al., 2002; Gautam et al., 2010; Pietsch and Hasenauer, 2002; Prietzel and Bachmann, 2012; Vesterdal et al., 2008). Other forest management impacts are (i) thinnings, which reduce total biomass and litter production as well as changes in microclimate (Jandl et al., 2007), (ii) whole tree harvesting (Johnson et al., 2002; Johnson and Curtis, 2001; Olsson et al., 1996) and the (iii) principal silvicultural management system (e.g. coppice with standards, clear cut, shelterwood, plenter system) (compare e.g. Laporte et al., 2003;

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Bauhus et al., 2004; Bruckman et al., 2011). Thinnings and clear cuts have similar effects on the soil processes, but differ in intensity. Forest openings (e.g. removal of the canopy) change the temperature and water regime (Aussenac, 2000). This induces faster mineralisation processes (Binkley, 1984; Piene and Cleve, 1978), and reduces biomass production and thus leaf and root litter input to the soil (Jandl et al., 2007; Skovsgaard et al., 2006). A long history of clear cuts and intensive use of forest biomass has reduced productivity due to soil carbon and nutrient loss in the Alpine region (Bochter et al., 1981; Glatzel, 1999; Pietsch and Hasenauer, 2002). In a recent meta-analysis covering more than 400 studies, Nave et al. (2010) concluded that overall harvesting operations and particularly large clear cut systems result in a significant reduction in the soil C storage of the forest floor.

Historically speaking, clear cutting was the main forest management system leading to the reported degradation effects (Spiecker et al., 2004). The clear cut system also led to pure even-aged forest stands due to their uniform light regime, which promotes the regeneration of light demanding tree species (Burschel and Huss, 2003; Mayer, 1999). As an alternative, continuous cover forestry systems, which avoid clear cutting and include the single tree selection or so called plenter forest system, are widely discussed (Hasenauer and Sterba, 2000; Pommerening and Murphy, 2004; Zingg et al., 1997). The principle idea of this management system is that small openings in the canopy (e.g. gaps) mimic the natural succession dynamics of forest stands more realistically and thus no or only minor degradation effects are evident. This is because little or no changes in the soil surface and in microclimate are evident and continuous litter input is provided (Vesterdal and Leifeld, 2007). Additionally we can assume that the light conditions within a forest stand may be used more effectively by different tree species or individual trees, since the ecological niches within a forest stand are utilised more efficiently (Binkley et al., 2013; Jandl, 2007; Pretzsch, 2014; Sterba, 2000). This improves growing conditions by avoiding degradation effects. Due to a more effective utilization of the available growing space, it may also lead to higher productivity rates as compared to the clear cut system (O'Hara et al., 2007).

Although several studies have investigated potential differences in long term timber production between a clear cut versus a continuous cover or plenter system (Kern, 1966; Mitscherlich, 1963; O'Hara et al., 2007), little is known about the effects on soils following changes in the management system from a previous clear cut system to a continuous cover single tree selection or plenter system. The objective of this study was to investigate the differences in soil carbon and nitrogen stocks by management system. We compared the differences in the soil C and N stocks of 10 pairs, each consisting of a pure even-aged Norway spruce forest (age class forest, AC) and a neighbouring single tree selection forest (plenter forest, PL), 50 years after the management regime of the PL was changed from clear cutting to single tree selections. We were specifically interested in finding out if a potential recovery of the soil, expressed as changes in the (i) mineral soil and (ii) litter layer of (iii) carbon, and (iv) nitrogen stocks, is detectable.

2. Material and methods

2.1. Study area

The investigated forests are owned by the forest enterprise 'Forstbetrieb Ligist, Souveräner Malteser Ritterorden' located in the western Styrian foothills in the mountain range Koralpe (highest peak 2140 m a.s.l.), Austria. The metamorphic, crystalline rock of the Koralpe consists of gneiss ('Stainzer Platten', gneissic banding) and schist but weathered hillside rock can be found in the area as well (GIS-Steiermark, 2013). The soil type is podzolic cambisol. The potential natural vegetation in this middle-montane zone (900–1300 m a.s.l.) is a mixed Norway spruce-silver fir-European beech forest (forest growth district 5.4 West-Styrian Mountains) (Kilian et al., 1994). The average annual temperature is 6.5 °C. Mean annual precipitation is 1000 mm with a peak in the summer months. High precipitation rates in May and September indicate the climate transition zone between temperate and Mediterranean climate. A high frequency of thunderstorms and heavy precipitation events are also typical for the area.

Since 1928 the forest company has owned 900 ha of forests in the study region (Matzer, 2011). For almost three centuries, these forests were managed as Norway spruce (*P. abies* L. Karst) dominated age class forests (AC). Until the early 20th century they were harvested with large scale clear cuts of up to 20 ha or more. In the early 1960s, the management system was changed to single-tree selection (PL) promoting stand structure, species mixture and natural regeneration (about 90% of the forest area). Especially tree species such as silver fir (*Abies alba*) and European beech (*Fagus sylvatica*) are supported (Matzer, 2011; Thurnher et al., 2011).

2.2. Study design

The principle objective of the study was to compare the soil carbon and nitrogen stocks of pairs of adjacent forest stands with different forest management. We selected 10 pairs of forest stands, one covering the typical characteristics of AC (age class forest managed as clear cuts) and one covering a typical PL (plenter forest or single tree selection forest). Historic records, provided by the forest enterprise, describe the historic management as age class forests until the 1960s (Spörk, 2011, personal communications, Thurnher et al., 2011); over the last 50 years large parts of the forest have gradually been transformed from the even-aged Norway spruce forests into plenter forests. This transformation process is still ongoing (Spörk, 2011, personal communications, Thurnher et al., 2011), yielding a mixture of AC and PL in the enterprise's forests. The location of the two stands of a pair (one AC, one PL) had to be in the same forest management unit (dt. 'Abteilung'). This approach assumes that the starting conditions – although no stand and soil data are available – were comparable 50 years ago and that the differences in the soil layers are management induced effects after 50 years of transformation. Since the selection of the pairs is essential for the study, the pairs (AC versus PL) had to be within a distance of less than 200 m and at the same site conditions, geology, elevation, slope, as well as aspect. The elevation of the selected forest sites ranged from 920 to 1160 m a.s.l. (Table 1).

In every forest stand we established a 15 m × 15 m sampling plot. Skidding trails and large canopy openings were avoided. We randomly selected the location of the north eastern corner of the north oriented plots. We took the soil samples 1 m clockwise from the corners. In case of trunks, stems, big tree roots or rocks, we shifted the sampling spot 15–175 cm clockwise. We collected the forest floor/litter layer in a 17.5 cm × 25.5 cm frame and removed living understorey vegetation. The mineral soil we sampled with a stainless steel root auger with a sampling cylinder of 15 cm in length and an inner diameter of 8 cm. The cylinder was repeatedly hammered into the soil at the same spot and the soil cores were separated so that we obtained the layers 0–20 cm, 20–50 cm and more than 50 cm in depth. The respective layers from the four corners were mixed.

2.3. Forest stand data

Forest stand data were recorded using four angle count samples (Bitterlich, 1948) per stand, located at every corner. A basal area factor of 4 was used (so each tree in the sample represents a basal