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ORIGINAL PAPER

EFFECT OF SHELTERWOOD CUTTINGS ON SOIL CHEMICAL PROPERTIES IN SCOTS PINE (*PINUS SYLVESTRIS* L.) FORESTS IN EUROPE'S HEMIBOREAL ZONE, IN LITHUANIA

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Abstract

An altered microclimate after harvesting may affect the soil nutrient content. There is a growing concern about clear cuttings. Shelterwood cuttings are an alternative practice to clear-cutting. Compared with clear-cutting, shelterwood cuttings cause fewer changes in the soil microclimate and in the physical, chemical and biological soil properties. Shelterwood harvesting may mitigate the impact of harvesting on the ecosystem's functioning. The aim of the study was to evaluate the effect of shelterwood and clear-cuttings on forest soil chemical properties relative to uncut sites, and to determine their changes after shelterwood cutting in pine-dominated stands on sandy soils of the European hemiboreal zone, in Lithuania. Nitrate and ammonium nitrogen in mineral soil was estimated in shelterwood, clear cuttings and in a mature stand. Changes in organic carbon, total nitrogen, nitrate and ammonium nitrogen, available phosphorus and potassium in mineral soil were estimated in 1-, 3-, 5- and 7-year-old shelterwood cuttings as well. Organic carbon in the soil's mineral layer in 1- to 7-year-old cuttings sites was higher than in uncut stands. Both organic carbon and total nitrogen were slightly higher in 1- to 5-year-old cuttings. Nitrate nitrogen was higher after tree cutting. The highest mineral nitrogen concentration was in clear cuttings. Changes in the concentration of available phosphorus were similar as in mineral nitrogen. The concentration of available potassium was higher only one year after cutting compared to the untouched stands. Results confirm that shelterwood cuttings had a weaker negative effect on soil nutrients, especially on mineral nitrogen, compared to clear cuttings. The effect of shelterwood cuttings on soil nutrient was short-lived and lasted up to 5 years.

Keywords: forest harvesting, nitrate, phosphorus, soil.

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INTRODUCTION

Natural and anthropogenic disturbances including forest management practices directly affect vegetation cover, microclimate and soil properties such as the content of organic matter and nutrients in soil (Keenan, Kimmins 1993, Brazaitis et al. 2005, Marozas et al. 2005, 2009, 2013, 2015, Kreutzweiser et al. 2008, Čiuldienė et al. 2017). Canopy removal during forest harvesting can increase the amounts of solar radiation and precipitation that reach the soil surface, thereby increasing soil temperature, diurnal temperature fluctuations and soil moisture (Keenan, Kimmins 1993). The fluctuations of soil moisture are increased after harvesting and the soil can be temporarily drier in cutting areas than in undisturbed forest due to the increased evaporation caused by higher soil temperatures and wind speeds (Redding et al. 2003).

The altered microclimate may affect the soil nutrient content after harvesting. The leaching of nutrients, increased microbial activity, decomposition of organic matter, higher rates of nitrogen mineralization and nitrification, elevated nitrate concentrations in soils following harvesting have been reported (Keenan, Kimmins 1993, Schmidt et al. 1996, Piirainen et al. 2002, 2007, Kaarakka et al. 2014). The effect of harvesting is the strongest during the first years after harvest and usually lasts 3 to 5 years or even longer (Kubin 1998, Prescott 2002).

There is a growing concern about clear cuttings. Partial-cut and selective harvesting systems are alternative practices to clear-cutting. Alternative silvicultural systems that retain some portion of the trees of a stand, such as shelterwood systems, have been introduced. Compared with clear-cutting, shelterwood cuttings cause fewer changes in soil microclimate and soil physical, chemical and biological properties (Keenan, Kimmins 1993, Bose et al. 2014). Shelterwood harvesting may mitigate the impact of harvesting on the ecosystem's functioning.

Previous research on the effects of forest cuttings on the soil system focused on the impacts of clear-cuttings, which was demonstrated to affect many soil properties, processes and biological populations. Little is known about the impact of shelterwood cuttings on the dynamics of nutrients in forest soils in Europe's hemiboreal zone (Bradley et al. 2001, Kaarakka et al. 2014, Clarke et al. 2015). Therefore, more research into the impact of shelterwood cuttings on forest soil chemical properties is needed.

Scots pine (*Pinus sylvestris* L.) is a dominant tree species in the hemiboreal forests of the Baltic region. In Lithuania, pine forests occupy 35.1% of all forested area, and mainly grow on poor soils. Cuttings are the major disturbance in these forests in Lithuania. Shelterwood cuttings have been increasing in the last decade.

The present study aimed at evaluating the effect of shelterwood and clear-cuttings on forest soil's chemical properties relative to uncut sites, and to determine their changes after shelterwood cutting in pine-dominated stands on sandy soils of the European hemiboreal zone.

We hypothesised that shelterwood cuttings have a weaker impact on forest soil's chemical properties, especially changes in the nitrogen content, than clear cuttings and that changes in soil's chemical properties diminish with time as the ground vegetation recovers.

MATERIAL AND METHODS

The study area was located in the central part of Lithuania (54°49′ N, 23°29′ E and 55°04′ N, 24°13′ E) and it lies in the transitional deciduous coniferous mixed forest hemiboreal zone of Europe (Figure 1).

Fig. 1. Location of the study area

The altitude above the sea level is about 70-90 m. The mean annual temp. ranges from +6.5 to +7.1°C, with a mean January (the coldest month) temp. of -3.6°C and a mean July (the warmest month) temp. of +17.7°C. The annual mean precipitation is between 600 and 700 mm. Permanent snow cover persists for 75 to 90 days (Galvonaitė 2013).

Sandy soils poor in nutrients (*Arenosols)* and Scots pine stands prevail in the study area. Dry bulk density in the upper soil layer (0-10 cm) was 1.43 ± 0.45 g cm^{-3}, texture of the soil is characterized as: sand 89.8 ± 1.1%, silt 4.6 ± 0.5%, and clay 3.3 ± 0.5%, base saturation 18.52 ± 4.52 mekv kg^{-1}, pH_{kcl} 4.7 ± 0.25, carbon content 1.11 ± 0.35%, nitrogen – 0.036 ± 0.015%.

The following species prevail in the ground vegetation cover: dwarf shrubs – *Vaccinium myrtillus*, *V. vitis-idaea*, *Calluna vulgaris*, and herbs – *Festuca ovina* and *Melampyrum pratens*, and mosses – *Dicranum polysetum*, *D. scoparium*, *Hylocomium splendens* and *Pleurozium schreberi*.

In order to compare mineral nitrogen forms ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) in soil, three composite soil samples from the 0-10 cm and 10-20 cm mineral topsoil were collected at ten systematically distributed points along 20 m transects in clear-cutting, shelterwood and mature stand. Mineral soil samples were collected using a soil auger. Clear and shelterwood cuttings were performed in the winter of 2013-2014. A nearby mature pine stand in a similar site was selected for comparison. The samples were collected in July 2015, when the age of cuttings was one year.

In order to determine the changes of chemical soil properties in pine forests after shelterwood cuttings, cut areas of different age were selected. The chronosequence approach was used to describe the succession by selecting sites in similar environments but of different time periods after cuttings. Shelterwood cuttings of different age (1, 3, 5, 7 year) were selected in pine stands. Cuttings were performed in 2008, 2010, 2012 and 2014. Soil samples were taken from cutting sites and nearby stands as control at the depth of 0-20 cm. The samples were collected in July 2015. Composite soil samples from the 20 points were collected randomly from each site in six replicates. Concentration of organic carbon (C), total nitrogen (N), nitrate (NO_3-N) and ammonium nitrogen (NH_4-N), available phosphorus and potassium were estimated.

For chemical analyses, the mineral soil samples were dried in an oven at 40°C. Soil samples were sieved through a 2 mm sieve. Soil chemical analyses were conducted in the Agrochemical Research Laboratory of LRCAF. The organic carbon (C) concentration was determined with a Heraeus apparatus (ISO 10694, dry combustion at 900°C), and total nitrogen (N) was analysed using the Kjeldahl method (ISO 11261). Concentrations of mineral N were determined by the spectrometric method (ISO 14256-2) in 1 M KCl extraction: NH_4-N using sodium phenolate and sodium hypochlorite, and NO_3^-N using sulphanilamide. Mineral N ($_{min}$N) was determined by summing up NH_4-N and NO_3^-N. The available potassium and available phosphorus were determined using the Egner-Riehm-Domingo (A-L) method (Egner et al. 1960). Results were calculated on the mass of dry soil. For data comparison, an ANOVA *post-hoc* LSD test was used.

RESULTS

Nitrate nitrogen was the highest in both soil layers in the clear cutting and it differed significantly from shelterwood cutting and nearby untouched stand. The concentration of nitrate nitrogen was higher in the deeper soil layer than in the topsoil layer (Figure 2*a*).

Ammonia nitrogen was the highest in the topsoil layer (0-10 cm) in clear cutting and it significantly differed from the shelterwood cutting and nearby untouched stand. Ammonia nitrogen did not differ significantly in the deeper

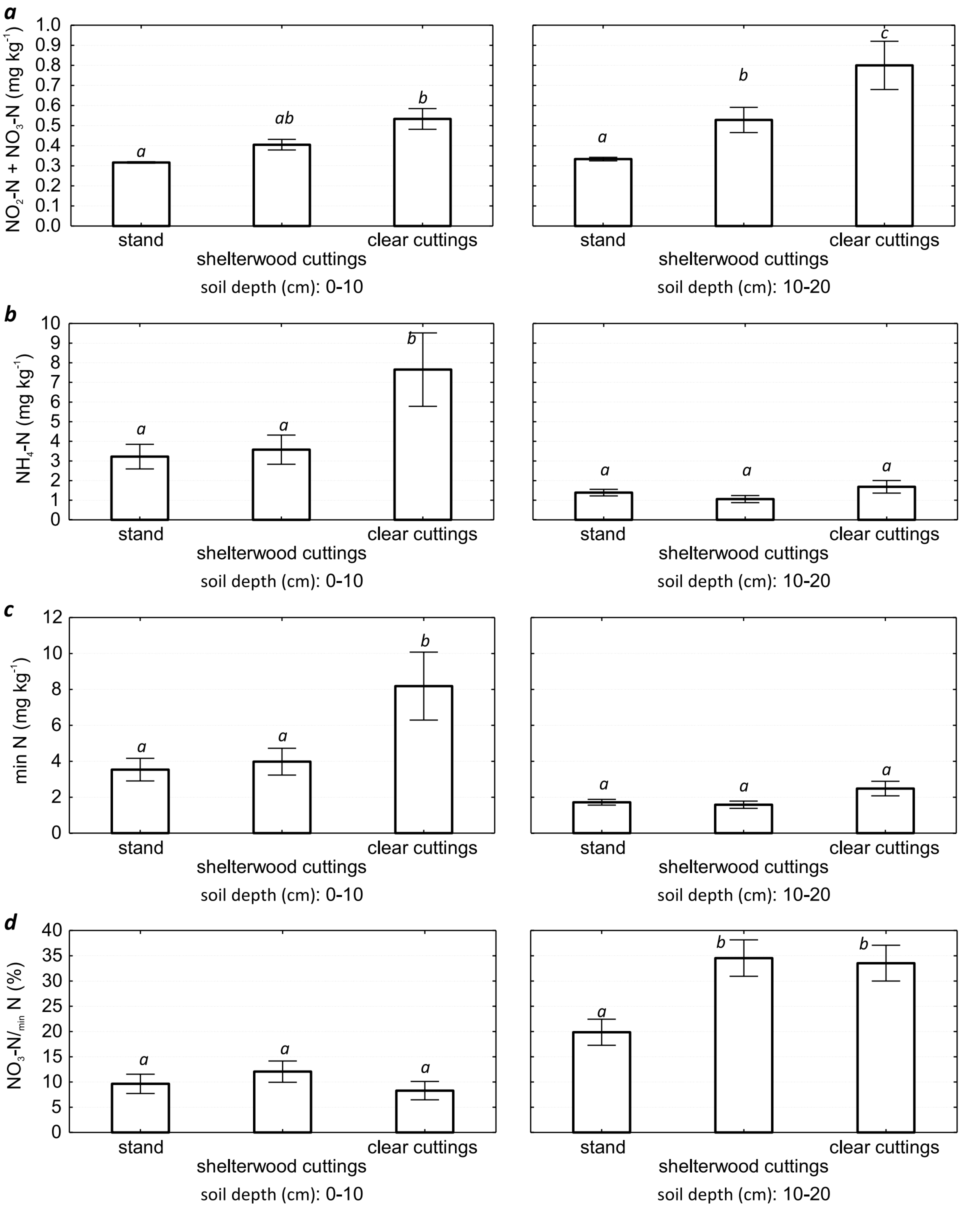

Fig. 2. Mean concentrations of nitrate nitrogen (*a*), ammonium nitrogen (*b*) mineral nitrogen (*c*) and percentage of nitrate in mineral nitrogen (*d*) in soil in clear-cutting, shelterwood cutting and nearby stand of pine forest (values are means ± se; different superscription letters in the rows indicate significant ($p < 0.05$) differences between means, ANOVA *post-hoc* LSD test; $n = 3$)

soil layers (Figure 2*b*). The mineral nitrogen concentration in the 0-10 cm soil layer was the highest in the clear cutting and significantly differed from that in the shelterwood cutting and the nearby untouched stand. Its concentration in the deeper soil layer (10-20 cm) sampled from the stand and the cuttings did not differ significantly (Figure 2*c*). The proportion of nitrate nitrogen from mineral nitrogen did not differ in the topsoil layer, but it was higher in the deeper soil layers in both cut areas and in comparison to the untouched stand (Figure 2*d*).

The mean concentration of organic carbon in the soil mineral layer in 1- to 7-year-old cutting sites was higher than that in the nearby untouched stands (Figure 3*a*). The mean concentration of total nitrogen did not differ significantly (Figure 3*b*). Moreover, both organic carbon and total nitrogen were slightly higher in 1- to 5-year-old cuttings than in the older (7-year-old) cuttings. The C/N ratio was significantly higher in the older cuttings (Figure 3*c*).

The mean concentration of ammonium nitrogen in soil was significantly lower in the 1- to 5-year-old cuttings compared to the nearby untouched stand. In the older cuttings (7-year-old) the concentration of ammonium nitrogen was higher and it did not differ significantly from that in the untouched stand (Figure 4*a*). In contrast, the concentration of nitrate nitrogen was higher in the 1- to 5-year-old cuttings than in the untouched stands. In the older cuttings (7-year-old) the concentration of nitrate nitrogen was lower and its difference from the untouched stands was not significant (Figure 4*b*).

The mineral nitrogen content in soil showed similar changes as ammonium nitrogen in the cuttings of different age (Figure 5*a*). The percentage of nitrate nitrogen in mineral N was significantly higher in the 1- to 5-year-old cuttings compared to the untouched stands and the older shelterwood cuttings (Figure 5*b*).

The concentration of available phosphorus in soil showed similar changes as mineral nitrogen (Figure 6*a*). The concentration of available potassium was significantly higher only in 1-year-old cuttings compared to the untouched stands (Figure 6*b*).

DISCUSSION

In undisturbed boreal forests, nutrients are effectively retained in the forest ecosystem, and their losses due to leaching or gaseous emissions are small (Piirainen et al. 2002, Finér et al. 2004). Forest harvesting can cause considerable changes in nutrient pools and fluxes.

Cuttings change the rates of decomposition and nutrient mineralization by altering soil conditions, moisture and temperature regimes, and water fluxes (Palviainen et al. 2005, Piirainen et al. 2007, Kreutzweiser et al. 2008). In general, these changes cause short-term increases in soil nutrient availability followed by increased leaching to waters (Prescott et al. 2000, Lindo, Visser 2003).

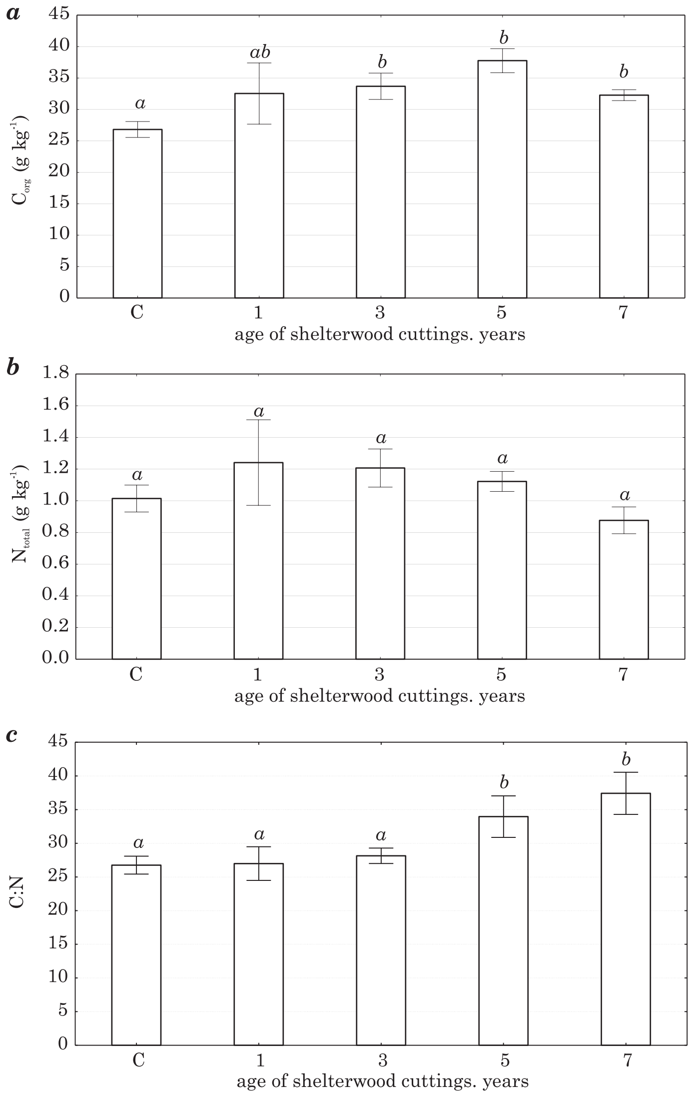

Fig. 3. Mean concentrations of organic carbon (C g kg^{-1}) (*a*), total nitrogen (N g kg^{-1}) (*b*) and ratio C/N (*c*) in *Arenosols* of mature pine forests and shelterwood cuttings of different age (values are means ± se; different superscription letters in the rows indicate significant ($p \leq 0.05$) differences between means, ANOVA *post-hoc* LSD test; C – in nearby untouched stands; $n = 6$)

We found the increased amount of organic carbon in the soil mineral layer within 1 to 7 years after shelterwood cuttings. Studies in Northern American hardwood forests showed reductions in upper soil carbon after

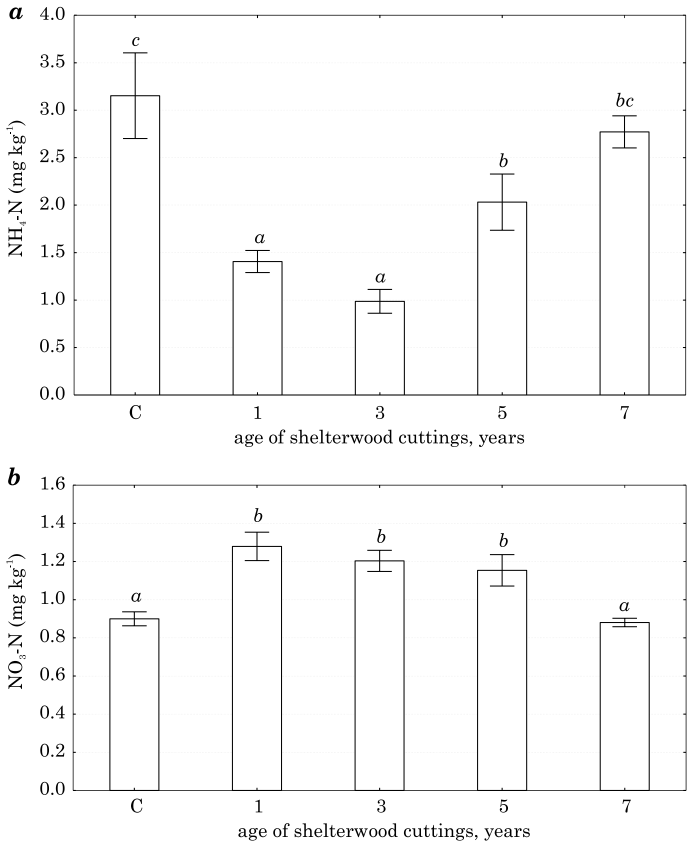

Fig. 4. Mean concentrations of ammonium nitrogen (NH_4-N) (*a*) and nitrate nitrogen (NO_3-N) (*b*) in *Arenosols* of mature pine forests and shelterwood cuttings of different age (values are means±se; different superscription letters in the rows indicate significant ($p \leq 0.05$) differences between means, ANOVA *post-hoc* LSD test; C – in nearby untouched stands; n = 6)

harvesting (YANAI et al. 2003). JOHNSON, CURTIS (2001), SANCHEZ et al. (2006) reported little or no change in soil carbon storage after forest harvesting across a variety of forest types. PENNOCK, VAN KESSEL (1997) found up to 24% less carbon in areas clear-cut 6 to 20 years earlier than in undisturbed areas. SCHMIDT et al. (1996) measured small decreases (1.2 times) in the carbon concentration of the forest floor 2 years after cutting in the boreal forest of Alberta. BELLEAU et al. (2006) detected increases of about 15% in carbon concentrations of upper organic layers until up to 2 years after cutting, but no changes were detected in mineral soil. BÉLANGER et al. (2003) found increases in carbon concentrations of mineral soils 3 years after harvesting. LISKI et al. (1998) found that clear cutting caused an initial (<10 years) increase in soil carbon from cutting residues, followed by a 5 to 10% reduction within

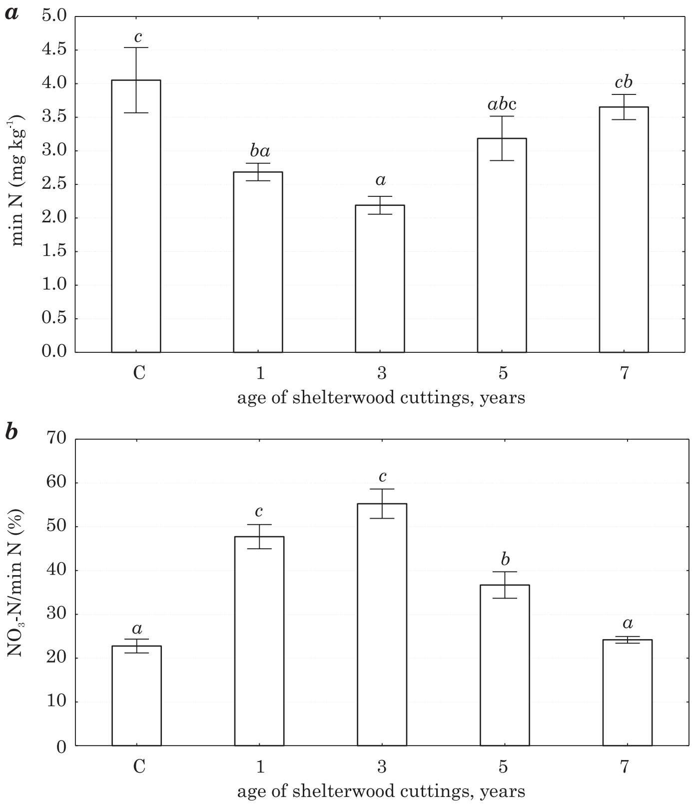

Fig 5. Mean concentrations of mineral nitrogen (NO_3-N + NH_4-N) (*a*) and percentage of nitrate nitrogen (NO_3-N) (*b*) in *Arenosols* of mature pine forests and shelterwood cuttings of different age (Values are means±se; different superscription letters in the rows indicate significant ($p \leq 0.05$) differences between means, ANOVA *post-hoc* LSD test; C – in nearby untouched stands; n = 6)

20 years, and a 14% reduction over 100 years. In a mountain forest in the Bavarian Limestone Alps, Christophel et al. (2015) found that organic carbon and N amount decreased in shallow calcareous forest soils after shelterwood cutting systems.

Nitrogen is the major forest nutrient. Boreal conifer forests are nitrogen limited and the N cycle is relatively closed in an undisturbed forest. Almost all mineralized N is taken up by roots and losses through leaching are small (Piirainen et al. 2002, Lindo, Visser 2003, Palviainen et al. 2004). Cuttings in conifer forests may increase nitrification (Prescott 1997), or may increase ammonification only (Bradley et al. 2001), or may have little effect on either ammonification or nitrification (Carmosini et al. 2002) in the forest floor.

In this study, we detected increased levels of mineral nitrogen after cuttings. Mineral nitrogen concentrations were higher in the clear cuttings

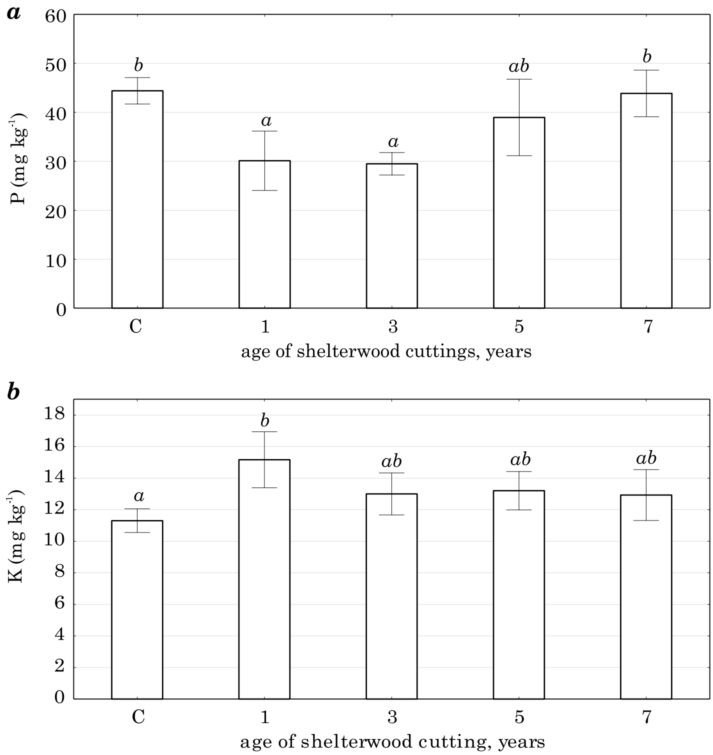

Fig. 6. Mean concentrations of available phosphorus (*a*) and potassium (*b*) in *Arenosols* of mature pine forests and shelterwood cuttings of different age (Values are means ± se; different superscription letters in the rows indicate significant ($p \leq 0.05$) differences between means, ANOVA *post-hoc* LSD test; C – in nearby untouched stands; $n = 6$)

compared to the shelterwood cuttings. We assume that mineralization and nitrification processes were more intensive in the clear cuttings compared to the shelterwood cuttings. Higher levels of nitrate nitrogen in deeper soil layers indicated that nitrate nitrogen leached from the soil. Leaching of mineral nitrogen was more intensive in the clear cuttings.

In general, non-clear cutting systems have a lower impact on soil chemical properties compared to clear cuttings. The study in Alberta's mixedwood forest showed that the negative impact to forest soil properties in partial cutting was lower compared to clear-cuttings (LINDO, VISSER 2003). Partial cuttings reduce the mineral N flush in forest floors compared to clearcutting, lowering the rate of ammonification and nitrification (PRESCOTT 1997, LAPOINTE et al. 2005).

The content of ammonium nitrogen and nitrate nitrogen in soil responded differently after shelterwood cuttings. The content of ammonium nitrogen decreased in 1 to 5 years after cuttings, while the nitrate nitrogen content in soil increased during the same period. The increase in mineral nitrogen in soil lasted for 1 to 5 years after cuttings. Cuttings may increase the amount of NO_3^- relative to that of NH_4^+ (Lapointe et al. 2005). Increases in NO_3^- concentrations after cuttings could be due to reduced root uptake or increased nitrification (Lindo, Visser 2003). Nitrification is known to be stimulated by an increase in the NH_4^+ content, temperature and soil moisture after forest cutting (Palviainen et al. 2004, 2005).

In this study, we found no significant changes in total nitrogen after shelterwood cuttings, but somewhat higher levels of total nitrogen were noticed at 5 years after cuttings. The highest influence of shelterwood cuttings on soil mineral nitrogen was observed in the period of 1 to 5 years old shelterwood cuttings.

Carmosini et al. (2002, 2003) detected increased NO_3^- and NH_4^+ in the forest floor of an aspen stand in the first year after cutting, but concentrations were diminished within a few years. Pennock, van Kessel (1997) compared content of nitrogen in soils between 1-3 year old clear-cuts and 6-20 year old clear-cuts and uncut boreal mixed wood forests. They found little effect on soil nitrogen content in recent cuttings, but content of nitrogen was about 27% lower in older cuttings. In pine forests Piirainen et al. (2007) detected that release of organic nitrogen continued for at least 5 years, while inorganic N leached for only 1-2 years after clear-cuttings. Kubin (1998) found that the concentration of NO_3^- rose for 3.5-5 years after clear-cutting in forests and may remain increased for ten years.

In this study we found lower concentrations of available phosphorus in soil in the 1-3 year-old cuttings compared to the untouched nearby stand and older cuttings (7 years-old).

Studies of cuttings impact on phosphorus concentration in soil also showed variable results. In the northern Quebec, Simard et al. (2001) reported no change in soil phosphorus concentration up to 11 years after cutting. Schmidt et al. (1996) reported 1.5 to 2 fold lower total and extractable phosphorus concentrations in forest floor layers 2 years after harvesting. Pennock, van Kessel (1997) found no difference in soluble inorganic phosphorus in the upper 15 cm of the soil at 6-20 years old cuttings compared to uncut sites. Whitson et al. (2005) also found significantly lower phosphorus concentrations in upper soil water of recently cut sites than at control sites. In Finland, Palviainen et al. (2004) found elevated concentrations of phosphorus in forest floor horizons of recently cut sites (3 years old).

In this study, the content of available potassium in soil was higher only one year after cutting and that can be attributed to the reduced K uptake by plants. In Norway spruce dominated, mixed boreal forest in eastern Finland, Piirainen et al. (2004) found increased fluxes of potassium in mineral soil. Bélanger et al. (2003) also reported increased exchangeable K concentrations in forest floor layer 3 years after stem-only cutting. In boreal forests in Alberta, Schmidt et al. (1996) determined that K decreased two years after cutting in the upper (30 cm) soil layer. Brais et al. (2004) found lower exchangeable K concentrations in soils of boreal mixed forests two years after cutting. Pennock and van Kessel (1997) found no short-term (<5 years) cutting impacts on soil potassium concentrations in the top soil of boreal mixed forests.

CONCLUSIONS

1. The mean concentration of organic carbon in the soil mineral layer in 1- to 7-year-old cutting sites was higher than in the nearby untouched stands. Both organic carbon and total nitrogen were slightly higher in the 1- to 5-year-old cuttings than in the older cuttings.

2. The content of nitrate nitrogen in soil was increased after cutting. The highest mineral nitrogen concentration was in the clear cuttings compared to the shelterwood cuttings. Higher levels of nitrate nitrogen in deeper soil layers indicated that nitrate nitrogen leached from the soil. Changes in the concentration of available phosphorus were similar as in the case of mineral nitrogen. The concentration of available potassium was higher only 1 year after cutting compared to the untouched stands.

3. Shelterwood cuttings had a weaker negative effect on the content of nutrients, especially mineral nitrogen, in soil compared to clear cuttings. The effect of shelterwood cuttings on soil nutrients was short-term and lasted up to 5 years.

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