Influence of wood ash recycling on chemical and biological condition of forest Arenosols

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ABSTRACT: The investigations were conducted in the frame of EU Research project *Wood for Energy – a Contribution to the Development of Sustainable Forest Management* (2001–2005). The integrated wood ash experiment was set up in a 38-year-old Scots pine (*Pinus sylvestris* L.) stand on Arenosols in SW part of Lithuania. Raw (not hardened) wood ash and nitrogen fertilizers were applied in 6 variants: 1.25 t ash/ha; 2.5 t ash/ha; 5.0 t ash/ha; 180 kg N/ha; 2.5 t ash + 180 kg N/ha and control (no treatment). The changes of soil pH, the content of some nutrients, heavy metals in Arenosols and soil solution, the abundance of ammonifiers, nitrifiers and denitrifiers in forest floor and mineral topsoil after the application of wood ash are presented and discussed in this paper.

Keywords: wood ash; scots pine stand; Arenosols; chemical properties; biological activity

The sustainable utilization of biomass fuels requires recycling the nutrients containing ashes back to the forests. The wood ash consists the macronutrients: calcium (Ca), potassium (K), magnesium (Mg), sodium (Na), phosphorus (P) but not nitrogen (N). Therewith, silicon (Si) and micro amounts of heavy metals (some of them, Cu and Zn, are micronutrients) are the compounds of wood ash (Ljung, Nordin 1997; Steenari et al. 1999; Mahmood 2000). Because of such chemical composition the wood ash fertilizing cause the returning of the essential nutrients to the forests, the decreasing of soil acidity, and increasing buffer capacity of the soil (Ohno, Erich 1990; Saarsalmi et al. 2001).

According to several studies wood ash application increase the pH of humus (organic) layer by 0.3–2.4 pH units during 1–19 years after the application of 1–7 t/ha of ash. Meanwhile, the pH of mineral topsoil increases only 5–10 years after application (Saarsalmi et al. 2001; Bramryd, Fransman 1995). The effects of wood ash treatment on soil acidity depend not only on the chemical composition and dose of the ash used but on the soil properties. The neutralization effects of wood ash that could be explained by increased contents of exchangeable Ca^{2+} and Mg^{2+} become evident at a slower rate in the mineral soil than in the organic layer (Bramryd, Fransman 1995; Mälkönen 1996; Levula et al. 2000; Saarsalmi et al. 2001).

It was stated that to compare with mineral topsoil the influence on soil solution pH at 30 cm and 50 cm depth was very low after the application of hardened and crushed as well granulated wood ash at four different locations in Sweden (Fransman, Nihlgård 1995; Arvidsson, Lundkvist 2001; Arvidsson et al. 2001). Meanwhile, some observations showed the increased downward transport of Ca^{2+}, Mg^{2+}, and K^{+} (Arvidsson, Lundkvist 2001; Rumpf et al. 2001).

Despite the nutrients, the addition of wood ash could affect soil chemistry negatively by accumulation of heavy metals. However, due to the high

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variability of metal concentrations most studies end up showing not significant increased levels of Zn, Cu, Cr, Ni, and Cd in the upper 4 cm of the organic horizon (Rosén et al. 1993; Bramryd, Fransman 1995; Rumpf et al. 2001).

After the wood ash application forest soil biological properties (microflora composition and biological activity) are particularly maintained by the changes of soil pH and nutrient enrichment (Persson, Wirén 1989). Due to the decreasing acidity and solubility of nutrients the increase in diversity of bacteria was indicated (Nodar et al. 1992; Bååth, Arnebrant 1994). Nevertheless, the wood ash as well as liming treatment has no significant effect on the bacterial biomass (Frostegård et al. 1993). Besides, wood ash induces the dominance of bacteria cluster instead of the fungi (Bååth et al. 1995; Liiri et al. 2002; Mahmood et al. 2003). Additionally, soil biological activity, in most cases, is followed by intension of microbial CO_2 respiration and ferment activity due to bacterial growth expansion (Fritze et al. 1994; Bååth, Arnebrant 1994).

The aim of this study was to evaluate the influence of not hardened wood ash recycling on the changes of chemical (pH, the content of the nutrients and heavy metals) and biological (the abundance of ammonifiers, nitrifiers and denitrifiers) condition of Arenosols and some chemical properties of soil solution.

MATERIAL AND METHODS

An integrated wood ash recycling experiment was established in SW part of Lithuania (54°55′N, 23°43′E, Kacergine forest district of Dubrava Experimental and Training Forest Enterprise) in a 38-year-old Scots pine (*Pinus sylvestris* L.) stand in June 2002 (Ozolincius et al. 2003).

The initial density of Scots pine plantation was around 8,000 trees per ha. Forest type – *Pinetum vacciniosum.* The sandy soil (limnoglacial plain overlying old fluvioglacial sands) was classified as *Hapli-Albic Arenosols* (ISSS-ISRIC-FAO 1998), forest floor (organic soil layer), being 8.1 ± 1.3 cm thickness consisted of L, F and H horizons. Generally, this stand represents typical Scots pine stands growing on poor sandy soils in Lithuania.

The total area of experiment is 3.2 ha. In this area 1.2 ha is used for the investigations. Totally there are 24 plots (25 × 20 m) grouped into 4 blocks with 6 treatments at each block: (1) 1.25 t/ha; (2) 2.5 t/ha; (3) 5.0 t/ha; (4) 180 kg N/ha; (5) – 2.5 t/ha of wood ash and 180 kg N/ha; and (6) control (no treatment). Before the wood ash application, the 6 suction lysimeters per plot (ceramic cups of P80 material, Ceramitech) were installed at 20 cm and 50 cm depths, in total – 144 lysimeters. The raw (not hardened) wood ash from district heating plants and N fertilizers (ammonium nitrate) were spreaded (Table 1). The contents of heavy metals did not exceed the recommended content in wood ash (Swedish Recommendations ... 2002).

Table 1. The chemical composition of wood ash applied in the field experiment

Elements	Applied content
Macronutrient (g/kg)	
Phosphorus	2.15
Potassium	5.29
Calcium	72.03
Magnesium	9.45
Heavy metals (mg/kg)	
Chromium	9.51
Cadmium	0.62
Lead	4.53
Nickel	8.05
Copper	13.08
Zinc	73.67

Soil sampling was carried out in October 2002, 4 months after wood ash application. From each plot, 20 soil subsamples were collected from the forest floor and from the upper layers of mineral soil (0–5, 5–10, and 10–20 cm). The soil samples were pooled together to produce one combined sample from each depth per plot or 4 combined samples for each treatment. Soil solution was sampled at 20 cm and 50 cm depths by tension lysimeters in the rainy seasons, April–May and November of 2003, respectively, 10 and 17 months after wood ash and N fertilizers application. The lysimeters were operated at a transient vacuum during two weeks using an initial tension of about –70 kPa. The soil solution samples from each depth were combined per plot (4 combined samples for each treatment) and analyzed.

The following chemical analyses of soil and soil solution samples were performed: pH ($CaCl_2$); total N, Mg, K, P; exchangeable Ca^{2+}, Mg^{2+}, K^{+}, and some heavy metals (Cr, Cd, Pb, Ni, Cu, and Zn) (UN-ECE/ICP – FORESTS 2002).

For evaluation of biological activity of forest Arenosols forest floor samples were collected in September 2002 (3 months after wood ash and

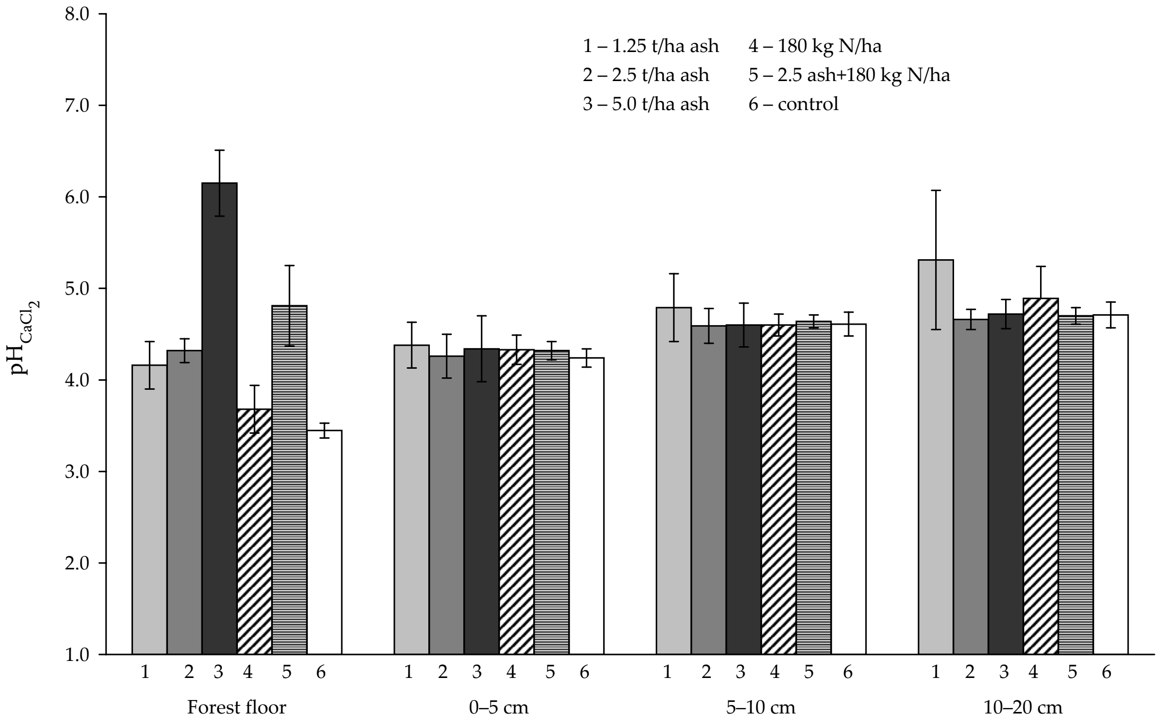

Fig. 1. The influence of different wood ash doses on forest floor and mineral soil acidity 4 months after the application. Mean values and SE are shown for each treatment, $n = 4$

N fertilizers application) from 12 places in each plot and composed into combined samples. Diluted combined forest floor samples solutions were used to evaluate the distribution of ammonifiers, nitrifiers and denitrifiers. Nutrient mediums used for growth of each group respectively were: agarized Meat-Peptone Agar, liquid Vinogradsky and Beriosow Mediums (Aseeva et al. 1966).

For statistical data analyses, *t*-tests were used to evaluate the significant effects of wood ash treatments. The effects of the treatments were treated as significant with $p < 0.05$.

RESULTS AND DISCUSSION

The changes of the some chemical parameters in Arenosols

The spreaded wood ash has influenced only the chemical composition of forest floor 4 months after the treatment. In this organic soil layer, the increase of total Ca, exchangeable Ca^{2+} and Mg^{2+} was statistically significant in each wood ash treatment. Due to that the acidity of forest floor has decreased from pH_{CaCl_2} 3.45 ± 0.08 (control) to pH_{CaCl_2} 6.15 ± 0.36 (5 t/ha of ash) (Fig. 1).

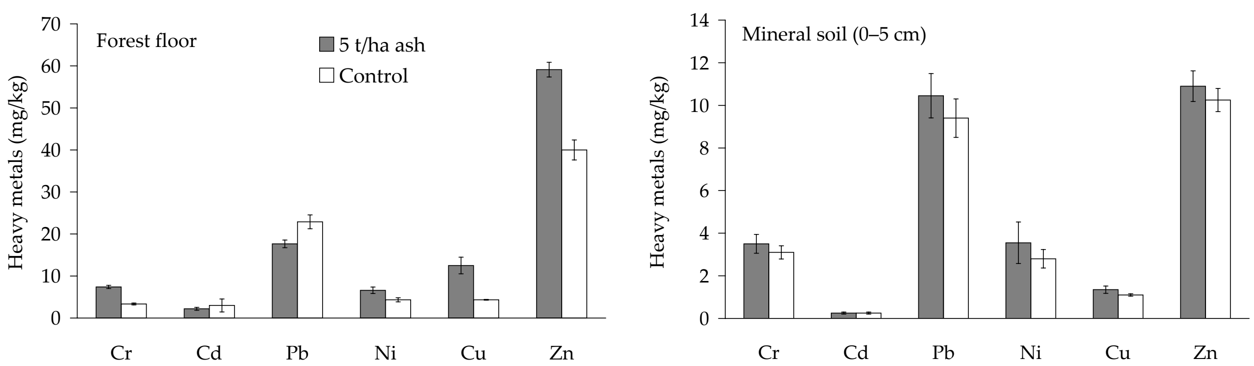

Fig. 2. The contents of heavy metals (Cr, Cd, Pb, Ni, Cu, and Zn) in forest floor and mineral topsoil 4 months after wood ash application. Mean values and SE are shown for each treatment, $n = 4$

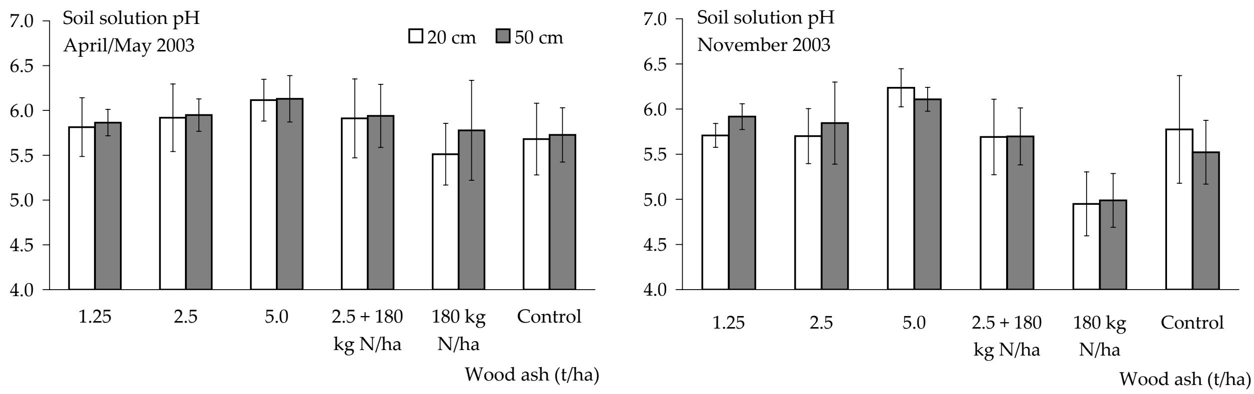

Fig. 3. The influence of different wood ash doses on soil solution pH 10 (April/May 2003) and 17 (November 2003) months after the application. Mean values and SE are shown for each treatment, n = 4

The increase of total N also was not statistically significant when the nitrogen fertilizers (180 kg N/ha) were applied. We could presume that the plants have taken up the nitrogen or the nitrogen compounds were leached out.

The content of heavy metals were determined in the forest floor and mineral topsoil (0–5 cm) after the highest wood ash dose (5 t/ha) application and control seeking to clarify the possible negative sequences on soil chemistry. The chemical analyses of some heavy metals (Cr, Cd, Pb, Ni, Cu, and Zn) have shown that the application of wood ash increased the contents of Cr, Ni, and Zn by 1.5–2, and Cu – by 3 times (Fig. 2). But such increase was determined only in the forest floor and did not exceed the critical levels in organic layers (Tyler 1992). It shows that the heavy metals were mobilized in the upper organic layer and were not leached to lower mineral horizons 4 months after the wood ash application.

The chemical composition of the soil solution

The investigations of soil solution were performed in April–May 2003 and November 2003. The soil solution acidity has not significantly differed between rooting zone (20 cm depth) and below roots (50 cm depth). Some variations in soil solution pH among the treatments were detected only after 17 months (Fig. 3).

The soil solution pH in both depths was significantly lower than control in nitrogen fertilizers (180 kg N/ha) treatment. However, such acidification effect of nitrogen compounds in treatment where the nitrogen fertilizers were applied together with wood ash was eliminated.

However, 10 months after the treatment, spreaded wood ash has increased the downward transport of exchangeable Ca^{2+} but has not increased the nitrogen leaching (total N, NO_3^- and NH_4^+) that was intensified only due to the application of nitrogen fertilizers. Similarly, the application of wood ash has direct influence on the leaching of K, Mg, and P compounds (data not shown). The same tendencies have not disappeared after 17 months after the vegetation period (Fig. 4).

Even the highest dose of wood ash (5 t/ha) has not caused the significant changes in the heavy metals content (Ni, Cu, Pb, and Zn) in soil solution in the

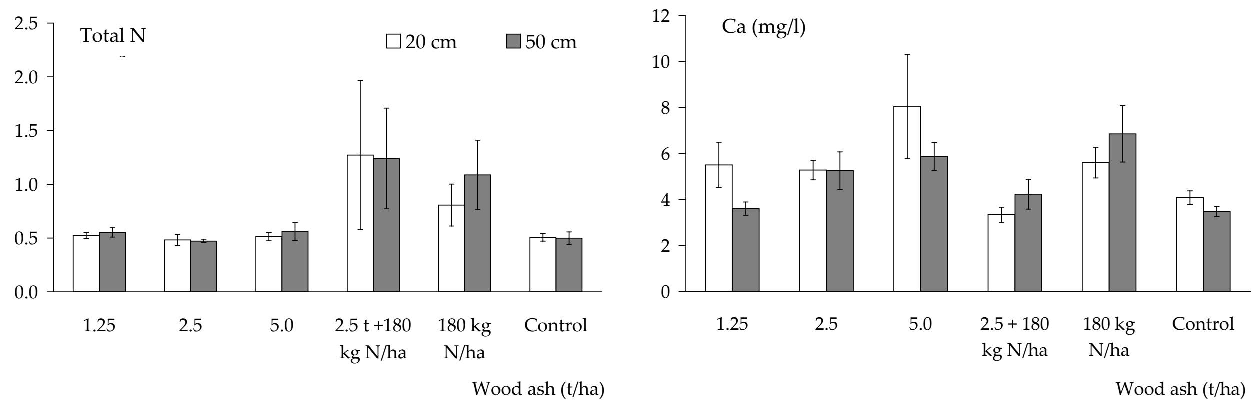

Fig. 4. The contents of total N and Ca in soil solution 17 months after wood ash N fertilizers application. Mean values and SE are shown for each treatment, n = 4

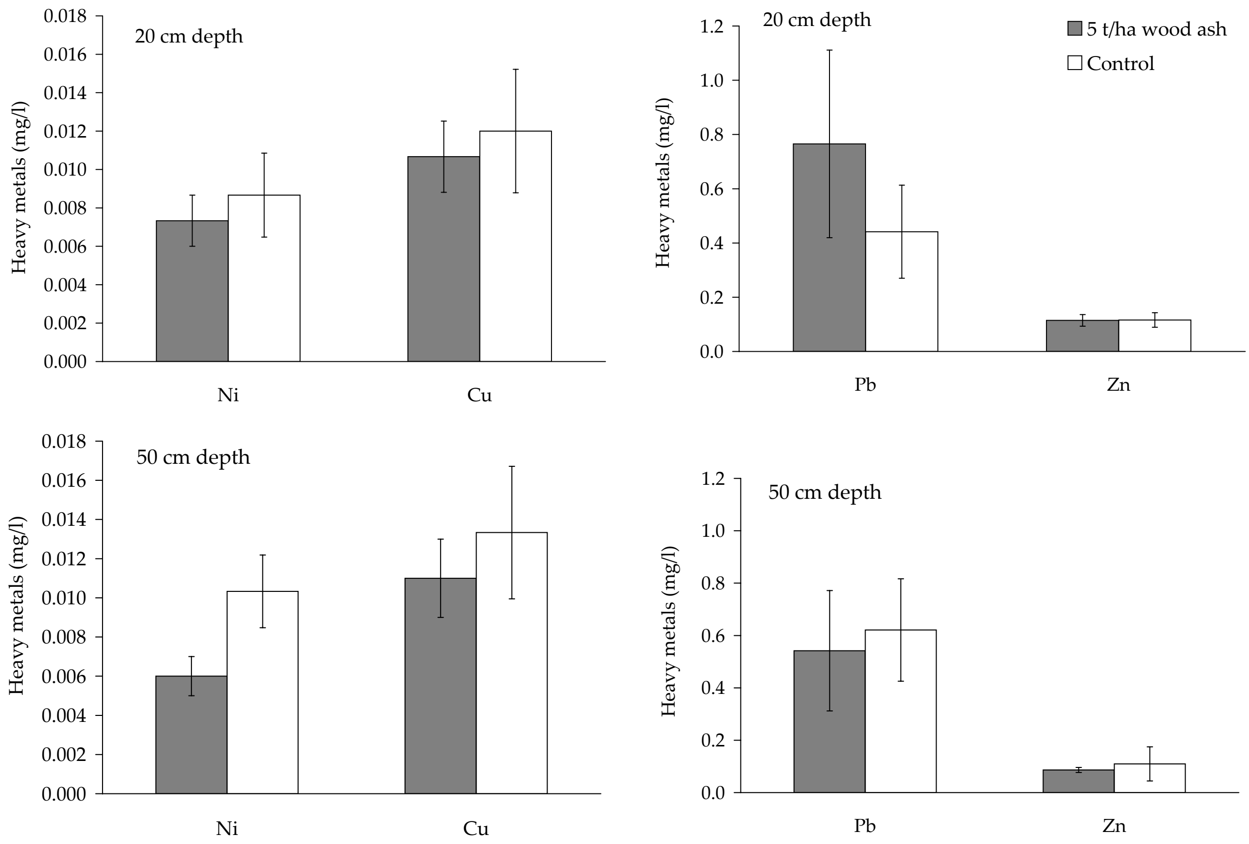

Fig. 5. The contents of heavy metals (Ni, Cu, Pb, and Zn) in soil solution 17 months after wood ash and N fertilizers application

rooting zone (at 20 cm depth) as well below roots (at 50 cm depth) 17 months after the treatment (Fig. 5).

Biological activity of microflora

Three months since wood ash application, the total number of ammonifying microorganisms in the forest floor has increased from 57,600 ths/g to 204,500 ths/g (Fig. 6(A)). The total number of nitrifying microorganisms was significantly lower: about 0.2 ths/g in control, thought the highest dose of wood ash as well as wood ash in complex with N fertilizers increased the number of nitrifiers by 6–7 times (Fig. 6(B)) while denitrifiers by about 40–60 times (Fig. 6(C)). It shows that applying N fertilizers in combination with wood ash the additional losses of nitrogen could be expected due to more intense denitrification.

Liming results the significant increase the intensity of ammonification, nitrification and denitrification, due to N availability in soil (Papen, Butterbach-Bahl 1999). Our experiment confirmed that the wood ash recycling to the forest could be treated as liming.

CONCLUSIONS

Wood ash application has increased the contents of total Ca, exchangeable Ca^{2+} and Mg^{2+} and due to that the decreased acidity in the forest floor was detected 4 months after the treatment. The application of wood ash has increased the contents of Cr, Ni, Zn, and Cu in the forest floor but obtained values have not exceeded the critical levels.

The soil solution pH has not significantly differed between rooting zone (20 cm depth) and below roots (50 cm depth), and only addition of 180 kg N/ha resulted in increased acidity of soil solution after 17 months. Wood ash and nitrogen fertilizers have intensified the downward transport of exchangeable Ca^{2+}, meanwhile, the leaching of the nitrogen compounds has increased only after the N fertilizers application. The application of 5 t/ha of wood ash has not shown the expressed changes in the contents of Ni, Cu, Pb, and Zn in soil solution even 17 months after the treatment.

Wood ash has affected positively and negatively the biological processes in the forest floor. The increase in the number of ammonifying and nitrifying microorganisms was beneficial due to nitrogen

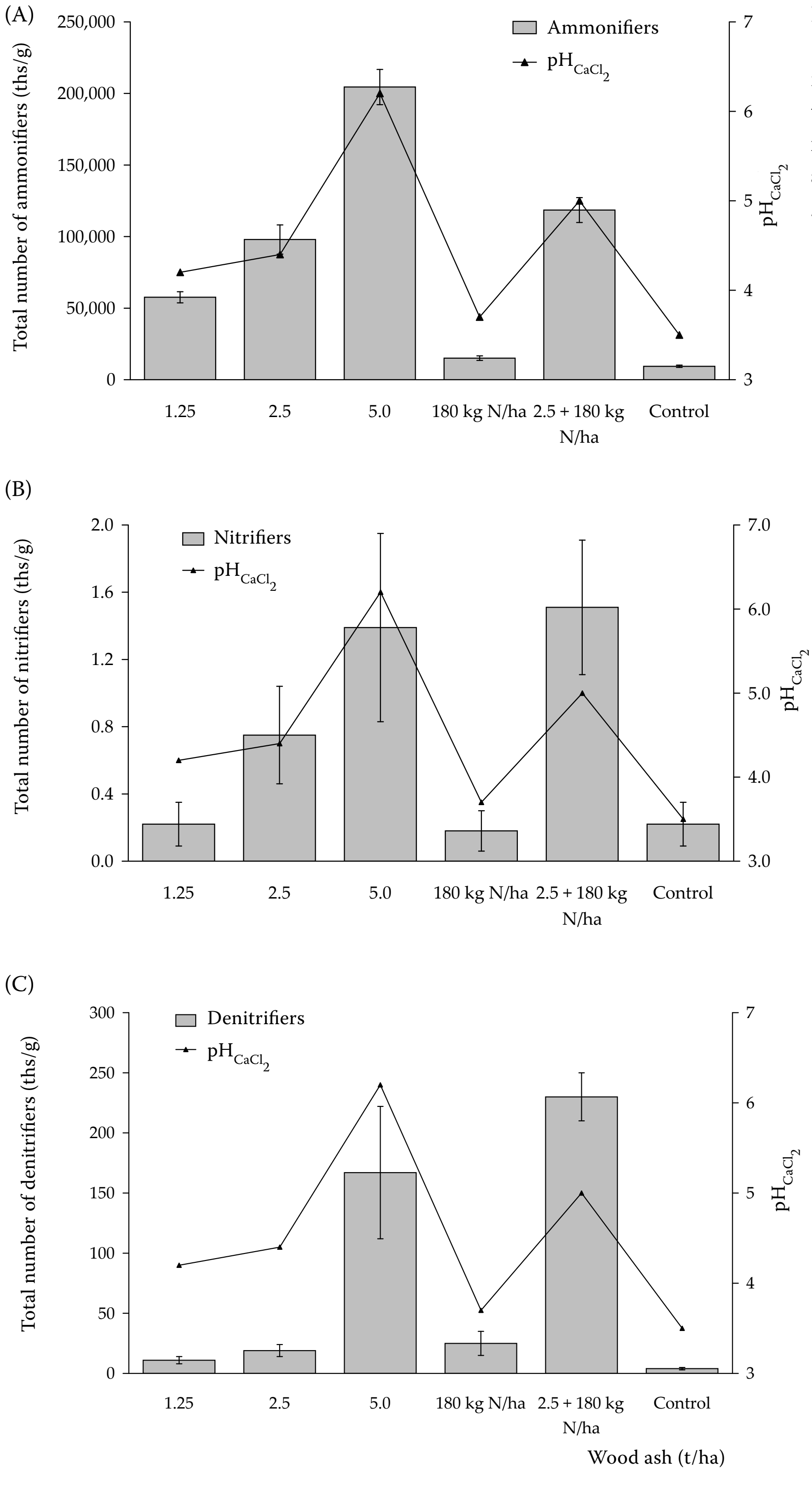

Fig. 6. The distribution of ammonifying (A), nitrifying (B) and denitrifying (C) microorganisms in the forest floor three months after wood ash and N fertilizers application. Mean values and SE are shown for each treatment, *n* = 4

mineralization. While due to increase intensity of denitrification the nitrogen looses were unfavorable to forest ecosystem. Nevertheless, the positive changes (increase intensity of ammonifying and nitrifying processes) prevailed over the denitrification as the total amount of ammonifiers and nitrifiers was significantly higher.

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Vliv recyklace dřevného popela na chemický a biologický stav lesních půd (arenosoly)

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ABSTRAKT: Integrovaný experiment s aplikací dřevného popela byl založen ve 38letých porostech borovice lesní (*Pinus sylvestris* [L.]). Půdním typem na pokusných plochách, které byly založeny v červnu 2002 na jihozápadě Litvy (54°55′ sev. šířky, 23°43′ vých. délky, lesní správa Kacergine, Dubrava Experimental and Training Forest Enterprise), byl arenosol. Celkem bylo založeno 24 ploch (25 × 20 m), které byl rozděleny do čtyř bloků, kde byl aplikován surový (tvrzený) dřevný popel a dusíkatá hnojiva v šesti variantách: 1,25 t popela/ha; 2,5 t popela/ha; 5 t popela/ha; 180 kgN/ha; 2,5 t popela + 180 kg N/ha a kontrola bez hnojení. Dřevný popel pozitivně, ale i negativně ovlivňoval biologické procesy ve svrchní humusové vrstvě. Zvýšil se počet amonifikačních a nitrifikačních mikroorganismů díky mineralizaci dusíku. Současně se zvýšila intenzita denitrifikace a ztráty dusíku.

Klíčová slova: dřevný popel; porosty borovice lesní; arenosoly; chemické vlastnosti; biologická aktivita

Integrovaný experiment s aplikací dřevného popela byl založen ve 38letých porostech borovice lesní (*Pinus sylvestris* [L.]). Půdním typem na pokusných plochách, které byly založeny v červnu 2002 na jihozápadě Litvy (54°55′ sev. šířky, 23°43′ vých. délky, lesní správa Kacergine, Dubrava Experimental and Training Forest Enterprise), byl arenosol. Celkem bylo založeno 24 ploch (25 × 20 m), které byl rozděleny do čtyř bloků, kde byl aplikován surový (tvrzený) dřevný popel a dusíkatá hnojiva v šesti variantách: 1,25 t popela/ha; 2,5 t popela/ha; 5 t popela/ha; 180 kg N/ha; 2,5 t popela + 180 kg N/ha a kontrola bez hnojení.

Aplikace dřevného popela zvýšila obsah celkového Ca, výměnného Ca^{2+} a Mg^{2+} a ovlivnila pokles kyselosti ve svrchní vrstvě lesní půdy (humusu) již po čtyřech měsících po aplikaci. Hnojení dřevným popelem zvýšilo obsahy Cr, Ni, Zn, and Cu ve svrchní vrstvě půdy, zjištěné hodnoty však nepřekročily kritickou hranici. Hodnoty pH půdního roztoku se významně nelišily v kořenové zóně (20 cm) a pod kořeny (50 cm), a pouze dávka 180 kgN/ha po 17 měsících zvýšila kyselost půdního roztoku. Popel a dusíkatá hnojiva urychlily vymývání výměnného Ca^{2+}, zatímco vymývání dusíkatých komponentů se zvýšilo pouze po aplikaci dusíkatých hnojiv. Aplikace popela v dávce 5 t/ha nevykazovala výrazné změny v obsahu Ni, Cu, Pb a Zn v půdním roztoku ani po 17 měsících po aplikaci.

Dřevný popel pozitivně, ale i negativně ovlivňoval biologické procesy ve svrchní humusové vrstvě. Zvýšil se počet amonifikačních a nitrifikačních mikroorganismů díky mineralizaci dusíku. Současně se zvýšila intenzita denitrifikace a ztráty dusíku. Nicméně pozitivní změny zvýšení intenzity amonifikačních a nitrifikačních procesů převažovaly nad denitrifikačními a celkové množství amonifokátorů a nitrifikátorů bylo významně vyšší.

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