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CHANGES IN MACRONUTRIENT CONCENTRATIONS IN SOIL SOLUTION FOLLOWING REGENERATION FELLING IN PINE AND SPRUCE STANDS: WHOLE-TREE HARVESTING VERSUS STEM-ONLY HARVESTING

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While conventional forest management in boreal and hemiboreal conditions has traditionally been targeted to use and enhance mainly provisioning services like timber production, the main goal of national and European forest policy is to ensure sustainable management of European forests in all aspects. Regeneration felling is a major disturbance in boreal and hemiboreal forests resulting in significant increase of organic matter on the forest floor in the form of logging residues (bark, small branches, tree tops) and severed roots (in case of stump harvesting), and can increase the risk of nutrient leaching. Recently, concern about the effect of forest management impact on macronutrient leaching potentially decreasing nutrient availability for the next forest generations and causing deterioration of water quality has been raised. In 2011, three objects to study the impact of different intensity regeneration felling (stem-only harvesting and whole-tree harvesting) were established in scientific research forests in Kalsnava forest district, eastern part of Latvia. Two sites were located on mineral soils (*Myrtillosa* and *Hylocomiosa* site type, dominant tree species *Pinus sylvestris* L.) and one on drained peat soil (*Oxalidosa turf. mel.* site type, dominant tree species *Picea abies* (L.) Karst.). Felling was performed in early spring 2013 with harvester, timber was extracted and logging residues were removed with forwarder, following "business as usual" principle. Soil solution samples were collected once or twice a month in 2012, 2013, 2014, 2015 and 2016. This study presents trends of pH and macronutrient (NO_3^--N, PO_4^{3-}-P, K) concentrations during five years – one year before harvesting and four years following harvesting. In general, significant forest management impact expressed as increase of macronutrient concentrations in soil solution was detected in the second and third year after harvesting, but in the fourth year concentrations started to decrease again.

Keywords: Intensive forest management, macronutrients, Norway spruce, Scots pine, soil solution

INTRODUCTION

Forestry or land use in general provides mankind with food, renewable energy and other specific supplies (Haberl et al., 2007; Millennium Ecosystem Assessment, 2005). While human population size and living standards continue to grow, but the amount of resources do not, we have to rely on sustainably intensified land use (Foley et al., 2011; Tilman et al., 2011). Forest management intensity determines to what extent related ecosystems are influenced, for example, intensified forestry production affects biogeochemical cycles (Luyssaert et al., 2012; Nabuurs et al., 2013), soils (Jandl et al., 2007), forest structure (Vilén et al., 2012) and biodiversity (Paillet et al., 2010).

Lately, low carbon footprint energy from renewable sources is taking increasing share of global energy supply (Whalen et al., 2017). In Latvia, the share of renewable energy resources in total consumed energy should reach 40 % by 2020 (7.4 % increase compared to 2005), while in the whole European Union this share must reach 20 % (European Parliament, 2009). One of the targets of European Commission's Bioeconomy Strategy and Action Plan is to use renewable biological resources sustainably while taking into account environmental and biodiversity protection including bioenergy from forestry (European Comission, 2012).

Timber is often considered as the most valuable resource in forestry, but logging residues consisting of branches, bark, stems and roots (lower value biomass) also make up significant energy source (Castro et al., 2017). Amid the recent decade in Nordic and Baltic countries stump harvesting has become more popular in forest management (Grelle et al., 2012; Lazdins et al., 2009; Persson, 2013; Uri et al., 2015), and as much as 140-200 $MWh\ ha^{-1}$ can be harvested (Hakkila, 2004; Hakkila Pentti, 2004). Lower value biomass removal can also reduce costs associated with site preparation for reforestation by removing excess debris (Barker et al., 2014; Fielding et al., 2012).

On the other hand, harvest of logging residues may cause increased nutrient removal from the site because of higher nutrient content in foliage and branches (Abbas et al., 2011; Hopmans and Elms, 2009; Tamminen et al., 2012; Walmsley et al., 2009). Leftover biomass may either serve as nutrient source or act as nutrient sink while decomposing (Barber and Van Lear, 1984; Devine et al., 2012; Strahm et al., 2005) and logging residues also play important role in determining soil microclimate and influence vegetation (Achat et al., 2015; Thiffault et al., 2011). Soil disturbance related to lower value biomass harvesting is mostly affecting top layers of soil (Carter and McDonald, 1998). Removal of whole tree biomass, taking into account the logistics, may significantly influence biological diversity and water quality in the site (Freedman et al., 1996; Harmon et al., 1986).

Considering these concerns, research is in progress to evaluate different scenarios of lower value biomass extraction from different forest type clearcuts considering environmental and forest regeneration aspects to optimize forestry activities.

MATERIALS AND METHODS

The study area is located in eastern part of Latvia in experimental forests of Kalsnava Forest district (*Figure 1.*). Climate is continental compared to other regions of Latvia (according to Jaunkalsnava meteorological station data situated 10 km distant). The annual precipitation amount was 1,023 *mm* in 2012, 590 *mm* in 2013, 823 *mm* in 2014, 688 *mm* in 2015 and 694 *mm* in 2016 with largest share (61–74 *%*) falling as rain from April to October. Mean annual air temperature was 4.4 *°C* in 2012, 5.1 *°C* in 2013, 5.0 *°C* in 2014, 5.9 *°C* in 2015 and 5.9 *°C* in 2016.

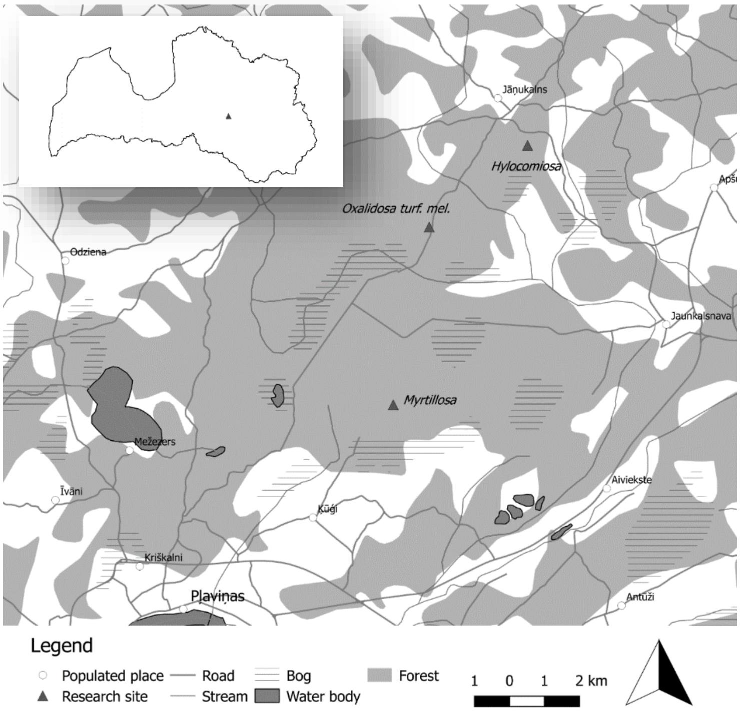

Figure 1. Location of research sites.

Research is carried out at three sites: two are located on mineral soils – *Myrtillosa* and *Hylocomiosa* site type, dominant tree species *Pinus sylvestris L.*; one on drained peat soil - *Oxalidosa turf. mel.* site type, dominant tree species *Picea abies (L.) Karst.* Drainage systems were made in 1960. All sites are located on slopes - 5° in *Oxalidosa turf.mel.*, 15° in *Hylocomiosa* and *Myrtillosa,* with bufferzone in the lower part. Site description is given in *Table 1.*

Table 1. Description of the study sites

Site	Dominant tree species	Mean diameter, *cm*	Mean eight, *m*	Basal area, m^2ha^{-1}	Standing volume before felling, $m^3\ ha^{-1}$
Hylocomiosa	*Pinus sylvestris* L.	34	31	35.3	541.3
Oxalidosa turf.mel.	*Picea abies* L. (Karst.)	31	25	17.4	315.0
Myrtillosa	*Pinus sylvestris* L.	31	26	21.2	270.9

At each site, three sampling plots were established: whole tree harvesting (WTH, only above-ground biomass harvested), stem-only harvesting (SOH) and control (C). Size of the plot varied from 3.00 to 3.75 *ha*. Three pairs of suction tube lysimeters (lysimeter cup made of porous ceramic – 92 *%* pure Al_2O_3 and body of trace metal-free PVC) at 2 depths (30 and 60 *cm*) per sample plot were installed in autumn 2011. Water samples were collected twice per month during the vegetation season in 2012 (reference period), 2013, and 2014 (first and second years following regeneration felling), after that in 2015 and 2016 samples were collected once per month. Regeneration felling was performed in early spring 2013 with harvester, timber was extracted and logging residues were removed with forwarder, following 'business as usual' principle. During harvest the soil was frozen, and no damage to the soil due to the movement of machinery was observed. At the whole-tree harvested plots all above-ground part of the tree was harvested (in practice this means that approximately 70 *%* of tree tops and branches were removed). At the stem-only harvested plots only the stemwood was removed and logging residues were evenly scattered throughout the plot. Sample and data collection from the sites is planned till year 2020.

The soil solution deposition samples were analyzed in the Forest Environment Laboratory at the *LSFRI Silava*. The following chemical parameters were measured in the water samples: pH determined according to LVS ISO 10523:2012, nitrate-nitrogen (NO_3^--N) concentration determined using FORMACSHT TOC/TN Analyzer (ND25 nitrogen detector); phosphate-phosphorus (PO_4^{3-}-P) determined using an ammonium molybdate spectrometric method according to ISO 6878 and potassium (K) determined using a flame emission spectrometric method according to ISO 9964-3:2000. Preservation and handling of water samples were done according to ISO 5667-3:2012.

RESULTS

Mean annual soil solution pH at C, SOH and WTH plots of all three sites before (in 2012) and after regeneration felling (in 2013-2016) are shown in *Figure 2*. During research period most alkaline soil solution was found in C and SOH plots in *Oxalidosa turf. mel.* site (mean annual soil solution pH values ranged from 7.30 ± 0.04 to 7.72 ± 0.05) that indirectly indicates the presence of confined aquifer discharge water input rich in carbonates. The most acidic soil solution was found in SOH plot in *Myrtillosa* site in the second, third, and fourth year after treatment (mean annual soil solution pH ranged from 5.07 ± 0.12 to 5.25 ± 0.13). In C plots, significant changes in soil solution pH during research period were not detected. Conversely, gradual pH value decrease in the soil solution after felling was observed nearly at all harvested plots, except the SOH plot in *Oxalidosa turf. mel.* site where decrease in the soil solution pH was not observed. Comparing mean annual soil solution pH before regeneration felling (in 2012) and after felling (in 2013-2016), the most significant decrease of mean annual soil solution pH value (by 1.7 pH units) after felling was observed in SOH plot in *Myrtillosa* site in 2016 (in the fourth year after treatment). Comparing mean annual soil solution pH after felling in SOH and WTH plots in *Myrtillosa* site, a more pronounced decrease of mean annual soil solution pH value was observed in the plot where logging residues were left on site (SOH plot). Conversely, in *Oxalidosa turf. mel.* site, mean annual soil solution pH value decreased only in WTH plot; furthermore, the most significant decrease of mean annual soil solution pH value was observed in the second year after felling. In *Hylocomiosa* site, mean annual soil solution pH value was not significantly affected by removal of logging residues (tree tops and branches), if compared to SOH plot.

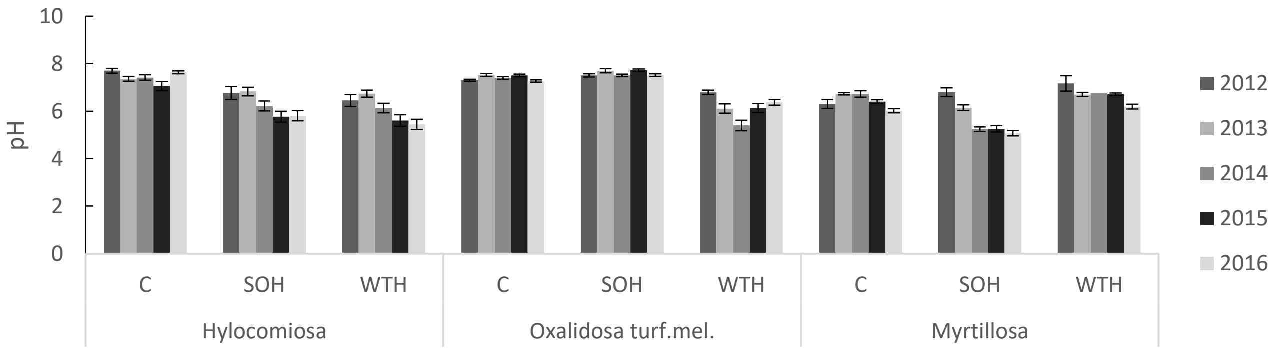

Figure 2. Mean annual soil solution pH at the study sites. Error bars represent standard error.

Mean annual NO_3^--N concentrations in soil solution at C, SOH and WTH plots of all three sites are shown in *Figure 3*. During research period mean annual NO_3^--N concentrations in soil solution ranged up to 10.7 ± 1.6 *mg L⁻¹*. Although some significant differences of mean annual NO_3^--N concentration in soil solution between plots were observed before regeneration felling (in 2012), mostly results show significant impact of felling on mean annual NO_3^--N concentration in soil solution. The most elevated NO_3^--N concentrations in soil solution were observed in the second and third year after felling (in 2014 and 2015), but in the third and fourth year after felling, depending on the site, mean annual NO_3^--N concentration in soil solution started to decrease or even reached pre-felling levels. On the contrary to all other harvested plots, at SOH plot in *Oxalidosa turf. mel.* site increase of mean annual NO_3^--N concentration in soil solution after felling was not observed and also increase of mean annual NO_3^--N concentration in soil solution after felling in WTH plot in *Myrtillosa* site was negligible.

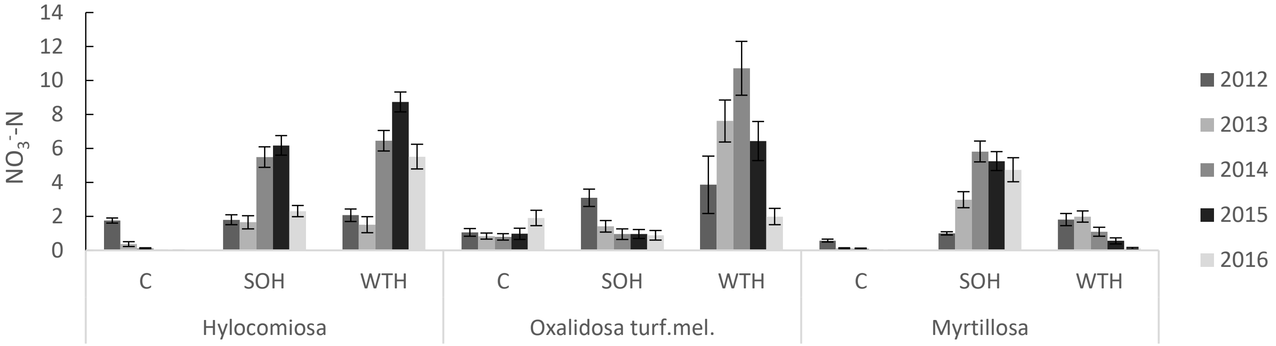

Figure 3. Mean annual NO_3^--N concentration in soil solution at the study sites. Error bars represent standard error.

Mean annual PO_4^{3-}-P concentration in soil solution at C, SOH and WTH plots of all three sites are shown in *Figure 4*. During research period mean annual PO_4^{3-}-P concentration in soil solution ranged up to 0.09 ± 0.04 *mg L*$^{-1}$. Significant impact of regeneration felling on PO_4^{3-}-P concentration in soil solution was not observed. However, elevated PO_4^{3-}-P concentrations in soil solution were observed in 2016, on the fourth year after felling, at WTH plots in *Hylocomiosa* and *Oxalidosa turf. mel.* sites.

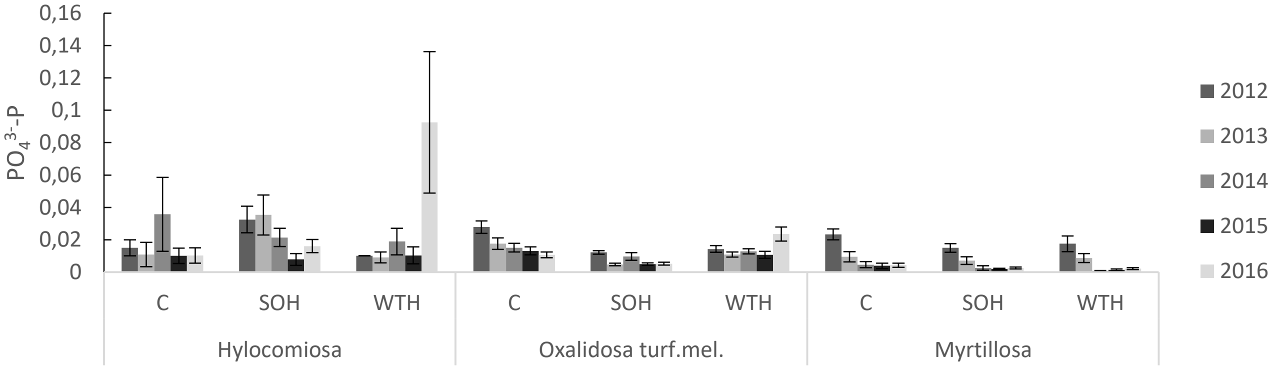

Figure 4. Mean annual PO_4^{3-}-P concentration in soil solution at the study sites. Error bars represent standard error.

In *Figure 5*, mean annual K concentration in soil solution at C, SOH and WTH plots of all three sites are shown. During research period, mean annual K concentration in soil solution ranged up to 6.6 ± 0.7 *mg L*$^{-1}$. On average, the highest K concentrations in soil solution were observed in *Hylocomiosa* site, but the lowest in C and SOH plots in *Oxalidosa turf. mel.* site. Trends in K concentration in soil solution after regeneration felling are similar to the changes in NO_3^--N concentration in soil solution. Elevated K concentrations in soil solution were observed in the first and second year after felling at SOH and WTH plots in *Hylocomiosa* site, at WTH plot in *Oxalidosa turf. mel.* site and SOH site in *Myrtillosa* site. In the all mentioned plots, peak K concentrations in soil solution were observed in the second year after felling (in 2014), but in the third and fourth year after felling K concentrations in soil solution started to decrease.

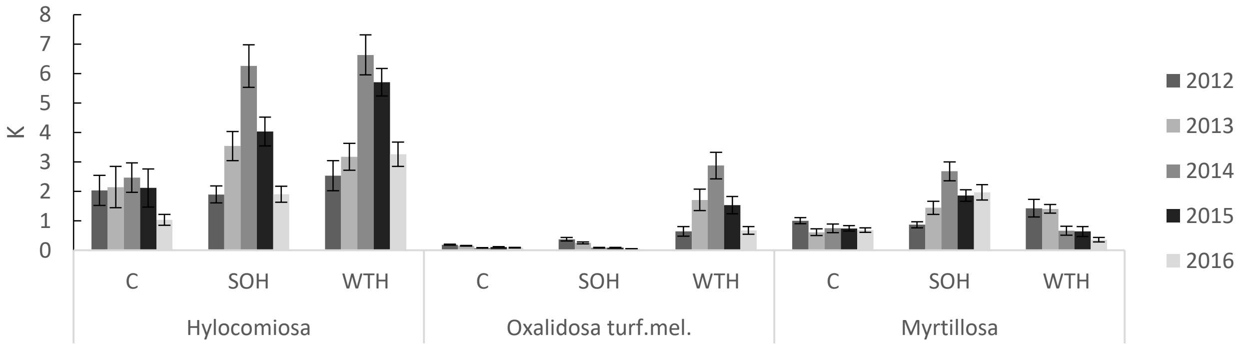

Figure 5. Mean annual K concentration in soil solution at the study sites. Error bars represent standard error.

CONCLUSIONS AND DISCUSSION

The effect of biomass harvesting on soil solution chemical composition and leaching of nutrients has been followed in numerous studies since the late 1960s, where the classic experiments at the Hubbard Brook Experimental Forest (HBEF) USA (Likens et al., 1970) illustrated the dramatic increase in leaching of nutrients from a catchment scale clear-cut. In general, the nutrient concentration in soil waters increase with peak nutrient concentrations within 2-3 years after clear-cut. The nutrient concentration often returns to pre-cutting levels within relatively short time, normally 3-5 years, especially if clear-cut is performed without any other disturbances (Raulund-Rasmussen et al., 2011). Even if soil-water chemistry is affected by the residue treatments, the response tends to differ between the sites (Ring et al., 2015).

We detected a strong response in nutrient concentrations following regeneration felling in the all three sites (except SOH plot in *Oxalidosa turf. mel.* site and WTH plot in *Myrtillosa* site). Results of our study confirm that NO_3^--N and K concentration in soil solution peak after 2-3 years and are back to pre-treatment levels after 3-4 years. Whole tree harvest impact on pH value is greater on soils with lower buffer capacity and shallow soils (Löfgren et al., 2017), which is the reason why significant pH value change in *Oxalidosa turf. mel.* site was not detected due to alkaline underground pressure water input. In *Myrtillosa* and *Hylocomiosa* site pH value dropped after clearcutting. Nitrate, phosphate and potassium concentrations generally increased after clearcutting due to leaching, but in 2015 and 2016 already tend to reach for values observed in the pre-treatment period.

Whole tree harvesting technique may cause growth reduction in first 8-year period for the next generation (Egnell and Ulvcrona, 2015) although change in site yield capacity and total amount of nutrients in the soil and forest floor are usually small (Brandtberg and Olsson, 2012). Lower value biomass removal may affect recovery speed of the site more intensively on acidic soils (Akselsson and Belyazid, 2018). On sandy soils macronutrient regeneration intensity by weathering and deposition may not provide enough for whole tree harvesting in long term (Vangansbeke et al., 2015). These factors will be further evaluated in the research sites.

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