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The effect of Norway spruce stump harvesting on net nitrogen mineralization and nutrient leaching

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ABSTRACT

Stumps of conifer trees are a prospective source of bioenergy and stump harvesting is a novel practice in forestry management in the Baltic and Nordic countries. However, as stump harvesting may cause possible environmental risks there has emerged a clear need for research focusing on sustainable forest management.

Three Norway spruce (*Picea abies*) clear-cut areas on different soils in Estonia were selected for the present study. We analysed the effect of stump harvesting on net nitrogen mineralization (NNM) and on nutrient leaching. On dry and sandy *Endogleyic Arenosol* (*Oxalis* site type), stump harvesting reduced the annul NNM flux significantly; 134 and 202 kg N ha yr^{-1} at the harvested and at the control site, respectively. In clear-cut area where *Endogleyic Cambisol* was dominating (*Hepatica* site type), stump harvesting had no effect on NNM (92 *vs* 88 kg N ha yr^{-1}). However, in a clear-cut area where the soil type was *Endogleyic Albic Podzol* (*Myrtillus* site type), stump harvesting increased the total annual NNM flux: 102 *vs* 70 kg N ha yr^{-1} at the harvested and at the control site, respectively. Stump harvesting affected also the proportion of nitrification and ammonification processes in NNM. At the *Myrtillys* site type stump harvesting increased the annual nitrogen (N) leaching flux. One year after stump harvesting, leaching at the harvested site was 11.7 *vs* 4.5 kg N ha^{-1} yr^{-1} at the control site. In the second year N leaching decreased and the difference levelled off. Increased N leaching was induced by a larger amount of water; average N concentration of the harvested and control sites did not differ. Although at the *Oxalis* site N leaching was larger at the harvested than at the control site, the total annual leached N flux was small ($\sim$2 kg N ha^{-1}). At the fertile *Hepatica* site type treatment had no impact on N leaching, which was only *ca* 1 kg N ha^{-1} yr^{-1}. Phosphorus (P) leaching was very small in all study areas, being below 0.1 kg P ha^{-1} yr^{-1}.

The effect of stump harvesting on annual NNM as well as on N leaching was soil specific and highly variable. Stump harvesting affected also the proportion of the nitrification and ammonification processes in total NNM. Considering the first short-term results obtained from different site types, we can conclude that harvesting of spruce stumps does not induce serious environmental hazards in relation of N cycling.

1. Introduction

During the last decade stump harvesting has become more actual in forest management practice in the Nordic and Baltic countries (Lazdins et al., 2009; Grelle et al., 2012; Persson, 2013; Uri et al., 2015) since the need for bioenergy is increasing and stumps are a prospective source of bioenergy. In Finland, stump harvesting showed a major increase from 2006 to 2007 when the area of stump harvesting increased by 50% (Peltola, 2008); in 2012 the volume of harvested stumps was about 1.1 mil m^3 (Finnish Statistical Yearbook of Forestry, 2013). In Estonia, large-scale stump harvesting is not yet a common practice, however the issue has gained more interest in forest management. Furthermore, in the light of the Paris Agreement 2015, the government of Estonia should ensure a significant reduction in the use of fossil oil shale and an increase in the share of bioenergy in the nearest future. This will obviously increase the demand for different sources of bioenergy and intensify the management of forests. However, large-scale stump harvesting should only be based on the results of relevant scientific research, considering also evaluation of different environmental risks related to stump harvesting. The first Estonian case study reporting preliminary results about the biomass and energetic value of harvested stumps and covering

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the issue of accompanying nutrient and carbon losses was published recently (Uri et al., 2015).

According to earlier studies, stump harvesting may lead to several positive effects. As stump harvesting acts as site preparation, (Saarinen, 2006; Berglund and Åström, 2007), it reduces the cost of cultivation of a new forest generation (Eriksson and Gustavsson, 2008). Stump removal may decrease pine weevil damage and infection by root pathogens (Hakkila, 2004; Vasaitis et al., 2008; Walmsley and Godbold, 2010), which improves the survival of the planting stock. However, some studies report possible negative environmental effects accompanying stump harvesting (Walmsley and Godbold, 2010; Eklöf et al., 2013; Uri et al., 2015). Stump harvesting operations caused large soil disturbance, which changed significantly the physical condition of the soils, affecting carbon and nutrient balance and the mineralization process (Walmsley and Godbold, 2010).

Considering the environmental effects of stump harvesting, special attention should be paid to nitrogen (N) cycling, since availability of N is one of the crucial factors limiting tree growth and photosynthetic activity in boreal forests (Luo et al., 2004). Most of inorganic N, available for plants uptake, is produced by the *in situ* net nitrogen mineralization (NNM) of soil organic matter (Tate, 1995). The NNM is one of the key processes of the N cycling in forest ecosystems, which is affected by many factors like tree species and soil disturbances, temperature, moisture, pH etc. (Zak et al., 1990; Tietema and Verstraten, 1992; Goodale and Aber, 2001; Lovett et al., 2002; Uri et al., 2008). Although NNM is an essential flux in the N cycle of boreal and temperate forests (Zak et al., 1990; Goodale and Aber, 2001; Andersson et al., 2002; Lovett et al., 2002; Uri et al., 2008), it has been found to be quite low in conifer stands (Nadelhoffer et al., 1984; Williams, 1992; Persson and Wirén, 1995). According to studies from Estonia, the conifer stand annual NNM flux ranges between 6 and 30 kg N ha^{-1} (Pajuste and Frey, 2003; Külla et al., 2004).

In relation to stump harvesting, it has been found that stump removal increases both NNM and nitrification already after one year of treatment (Kataja-aho et al., 2012). Compared to soil preparation (mounding), stump harvesting has a stronger impact on soil C and N dynamics through extensive soil disturbances (Kataja-aho et al., 2012). On the one hand, the increased NNM flux may lead to further losses of N through leaching or gaseous emissions unless it is utilized by trees or other vegetation (Piirainen et al., 2007). Increased N mineralization can have a positive effect on subsequent tree production through higher N availability (Kataja-aho et al., 2012). However, considering stump harvesting as an extensive soil disturbance, one should also bear in mind that most soil preparation methods for forest regeneration cause disturbances of the soil that affect its properties and functioning (Schmidt et al., 1996; Worrell and Hampson, 1997; Eisenbies et al., 2005).

The main aim of the present study was to estimate the short-term effects of Norway spruce stump harvesting on annual NNM and on the nitrogen and phosphorus leaching fluxes in different soils.

The working hypotheses of the present study were: (1) NNM will increase after stump harvesting in Norway spruce clear-cut as a result of soil disturbances; (2) stump harvesting may initiate larger nitrogen and phosphorus losses from the ecosystem due to increased leaching.

2. Materials and methods

2.1. Description of the study sites

Three Norway spruce clear-cut areas (named as Elva, Rõuge and Orguse) of different soil types were selected for the study (Table 1). All study areas were divided into four sites with an equal area: two control sites and two stump harvesting sites. The area of the sites varied between the study areas, being at 0.15–0.25 ha. In the Elva area the replicates were located in a "chessboard" pattern and in the other areas they were located alternately in one row (Uri et al., 2015). The data from the two harvested sites and the data from the two control sites were pooled and treated as "harvested" and "control". Clear-cutting was done at the end of 2010; logging residues were left on site and stump harvesting was carried out in October 2011. Selectively, only spruce stumps were harvested and the stumps of deciduous trees and pine stumps were left on site. For stump harvesting, a Pallari KH 160 stump extractor combined with a hydraulic excavator was used (Uri et al., 2015).

2.2. Soil

In all study areas 14 soil pits were dug to a depth of 1.0 m: seven pits (4 + 3) at the stump-harvested sites and seven at the control sites. All pits were located randomly along the diagonal traversing the site. The soil profile was described and the soil type was determined according to the WRB (2006). Soil texture was evaluated in the field using the texture by-hand-feel method. Soil bulk density samples were taken with a 50 cm^3 cylinder from different depth layers and dried (105 °C) to constant weight and weighed to 0.001 g. For chemical analyses, subsamples were taken from 10 random points at all study sites, i.e. 20 soil sampling points per treatment for each study area (Table 2). Sampling was done, using a soil corer (∅ 40 mm), from five depth layers to a depth of 50 cm. However, in the present study only soil data from the upper two soil layers (0–10 cm and 10–20 cm) were used. Samples from 10 random points were pooled to form three composite samples. Since all studied soils were fertile, no organic soil layer had been formed and sampling was done only from the mineral soil layers. Only in Rõuge area a thin fragmentary organic layer occurred in places. The site selection reflects the generally known silvicultural knowledge of spruce: this species thrives on deep, moist, well-aerated soils at nutrient rich sites.

2.3. Net nitrogen mineralization

The method with buried polyethylene bags was used to estimate *in situ* net nitrogen mineralization (NNM). The method is widely used and has been described in detail in many earlier studies (Eno, 1960; Adams et al., 1989; Hart et al., 1994; Uri

Table 1
Main characteristics of the study areas (Uri et al., 2015).

Name	Location	Study area (ha)	Soil type	Site type	Average stump diameter (cm)	Number of harvested stumps (ha^{-1})	Stock of harvested stumps (m^3 ha^{-1})
Elva	58°19′50.40″N 26°31′34.70″E	0.99	*Endogleyic Arenosol*	*Oxalis*	43	356	130
Orguse	59°4′17.3″N 26°21′51.6″E	0.64	*Endogleyic Cambisol*	*Hepatica*	39	239	63
Rõuge	57°42′33.90″N 26°45′20.70″E	0.5	*Endogleyic Albic Podzol*	*Myrtillus*	35	327	103