Forest Ecology and Management 325 (2014) 99–107

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Phosphorus export from drained Scots pine mires after clear-felling and bioenergy harvesting

Annu Kaila [a,b,*], Sakari Sarkkola [a], Ari Laurén [c], Liisa Ukonmaanaho [a], Harri Koivusalo [d], Liwen Xiao [f], Connie O'Driscoll [f], Zaki-Ul-Zaman Asam [f], Arja Tervahauta [a], Mika Nieminen [a]

[a] Finnish Forest Research Institute, PO Box 18, FI-01301 Vantaa, Finland
[b] University of Helsinki, Department of Forest Sciences, Forest Sciences Building, Viikki, PO Box 27, FI-00014 Helsinki, Finland
[c] Finnish Forest Research Institute, PO Box 68, FI-80101 Joensuu, Finland
[d] Aalto University School of Engineering, Department of Civil and Environmental Engineering, Water Resources Engineering, PO Box 15200, FI-00076 Aalto, Finland
[f] Trinity College Dublin, School of Engineering, College Green, Dublin 2, Ireland

ARTICLE INFO

Article history:
Received 13 December 2013
Received in revised form 7 March 2014
Accepted 12 March 2014
Available online 24 April 2014

Keywords:
Peatland forestry
Phosphorus
Water table level
Clear-felling
Whole-tree harvesting
Stump harvesting

ABSTRACT

We studied phosphorous (P) export after clear-felling from eight Scots pine dominated, hydrologically isolated catchment areas located on a low-P sorptive peatland site in southern Finland, using the paired-catchments approach. Four of the catchment areas were clear-felled traditionally with stem-only harvesting, two areas were clear-felled using whole-tree harvesting, and the remaining two areas were treated with both whole-tree harvesting and stump harvesting. The effect of clear-felling on P loads varied considerably between the catchment areas from no increase to an increase of over 1.5 kg ha^{-1} of P during the three-year-study period. The most significant factor explaining the variation in P loads and the variation in P concentrations in outflow water from clear-felled peatland catchments was the post-harvest water level position. At water table levels <20 cm below ground level (bgl), the P release from peat was greatly increased, and no influence was observed on P release at levels greater than 30 cm bgl. The water table depth explained about 50% of the variation in harvest induced P export, while the harvest method and the peat P sorption characteristics were not significant in explaining harvest-induced P loads or P concentrations after harvesting. The results of our study suggest that management of harvest residues may not be an efficient means of managing P export in operational forestry. In addition, forest management practices that do not lead to a rising of water table level near the soil surface in the entire harvest area, such as strip cutting and small-scale clear-cutting or harvesting small canopy openings, should be studied in order to reduce P export.

1. Introduction

About 15 million hectares (ha) of peat soils have been drained for forestry in temperate and boreal zones (Paavilainen and Päivänen, 1995). A large proportion of these forests are approaching harvestable age and the rate of forest clear-felling on drained peatlands is rapidly increasing. An increasing interest in the use of harvest residues (branches, twigs and needles) for bioenergy has led to peatland forests also being more intensively harvested. Whole-tree harvesting (WTH) has been increasing and even stumps, in addition to above-ground harvest residues, are gaining interest as a source of bioenergy (Kiikkilä et al., 2014). The phosphorus (P) export to lakes and rivers after harvesting may be substantially higher from peatland forests than from mineral soil forests. Finér et al. (2010), utilizing the available data from 9 mineral soil catchments from Finland and 5 peatland catchments from Finland and Sweden, estimated that the average P export from mineral soil forests during the first four years after clear-felling was 0.05 kg ha^{-1} year^{-1}, but the export from peatland dominated catchments was two-fold higher, 0.10 kg ha^{-1} year^{-1}. These estimations for peatland forests were based on the data from minerotrophic, Norway spruce dominated catchments (Lundin, 1999; Nieminen 2004), which generally have high P adsorption capacity (Nieminen and Jarva, 1996). Evidence from low productive Scots pine mires in Finland (Nieminen, 2003) and upland blanket peat catchments in Ireland (Rodgers et al., 2010) showed that the export of P following harvesting may exceed 1 kg ha^{-1} year^{-1}, where the peat has minor adsorption capacity against P leaching. However, enhanced P export after clear-felling has been shown to be relatively short-term, reaching its peak during the second year after

* Corresponding author at: Finnish Forest Research Institute, PO Box 18, FI-01301 Vantaa, Finland.
E-mail address: annu.kaila@metla.fi (A. Kaila).

http://dx.doi.org/10.1016/j.foreco.2014.03.025
0378-1127/

harvesting and largely diminishing after three to four years (Nieminen, 2003; Rodgers et al., 2010).

Harvest residues left on site in conventional stem-only harvesting are a potentially high source of nutrients to water-courses. While nitrogen (N) is mostly accumulated in harvest residues during the first few years after harvesting, P release begins during the early phases of decomposition (Asam, 2012; Kaila et al., 2012b; Palviainen et al., 2004). Rodgers et al. (2010) and Asam et al. (2014) in their studies on blanket peat catchments found significantly higher water extractable P concentrations in peat below harvest residues than from respective residue-free areas. Asam et al. (2014) also found two- to three-fold higher P concentrations in the outflow water from hydrologically isolated mini-catchments with harvest residues compared to the catchments without harvest residues. The harvest residues may increase P export to water courses not only through direct P release from the residues, but also because modern harvesting practises deposit harvest residues in distinct piles, where the variation in soil temperature and moisture are likely to be less than in pile-free areas, leading to increased mineralization of nutrients from the soil below harvest residue piles (Rosén and Lundmark-Thelin, 1987). Nutrient leaching beneath piles may also increase because vegetation re-establishment is restricted under piles and thus there is no plant uptake to inhibit nutrient leaching (e.g. Emmett et al., 1991; Rosén and Lundmark-Thelin, 1987; Titus and Malcolm, 1991; Wall, 2008). This evidence suggests that the removal of harvest residues could be an efficient means of decreasing P export to water courses from peat soils. In addition, more frequent machine travel due to harvest residue removal, and soil disturbance caused by stump harvesting, may increase soil erosion and thus increase the export of particulate P. However, management practices such as harvesting logging residues during the frozen soil period in winter and leaving the stumps alongside ditches intact, could be an efficient means to reduce erosion and subsequent particulate P export.

The aim of the present study was to quantify P export from drained Scots pine dominated peatland forests after clear-felling with the special aim to investigate the impacts of WTH and stump harvesting on P export. Earlier studies from Finland (Nieminen, 2004) and Sweden (Lundin, 1999) with minor P losses indicate that harvest residues may not be a significant source of P to water courses from fertile, minerotrophic peats due to their high P adsorption capacity. In contrast, Al- and Fe-poor ombro–oligotrophic peats with low P adsorption capacity may not retain much of the P released from harvest residues. In addition, low productive sites experiencing northern climatic conditions may not retain much of the nutrients released from harvest residues because the long dormant season and low soil nutrient levels delay the re-establishment of plant nutrient uptake (Tamm et al., 1974). We hypothesise that P export is different following WTH and stump harvesting compared to conventional stem-only harvesting.

2. Material and methods

2.1. Study site and treatments

The experimental study was carried out in Vilppula, south-central Finland (62°04′N, 24°34′E). The long-term (1960–1990) mean annual precipitation in the Vilppula region is 600 mm and the mean annual air temperature is +3.4 °C, with mean values of −8.4 °C in February and +16.8 °C in July. The average duration of the growing season, defined as the number of days with a mean temperature above +5 °C, is 164 d. During the study period (2007–2011), the annual precipitation ranged from 480 to 820 mm, and the mean annual temperature from 2.5 to 4.6 °C (Table 1). Weather data was obtained from a weather station in Jyväskylä, 70 km north of the study area. The station is operated by Finnish Meteorological Institute.

Table 1
Mean temperatures (°C) and sums of annual precipitation (mm year^{-1}) during the study period from Jyväskylä weather station operated by Finnish Meteorilogical Institute, 70 km from the study area.

	2007	2008	2009	2010	2011
February mean (°C)	−14.5	−2.5	−6.5	−12.0	−15.0
July mean (°C)	17	15	16	22	18
Annual mean (°C)	4.2	4.6	3.6	2.5	4.3
Precipitation (mm year^{-1})	613	819	479	552	732

The study site covers an area of about 10 ha. The peat layer at the site is at least 2 m thick and consists of moderately and highly decomposed *Sphagnum* peat with remnants of wood and *Eriophorum vaginatum*. The peat layer is underlain by clay soil.

In 2003, nine artificially delineated catchments were established by hydrologically isolating them from the surrounding peatland. A double-ditch was dug around the perimeter of each catchment area, and an earth embankment with an outflow pipe (∅ = 10 cm) was established in the outlet ditch of each catchment area for runoff quantity and quality monitoring (Fig. 1). All nine catchments were dominated by pure Scots pine stands (*Pinus Sylvestris* L.) with stand volumes ranging between 100 and 200 m^{-3} ha^{-1} (Table 2), and were classified as nutrient poor Dwarf shrub (Vatkg) site type group (Vasander and Laine, 2008). Before harvesting the ground layer was characterized by an abundant occurrence of *Ledum palustre*, and after harvesting, by the occurrence of *E. vaginatum*. The stands in the areas 1–4 were first generation Scots pine stands, and the stands in areas 5–9 were of the second tree rotation.

Peat soil analysis showed that catchment 1 (CC 1) was more fertile than the other catchments with higher values of N, P, Fe, and peat soil pH (Table 2). The phosphorus desorption–sorption behavior of the 9 areas was determined using P adsorption isotherms (Cuttle, 1983; Nieminen and Jarva, 1996) as follows. Dried and milled (∅ = 2 mm) peat samples from a depth of 0–20 cm were first moistened in the laboratory (+4 °C) for about a month, after which they (equivalent to 1 g dry weight) were added to bottles

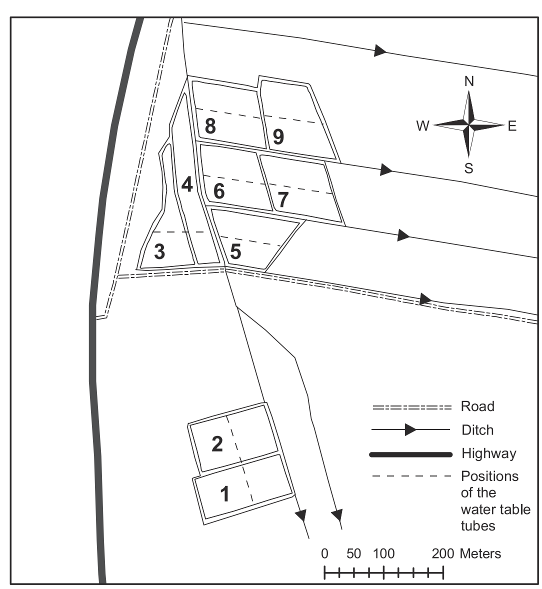

Fig. 1. Map of the 9 artificial catchment areas on drained peatland in Vilppula, southern Finland. The positions of the water table tubes (5/area) are indicated by dashed lines.