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SUFFICIENCY OF POTASSIUM (K) FOR WOOD PRODUCTION – LONG-TERM EFFECTS OF FOREST MANAGEMENT ON THE K-BALANCE OF DRAINED BOREAL PEATLANDS

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SUMMARY

Potassium (K) is often a minimum growth-limiting nutrient in boreal peatland forests, mostly on thick-peated sites, and its deficiency may decrease the vitality and growth of trees. Timber harvestings, particularly clear fellings by whole-tree harvesting (WTH), may result in significant K losses by removing not only the K in the stems as in stem-only harvesting (SOH), but also the K in branches, twigs, and needles. Furthermore, the forest harvestings as well as ditch network maintenance (DNM) treatments enhance the off-site hydrological leaching losses of K. Increased interest in bioenergy harvesting in peatland forests has created an urgent need to clarify, if forest management results in severe depletion of site K stores in peatland forests. Based on previous data and the results of our recent field experiments, we quantified the total K balance of drained *Pinus sylvestris* and *Picea abies* dominated peatland forests over the 80-year rotation period under the conditions typical for drained peatlands in Finland. The results showed that the loss of K induced by biomass removal in WTH plus stump harvesting was 2–5 times larger (75–97 kg/ha) than in SOH (15–30 kg/ha), even though –as typical in mechanized WTH with harvesters and forwarders- about 30% of the harvest residues were left on-site. In WTH without stump harvesting, the K-losses induced by biomass removal were about 50–65 kg/ha. About two thirds of the K removed along with biomass removal in WTH plus stump harvesting was in the needle and branch biomass and about 1one-third was in the stumps and roots. When adding to these removals the additional hydrological K-losses induced by harvesting (poor sites: 9 kg ha^{-1}, fertile sites: 28 kg/ha) and two DNM treatments (8.3 kg/ha/treatment), the background hydrological K losses (1–2 kg/ha/year), as well as considering the K input by deposition (ca. 1 kg/ha/yr.), the net total off-site K-loss in SOH was 30–40 kg/ha in poor sites and 135–155 kg/ha in fertile sites during the 80-year rotation period. Respectively, for WTH they were 50–75 kg/ha in poor sites and 160–210 kg/ha in fertile sites. When comparing these losses with the typical K-store in thick-peated soils (<100 kg/ha in the 50 cm-thick surface peat), it appears that, without significant additional K input through fertilization, the K stores are not sufficient to ensure satisfactory stand K nutrition during the development of the next stand generation. Avoiding WTH, i.e. the removal of harvesting residues, decreases the off-site K losses, but may not completely eliminate the risk for K depletion, particularly in fertile thick-peated peatland sites. If repeated K-fertilizations are needed to sustain forestry on these sites, their economic feasibility should be clarified.

Keywords*: K-loss, forestry, whole-tree harvesting, leaching*

INTRODUCTION

For plants, potassium (K) is an important macronutrient participating in nutrient transport, function of the stomas in leaf cells, as well as syntheses of protein, starch and energy compounds in cells (Mengel & Kirkby 2001). Thus, it has considerable effects on tree growth and vitality. In mineral soil sites, K is rarely a minimum nutrient, because of mostly large availability of K from stores in the mineral soil and bedrock such as clay minerals. However, in boreal peatlands, particularly on thick-peated sites, it is often a minimum growth-limiting nutrient and its deficiency may widely decrease the vitality and growth of trees (Finér 1989, Laiho & Laine 1995, Hoosbeek *et al.,* 2002, Westman & Laiho 2003).

Growth losses caused by K-deficiencies may be particularly significant for forestry on drained peatlands reclaimed for timber production. It has been estimated that in Finland, on about 1 M hectare of drained forested peatlands, i.e., ca 20% of the total drained area, tree stands are suffering from K-deficiency (Moilanen *et al.,* 2010). This is because the K stores in the rooting zone of peat, especially in sites that were originally very wet and sparsely forested, are generally small (Kaunisto & Tukeva 1984, Saarinen 1997, Laiho *et al.,* 1998), and the relatively high supply of nitrogen (N) in peat increases the demand of potassium and other nutrients so that the available K-stores are insufficient (Tripler *et al.,* 2006). Most of the sites with K-deficiency are dominated by Scots pine (*Pinus sylvestris*) growing on ombrotrophic and poor minerotrophic sites, whereas risk of K-deficiency may also occur on more fertile sites, where the dominant tree species is usually Norway spruce (*Picea abies*) with varying mixture of downy birch (*Betula pubescens*).

On thick-peated sites, most of the K-stores in the ecosystem are bound in the tree biomass, and forest harvestings, particularly clear fellings by whole-tree harvesting (WTH), may result in significant K-losses. In this method not only the potassium in the stems as in stem-only harvesting (SOH), but also that bound in branches, twigs, and needles are removed. Furthermore, the forest harvestings as well as ditch network maintenance (DNM) treatments enhance the off-site hydrological K-losses (Joensuu *et al.,* 2002). Atmospheric deposition does not necessarily provide a sufficient input of potassium to compensate for the losses caused by forestry treatments. Other natural K-supplies are also small in thick-peated sites.

Interest in the use of wood-based fuels for bioenergy is drastically increasing and the increased demand may lead to intensified harvesting also in in this kind of peatland sites. This has created an urgent need to clarify, if forest management results in severe depletion of site K-stores in peatland forests

Our study aim was to quantify the total K-balance of drained nutrient poor Scots pine and fertile Norway spruce dominated forest stands over the 80-year stand rotation period in drained peatlands in Finland. For balance calculations and simulations, the input data of the potassium amounts in the stand biomass, surface vegetation, peat and harvest induced K losses were obtained from the previous data and the results of our recent field experiments. The premises for the calculations were that the stands were harvested by clear fellings (stem-only harvesting vs. whole tree harvesting + stump removal) and ditch network maintenance was carried out twice during the stand rotation.

MATERIALS AND METHODS

We quantified the K-balance components of average Scots pine and Norway spruce dominated stands on ombrotrophic and minerotrophic drained peatland sites using the input data from the following studies:

For spruce peatlands, the total potassium bound in the biomass and the removal of potassium in harvested biomass in WTH and SOH harvesting treatments were estimated by using biomass estimates by Nieminen *et al.* (2016) and for pine peatlands, the respective estimates were done by applying equations of biomass and nutrient contents presented by Laiho (1997). Nieminen *et al.* (2016) presents biomass measurements and nutrient stores in an experimental Norway spruce stand located in southern Finland. The have estimated the biomass and nutrient removals in clear-cuttings by conventional stem-only harvesting (SOH), where only the stems down to a diameter limit of 7 cm were removed and in whole-tree harvesting (WTH), where the harvest residues (needles, branches, twigs) were collected following SOH. Additionally, in the most intensive WTH treatment, both the cutting residues as well as the stumps (stump + coarse roots) were harvested.

In the study of Laiho (1997), stand-level biomass and nutrient content regression equations were presented for above-ground tree components in Scots pine dominated drained peatland stands. The equations were based on detailed biomass sampling of 80 sample trees from six sample stands located in southern Finland, and generalization of the allometric relationships to stand level based on diameter, height, and crown height measured for all trees.

The additional leaching of potassium caused by forestry treatments was estimated for ditch network maintenance (DNM) and regeneration harvesting (clear felling) treatments: For DNM, the K-export estimates presented by Joensuu *et al.* (2002) were used. The estimates are based on the long-term monitoring of element exports from 40 drainage areas throughout in Finland.

For regeneration harvestings, the K-losses were quantified for SOH and WTH treatments from 17 experimental catchments in southern and central Finland (Sarkkola *et al.* unpublished). The ditch-outflow K-concentration and water-borne K-export data were analysed by using calibration-period control area method and regression modelling. The K-concentrations and runoff were monitored for 1–2 years before and 3-4 years after treatment and the duration of the harvest impact on K export were estimated by utilizing data from one pair of managed and non-managed catchment. Furthermore, the background K-export (off-site export without the treatment impact) was also quantified.

Finally, the airborne annual deposition of potassium i.e. the external K-input to ecosystem was determined according to the estimates presented by Ruoho-Airola (2003). Other possible K-inputs such as fertilizations, mineralization and moving from surrounding mineral soil sites were neglected from the calculations. Particularly in thick-peated sites, on which we were concentrated in these calculations, the source of potassium from mineral soils can be considered extremely small.

The simulations of the annual changes in the stand K-contents were calculated to the rotation period of 80 years and it was started from stand regeneration treatment with eight year post-harvest period, when the treatment has significant impact on the K-exports. DNM treatment was carried out two times during the rotation period, which is following the widely used forestry practice in Finland. Otherwise, the annual K-losses were expected to be at the given background level with constant K- input of the atmospheric deposition.

RESULTS AND DISCUSSION

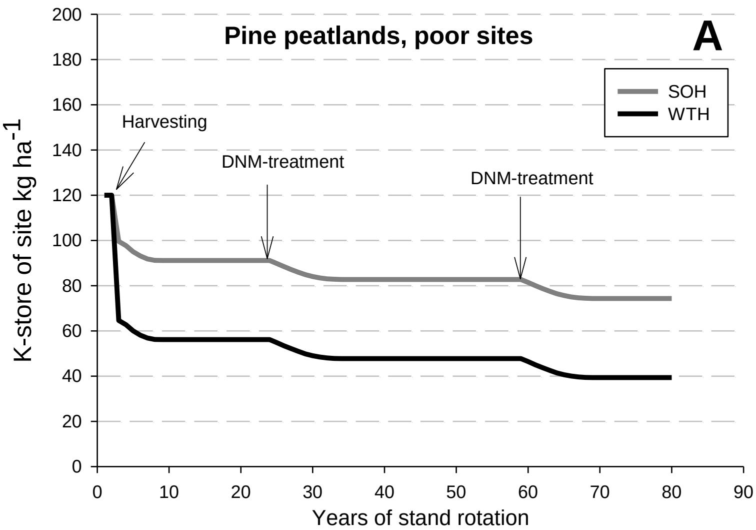
The loss of potassium induced by biomass removal in WTH plus stump harvesting was 2-5 times larger (75–97 kg/ha) than in SOH (15–30 kg/ha). This was evident even though – as is typical in mechanized WTH with harvesters and forwarders - about 30% of the harvest residues were left on-site (Nurmi 2007, Hytönen and Moilanen 2014). In WTH without stump harvesting, the K-losses induced by biomass removal were about 50-65 kg/ha. About two thirds of the potassium removed along with biomass removal in WTH plus stump harvesting was in the needle and branch biomass and about one third was in the stumps and roots. For the patterns of temporal changes in K-stores in poor and fertile sites, see Fig. 1.

When adding to these removals the hydrological K-losses induced by harvesting (poor sites: 9 kg ha^{-1}, fertile sites: 28 kg/ha) and two DNM treatments (8.3 kg/ha/treatment), the background hydrological K losses (1–2 kg/ha/year), as well as considering the K input by deposition (ca. 1 kg/ha/yr.), the net total off-site K-loss in SOH was 30–40 kg/ha in poor sites and 135–155 kg/ha in fertile sites during the 80-year rotation period. Respectively, for WTH they were 50–75 kg/ha in poor sites and 160–210 kg/ha in fertile sites. When comparing these losses with the typical K-store in peat in thick-peated soils (<100 kg/ha in the 50 cm-thick surface peat), it appears that without significant additional K-input through e.g. fertilization, the K-stores are not sufficient to ensure satisfactory potassium status in trees during the development of the next stand generation.

It has been widely known that the originally wet and treeless or sparsely forested nitrogen-rich minerotrophic sites are potential K-deficiency risk areas due to their very low K-contents in peat (Kaunisto and Paavilainen 1988). However our calculations showed that even in sites earlier considered to have high applicability for whole-tree harvestings such as thick-peated fertile spruce peatlands (Päivänen & Hånell 2012), the K-stores in site may decrease too much for undisturbed stand growth, if the harvesting residues are removed together with stem wood. Avoiding WTH decreases the off-site K-losses, but may not completely eliminate the risk for K depletion, however. The risk of severe K-depletion caused by WTH may even be larger in fertile thick-peated sites than in poor ones even though the K-stores in peat are generally larger (Figure 1). This is because in spruce stands, proportionally larger amount of potassium is bound in the tree biomass than in pine stands, and the annual background K-loss exceeds the simultaneous input of deposition to the ecosystem.

CONCLUSIONS

Our data showed that the thick-peated sites may have large potential for sever K-depletion irrespective of their fertility. It is evident that in such sites, where the K-stores in peat are larger than the net removal, the K-stores are sufficient to ensure productive forestry also if stands were managed by intensive WTH-treatments. Thus, it would be important to develop tools to recognize better the potential risk areas of anticipated K-deficiency in the field. Respectively, if repeated K-fertilizations are needed to sustain forestry on these sites, their economic feasibility should be clarified before initiation of regeneration activities in drained peatland forests on a large scale.



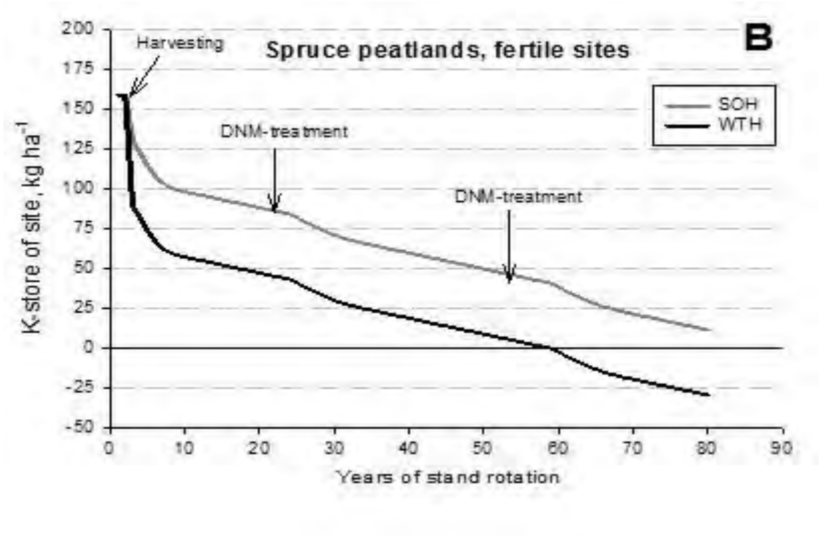


Figure 1: The simulated effects of forest management treatments on the K-balance on poor Scots pine dominated forest sites (A) and on fertile Norway spruce dominated sites (B) on drained peatlands in Finland during the 80-year stand rotation period. For poor sites (A), the initial K-contents were set to be: Peat (0-20 cm): K 50 kg/ha, surface vegetation 20 kg/ha and the K-content of tree stand: 48 kg/ha. For fertile sites (B), the respective K-contents used as initial values were 80 kg/ha, 20 kg/ha and 60 kg/ha. The off-site K-leaching induced by cuttings and ditch network maintenance as well as background K leaching and atmospheric deposition were also taken into considerations as described in the text. SOH=stem-only harvesting; WTH=whole-tree harvesting.

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