BIOMASS AND BIOENERGY 54 (2013) 250–259

Available online at www.sciencedirect.com

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Carbon and nutrients of Scots pine stands on sandy soils in Lithuania in relation to bioenergy sustainability

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ARTICLE INFO

Article history:
Received 9 May 2012
Received in revised form
15 March 2013
Accepted 20 March 2013
Available online 13 May 2013

Keywords:
Scots pine
Pinus sylvestris
Aboveground biomass
Forest bioenergy
Carbon
Nutrients

ABSTRACT

Sustainable forestry is based on the principle that harvesting practices should avoid negative influence on soil fertility, wood production and long-term soil carbon (C) stocks. We examined C and nutrient concentrations and stocks of Scots pine (*Pinus sylvestris* L.) stands on *Arenosols* in south-western Lithuania. The stands were 10, 20, 40, 50 and 65 years of age. C concentrations were relatively constant, while the concentrations of N, P, K, Ca, Mg and S often varied between compartments and stand ages.

The total aboveground stocks of nitrogen (N) were estimated to be in the range of 185–260 kg ha^{-1}, and 78–189 kg ha^{-1} for calcium (Ca), 75–104 kg ha^{-1} for potassium (K), 22–33 kg ha^{-1} for phosphorus (P), 21–41 kg ha^{-1} for magnesium (Mg) and 16–28 kg ha^{-1} for sulphur (S). Corresponding stocks of the crown alone were 139–207 kg ha^{-1} of N, 54–88 kg ha^{-1} of Ca, 44–79 kg ha^{-1} of K, 15–26 kg ha^{-1} of P, 15–23 kg ha^{-1} of Mg, and 11–15 kg ha^{-1} of S. Biomass, C and nutrient stocks in the crown did not change with age, whereas the stemwood stocks increased with stand age. The total removals of C and N over a whole 100-year rotation were simulated to be 129 Mg ha^{-1} and 449 kg ha^{-1}, respectively. An example scenario was created to compare the magnitude of potential nutrient removals with the atmospheric influx, soil stocks, and the internal litterfall flux. We suggest that intensified utilisation of these stands for bioenergy may be sustainable.

1. Introduction

The use of forest fuel is continuously increasing in the European Community, especially in the Nordic-Baltic region [1]. The substitution of fossil fuel with renewable biomass in energy consumption decreases the emissions of greenhouse gases to the atmosphere and mitigates the global warming. The use of renewable biomass may also increase the security of energy supplies and diminish the dependency on imported non-renewable fossil fuels. Forests may contribute significant amounts of biomass fuel for energy production [2], but the practices introduced for this purpose may jeopardise the

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http://dx.doi.org/10.1016/j.biombioe.2013.03.034

sustainability of the forest management which is implemented through legislation and sometimes voluntary forest management certification.

Various practices are used in the Nordic and Baltic countries. Sweden and Finland typically harvest the logging residues for energy, while whole-trees from thinnings are more often used in Denmark [3]. Harvesting of stumps for energy is increasing in Finland and Sweden (see e.g. Ref. [4]). Harvest of the logging residues for energy is the most common of these practices in Lithuania [5]. The utilisation of logging residues increases the removal of the nutrients from the forest ecosystem considerably since the nutrient rich branches are exported in addition to stemwood. Branches, needles and tops have higher concentrations of the nutrients than the merchantable stemwood. If all logging residues are removed from the forest, the amount of nutrients lost due to biomass removal has been calculated to increase by 1.5–5 times compared to traditional stemwood harvesting [6–8]. These harvesting practices also reduce the input of organic matter to the soil and thereby the short-term, and possibly also the long-term, carbon (C) stocks in the soil [9,10].

Sustainable forest management should be based on the principle that harvesting practices avoid negative influence on soil fertility, wood production and long-term soil C stocks. Effects vary from site to site [11], but for example a series of field experiments from Finland, Norway, and Sweden demonstrate average yield reductions of 5–6% in Norway spruce and Scots pine stands 10 years after harvesting of whole-trees in thinnings [12]. Growth reduction has also been recorded in the field experiments after removal of logging residues [13], and such effects are also of concern when stumps are harvested [14]. Most often the growth reductions are attributed to the reduced input of nitrogen (N) that would otherwise become available from the decomposing residues, but on some site types, the decreased input of other nutrients may also be involved [11]. Nutrient removals may to a varying extent be compensated by natural mineral weathering, but the natural soil weathering is not always able to compensate the loss of base cations [8,15]. Some nutrients may also be added with atmospheric deposition [16].

In many countries, particularly in Scandinavia, many studies were performed to clarify how the intensified removal of biomass for biofuel could influence the forest ecosystems. Presently, there is a lack of data from the long-term studies, which demonstrates if, and under which conditions, and increased removal of biomass affects the productivity of the stand or negatively affects the nutrient pools of the soil [17–19]. The longest time series exist for spruce stands where the effects of the brash removal in thinnings and final fellings were studied for 10–20 years, but the studies do not fully uncover the causes behind the observed changes [20–23]. Long-term experiments are often too expensive to test if soil nutrient depletion or growth loss will take place. Estimates of nutrient balances can be useful to indicate if a depletion of nutrients will take place when more biomass is harvested [8]. Estimates of reduced organic matter inputs to the soil may also be used to model the development in soil C pools (e.g., [24]).

Scots pine stands occupy more than 35% of the total forest area in Lithuania, and more than half of these stands (about 57%) grow on poor sandy soils of a normal moisture regime [25,26]. Biomass and chemical composition of Scots pine trees and stands were only scarcely studied in Lithuania [27,28].

These types of stands are potential objects for forest fuel harvesting, and environmental consequences need to be evaluated, e.g. by setting up nutrient balances and modelling the development in soil carbon (C) contents. As an input to such evaluation tools, our study focused on the estimation of biomass and nutrient removals in Scots pine stands on nutrient poor sandy soils in Lithuania. The study continues a study on the aboveground biomass for Scots pine in Lithuania [29]. More specifically, the objectives were to evaluate the concentrations and stocks of C and the main macronutrients (N, P, K, Ca, Mg and S), of the aboveground biomass compartments for Lithuanian Scots pine stands of different stand ages. We also assessed the potential removal of C and nutrients due to forest fuel extraction.

2. Material and methods

2.1. Site description

The study was carried out in Kacergine in south-western Lithuania (54°50′–54°55′ N, 23°40′–23°43′ E) at the land of Dubrava Experimental and Training Forest Enterprise. The parent material in this area was glaciolacustrine plain (elevation 75–90 m a.s.l.) overlying glaciofluvial sand from the Riss-Wurm (Weichselian) glaciation. The mean annual temperature was 6.5 °C and the mean annual precipitation was 686 mm.

Five Scots pine (*Pinus sylvestris* L.) stands of different age (10, 20, 40, 50, and 65-year-old) were selected subjectively to represent typical Scots pine stands within this area (Table 1). The five stands were all located within a radius of about 2 km.

All plots, except the 10-year-old stand, were planted on arable land. The forest type was *Pinetum vacciniosum* for all plots, and the forest site type was Nb – oligotrophic mineral soil of a normal moisture regime, according to the Lithuanian classification [30]. The soils were classified as well-drained *Haplic Arenosol* and consisted of coarse sand with low (<5%) clay + silt content [31,32].

To provide basic information about the soil, soil samples of the organic layer and mineral horizons (0–100 cm) were removed. Three composite samples were combined from 6 subsamples collected systematically in each sample plot (the

Table 1 – Main characteristics of the sampled Scots pine stands.

Age, y	Tree number ha^{-1}	DBH[a], cm	Mean height, m	Basal area, $m^2\ ha^{-1}$	Volume, $m^3\ ha^{-1}$
10	2893	6.8	5.1	10.4	47.6
20	2000	11.0	8.5	18.9	89.9
40	1498	14.3	14.8	24.0	174.4
50	915	20.7	18.8	30.8	277.6
65	727	23.2	20.9	30.7	305.7

a DBH: diameter at breast height (1.3 m above the ground).