Review
Toward the rational use of forest biomass: Lithuanian case study

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ABSTRACT: This paper contains the information about some principles of sustainable forestry which are still relevant in the world. In 2002, Lithuania started research on the nutrient balance in forest ecosystems when the forest fuel is harvested. The consequences of the intensive forest fuel harvesting on the forest ecosystem were analysed. At the same time, the experiment on the compensatory wood ash fertilizing was established in Lithuania. After the initial calculations, having the experimental data, the Ministry of Environment of the Republic of Lithuania has initiated the preparation of the Recommendations for compensating wood ash fertilization in the forests. This review briefly systematizes and analyses the main results of the related research and some ideas for the future studies are also presented.

Keywords: forest fuel harvesting; nutrients; wood ash; fertilization; environmental restrictions

The bioenergy sector covers several aspects, ranging from consumer safety to the mitigation of climate change. Some economists are of the opinion that the forest residues as an energy source have a positive impact on both ecological and economic conditions (Sadauskienė et al. 2011) while ecologists more unambiguously discuss about the consequences of biomass harvesting for the surrounding environment. At present, the extraction of forest residues (branches, needles, tops) is predicted to increase in all the European Union. In Lithuania, fuel wood also constitutes a significant amount of the primary energy sources nowadays. The amount of wood residues is increasing due to an increase in production in the wood processing industry; also forests are harvested more and more intensively. Each year, about 30% of the biomass is left on clear felled sites (Kairiūkštis, Jaskelevičius 2003). It is clear that this amount can be used as fuel wood in the future. Still, there is a possibility to increase the utilization of wood for energy up to 5 million m^3 in Lithuania, and this could give about 25–30 thousand tons of wood ash per year. As the ash-waste problem is becoming more urgent, one of the decisions could be to recycle ash to the forest. Although Lithuania is a relatively small area, the country's forest coverage is 33.2%. Researchers analyse and solve the problems of harvesting forest fuel locally, rather blindly apply the Northern and Western European models. Since 2002, Lithuania has carried out several studies aiming to identify and analyse the chemical composition of tree biomass, nutrient stocks in different compartments of tree biomass, element accumulations in soils, influxes from the precipitation, etc. (Miksys et al. 2007), and to investigate the ecological effects of forest fuel (wood) ash fertilization on the forest ecosystem (Ozolincius et al. 2005; 2006; 2007a–c; Karltun et al. 2008). Finally, summarizing large databases of experimentally collected data, including the impact of additional environmental factors, the recommendations for ash recycling to the forest managers were prepared. These guidelines were primarily based on the risk assessment of different forest ecosystems and their mitigation, in order to guarantee any measure of environmental friendliness.

Several intensive experiments were carried out in Lithuania in order to evaluate the ecological consequences of forest fuel harvesting on the forest ecosystem (Armolaitis et al. 2008; Raulund-Rasmussen et al. 2008). Some studies aimed to clarify how to reduce the damage to forest ecosystems by introducing some specific environmental restrictions or recommending fertilization of forests with fuel ash (Ozolincius et al. 2004, 2005, 2006, 2007a–c; Karltun et al. 2008, etc.).

The aim of this paper is to summarize and analyse the Lithuanian case studies on the aboveground tree biomass, nutrient losses induced by stem-only and whole tree harvesting, which have been carried over the past 10 years. Also, this brief overview gives the possibility to find the main material of the wood ash fertilization experiments carried out in Lithuania. The article ends with the review of the Recommendations for compensating wood ash fertilization that allow such activities for commercial forests of Lithuania.

The starting point: ecology vs. economics

The use of biofuel depends on several factors: fossil fuel (oil, natural gas and coal) prices, government policy, in some cases it becomes an urgent issue. During the Soviet years (in Lithuania, this period lasted until 1990), while the gas and oil were cheap, the biofuel heating was not intense in Lithuania. The biofuel use was mostly concentrated in private houses usually in the rural areas, where was no central heating. There was an opinion that even the use of waste fuels from the timber industry was uneconomic (Sadauskienė et al. 2011). Recently, the use of fuel wood increased due to the increasing prices of the imported energy sources, also implementing the target to become an independent country of the imported fuel. Biomass and waste, water, solar or wind energy for heat and electricity production are factors determining sustainable development, and also the implementation of the Climate Change Convention and Kyoto Protocol commitments. Lithuanians are convinced that the country has a sufficient scientific, technological and industrial potential for renewable energy development (Kairiūkštis et al. 2003). For instance, in 2010 the available land area for biomass production for the energy sector was more than 500 thousand hectares, and in the next 10 year-period this area is predicted to increase (Energy Agency 2011).

Lithuania has an obligation that the energy from renewable sources in the gross final consumption of energy for 2020 will not be less than 23% (Directive 2009/28/EC). In 2009, renewable energy resources accounted only for 18% of the general energy. Lithuania mostly focuses on the renewable energy sources such as water, wind and biomass. Usually the use of the renewable energy sources faces the market barriers, i.e. high initial investment or competitiveness of new technologies with the old ones. However, in the long term, local renewable energy resources bring economic benefits.

In 2010, biomass and biomass power plants produced 13% of electricity from total electricity produced from renewable energy sources in Lithuania. However, biomass is the most valuable in heat production. The use of biomass in the heating sector was 19% in 2009, while the goal for 2020 is about 70%. The biomass use in the heating sector does not grow rapidly because the number of well-equipped boilers for biomass is still insufficient.

In some cases, we also have the inefficient use of biomass, i.e. about 70% of individual houses still use forest fuel only for the household heating.

Approximately 82% of total biomass is accumulated in forests. The main biomass resources are firewood, waste from the wood processing industry and logging residues.

Potentially about 2.5 million m^3 of logging waste (branches, tops, stumps and roots) are produced in clear-cuts according to State Forest Service data. However, because of various environmental requirements and technological aspects, now it is possible to extract about 750 thousand m^3 of this amount and to use it in the energy sector (Sadauskienė et al. 2011).

From environmental aspects, the expansion of the consumption of primary biomass for bioenergy causes an increased export of nutrients from the forest. The second point is related to the increased production of fuel wood wastes, i.e. ash. It raises a double ecological problem.

The loss of nutrients from the forest ecosystem increases considerably, since the exported fractions of branches, needles and tops have higher concentrations of nutrients than the stem wood (Lundborg 1998; Skogsstyrelsen 2002; Armolaitis et al. 2008). Removal of all residues from the forest ecosystem (in the case of clear felling) causes various changes (Skogsstyrelsen 2002; Varnagirytė 2006; Ozolinčius et al. 2011, etc.). First of all, the reduction of organic matter and carbon stocks in soil may decrease soil fertility. Further, the decrease of stand biomass and amount of litterfall induces the formation of thinner and more acidic forest floor and mineral soil layers, changes in the nutrient balance. Therefore, the changes of vegetation species, weed growth, climatic conditions may reduce the productivity of forest stands. Further consequences may be associated not only with vegetation changes but also with the reduction of the number of insect species, also declining forest biodiversity: undergrowth, deciduous trees, tree species with edible fruits disappear from the ecosystem. It is also possible that certain mechanical soil damage occurs: heavy forest machinery compresses the soil, the soil loses its natural structure. Forest seedlings can also be mechanically damaged and this can disturb natural forest regeneration. Incorrectly stored forest residues from logging can become a place for pest outbreaks, etc. The abovementioned observations were widely discussed in literature (Olsson et al. 1996; Egnell et al. 1998; Lundborg 1998a; Jacobson et al. 2000, Egnell 2011, etc.).

Chemistry of aboveground biomass, potential nutrient losses and consequences

The study of the aboveground biomass was focused on the estimation of biomass removals and nutrient budgets for Scots pine on nutrient poor soils in Lithuania (Miksys et al. 2007; Armolaitis et al. 2008; Raulund-Rasmussen et al. 2008). Until then, in Lithuania there was not much data on biomass and chemical composition of Scots pine trees and stands and such studies were carried out very episodically (Vaičys 1975). Thus, recent studies have been designed and conducted on the basis of modern methods, and were relevant at wide gradient, i.e. from the local to the regional scale. Some ideas of the experiments, the problems and their solutions can be successfully adapted in other countries where soil conditions and forest sites are similar to Lithuania.

Studies aiming to estimate the chemical composition of the aboveground biomass and evaluate the stores of carbon (C) and some macronutrients (N, P, K, Ca, Mg and S) were carried out in 2003 in the south-western part of Lithuania (54°50'–54°55'N, 23°40'–23°43'E). Five Scots pine (*Pinus sylvestris* L.) stands of 10, 20, 40, 50, and 65 years of age were selected subjectively to represent typical Scots pine stands within this area. The forest site type was oligotrophic mineral soil of normal moisture levels (Nb), the forest type according to the Lithuanian classification was *Pinetum vacciniosum* (Vaičys et al. 2006) and soils were classified as well-drained Haplic Arenosol (Buivydaitė et al. 2001; FAO/UN 2006). These characteristics were typical of Scots pine stands which comprise over 35% in Lithuania. Aboveground biomass samples (needles, living and dead branches, stem wood and bark) were chemically analysed with the purpose to estimate total tree biomass and nutrient contents. The main results of this study showed that in the Scots pine stands of 10–65 years of age, the concentration of organic C in different aboveground compartments was about 49–52% (Armolaitis et al. 2008). The highest concentrations of N, P and K were found in needles, Mg – in needles and bark, Ca – in bark. With the increasing stand age, Scots pine crown (tops, living and dead branches with needles) biomass was about 23–33 $t \cdot ha^{-1}$ DW. The difference was found for the stores of C and other macronutrients (N, P, K, Ca, Mg and S) in the stem which increased due to the stem biomass increment.

The stores of N, P and K in the aboveground Scots pine biomass were 185–260 $kg \cdot ha^{-1}$ of N, 22 to 33 $kg \cdot ha^{-1}$ of P and 75–104 $kg \cdot ha^{-1}$ of K and varied little with the increasing stand age. On the basis of these data and calculation results, the potential carbon and nutrient losses due to fuel wood extraction were also calculated (Armolaitis et al. 2008). The study only confirmed the results that when forest fuel is extracted in Scots pine stands, during the main forest management operations (thinnings at 30, 50 and 70 years of age, sanitary fellings in 80–90-years-old stands), an additional amount of nutrients is removed. It increases 2–3 times. Over a relatively long period of 100 years (one rotation) about 450 kg N, 260 kg Ca, 170 kg K, 70 kg Mg, 50 kg P, and 40 kg S per 1 ha could be lost with felling residues and stems. The nutrient removal with forest fuel comprises 280 $kg \cdot ha^{-1}$ of N, 25–30 $kg \cdot ha^{-1}$ of each, S, P and Mg, and 100 to 110 $kg \cdot ha^{-1}$ of K and Ca (Armolaitis et al. 2008).

Organic C and nutrient losses due to the forest fuel extraction in Scots pine stands during 100-year rotation were compared with nutrient pools in Arenosols, also influxes with forest floor and atmospheric depositions (Armolaitis et al. 2008). The results of this comparison showed that deposition compensated main nutrient losses, also during 100-year rotation the return of the nutrients with litterfall by 4–10 times exceeds the nutrient removal with forest fuel. All losses of the nutrients during a 100-year period were not high, i.e. for Mg, P and K losses were less than 2%.

In general, we emphasize the term ecology only if it comes to the conclusion that the biofuel burning reduces the greenhouse gas emissions. But explaining in more detail, the potential consequences to the ecosystem could occur when all logging residues are extracted for several years or decades. Therefore it is important to discuss the rational use of forest resources and future forest productivity.

Experimental wood ash fertilization

According to the idea of the sustainable removal of biomass from the forest followed by balanced nutrient cycle, in Lithuania some experiments based on the compensatory wood ash fertilization were carried out in Scots pine stands. The wood ash experiment was established in 2002 with the purpose to provide relevant knowledge, to synthesize the knowledge of a design of wood ash experiments and practical wood ash recycling. For the compensation of the nutrient loss, the ash dosage was calculated by a nutritional balance method. Ash was applied with the addition of nitrogen (N), which is often missing in ash. The wood ash doses from 1.25 to 5 $t \cdot ha^{-1}$ were applied, 180 $kg \cdot ha^{-1}$ of N and the complex treatment of 2.5 $t \cdot ha^{-1}$ ash together with 180 $kg \cdot ha^{-1}$ of N were used. From the scientific perspective, the most important points were to realize the effects of the maximum (5 $t \cdot ha^{-1}$) ash dose and the comparison between the pure ash and complex ash plus N treatment.

Samples of soil, soil solution, fine roots and mycorrhiza, microbiota, ground vegetation, foliage, throughfall, litterfall and tree biomass were collected, also tree growth was measured. It is possible to find a number of published results from this experiment based on wood ash application to the forest, some of them, unfortunately, are published in the original language (Ozolincius et al. 2005; 2006; 2007a–c; Varnagirytė 2006; Karltun et al. 2008). More recent data aiming to clarify the long-term effects on the ecosystem is still unpublished.

The most detailed description of the Lithuanian ash experiment was given by Ozolincius et al. (2007b). The obtained results showed that the O horizon had a high capacity to ash alkalinity and divalent cations and prevented penetration to the mineral soil. However, the addition of wood ash resulted in leaching losses of K^+ and Mg^{2+}. Leaching of N occurred after the application of N fertilizer. The effects of wood ash on Scots pine needle chemistry did not show nutrient imbalances, except for an increased uptake of Ca after N addition.

Significant ash effects on heavy metal (Cr, Ni, Cu, Zn) contents in the O-horizon, and significant downward transport after two years for Zn and Ni were found (Ozolinčius, Varnagirytė 2005; Varnagirytė 2006). The wood ash application increased the concentrations of Cd, Pb and Zn in the current year needles.

Wood ash significantly reduced the coverage of the moss layer (Ozolinčius et al. 2007a), while it was not unexpected that the higher ash dose gave the higher response. Some small changes after N addition were fixed in the mean coverage of the vascular plant layer. There was no significant impact on the biomass of mosses. The application of maximum (5 $t \cdot ha^{-1}$) ash dose significantly ($P < 0.05$) increased the concentrations of P, Ca and Mg in the *Pleurozium schreberi*, and the higher concentrations of N were detected after the treatment with 180 $kg \cdot ha^{-1}$ of N.

According to Ozolincius et al. (2007c), the study based on the effects of wood ash and nitrogen fertilization on Scots pine crown biomass, raised the hypothesis that wood ash applied together with N fertilizers could give an extra response in the tree crown growth compared with ash and pure N treatment. The published data highlights the idea that N significantly increased the biomass of the current and one-year old shoots and needles but no changes were found in the older parts of the crown. However, the effect of wood ash was insignificant. The mass of the current and one-year old year needles increased only in the top sections of the crown. When wood ash was added in combination with N, an extra response in the crown expansion, especially in the top and middle sections, was determined. In conclusion, it was stated that the wood ash fertilization in combination with N could be preferably proposed rather than the application of ash or N alone.

This short-term ash fertilization experiment, which was carried out in Lithuania, had a few drawbacks: there is still a lack of long-term data, the effect of another type of ash (for example stabilized ash) has not been studied, no data from other sites with different soil fertility and moisture are available. Nevertheless, summarizing the main implemented ideas and following some general trends, the guidelines for wood ash recycling in the forest at a country level were prepared.

Practical wood ash recycling: what is recommended in Lithuania?

Preliminary Recommendations for compensating wood ash fertilization were prepared in 2006. Further, successfully investigating and analysing the effects and consequences, also in accordance with the experience of foreign countries, revised and more detailed recommendations were republished in 2011 (Ozolinčius et al. 2011). This work was carried out aiming that compensatory wood ash fertilization should guarantee sustainable forestry based on the following requirements: the loss of essential nutrients after the forest fuel extraction should be fully recycled; and the content of heavy metals in wood ash should not exceed the amount of heavy metals in removed forest fuel. According to geographically broader, i.e. Scandinavian and Baltic experience (Skogsstyrelsen 2002; Andersson, Budrys 2003; Stupak et al. 2007), some of the indicators and measurements were adapted for Lithuanian conditions. Recommendations highlighted that the quality of forest fuel ash should be defined by minimal concentrations of the plant essential macronutrients (K, P, Ca and Mg) and maximal concentrations of heavy metals (Ozolinčius et al. 2011). Also the presence of radionuclides and polyaromatic hydrocarbons in ash diminish its quality.

Wood ash stabilisation requirements were also defined. Lithuanian ash recycling guidelines stated that raw or non-stabilized forest fuel ash is more risky to the forest ecosystem because it could intensify the leaching of chemical substances, cause the immediate effect on ground vegetation and soil chemistry if compared with chemically or physically stabilized ash (Ozolincius et al. 2004, 2005, 2006, 2007a–c; Varnagirytė 2006). Ash stabilization and recycling to forest ecosystems was described in considerable details in several foreign studies (Greger et al. 1995; Lundborg 1998a, b, etc.). There are some positive aspects of such fertilization, for instance, stabilized ash dissolves more slowly in the soil and has a smaller impact on forest ecosystems; technically it is easier to spread stabilized ash in the forest.

On the national level (Lithuanian case), the wood ash fertilization is recommended to apply to forest stands growing on mineral soils of normal moisture or temporarily over-moisturized mineral soils. The wood ash doses of 1.5–3.5 $t\cdot ha^{-1}$ could be applied twice during the stand rotation (Table 1). Following stricter requirements, for the preservation of biological diversity, wood ash could also be applied to less fertile forest sites. In such forest sites, the recommended wood ash doses should be less than 2 $t\cdot ha^{-1}$ of ash, because these sites lose less nutrients during the forest biomass harvesting procedure than more fertile sites.

It is rational to additionally apply nitrogen (70 to 120 $kg\cdot ha^{-1}$ of N) together with forest fuel ash application. The well-known finding points that biomass ash comprises the main nutrients except nitrogen that evaporates during combustion. Still, there could be a shortage of nitrogen in the ecosystem when all aboveground biomass (stem, needles and branches) is removed from the forest. According to the calculations performed in Lithuania (Armolaitis et al. 2008; Ozolinčius et al. 2010), the main nutrients in the crown biomass in descending order range as follows: N, Ca, K, P, Mg and S. The nitrogen amounts to about 140–200 $kg\cdot ha^{-1}$, i.e. a significant part of all above-mentioned nutrients.

When forest fertilization is recommended, at the first stage, the wood ash together with N should be applied during the stand thinning, the second time – in the middle-aged or premature stands. Some environmental restrictions are also highlighted. The forest fuel ash should not be applied: in the sites nearer than 50 m to the area with open water bodies (ponds, streams, hydromelioration ditches, etc.) or waterlogged plots; on the permanent snow cover because of a high leaching risk, in forest stands with abundant underbrush and undergrowth cover. There are some specific cases when ash recycling could lead to an atypical environmental response. Forest fuel ash as fertilizer could also be used on nutrient poor sandy soils in the abandoned agricultural land but it could be applied just before or together with the soil preparation for afforestation (5–6 $t\cdot ha^{-1}$) and no N fertilizers should be used.

Summarizing, we return to the connection between ecology and economics. After the recommendations were completed, forest fertilization with ash or compensatory ash fertilization did not become the issue of nowadays in Lithuania or the publically perceived phenomenon. The foresters,

Table 1. Forest fuel ash and nitrogen dosages for fertilization of Lithuanian commercial forests (adapted from Ozolinčius et al. 2011)

Forest site*	Ash doses** ($t\cdot ha^{-1}$)	Nitrogen doses ($kg\cdot ha^{-1}$)
Nae, Na	1.5–2.0	70
Nb, Lb	2.5–3.0	90
Nc, Nd, Lc, Ld	3.0–3.5	120
Pa^n, Pb^n	2.0–2.5	70
Pc^n	2.5–3.0	90

*indicates forest sites according to the Lithuanian forest site classification (Vaičys et al. 2006): Nae – degraded (by wind, water erosion or forest fires) mineral soils of normal moisture, Na – very oligotrophic/very infertile mineral soils of normal moisture, Nb – oligotrophic/infertile mineral soils of normal moisture, Nc – mesoeutrophic/fertile mineral soils of normal moisture, Nd – eutrophic/very fertile mineral soils of normal moisture, Lb – oligotrophic/infertile temporarily over-moisturized mineral soils, Lc – mesoeutrophic/fertile temporarily over-moisturized mineral soils, Ld – eutrophic/very fertile temporarily over-moisturized mineral soils, Pa^n – very oligotrophic/very infertile peat drained soils, Pb^n – oligotrophic/infertile peat drained soils, Pc^n – mesoeutrophic/fertile peat drained soils,** indicates recommended ash doses should be spread twice: (1) in combination with thinnings when the net for the haul timber is established, (2) in middle-aged and premature stands together with N fertilizers. Wood ash fertilization is performed in clear cuts (no N fertilization) if there was no ash fertilization in the former stand forest managers and private forest owners are very cautious concerning all recommendations or even suggestions for ash fertilization. Economists immediately begin to discuss about the whole chain: from storage of wood ash, transportation, logistics and spreading costs to feedback mechanisms. If such forest fertilization was successful in practice, our country still lacks more detailed environmental impact assessment, combined with an economic justification.

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