Forest Ecology and Management 348 (2015) 226–240

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Tamm Review

Recycling of ash – For the good of the environment? ☆

Noora Huotari [a,1], Eila Tillman-Sutela [a,2], Mikko Moilanen [a], Raija Laiho [b,*]

[a] Natural Resources Institute Finland, Oulu Unit, P.O. Box 413 (Paavo Havaksen tie 3), FI-90014 University of Oulu, Finland
[b] Natural Resources Institute Finland, Parkano Unit, Kaironiementie 15, FI-39700 Parkano, Finland

ARTICLE INFO

Article history:
Available online 28 March 2015

Keywords:
Ash fertilisation
Soil
Vegetation
Fauna
Leaching
Greenhouse gas emissions

ABSTRACT

The increasing use of wood fuels to replace fossil fuels in energy and heat production results in increasing amounts of waste in the form of ash. Since wood ash contains nutrients that trees need in the right proportions, except for N, it is a potentially excellent forest fertiliser. However, any harmful elements, e.g., heavy metals are also concentrated in the ash, which has raised concern about possible adverse effects that ash fertilisation could induce in the environment. A considerable body of new results has been published on ash fertilisation impacts on, e.g., heavy metal concentrations in berries and mushrooms, ground vegetation, soil microbial processes, greenhouse gas emissions and watercourses. In this review, we synthesise this information to map the environmental benefits and risks related to ash fertilisation. We pay special attention to peatland forests, N-rich ecosystems where ash may induce considerable increases in timber production, but for which a thorough evaluation of environmental impacts has been lacking. The longest monitoring periods currently span more than five decades. In well-targeted sites, ash increases tree production and/or reduces soil acidity for decades. No enrichment of heavy metals in the food webs or leaching of heavy metals to watercourses has been reported. CO_2 emissions increase in the longer term (10–50 years), especially from N-rich peat soils. Also, changes in plant community may be so extensive that ash application cannot be recommended where conservation of the original vegetation is required. Immobilisation of heavy metals in soil depends on the neutralising effect of ash on soil acidity. The most crucial question that remains to be answered is how long this effect lasts, and what happens thereafter. Future research should investigate further whether heavy metals may accumulate in plant roots, even if above-ground parts remain unaffected. Finally, the duration of the impact of ash fertilisation on the nutrition of peatland trees, as well as optimal schedules of repeated fertilisations for different rotations, still need to be verified.

Contents

1. Introduction . . . 227
2. Nutrition and growth of trees . . . 228
   2.1. Drained peatland forests . . . 228
   2.2. Cut-away peatlands and arable peat soils . . . 229
   2.3. Mineral soils . . . 229
3. Soil . . . 229
   3.1. Acidity (pH) and nutrients of soil . . . 229
   3.2. Heavy metals . . . 231
   3.3. Soil communities . . . 231
4. Greenhouse gas emissions . . . 232

☆ This work was done in the Finnish Forest Research Institute, which became part of Natural Resources Institute Finland as of January 1, 2015.

* Corresponding author. Tel.: +358 50 395 2078.
E-mail addresses: noora.huotari@vapo.fi (N. Huotari), mikko.moilanen@luke.fi (M. Moilanen), raija.laiho@luke.fi (R. Laiho).
[1] Present address: Vapo Oy, Elektroniikkatie 10 M2, P.O. Box 318, FI-90101 Oulu, Finland.
[2] Retired.

http://dx.doi.org/10.1016/j.foreco.2015.03.008

5. Vegetation . . . 233
5.1. Plant community composition . . . 233
5.2. Nutrient and heavy metal concentrations of plants . . . 233
6. Berries and mushrooms . . . 233
7. Fauna . . . 234
8. Watercourses . . . 235
9. Conclusions and recommendations for further research . . . 236
Acknowledgements . . . 237
References . . . 237

1. Introduction

The demand for bioenergy has increased recently in Europe and Scandinavia due to the EU's target to reach a 20% share of energy derived from renewable sources by 2020. Wood fuels are one of the most significant energy sources in attempting to reach the target. Wood mixed with peat is also a common fuel used in combined heat and power plants in Scandinavia. This results in the generation of large amounts of ash as waste at the power plants. Recently, approximately 600,000 Mg (1000 kg) of wood, peat and mixed ash were generated annually in Finland and 350,000 Mg in Sweden as a by-product of energy production (Emilsson, 2006; Väätäinen et al., 2011; Klemedtsson et al., 2010). The element concentrations of the ashes, as well as their other chemical constituents, vary considerably depending on the incinerated material and the incineration technique (Pitman, 2006; Augusto et al., 2008; Nurmesniemi et al., 2011; Vassilev et al., 2013).

Since wood ash basically contains adequate proportions of all the nutrients that trees need to grow, excluding nitrogen (N) (e.g., Karltun et al., 2008), it is a potentially excellent forest fertiliser, especially in sites where N does not limit tree growth, such as peatland forests. Peat ash is usually poor in potassium (K) since K concentrations in peat are generally low, except for the topmost 0–30 cm (Laiho et al., 1999) and the bottom layers close to mineral soil which are generally not harvested. Nowadays, wood ash is stabilised by granulating or self-hardening with water before forest spreading. Stabilisation is done to avoid undesired effects on vegetation and leaching of nutrients. However, in most of the studies started prior to the 1990s untreated, dust-like loose ashes have been applied. The impacts of loose and granulated ash differ to some extent, which should be borne in mind when comparing the results of different studies (e.g., Eriksson et al., 1998). Ash can also be 'enhanced' during the granulation process by mixing together different types of ash or by adding nutrients. Boron (B), and occasionally potassium (K), is nowadays added into ash products that are intended for forest fertilisation (Moilanen et al., 2012). Mixtures of wood ash and other waste materials, e.g., oil shale ash or charcoal have also been tested. An oil shale component further increases the alkalinity of the ash (Kikamägi et al., 2014), while charcoal reduces both alkalinity and nutrient concentrations (Omil et al., 2013).

In addition to nutrients, any heavy metals[3] contained in the source materials, such as cadmium (Cd), arsenic (As), chromium (Cr) and nickel (Ni), are also concentrated in ash (e.g., Reimann et al., 2008). Usually, concentrations of heavy metals are smaller in peat ash than wood ash (Korpilahti, 2004), although peat ash contains more As than wood ash. Several elements that are classified as heavy metals, e.g., manganese (Mn), copper (Cu), and zinc (Zn), are indispensable micronutrients for plants. Such heavy metals as Cd and lead (Pb) are, however, harmful or toxic to plants and other organisms even at low levels. Wood-derived ashes also contain varying concentrations of radiocaesium (^{137}Cs), which can be traced to the accident at the Chernobyl nuclear power plant in 1986 (Rantavaara and Aro, 2008; Vetikko et al., 2010).

The potentially harmful concentration levels of these substances have raised concern over the possible adverse effects of ash fertilisation on the environment (e.g., Reimann et al., 2008). According to European legislation, ash is regarded as a waste product and many countries lack regulations or recommendations concerning ash fertilisation (Emilsson, 2006). In Finland, for instance, ash that is generated in the incineration of wood, peat or field biomass can be used as a forest fertiliser. The utilisation of ash as fertiliser is regulated by the Fertiliser Product Act (539/2006) and related decrees (Ministry of Agriculture and Forestry Decrees 24/11 and 11/12), which specify the permitted minimum concentrations for P, K and calcium (Ca), as well as maximum concentrations for harmful heavy metals. Such regulations help ensure that ash fertiliser products are of consistent quality, safe and suitable for their intended use.

Recycling of wood and peat ash as forest fertilisers has several environmental advantages: it reduces the need for waste dumps, promotes recycling of nutrients, increases tree production (Silfverberg, 1996; Ernfors et al., 2010) and reverses acidification of forest soils (Brunner et al., 2004). However, the review by Aronsson and Ekelund (2004) concluded that the biological effects of wood ash application on forest soil and aquatic ecosystems were ambiguous. Since then, experiments have matured and a considerable body of new results has been produced regarding ash fertilisation impacts on, e.g., heavy metal concentrations in berries and mushrooms (Moilanen et al., 2006), ground vegetation (Huotari et al., 2007, 2009, 2011), soil microbial processes (Rosenberg et al., 2010; Saarsalmi et al., 2010, 2012), greenhouse gas emissions (Maljanen et al., 2006a,b; Ernfors et al., 2010; Klemedtsson et al., 2010) and watercourses (Piirainen et al., 2013). Also, the new reports provide insight into the responses in peatland forests, which have received little attention in earlier papers (e.g., Augusto et al., 2008). Thus, we considered it necessary to compile a new synthesis on the environmental effects of ash fertilisation.

In this review, we will evaluate available information on the effects of ash fertilisation on (i) tree stand characteristics, (ii) soil properties, including microbial communities and other soil organisms, (iii) greenhouse gas emissions, (iv) vegetation composition and heavy metal concentrations, (v) animals, and (vi) watercourses. First, we will briefly review the effects of ash on tree growth and nutritional status in different sites because increased wood production is a prerequisite for the wise use of ash as a fertiliser. However, we will not consider profitability or impacts on

[3] We use, in the absence of a better collective term, 'heavy metals' to refer to metals and semimetals that have been associated with contamination and potential toxicity or ecotoxicity, as well as some metals that are actually required by living organisms. We acknowledge the vagueness of this term (e.g., Duffus, 2002), and try to be as specific as concisely possible.