Forest Ecology and Management 357 (2015) 42–49

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Chemical and microbiological properties of alpine forest soils: Effects of pelletized ashes in a short-term trial

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ARTICLE INFO

Article history:
Received 23 June 2015
Received in revised form 29 July 2015
Accepted 11 August 2015
Available online 25 August 2015

Keywords:
Alpine landscape
Wood ash
Pellets
Nutrient stocks
Soil
Leaching

ABSTRACT

The application of wood ash to forest soils has been used to compensate nutrient loss and avoid soil and water acidification. Using ashes in a non-stabilized form might negatively affect forest ecosystems. Bearing this in mind, together with landscape restrictions and socio-economic parameters, it underlines the importance of using pelletized ashes as soil additives in alpine areas. Therefore, in this study we evaluated the effects of pelletized ashes on the chemical and microbiological properties of four soils representative for the central Alps [rendzic Leptosol (L), fibric Histosol (H), haplic Podzol (P), and dystric Cambisol (Cm)] in a microcosm trial during 22 weeks. The following ash-pellet treatments were at a ratio equivalent to 2 Mg ha^{-1}: pellets without any additive (A); or in combination with bark, compost, and digestate (B–D). A control without ashes (Ct) was also included.

Weekly measurements of pH and electrical conductivity (EC) from the soil leachates were performed. A higher pH, relative to Ct, was found in treatment A for Podsol. Additionally, treatments B and C led to a pH rise in Leptosol. Electrical conductivity, total C and N, and inorganic N forms were not significantly affected by the pelletized treatments regardless the soil type. A similar trend was recorded for pH and EC levels from the leachate samples. A lower metabolic quotient (qCO_2), relative to Ct, was recorded in Podsol following treatment A. However, when pellet ashes were applied in combination with digestate, a higher qCO_2 than that in Ct was found for this type of soil, which might indicate a lower microbial C utilization efficiency and/or microbial stress. This latter treatment also resulted in a lower dehydrogenase activity in Podsol, whilst soil protease activity and N mineralization were not affected in any of the studied soils. We conclude that ash amendment in pellets form on certain soils improves their acidity levels without causing extreme effects.

1. Introduction

Use of wood for production of heat and energy is in many places displacing fossil fuels in response to the energy targets established by the European Union (European Commission, 2010). By 2020, around 20% of the energy production is expected to be derived from renewable sources, with wooden material from forestry and forest-based industries being one of the main biomass sources in EU countries such as Finland, Lithuania, Hungary and Austria (AEBIOM, 2011). This implies the production of waste ashes, which must be properly managed to exploit their fertilizing potential while avoiding potential negative environmental impacts (Insam and Knapp, 2011; Bougnom et al., 2012; Fernández-Delgado Juárez et al., 2013; Ekvall et al., 2014).

The continuous extraction of wood and logging residues from forest ecosystems has caused a nutrient depletion, which may induce soil acidification due to a low acid neutralizing capacity (Federer et al., 1989; Glatzel, 1991; Clarke, 2012). To counteract, two different approaches can be chosen: (a) reduce harvesting intensities depending on the nutritional status of the site (Rosenberg and Jacobson, 2004; Achat et al., 2015; Pyttel et al., 2015); and (b) re-introduction of the nutrients that were extracted as a result of biomass harvesting (nutrient compensation) with the addition of wood ash (Augusto et al., 2008; Saarsalmi et al., 2012).

The potential benefits and drawbacks of using wood ash as a mineral supplement have already been tested in various studies

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http://dx.doi.org/10.1016/j.foreco.2015.08.014
0378-1127/

(Omil et al., 2011; Saarsalmi et al., 2012; Huotari et al., 2015). It is well-known that wood ash contains major elements such as Ca, Mg, K and P, along with micronutrients including Fe, Mn, Zn and Cu, all needed for the functioning and productivity of forest ecosystems, with the exception of C and N that are mostly volatilized during the combustion process. However, the effects of wood ash may vary depending on its application rate and form (loose, hardened or granulated), as well as on the soil type (Perkiömäki and Fritze, 2002; Pitman, 2006). Along these lines, the use of loose ash has been found to induce negative effects on soil properties in the short-term, mainly due to its rapid dissolution which may lead to nutrient losses via leaching (Ozolinčius et al., 2005); and to a sharp increase in soil solution pH and salt concentration (Clapham and Zibilske, 1992; Zimmermann et al., 2002). Additionally, it may also negatively affect the populations of bryophytes and lichens (Pitman, 2006; Ozolinčius et al., 2007), as well as the soil fauna (Huotari et al., 2015), all of them playing an important role in forest nutrient cycling. It is known that soil pH regulates the magnitude of several processes, such as the solubility of metals and organic substances (Zimmermann et al., 2002). Consequently, several studies underline the benefits of using granulated or pelletized ashes in comparison with the use of loose ash (Steenari et al., 1999; Pitman, 2006; Callesen et al., 2007) in order to promote the long-lasting fertilization effect and neutralization properties of the ashes. Some studies suggest that the dissolution of granulated wood ash is delayed compared with untreated wood ash because of the increased grain size and the formation of less soluble compounds (Steenari and Lindqvist, 1997; Steenari et al., 1999; Nieminen et al., 2005). Nonetheless, there is still a gap of knowledge regarding the impact of stabilized (hardened or granulated) ash in forest systems (Huotari et al., 2015). Furthermore, most of the studies are mainly focused on the effects of stabilized ashes on plants and tree growth (Moilanen et al., 2013), rather than on the soil.

The use of ashes as a nutrient supplement in the forestry sector has a longer tradition in the Baltic and Fennoscandian countries (boreal forests) than in the central Alps. This is attributed to the fact that in the central Alps the forest is often located on very steep slopes; and secondly, due to the economical importance of tourisms, along with the "patchiness" in the alpine forests broad scale applications are uncommon. All in all this increases the difficulty of the re-circulations of nutrients from wood ash into the soil, which has not been fully embraced by the forest owners and the local communities. Therefore, the main aim of this study was to test the impact of pelletized ashes on the chemical and microbiological properties of several soils representative for the central Alps. Moreover, we investigated if such changes in soil properties derived from the use of pelletized ashes will also affect the soil-leachate chemistry.

2. Material and methods

2.1. Soil description and experimental design

For this study four representative forest soils from the Austrian Alps were chosen. Two soils developed on calcareous materials: rendzic Leptosol (L) (Terfens, 47°12′49″N 11°19′42″O) and fibric Histosol (H) (Zirl, 47°17′7″N 11°15′30″O); and two soils developed on noncalcareous materials: haplic Podzol (P) (Götzens, 47°12′49″N 11°19′42″O) and dystric Cambisol (Cm) (Götzens, 47°13′24″N 11°19′50″O). The sampling was performed on the 16th and 17th October, 2012. At each study site 15 soil cores (0–40 cm, Ø 11 cm) were randomly taken from a 15 × 15 m plot for the set-up of the microcosm experiment.

The laboratory-scale pellets were produced at the Institute for Material Technology (Universität Innsbruck) by using bottom ash and including the following additives at a specific ratio (ash:additive, w/w dry weight): spruce bark (75:25), sewage sludge compost (80:20) and anaerobic digested cattle slurry (95:5) (Fernández-Delgado Juárez et al., 2014). Pellets without any additive (100:0) were also used in the present study. The main properties of the pellets are shown in Table 1.

The experimental set-up was performed in Perspex columns (11 cm diameter, 40 cm depth) with a tight mesh (0.5 mm pore size) in the bottom of each column, and they were filled in with the undisturbed soil core collected *in situ* at each study site. For each type of soil, the abovementioned four ash-pellet treatments were applied on the surface of the soil column at a ratio equivalent to 2 Mg ha^{-1} of ashes according to the Austrian guidelines (Bundesministerium für Land- und Forstwirtschaft, 2011). A control treatment consisting of the soil core without addition of any pellet (Ct) was also included. A total of 60 experimental units (5 amendments × 4 soil types × 3 replicates) were set-up. After an equilibration period of 4 days at 4 °C, all columns were randomly placed into an incubation chamber at 8 °C (that is the average temperature for the months of October–November in the study areas) with a light/darkness cycle of 8/16. Soil cores were weekly watered with distilled water, considering the average rainfall regime (970–1500 mm/year rainfall) of the autumn season from

Table 1
Nutrient and heavy metal content of the pellets used in this study, including the limit values for quality ashes A and B according to the Austrian Guidelines for Ash Use (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasser, 2011). Values are expressed on a dry weight (dw) basis. Values are means with the standard error (SE) in brackets ($n = 3$).

	Limits for different ash qualities		Nutrient and heavy metal contents			
	A	B	Pellet-ash (A)	Pellet-bark (B)	Pellet-compost (C)	Pellet-digestate (D)
pH	–	–	10.9 (0.1)	10.0 (0.1)	10.7 (0.1)	11.7 (0.1)
EC (mS cm^{-1})	–	–	0.78 (0.02)	0.66 (0.01)	1.24 (0.04)	1.33 (0.04)
VS (g kg^{-1})	–	–	103 (2.3)	220 (0.8)	123 (1.7)	54.3 (0.8)
C (g kg^{-1})	–	–	38.5 (1.6)	121 (4.2)	73.1 (3.0)	36.8 (3.1)
N (g kg^{-1})	–	–	0.25 (0.04)	1.65 (0.24)	4.69 (0.23)	0.52 (0.03)
Ca (g kg^{-1})	–	–	77.1 (1.94)	74.2 (1.45)	77.4 (4.09)	88.1 (0.89)
Mg (g kg^{-1})	–	–	36.4 (0.61)	26.7 (0.79)	26.8 (1.25)	30.1 (1.47)
K (g kg^{-1})	–	–	37.4 (0.54)	29.6 (0.41)	34.9 (0.51)	34.5 (0.24)
As (mg kg^{-1})	20	20	0 (0)	0.72 (0.46)	1.33 (0.80)	1.11 (0.77)
Zn (mg kg^{-1})	1200	1500	1.56 (0.11)	2.98 (0.18)	6.07 (0.44)	2.32 (0.20)
Cu (mg kg^{-1})	200	250	1.58 (0.12)	3.45 (0.15)	4.92 (0.29)	1.55 (0.08)
Cr (mg kg^{-1})	150	250	10.3 (0.59)	11.0 (0.69)	11.0 (1.18)	9.00 (0.31)
Pb (mg kg^{-1})	100	200	2.66 (0.70)	1.06 (0.3)	1.80 (0.06)	0.60 (0.21)
Ni (mg kg^{-1})	150	200	3.47 (0.12)	2.91 (0.19)	3.52 (0.23)	2.72 (0.21)
Cd (mg kg^{-1})	5	8	0 (0)	0 (0)	0 (0)	0 (0)