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Sewage sludge as a soil amendment in a *Larix decidua* plantation: Effects on tree growth and floristic diversity

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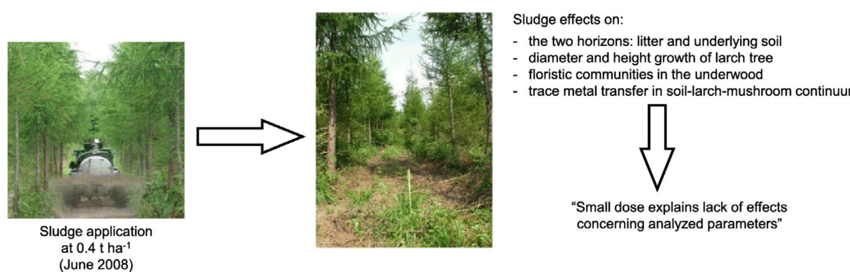
HIGHLIGHTS

- The impacts of sewage sludge application in larch plantation were studied.
- Lack of sewage sludge effects on soil and underwood diversity.
- No significant effects on diameter and height growth of larch tree
- No accumulation of Cu, Zn, Pb and Cd in larch needles and edible sporocarps
- Small dose (0.4 t DW ha^{-1}) explains lack of effects on analyzed parameters

GRAPHICAL ABSTRACT



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ABSTRACT

Sewage sludge application in forest plantations is an interesting complementary alternative practice to sewage sludge reutilization and recycling, with a significant and sustainable net effect in climate change mitigation. However, to optimize it a detailed knowledge of its effects on ecosystem components such as plants, soil, water and fauna is needed. We investigated the effects of sewage sludge application on soil, tree growth and floristic diversity in a ten-year-old plantation of European larch (*Larix decidua* Mill.). Our one-hectare study site, located at Mélisey, Haute-Saône, France (47°753′ Lat., 6°580′ Long.), was subdivided into six plots. Three plots, alternating with three control plots (no sewage sludge application), were amended in June 2008 with 0.4 t DW ha^{-1} obtained from a municipal urban wastewater treatment plant in Mélisey. Within each plot, one subplot was delimited and sludge was again manually applied at 3 t of DW ha^{-1} in July 2009 and March 2010 to the soil surface of the amended subplots without incorporation. The results showed no effect on radial and height growth of European larch amended with 0.4 t DW ha^{-1}. While a significant temporary increase in pH, macro-element contents (N, P and Ca) and the trace metal (Cu and Zn) concentration in the soil was observed, it had no significant effect on needles and sporocarp contents. The number of species in the amended subplots with 3 t DW ha^{-1} $year^{-1}$ increased by 80% compared to the control. However, the relative species abundance present only in amended subplots remains <1, except for *Hypericum humifusum*.

1. Introduction

Sustainable water quality management is a major concern in today's context of climate change. Rising temperatures have led to extensive wastewater treatment in order to produce water of suitable quality to be returned to the receiver environment with minimal impact on the ecosystem or on public health. These treatments also generate sewage sludge (SS), a complex sub-product that has been extensively spread over agricultural lands as fertilizer (Singh and Agrawal, 2008). In France, for example, 73% of municipal sludge is currently considered to be of value in agriculture (Legroux and Truchot, 2009). Recently,

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however, farmers have shown reluctance towards sludge as they have been heavily influenced by a negative public opinion about certain pollutants, emanations of unpleasant odors and real concerns about health-related risks (Bourioug et al., 2015a).

A recent rise in the potential demand for energy biomass production has resulted in an increased interest in forest plantation. However, though forest growth and yield depend on soil fertility, tree crop rotations may cause soil nutrient depletion (Jama and Nowak, 2012). Thus, SS application in forest plantations is an interesting alternative practice to SS reutilization and recycling, with a significant and sustainable net effect on climate change mitigation. In addition, it is assumed, due to the small percentage of forest products found in the human diet (Przewrocki et al., 2004), that health endangerment as a consequence of pollutant transfer is lower than from agriculture generally.

Certain soils are well suited to woodland development, and are therefore subject to practices such as coppicing to produce biomass for energy production purposes and wood products. In these plantations, the spreading of sludge on the forest floor can improve soil characteristics by, for example, providing macro- and microelements, improving soil organic matter, increasing water retention and pH, etc. (Bailly et al., 2004; Ferrer et al., 2011; Bourioug et al., 2015b) and thus enhance tree growth (Saruhan et al., 2010). In addition, sludge encourages soil aeration by stimulating root growth and increasing worm and micro-organism populations (Singh and Agrawal, 2008; Lyberatos et al., 2011). The net effect is, thus, improved soil quality and greater biomass yields.

However, there are various types of contaminants present in SS such as trace metals, organic pollutants, medically active substances, etc. Sludge spreading therefore requires intensive monitoring of ecosystem components such as plants, soil, water and fauna to identify any possible positive or negative impacts on plant productivity, on the environment and on human health (Carnus and Thomas-Chery, 2007; Bourioug et al., 2015a).

The objective of this study was to determine the effects of SS application on the soil, and on the diameter and height growth, and on floristic diversity in a ten-year-old plantation of European larch (*Larix decidua* Mill.).

2. Materials and methods

2.1. Experiment site and sewage sludge properties

The experiment was carried out in a 10-year-old coniferous *Larix decidua* plantation with inter- and intra-row spacing of 3.5 and 2.5 m respectively, located at Mélisey, Haute-Saône, France (47°753′ Lat., 6°580′ Long.) (Fig. 1). The climate is semi-continental with the highest monthly temperature at 27.8 °C in July and the lowest at −3.7 °C in January. Annual precipitation is 662 mm (data 2010) (Linternaute.com, 2004). The soil is a clay loam with 18% clay, 33.7% loam and 48.3% sand and classified as a pseudo luvisol with dysmull. The study site, located at an altitude of 384 m, measured 100 m × 105 m with a slope of about 10% and was subdivided into six plots (17.5 m × 100 m). Three of the six plots (A1, A2 and A3) were amended in June 2008 with 0.4 t DW ha^{-1} (tons dry weight per hectare) of SS obtained from a municipal urban wastewater treatment plant in Mélisey. Three alternating control plots (C1, C2 and C3) received no sewage sludge application. Within each plot, one 2.5 × 2.5 m subplot was delimited randomly (A′1, A′2, A′3, C′1, C′2 and C′3) (Fig. 2). SS was again, in July 2009 and March 2010, manually applied to the soil surface of the amended subplots without incorporation, 3 t DW ha^{-1} each time. The physico-chemical characteristics of the soil and SS are provided in Table 1.

2.2. Sampling

For each subplot, the soil was sampled at both litter level (0 to 5 cm depth) and in the underlying soil (5 to 20 cm depth). At each depth, we

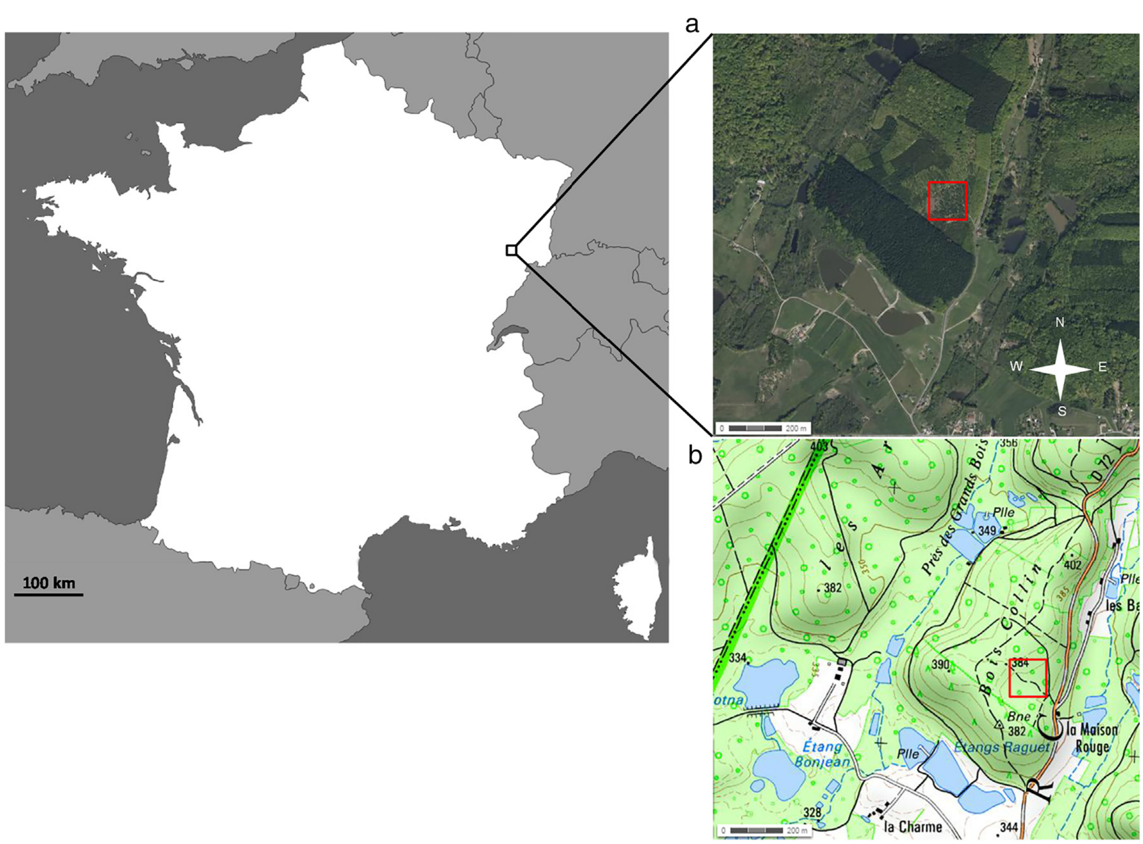

Fig. 1. Geographic location study site (Mélisey, Haute-Saône, France (47°753′ Lat., 6°580′ Long.)). a: Aerial photo, b: Topographic map (Adapted from Geoportail France, 2015).