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Sewage sludge application in a plantation: Effects on trace metal transfer in soil–plant–snail continuum

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HIGHLIGHTS

- Sewage sludge application in forest plantation ecosystems
- Evaluation of risk of trace metal leaching
- Trace metal transfer into the soil–plant–snail food chain
- Snail mortality rate less than 1%

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ABSTRACT

We studied the potential bioaccumulation of Cu, Zn, Pb and Cd by the snail *Cantareus aspersus* and evaluated the risk of leaching after application of sewage sludge to forest plantation ecosystems. Sewage sludge was applied to the soil surface at two loading rates (0, and 6 tons ha^{-1} in dry matter) without incorporation into the soil so as to identify the sources of trace metal contamination in soil and plants and to evaluate effects on snail growth. The results indicated a snail mortality rate of less than 1% during the experiment, while their dry weight decreased significantly (<0.001) in all treatment modalities. Thus, snails showed no acute toxicity symptoms after soil amendment with sewage sludge over the exposure period considered. Additions of sewage sludge led to higher levels of trace metals in forest litter compared to control subplots, but similar trace metal concentrations were observed in sampling plants. Bioaccumulation study demonstrated that Zn had not accumulated in snails compared to Cu which accumulated only after 28 days of exposure to amended subplots. However, Pb and Cd contents in snails increased significantly after 14 and 28 days of exposure in both the control and amended subplots. At the last sampling date, in comparison to controls the Cd increase was higher in snails exposed to amended subplots. Thus, sludge spread therefore appears to be responsible for the observed bioaccumulation for Cu and Cd after 28 days of exposure. Concerning Pb accumulation, the results from litter–soil–plant compartments suggest that soil is this metal's best transfer source.

1. Introduction

Sewage sludge, a byproduct of sewage treatment processes and comprised of a plethora of lysed microorganisms, organic and inorganic components, is currently becoming a worldwide issue associated with treatment plants due to growing population and urban pressure. Millions of tons of sewage sludge are annually produced primarily in Japan (70 million tons), China (30 million tons) and the USA (6 million tons) (Matsubara and Itoh, 2006; McClellan and Halden, 2010; Kelessidis and Stasinakis, 2012); France has not escaped this trend with a production estimated at 1.2 million dry tons in 2008. Efforts have been made to optimize disposal practices by improving sludge treatment (Kelessidis and Stasinakis, 2012). For example, the addition of sewage sludge to agricultural soil may be a responsible managerial practice that also provides soils with nutrients of value to growing crops, especially N and P (Arenas-Lago et al., 2013; Cerqueira et al., 2011, 2012). In France, for example, 73% of municipal sludge is currently considered to be of value in agriculture (Legroux and Truchot, 2009). On the other hand, sludge may contain substantial amounts of trace metals (TMs) which may be transferred to the human diet via crop uptake and become a health hazard (Muchuweti et al., 2006; Bergkvist et al., 2003). In addition, worldwide, the risks associated with the application of sludge and other refuse to forest plantations are much lower than in agriculture (Roy and Couillard, 1997; Singh and Bhati, 2005; Müller da Silva et al., 2011; Oliveira et al., 2012a,b; Quispe et al., 2012; Ribeiro

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et al., 2013a,b; Silva et al., 2011a,b,c). For example, the use of sewage sludge was envisaged for the short rotation coppice to achieve high biomass production, and also to enhance tree growth and improve several soil characteristics (Mosquera-Losada et al., 2001). This alternative, however, requires intensive monitoring of ecosystem components such as plants, soil, water and fauna to identify any possible positive or negative impacts of sludge on plant productivity, on the environment and on human health (Carnus, 2006). Among animals, snails play an essential role in soil and food chain functioning, being intimately associated with the soil, plants and secondary consumers. Considered good bioindicators, they may accumulate TMs in contaminated environments and themselves become a source of contamination for both terrestrial invertebrates and vertebrates, including humans (Scheifler et al., 2006). Whereas the effects in microcosm experiments of exposition to TMs of the calibrated brown garden snail *Cantareus aspersus* (syn. *Helix aspersa*) have been reported (Scheifler et al., 2003; Regoli et al., 2006), knowledge of both TM transfer in soil–plant–snail continuum and TM leaching is scarce.

The objectives of this study were (i) to determine whether any bioaccumulation of 4 TMs, Cu, Zn, Pb and Cd could be detected in *C. aspersus*, and (ii) to evaluate the risk of TM leaching after sewage sludge application in forest plantation ecosystems.

2. Materials and methods

2.1. Experimental site and sewage sludge properties

The experiment was carried out in a 10 year-old coniferous *Larix decidua* plantation located at Mélisey, Haute-Saône, France (47°753′ Lat., 6°580′ Long.). The herbaceous layer consists of *Carex pilulifera*. The climate is semi-continental with the highest monthly temperature of 27.8 °C in July and the lowest at −3.7 °C in January. Annual precipitation is 662 mm (data 2010) (Linternaute.com, 2014). The soil is a clay loam with 18.6% clay, 38% loam and 36.9% sand and classified as a pseudo luvisol with dysmull. The study site, located at an altitude of 328 m, measured 100 m × 105 m with about a 10% slope and was subdivided into six plots (17.5 m × 100 m). Three of the six plots were amended in June 2008 with 0.4 tons per hectare of sewage sludge obtained from a municipal urban wastewater treatment plant in Mélisey. Three alternating control plots received no sewage sludge application. Within each plot, six subplots were delimited (Fig. 1). In July 2009 and March 2010, sewage sludge was again manually applied to the soil surface of the amended subplots, without incorporation into the soil, 3 tons of dry matter per hectare each time. The physico-chemical characteristics of the soil and sewage sludge are provided in Table 1.

2.2. Soil solution

For each subplot, the soil solution was sampled at depths of 20 and 40 cm with porous ceramic cylinders (Fig. 2A). At each depth three porous ceramic cylinders were installed, collecting three samples which were then mixed together to obtain a composite sample. Samples were collected monthly starting in April 2010, immediately following the second sewage sludge application to the subplots. The solutions were then passed through a 0.45 μm membrane filter before trace metal analysis.

2.3. Snails, plant and soil

Three stainless steel microcosms (0.25 m diameter, 0.25 m high) containing 10 sub-adult snails (5 g) (Fig. 2B and C) were deployed in each subplot. Each microcosm also contained three pieces of tile placed

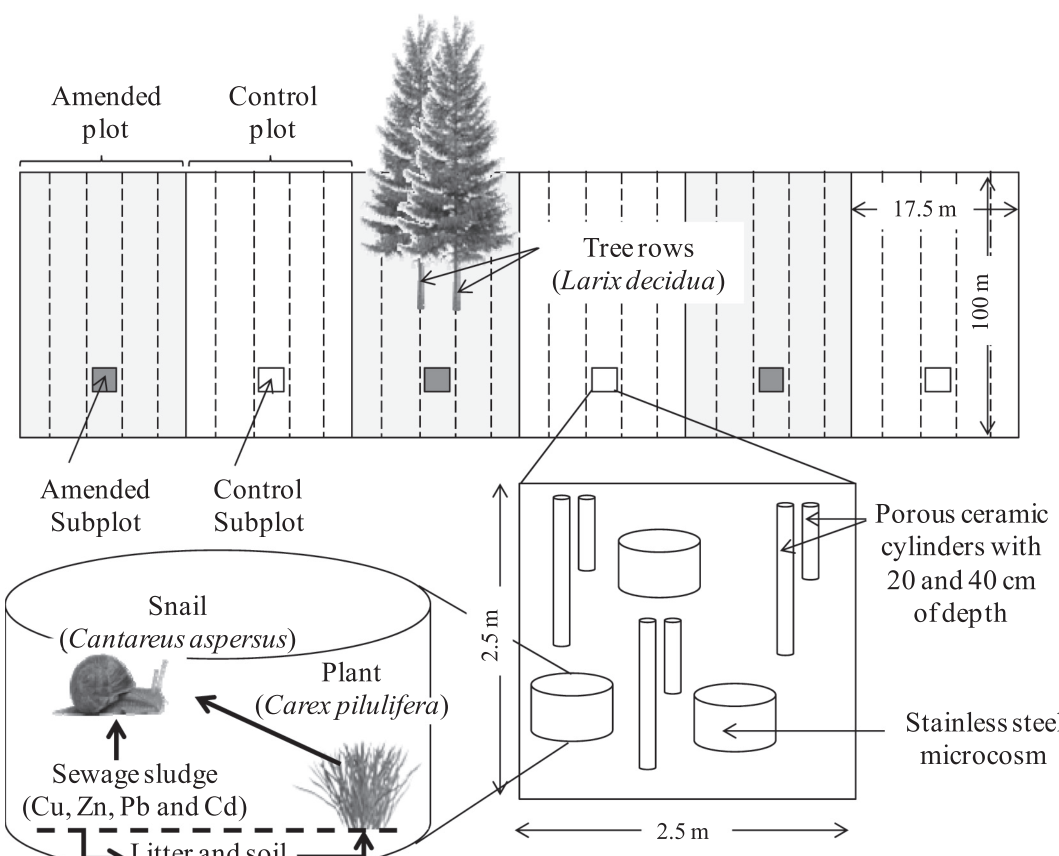

Fig. 1. Schematic representation of study area.