Effect of different types of sewage sludge on Cu concentration in soil and pasture in a silvopastoral system established under *Pseudotsuga menziesii* L.

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Abstract
The concentration of heavy metals in the sewage sludge and its effect on the soil and plants is different depending on the process used to stabilise the sewage sludge. The objective of this study was to evaluate the effect of the fertilisation with municipal sewage sludge that has been stabilized using anaerobic digestion, composting, and pelletisation on the total and available Cu concentration in soil and the Cu levels of pasture compared to control treatments (mineral and no fertilisation) in a silvopastoral system under *Pseudotsuga menziesii* L. The results obtained showed that the composted sludge is the type of residue that increased more the total and Mehlich Cu in the soil due to higher inputs of Cu made with it. However, the annual applications of pelletised sludge implied a higher concentration of Cu in the pasture than the other treatments but without cause harmful effects on plants and animals.

Keywords: anaerobic digestion, composting, pelletisation, heavy metals

Introduction

Silvopastoral systems are a type of agroforestry system promoted by the EU (Council Regulation 1698/2005) [1] in which trees, forage and livestock production are combined [2]. In Galicia (Spain), the productivity of silvopastoral systems at both the understory and the tree level is limited by the soil acidity [3]. The application of inorganic and organic fertilisers could improve soil fertility and therefore increase the tree growth and the pasture production in the silvopastoral systems [4]. The recent increases in inorganic fertiliser prices along with increasing environmental concerns have reduced the use of inorganic nitrogen fertilisers in the EU [5]. Inorganic fertilisers are currently being replaced by organic fertilisers, such as sewage sludge, because of the lower cost of this nitrogen resource and the promotion of using sewage sludge by the EU (European Directive 86/278) [6] in order to recycle nutrients. However, one of the main problems of use of sewage sludge as fertiliser is its higher content of heavy metals (mainly Zn and Cu) than soils, which is controlled by EU (European Directive 86/278) [6] and by the national directives (R.D 1310/1990) [7].
In Spain, sewage sludge should be stabilized before using as fertiliser in agricultural production systems (R.D 1310/1990) [7], which changes the fertiliser properties of the delivered sewage sludge [8]. Anaerobic digestion and composting are the most important types of sludge stabilization promoted by the EU (European Directive 86/278) [6]. However, both types of waste contain high proportions of water that could be reduced by 98% through pelletization of anaerobic sludge via a thermic treatment, which consequently reduces storage, transport and spreading costs compared with anaerobic or composted sludge [9].
The objective of this study was to evaluate the effect of the fertilisation with municipal sewage sludge that has been stabilized using anaerobic digestion, composting, and pelletisation on the total and available Cu concentration in soil and the Cu levels of pasture compared to control treatments (mineral and no fertilisation) in a silvopastoral system under *Pseudotsuga menziesii* L.

Material and Methods

The experiment was established in Baltar, A Pastoriza (Lugo, Galicia, NW Spain) at an altitude of 475 m above sea level. Pasture was sown with a mixture of *Dactylis glomerata* L. var. Artabro (12.5 kg ha^{-1}), *Lolium perenne* L. var. Brigantia (12.5 kg ha^{-1}) and *Trifolium repens* L. var. Huia (4 kg ha^{-1}) in December 2004. *Pseudotsuga menziesii* L. were planted at a density of 952 trees ha^{-1} after pasture

sowing in February 2005. The experimental design was a randomized complete block with three replicates and five treatments. Each experimental unit had an area of 168 m^2 and 25 trees planted with an arrangement of 5×5 stems, forming a perfect square. Treatments consisted of (a) no fertilisation (NF); (b) mineral fertilisation (MIN) of 500 kg ha^{-1} 8:24:16 compound fertiliser ($N:P_2O_5:K_2O$) at the beginning of the growing season and 40 kg N ha^{-1} before first harvest; (c) fertilisation with anaerobically digested sludge (ANA) with an input of 320 kg total N ha^{-1} before pasture sowing; (d) fertilisation with composted sewage sludge (COM) with an input of 320 kg total N ha^{-1} before pasture sowing and (e) application of pelletised sewage sludge (PEL), which involves a contribution of 320 kg total N ha^{-1} splitted as 134 kg total N ha^{-1} just before pasture sowing in 2004 and 93 kg N ha^{-1} at the end of 2005 and 2006. Sewage sludge was applied superficially and the calculation of the required amounts was conducted according to the percentage of total N and dry matter contents [10] and taking into account the Spanish regulation (R.D 1310/1990) [7] regarding the heavy metal concentration for sewage sludge application. To estimate the total and available Cu concentration in soil a composite soil sample per plot was collected at a depth of 25 cm, as described in the RD 1310/1990 [7] in March 2009. The pasture Cu content was determined by taking four samples of pasture per plot at random (0.3 × 0.3 m^2) in May and December 2008 (only significant results are shown). Soil total [11] and available Cu [12], as well as the pasture Cu concentration [11], were estimated in the laboratory. Data were analysed using ANOVA and differences between averages were shown by the LSD test, if ANOVA was significant [13].

Results and discussion

In Figure 1 can be observed that the composted sludge (COM) increased more the total soil Cu than the other treatments (NF, MIN, ANA and PEL) ($p<0.05$), finding the same trend when the amount of Cu extracted with Mehlich 3 was evaluated ($p>0.05$). The differences found between the three types of sludge analysed in this experiment could be explained by its different composition and rate of mineralization [9]. The dose of composted sludge applied was higher to meet the N required by crops [10] than the dose of anaerobic or pelletised sludge. The composted sludge has a lower concentration of N than the anaerobic and pelletised sludge which increases the inputs of Cu to the soil applied with the composted sludge. The COM treatment applied around 4.46 kg Cu ha^{-1}; meanwhile, only 3.59 and 1.92 kg Cu ha^{-1} was added with the ANA and PEL treatments, respectively. Other authors in silvopastoral systems established under *Fraxinus excelsior* L. [8] and in experiments carried out in China [14] also observed that the use of composted sludge as fertiliser increased more the Cu concentration in the soil than the anaerobic and pelletised sludge. Although the composted sludge increased the concentration of Cu in the soil, the total Cu values obtained were below the maximum specified by Spanish law for soils in which urban sewage sludge is applied (50 mg kg^{-1}) (R.D 1310/1990) [7].

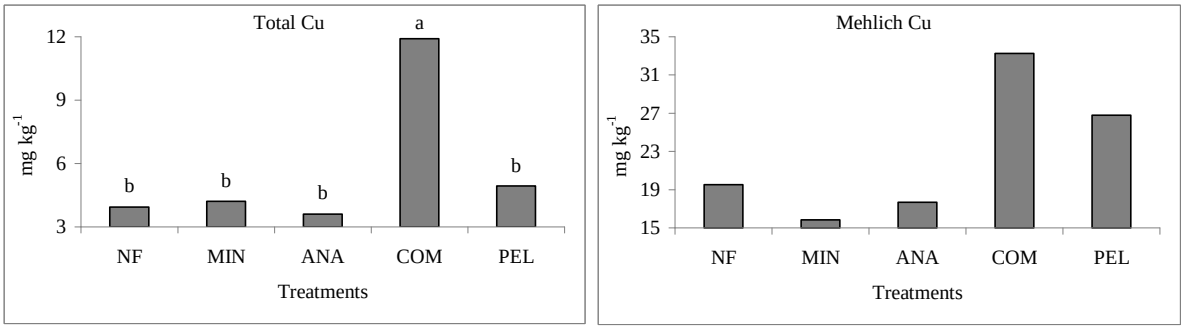

Figure 1. Total Cu concentration (mg kg^{-1}) in soil and amount of Cu (mg kg^{-1}) extracted by Mehlich in each treatment. NF: no fertilisation, MIN: mineral; ANA: anaerobic sludge, COM: composted sludge and PEL: pelletised sludge. Different letters indicate significant differences between treatments.

On the other hand, the Cu concentrations in the pasture in this experiment (3.87-6.8 mg kg^{-1}) (Figure 2) was slightly below the usual in plant range (10-80 mg kg^{-1}) [15] and below the levels considered excessive or toxic for plants (20 and 100 mg kg^{-1}) [16]. This variable of study was significantly higher when pelletised sluge (PEL) was applied compared with the other treatments (NF, MIN, ANA, COM,

PEL) ($p>0.05$) probably because this type of sewage sludge was applied in several times which facility its incorporation into the soil. With regard to the animals, Cu levels of pasture were below the minimum maintenance needs to for cattle (10 mg kg^{-1}) [17], goat (10 mg kg^{-1}) [18] and horses (10 mg kg^{-1}) [19] in all treatments which makes necessary to supply this element to animals. In the case of the sheep, the pelletised sludge met the requirements for maintenance (4.6-7.4 mg kg^{-1}) [20] but in the other treatments, supplements of this element to the sheep would be recommended if their nourishment was derived solely from these pastures.

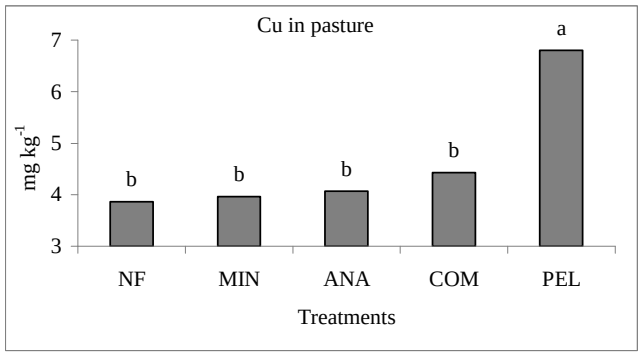

Figure 2. Concentration of Cu in pasture (mg kg^{-1}) in May 2008. NF: no fertilisation, MIN: mineral; ANA: anaerobic sludge, COM: composted sludge and PEL: pelletised sludge. Different letters indicate significant differences between treatments.

Conclusion

Composted sludge is the type of residue that increased more the total and Mehlich Cu in the soil due to higher inputs of Cu made with it because its rate mineralization and its N concentration is lower compared with the other tested sludge types. However, the annual applications of pelletised sludge implied a higher concentration of Cu in the pasture than the other treatments but without cause harmful effects on plants and animals.

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