Zn pasture and soil concentrations in *Quercus rubra* L. silvopastoral systems fertilised with sewage sludge

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Abstract

When sewage sludge is used as fertiliser it is important to apply an adequate dose of this residue to avoid the accumulation and leaching of heavy metals as Zn through soil profile. The objective of this experiment was to evaluate the effects of different dose of municipal sewage sludge (100, 200 and 400 kg total N ha^{-1}) on the total and available Zn concentration at different soil depths (0-25 and 25-50 cm) and the Zn levels of pasture compared to control treatment (no fertilisation) in a silvopastoral system under *Quercus rubra* L. in Galicia (Spain). The results obtained in this study showed that the use of sewage sludge as fertiliser increased the concentration of Zn in the first 25 cm of soil and in the pasture, mainly when high doses of sewage sludge were applied (400 kg total N ha^{-1}), but never exceeded the maximums set by Spanish regulations and did not cause harmful effects on plants and animals.

Keywords: dose, organic fertiliser, leaching, heavy metals

Introduction

Silvopastoral systems are traditional land use systems in which trees, animals and pasture are integrated in the same area [1]. Recently, the establishment of silvopastoral systems is promoted by the EU (Council Regulation 1698/2005) [2] mainly due to many environmental advantages (improvement of nutrient recycling, control of soil erosion, reduction in fire risk and increase in carbon sequestration) [3] [4].

Quercus rubra L. is a native species from the Atlantic coast of North America that is widely used for reforestation in Galicia (Spain) and in other regions of Northern Spain. The establishment of silvopastoral systems with *Quercus rubra* L. may be interesting from an economic point of view because its growth is faster compared with the native *Quercus robur* L. which yields earlier profits for forest farmers [5].

On the other hand, in Galicia (Spain) the natural soils have low fertility due to their acidity [6] which could limit the productivity of silvopastoral systems (understory and tree). The use of organic fertilisers as sewage sludge could improve soil fertility as well as tree and pasture productivity in silvopastoral systems [3]. However, the use of this residue as a fertiliser must take into consideration its heavy metal concentration (mainly Zn) which is higher than that normally found in soils [7]. In Europe (European Directive 86/278) [8] and Spain (R.D.1310/1990) [9], there are regulations that limit the total heavy metal concentration in soil and sewage sludge to minimise the harmful effects of sewage sludge fertilisation on soil, vegetation, animals and human health.

Moreover, when sewage sludge is used as fertilizer it is important to apply an adequate dose of this residue. A sewage sludge application dose exceeding the crop needs could result in nitrate contamination of the ground water by leaching [10].

The aim of this study was to evaluate the effects of different dose of municipal sewage sludge (100, 200 and 400 kg total N ha^{-1}) on the total and available Zn concentration at different soil depths (0-25 and 25-50 cm) and the Zn levels of pasture compared to control treatment (no fertilisation) in a silvopastoral system under *Quercus rubra* L. in Galicia (Spain).

Material and Methods

The experiment was conducted in an agricultural abandoned land in A Pastoriza (Lugo, Galicia, NW Spain) at an altitude of 550 m above sea level. The 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 autumn 2001, with bared root plants of *Quercus rubra* L. being planted at a density of 1,112 trees ha^{-1}. The experiment design was as a randomized complete block with three replicates and four treatments. Each experimental unit had an area of 144 m^2 and 25 trees planted with an arrangement of 5 x 5 stems, forming a perfect square. Treatments consisted of no fertilisation (0N) and fertilisation with anaerobically digested sludge with an input of 100 kg total N ha^{-1} (100N), 200 kg total N ha^{-1} (200N) and 400 kg total N ha^{-1} (400N) in March 2002 and 2003. The calculation of the required amounts of sludge was conducted according to the percentage of total nitrogen [10] and taking into account the Spanish regulation (R.D.1310/1990) [9] regarding the heavy metal concentration for sewage sludge application. To estimate the total and available Zn concentration in soil, in January 2009, a composite soil sample per plot was collected to 50 cm and divided in the field into two subsamples corresponding to different sampling depth classes of 0–25 and 25–50 cm [11]. The pasture Zn content was determined by taking four samples of pasture per plot at random (0.3 × 0.3 m^2) in May and December 2008. Soil total [12] and available Zn [13], as well as the pasture Zn concentration [12] were estimated in the laboratory. Data were analysed using ANOVA and differences between averages were shown by the LSD test, if ANOVA was significant [14].

Results and discussion

In this experiment, the ANOVA analysis showed that in the 100N and 400N treatments the soil total Zn was significantly higher in the upper soil layer than at lower depth ($p<0.05$) (Figure 1). This trend was also observed in the other treatments established (0N and 200N) and when the amount of Zn extracted with Mehlich 3 was evaluated and could be explained by several factors. Firstly, the application of sewage sludge in the soil surface could increased more the Zn concentration in 0-25 cm depth than in the 25-50 cm depth because Zn is the most abundant heavy metal in sewage sludge [15] and secondly Zn may be retained in the first 25 cm of the soil as a result of their adsorption on organic matter. In this study, the percentage of soil organic matter decreased significantly with soil depth (0-25 cm: 88.6^{a}, 25-50 cm: 32.07^{b} expressed as g kg^{-1}) ($p<0.001$) (in all cases different superscript letters indicate significant differences between soil depths). The increase of Zn concentration in the first centimetres of soil due to the repeated application of sewage sludge is consistent with the observations made by other researchers [16] [17].

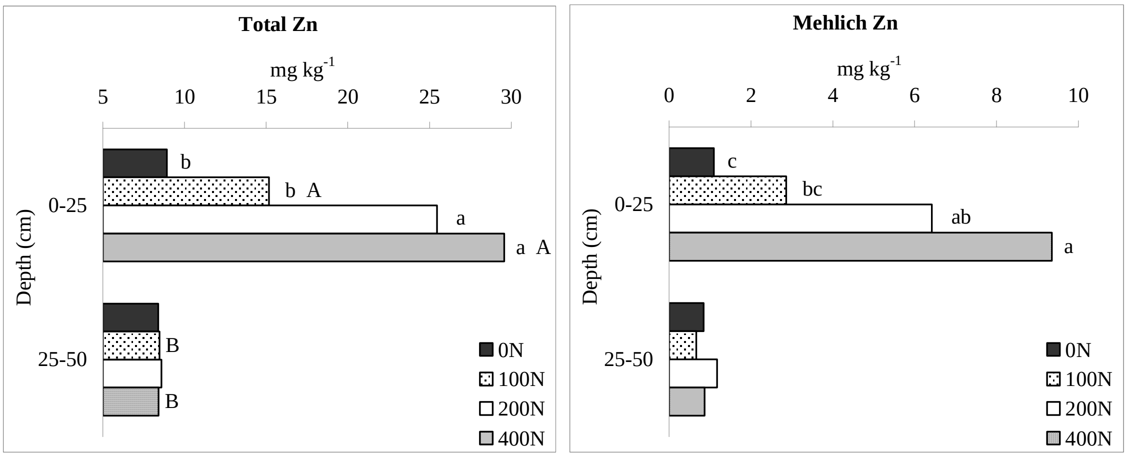

Figure 1. Total Zn concentration (mg kg^{-1}) in soil and amount of Zn (mg kg^{-1}) extracted by Mehlich in each treatment at two soil depths (0–25 and 25–50 cm). 0N: no fertiliser; 100N: 100 kg total N ha^{-1}; 200N: 200 kg total N ha^{-1} and 400N: 400 kg total N ha^{-1}. Different uppercase letters indicate significant differences between soil depths within the same treatment, while different lowercase letters indicate differences between treatments within a specified soil depth.

Regarding to the effect of the treatments established (Figure 1), it was only observed differences between treatments on the levels of total and Mehlich 3 soil Zn in the first 25 cm of soil. In general, the application of medium (200N) and high (400N) dose of sewage sludge increased more the concentration of total and available Zn in this soil depth (0-25 cm) than the other treatments (0N and 100N). This result could be due to the Zn was present in the sewage sludge in greater amounts than the background values in the receiving soil [7] and because the amount of Zn applied to the soil during

2002 and 2003 with the high (16.85 kg Zn ha^{-1}) dose of sewage sludge was higher than with the low (4.21 kg Zn ha^{-1}) and medium (8.05 kg Zn ha^{-1}) dose. Although, the fertilisation with sewage sludge increased the concentration of Zn in the soil, the total Zn values obtained were below the maximum specified by Spanish law for soils in which urban sewage sludge is applied (150 mg kg^{-1}) (RD 1310/1990) [9]. This may be explained by the fact that this study was located in an area without nearby pollution sources and that the soil had initial low levels of this element (11.9 mg Zn kg^{-1}).
On the other hand, in Figure 2 can be observed that an increase of available Zn in the soil increased the Zn concentration in the pasture [18] because in the harvest of May 2008 the high (400N) dose of sewage sludge implied a higher concentrations of Zn in pasture compared with the 0N and 100N treatments but not exceeding the levels of 100 and 400 mg Zn kg^{-1}, which are considered excessive and toxic, respectively, for plants [7]. With regard to animals, the maximum Zn in the forage concentrations established for bovines (500 mg Zn kg^{-1}) and ovine (300 mg Zn kg^{-1}) were never exceeded, which indicated that the pasture of this experiment was adequate for animal consumption [19].

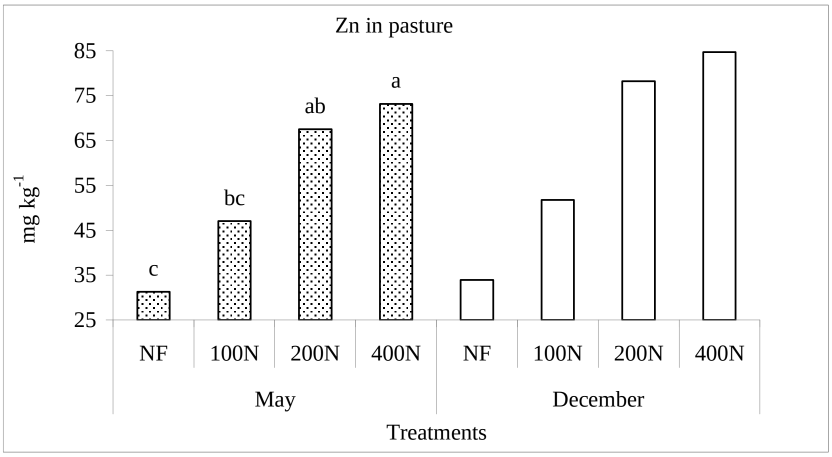

Figure 2. Concentration of Zn in pasture (mg kg^{-1}) under the different fertiliser treatments in May and December 2008. 0N: no fertiliser; 100N: 100 kg total N ha^{-1}; 200N: 200 kg total N ha^{-1} and 400N: 400 kg total N ha^{-1} Different letters indicate significant differences between treatments in each harvest.

Conclusion

The application of sewage sludge increased the Zn concentration in the first 25 cm of soil and in the pasture, mainly when high doses (400 kg total N ha^{-1}) of sewage sludge were applied but never exceeded the maximums set by Spanish regulations and did not cause harmful effects on plants and animals.

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