EFFECTS OF THE FERTILISATION WITH SEWAGE SLUDGE ON CU CONCENTRATION IN SOIL AND PASTURE IN PASTORAL SYSTEMS, FORESTRY SYSTEMS AND SILVOPASTORAL SYSTEMS DEVELOPED UNDER *PINUS RADIATA* D. DON

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1 INTRODUCTION

Sewage sludge application as fertiliser is an increasing managing practice because of it benefits to soil and crops due to its specific organic matter and macronutrient content, particularly N and to a lesser extent of P, K, Ca and Mg (MMA, 2006). However, the use of this residue as a fertiliser must take into consideration the heavy metal concentration, especially Cu concentration that is higher than that normally found in soils (Smith, 1996).

Copper is an essential metal for many organisms, but it is also very toxic. Copper is known to have a number of negative effects both on crops (Baryla et al., 2000) and microorganisms in the soil, which could have a negative effect on the fertility of the soil (Martensson and Torstensson, 1997). In Spain, R.D.1310/1990 (BOE, 1990) and European Directive 86/278 (EU, 1986) limit the total heavy metal concentration in soil and sewage sludge in order to prevent harmful effects on soil, vegetation, animals and, finally, human health.

Heavy metals, in general, have a low solubility in basic soils, as the concentration of metals in soil water depends on soil parameters such as pH, redox potential, organic matter content (SOM) and the total amount of metal present in the soil (McBride, 1994). All heavy metals have a specific pH underneath which their solubility is drastically increased. For copper, this pH is 5.5 (Martinez and Motto, 2000).

The aim of this study was to evaluate the effects of municipal sewage sludge application on the concentrations of Cu in soil and pasture compared to control treatments (mineral and no fertilisation) in pastoral systems, forestry systems and silvopastoral systems developed under *Pinus radiata* D. Don and established in agricultural and forest soil.

2 MATERIALS AND METHODS

The experiment was established in December 2006 through the use of 24 pots of 2 m^3 that were installed in Piugos (Lugo, Galicia, NW Spain, European Atlantic Biogeographic Region) at an altitude of 470 m above sea level. Half of the pots were filled with agronomic soil (12 pots) from Sarria (Lugo, Galicia, NW Spain) and with forest soil (12 pots) from Cantera de Bascuas (Condesmo, Lugo, Galicia, NW Spain).

The experimental design was a randomised block with three replicas and eight treatments. The treatments established are traditional treatments in the area of study (agronomic soil without tree, forest soil without pasture, and silvopastoral systems). Treatments consisted of: (1) Agronomic soil + pasture sowing (Agronomic + P); (2) Agronomic soil + pasture sowing + sewage sludge (Agronomic + PS); (3) Agronomic soil + pasture sowing + mineral (Agronomic + PM); (4) Agronomic soil + pasture sowing + mineral + tree (Agronomic + PMT); (5) Forest soil + sewage sludge + tree (Forest + ST); (6) Forest soil + mineral + tree (Forest + MT); (7) Forest soil + pasture sowing + sewage sludge + tree (Forest + PST) and (8) Forest soil + pasture sowing + mineral + tree (Forest + PMT). Where:

- Pasture sowing (P): 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 2006.
- Tree (T): a one year old *Pinus radiata* D. Don tree was planted in January 2007.
- Sewage sludge (S): fertilisation with anaerobically digested sludge with an input of 320 kg total N ha^{-1} in December 2006.

– Mineral (M): in the Agronomic + PM, Agronomic + PMT, Forest + MT, and Forest + PMT treatments 500 kg ha^{-1} of 8 (% N):24 (% P_2O_5):16 (% K_2O) were applied at the beginning of the years 2007, 2008, and 2009 and 40 kg N ha^{-1} as calcium ammonium nitrate 26% after each harvest.

Sewage sludge was taken from municipal waste treatment plant of Lugo and was applied superficially. The calculation of the required amounts was conducted according to the percentage of total N (3.5%) and dry matter contents (20.47%) (EPA, 1994) and taking into account the European Union Directive 86/278/CEE (EU, 1986) and the Spanish regulation (R.D.1310/1990) (BOE, 1990) regarding the heavy metal concentration for sewage sludge application.

Soil samples were collected at a depth of 25 cm as described in the RD 1310/1990 (BOE, 1990) in March 2008 and pasture copper was estimated by taking two samples of pasture per pot at random (0.3 x 0.3 m^2) in May 2007, June 2007 and August 2007. Soil total (CEM, 1994) and available copper (Mehlich, 1985) as well as pasture copper concentration (CEM, 1994) were estimated in the laboratory.

Data were analyzed using ANOVA and differences between averages were shown by the test LSD using the statistical package SAS (SAS, 2001).

3 RESULTS AND DISCUSSION

The total and Mehlich soil levels of copper in 2008 can be seen in Figure 1. The total values of Cu can be considered to be low when compared to the usual range for natural soils described by several authors, such as Barber (1995) (1-50 mg kg^{-1}) and Kabata-Pendias and Pendias (2001) (6-60 mg kg^{-1}). Moreover, all values (4.6-13.7 mg kg^{-1}) were very low compared to the Spanish regulation limits (50 mg kg^{-1}) (R.D.1310/1990) (BOE, 1990). This may be explained by the fact that this experiment was located in an area without nearby pollution sources.

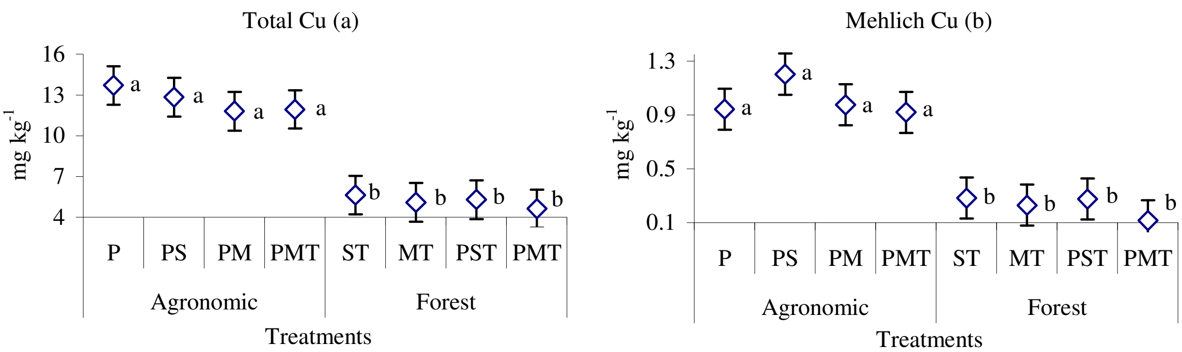

FIGURE 1 **Total Cu concentration (mg kg^{-1}) in soil (a) and amount of Cu (mg kg^{-1}) extracted by Mehlich (b) in each treatment in 2008. P: sowing of pasture, S: sewage sludge, M: mineral; T: tree. Different letters indicate significant differences between treatments. Vertical lines indicate mean standard errors.**

There were not found differences between treatments when only agronomic or forest soils were taken in to account. However, when agronomic and forest soils were compared was found that the concentration of total and Mehlich Cu was significantly higher in the Agronomic treatments than in the Forest treatments ($p<0.001$).

The effect of different treatments on the extractable Cu depended on the influence of these treatments on the factors that affect their availability, such as pH and SOM (López-Mosquera et al., 2005). In this study the relationship between extractable Cu and soil pH was weak because the agronomic and the forest soils had similar soil pH (pH of 4.8-4.9 to agronomic soils and pH of 4.4-4.5 to forest soils). However the percentage of SOM tended to be lower in the forest soils than in the agronomic soils and therefore the availability of Cu also was lower in the forest soils than in the agronomic soils because the Cu is not incorporated into the soils and could be leached through the soil profile (Kabata-Pendias and Pendias, 2001). High levels of SOM could also reduce the negative effect of Cu, because SOM reduces their availability due to the formation of stable organo-metallic complexes (Kabata-Pendias and Pendias, 2001) but this effect was not found in this study. Other experiments carried out in the area in an agronomic soil and with a pH close to neutral (6.3) (Mosquera-Losada et al., 2009) had described an increase of the availability of Cu due to changes in pH caused by sewage application because this type of organic fertilisation have an important effect of mineralisation, which mobilizes heavy metals and favours their incorporation into the soil.

The range of Cu concentrations in the pasture in this experiment (2.8-7.9 mg kg^{-1} in the harvest of May 2007 and 3.8-6.1 mg kg^{-1} in the harvest of August 2007) (Figure 2) was slightly below the usual in plant range (10-80 mg kg^{-1}) (Loué, 1988) and below the levels considered excessive or toxic for plants (20 and 100 mg kg^{-1}) by Kabata-Pendias and Pendias (2001). This variable of study was significantly affected by treatments in May and August 2007 ($p<0.001$ and $p<0.05$, respectively) but in June 2007 there was not a significant effect of the treatments on concentration of Cu in pasture (data not shown). In the harvest of May 2007, no differences were found on Cu in pasture within Agronomic treatments but, on the contrary, the concentration of Cu in pasture was higher in Forest treatment without pasture sown and with organic fertilisation (ST) than in the all other Forest treatments. This result can be explained by the lower proportion of *Dactylis glomerata* L. in the ST treatment than in the other Forest treatments because this species not accumulate Cu (Mosquera-Losada et al., 2001). In the harvest of August 2007, no differences in the Cu pasture concentration were found within agronomic or forest soils. However, the Agronomic + PMT treatment had pasture with highest Cu concentration than the Forest + PMT treatment due to the higher availability of Cu in the agronomic soils than in the forest soils.

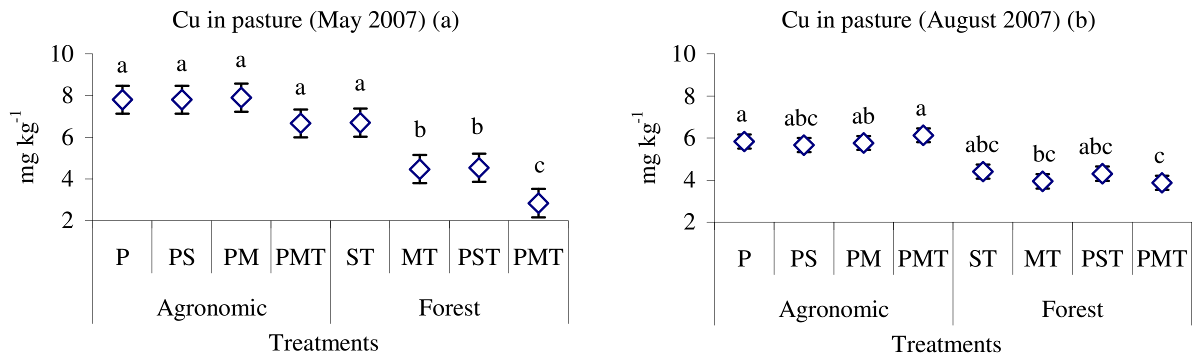

FIGURE 2 **Concentrations of Cu in pasture (mg kg^{-1}) in the harvest of May 2007 (a) and August 2007 (b). P: sowing of pasture, S: sewage sludge, M: mineral; T: tree. Different letters indicate significant differences between treatments. Vertical lines indicate mean standard errors.**

With regard to the animals, Cu levels of pasture were below the minimum maintenance needs to for cattle (10 mg kg^{-1}) (NRC, 2000), goat (10 mg kg^{-1}) (Lamand, 1981) and horses (10 mg kg^{-1}) (NRC, 1989) in all treatments in both harvests which makes necessary to supply this element to animals. In the case of the sheep, the agronomic soils met the requirements for maintenance (4.6-7.4 mg kg^{-1}) (NRC, 1985) but in the forest soils, with the exception of ST treatment, supplements of these elements to the sheep would be recommended if their nourishment was derived solely from these pastures.

4 CONCLUSIONS

The total and Mehlich soil levels of Cu were lower in the forest soils than in the agronomic soils due to the lower percentage of SOM which caused that Cu is not storaged into the soils and could be leached through the soil profile. The highest availability of Cu in the soil and the lowest proportion of *Dactylis glomerata* L. in the pasture increased the concentration of Cu in pasture. Sewage sludge inputs did not cause harmful effects of Copper from a plant and animal point of view.

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