Effect of lime and sewage sludge fertilisation on flora biodiversity in a silvopastoral system under *Pinus radiata D. Don*

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Abstract

In the silvopastoral systems, the liming and the fertilisation are usually carried out to increase the productivity but these techniques can also modify the flora biodiversity of the understory. The aim of this study was to evaluate the effect of liming and the application of two doses of sewage sludge (50 and 100 kg total N ha^{-1}) on the flora biodiversity in a silvopastoral system established in an area reforested with *Pinus radiata* D. Don in Galicia (NW Spain). The results of this experiment showed that the improvement of the soil fertility caused by the liming and the fertilisation with sewage sludge decreased the proportion of shrubs in the understory, which have a positive impact on the reducing fire risk.

Keywords: agroforestry, afforestation, herbaceous, shrubs, fire risk

1. Introduction

Galicia (NW Spain) is characterized by having two thirds of its area allocated to forestland (IV IFN, 2011) which implied that this region is one of the most fire-prone areas in the country. Therefore, it is import to find ecological and low cost methods with which to decrease the fire risk. In this context, the silvopasture (combining woody vegetation with pasture and animal production) (Mosquera-Losada *et al*., 2016) helps to reduce fuel loads in the understory and thus the fire risk due to the integration of grazing in the forest. In addition to adequate management of the forest areas to prevent the forest fires and to guarantee the duration and the profitability of the plantations, it is also important to preserve the biodiversity of the area. Several studies have showed that the silvopasture promotes the biodiversity through the creation of micro-sites (shaded and unshaded areas) as well as through the reduction of habitat fragmentation (Rois *et al*., 2006).On the other hand, in Galicia, the high acidity of the soils can limit the productivity (understory and tree) of the silvopastoral systems. The best way to enhance productivity is through the liming and the use of inorganic or organic fertilisers as the sewage sludge (Ferreiro-Domínguez *et al*., 2014). However, the use of fertilisers, as well as liming, can modify the botanical composition of the understory due to the modification of the relationship of species (presence of monocots vs. dicots), different functional ecological traits (presence of annual vs. perennial species) or richness. Different studies have been carried out in grasslands (Buttler *et al*., 2008; Plantureux *et al*., 2005), in order to see how biodiversity is affected by the liming or the fertilisers but few long-term studies have been carried out on temperate agroforestry systems established in very acid soils. The aim of this study was to evaluate the effect of liming and the application of two doses of sewage sludge (50 and 100 kg total N ha^{-1}) on the flora biodiversity in a silvopastoral system established in an area reforested with *Pinus radiata* D. Don in Galicia.

2. Materials and methods

The experiment was conducted in San Breixo Forest Community (Lugo, Galicia, northwestern Spain, European Atlantic Biogeo-graphic Region). In 1998, a plantation of *Pinus radiata* D. Don was established at a density of 1667 trees ha^{-1} after harvesting a 30 year old *Pinus radiata* D. Don. Scrubland was the main understory vegetation before planting, which included species such as *Ulex gallii* Planch., *Erica cinerea* L., *Calluna vulgaris* L., *Genistella tridentata* L., *Rubus* spp., *Avenula sulcata* (J. Gay ex Delastre), *Agrostis curtisii* Kerguelen and *Holcus mollis* L.

In October 1999, when forestry plants were 1 year old, an experiment with a randomised block design was performed in 15 experimental plots (five treatments × three replicates) of 96 m^2, each consisting of 25 trees arranged in a 5 m × 5 m frame with a distance of 3 m between rows and 2 m between lines. Each plot was sown in the autumn of 1999 with a mixture of 25 kg ha^{-1} *Lolium perenne* var. Brigantia, 10 kg ha^{-1} *Dactylis glomerata* var. Artabro and 4 kg ha^{-1} *Trifolium repens* cv. Huia after ploughing. The established treatments were two sewage sludge doses based on N application (T1: 50 kg total N $ha^{-1}$and T2:100 kg total N ha^{-1}), with or without liming applied in 1999 before sowing (2.5 t $CaCO_3 ha^{-1}$). A no fertilisation (NF) treatment was also established as a control in the unlimed plots. Sewage sludge was superficially applied during 2000, 2001, 2002 and 2003. A composite soil sample per plot was randomly taken at adepth of 25 cm in December 2003 and 2008 as described in R.D. 1310/1990 (BOE, 1990). In the laboratory an extraction with 0.6 N $BaCl_2$ was used to determine the concentrations of Al and the exchangeable cations (K, Ca, Mg and Na) in the exchange complex (Mosquera and Mombiela, 1986). The exchangeable K, Ca, Mg and Na concentrations were measured with a VARIAN 220FS spectrophotometer using the atomic emissions for K and Na and the absorptions for Ca and Mg. The Al concentration was analysed after validation with 0.01 N NaOH using phenolphthalein (1%) in an alcohol-based solution as an indicator (Mosquera and Mombiela, 1986). The effective cation exchange capacity (ECEC) was determined by taking the sum of K + Ca + Mg + Na + Al and the saturation percentage of Al, K, Ca, Mg and Na using the quotients Al/ECEC, K/ECEC, Ca/ECEC Mg/ECEC and Na/ECEC, respectively (Mosquera and Mombiela, 1986).Botanical composition of the understory was determined by randomly collecting four samples. The four samples were cut with an electric hand clipper at a height of 2.5 cm per plot (0.3 m × 0.3 m) in June and November 2003 and in June and November 2008. At the laboratory, two samples were separated by hand according to the different species, pine needles and senescent material and then dried (72 h at 60ºC) to determine their composition on a dry weight basis. Annual abundance diagrams omitting the percentage of pine needles and senescent material were completed (Magurran, 1988).The data obtained were analysed by ANOVA (PROC GLM procedure). The LSD test was used for subsequent pairwise comparisons if the ANOVA was significant. The statistical software package SAS (2001) was used for all analyses.

3. Results

The saturation percentages of the different cations (Al, K, Ca, Mg and Na) in the soil ECEC can be seen in Figure 1. In general, the Ca saturation percentage in 2003 was positively affected by lime when the same doses of sewage sludge were compared ($p < 0.01$), being the effect of lime the opposite when the Al saturation percentage ($p < 0.01$) was considered. However, within the same dose of lime, sewage sludge alone did not affect the saturation percentage of Ca or Al. Moreover, the combination of sewage sludge and lime in 2003 increased and reduced the levels of Ca and Al, respectively, with respect to the NF treatment. Finally, in 2008, all treatments had a higher Ca saturation percentage than the NF treatment ($p < 0.05$), the opposite being true if the Al saturation percentage was evaluated ($p < 0.05$).Abundance diagrams for the different fertilisation treatments in 2003 and 2008 are shown in Figure 2. In both years, *Dactylis glomerata* L. was the dominant species when the lime was combined with sewage sludge and the high doses of sewage sludge (T2) without lime were applied to the soil. In the Lime T2 treatment the proportion of this specie was over 80% during all studied period. However, in this experiment the establishment of the other sown species (*Lolium perenne* L. and *Trifolium repens* L.) was not adequated. In general, in the NF treatment and in the treatment in which low doses of sewage sludge (T1) without lime were applied, the shrubs as *Erica cinerea* L. and *Ulex gallii* Planch. shared dominance with herbaceus species as *Agrostis capillaris* L. and *Agrostis curtisii* Kerguélen.

4. Discussion

This experiment was established in an acidic soil of Galicia (initial soil pH in water: 4.28) with a high Al saturation percentage in the exchange complex. In this region the acidity of the soils can be explained by the type of bedrock (mainly quartz) but also by the cations leaching trough the soil profile caused by the high rainfall levels, with well over 1000 mm a year across almost the entire region (Lorenzo *et al*., 2010). However, at the beginning of this study, it was found a positive effect of lime on the Ca in the exchange complex probably due to the inputs of Ca to the soil associated to the liming as it was previously described by López-Díaz *et al*. (2007) in a silvopastoral system established in the same area with *Pinus radiata* D. Don. In 2003, the positive effect of lime on the Ca in the exchange complex was greater than that of sewage sludge, which might be because the lime was responsible for higher inputs of Ca to the soil than sewage sludge (Mosquera-Losada *et al*., 2011b). However, the residual effect of lime gradually declined in the years following its application and in 2008, the effect of sewage sludge was still observed, which indicates that sewage has a higher residual effect on the soil chemical and physical properities than lime (EPA, 1994). On the other hand, the NF treatment showed a higher Al saturation percentage in the exchange complex and therefore a lower Ca saturation percentage than the limed treatments in 2003 and all treatments in 2008. This result is indicative of a positive effect of lime and sewage sludge on soil fertility. In general, lime and sewage sludge can increase exchangeable Ca, which tends to improve the physical and chemical properties of the soil and microbial activit, causing organic mineralisation and therefore, nutrient release to the soil (Wheeler, 1998). The improvement of the soil fertility associated to the liming and the fertilisation with sewage sludge could modify the pasture production in the understory but aslo its botanical composition as it was observed in this experiment in which the proportion of herbaceous species, mainly *Dactylis glomerata* L., was higher when the lime and the sewage sludge were applied compared with the NF treatment. In the unfertilised plots in which the soil nutritive conditions remained very poor (high Al saturation percentage), the proportion of shrubs (*Erica cinerea* L. and *Ulex gallii* Planch.) was high. The reduction in the proportion of shrubs in the understory due to the improvement of soil fertility has been previously described by numerous authors (Mosquera-Losada *et al*., 2011a) and is highly relevant for management from an environmental perspective in the region in which this experiment was performed. *Pinus radiata* D. Don forest stands in Galicia are highly productive, because of the mild climate in the area, but understory fuel accumulation is also high and loads of 30–50 Mg DM ha^{-1} are frequent (Ruiz-González *et al*., 2009) which imply that Galicia is one of the most fire-prone areas in the country. Therefore, the reduction in shrub proportion in the understory might reduce the fire risk, as shrubs are more inflammable than herbaceous vegetation (Silva-Pando *et al*., 2002). Moreover, the presence of herbaceous species instead of shrub species improves forage quality of the understory and increases profitability from the same unit of land. Finally, it is important to be aware that although the soil fertility improved with liming and fertilization with sewage sludge the establisment of the sown species *Lolium perenne* L. and *Trifolium repens* L. in the understory of this study was not adequated probably because these species are not adapted to the shade conditions generated by the trees (Mosquera-Losada *et al*., 2001). For this reason when silvopastoral systems are established it is important to use pasture species that persist well in shaded conditions as *Dactylis glomerata* L.

5. Conclusion

The improvement of the soil fertility caused by liming and the fertilisation with sewage sludge modified the botanical composition of the understory, decreasing the proportion of shrubs, which have a positive impact on the reducing fire risk.

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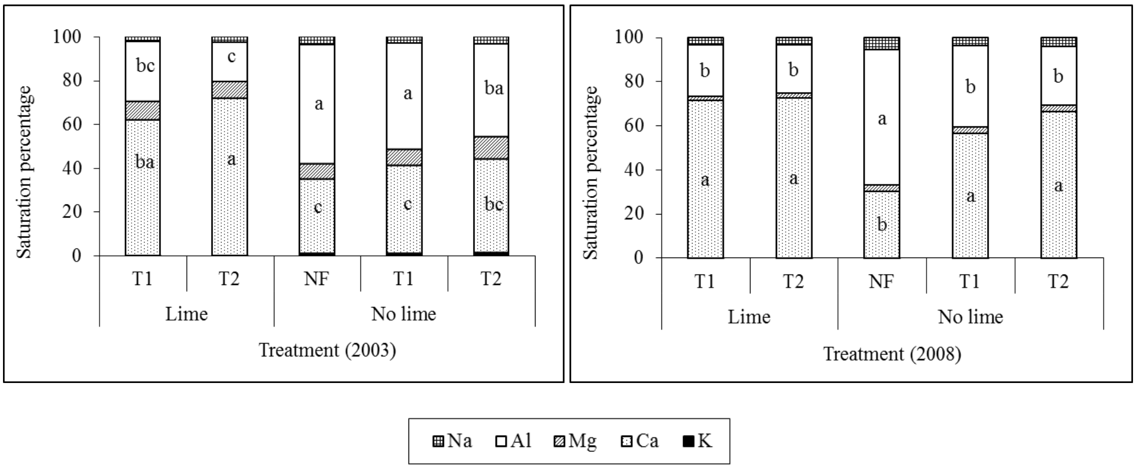
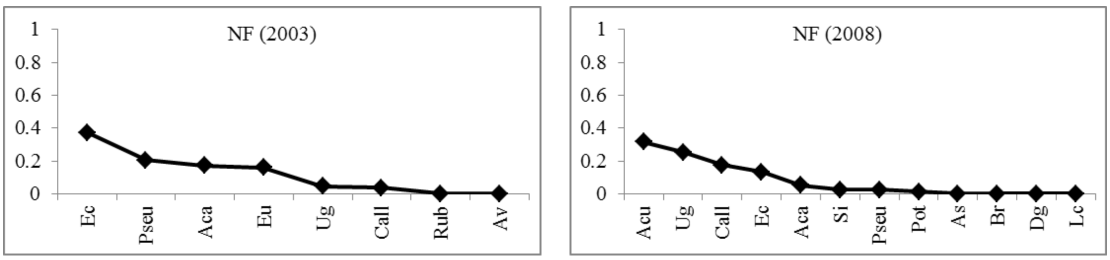


Figure 1: Saturation percentage of Al, Mg, Ca, Na, and K in the soil exchange complex (%) under each treatment in 2003 and 2008. NF: no fertiliser; T1: low sewage sludge doses (50 kg total N ha^{-1}); T2: high sewage sludge doses (100 kg total N ha^{-1}). Different letters indicate significantdifferences between treatments within the same year and treatments are no significantly different if no letters are shown.



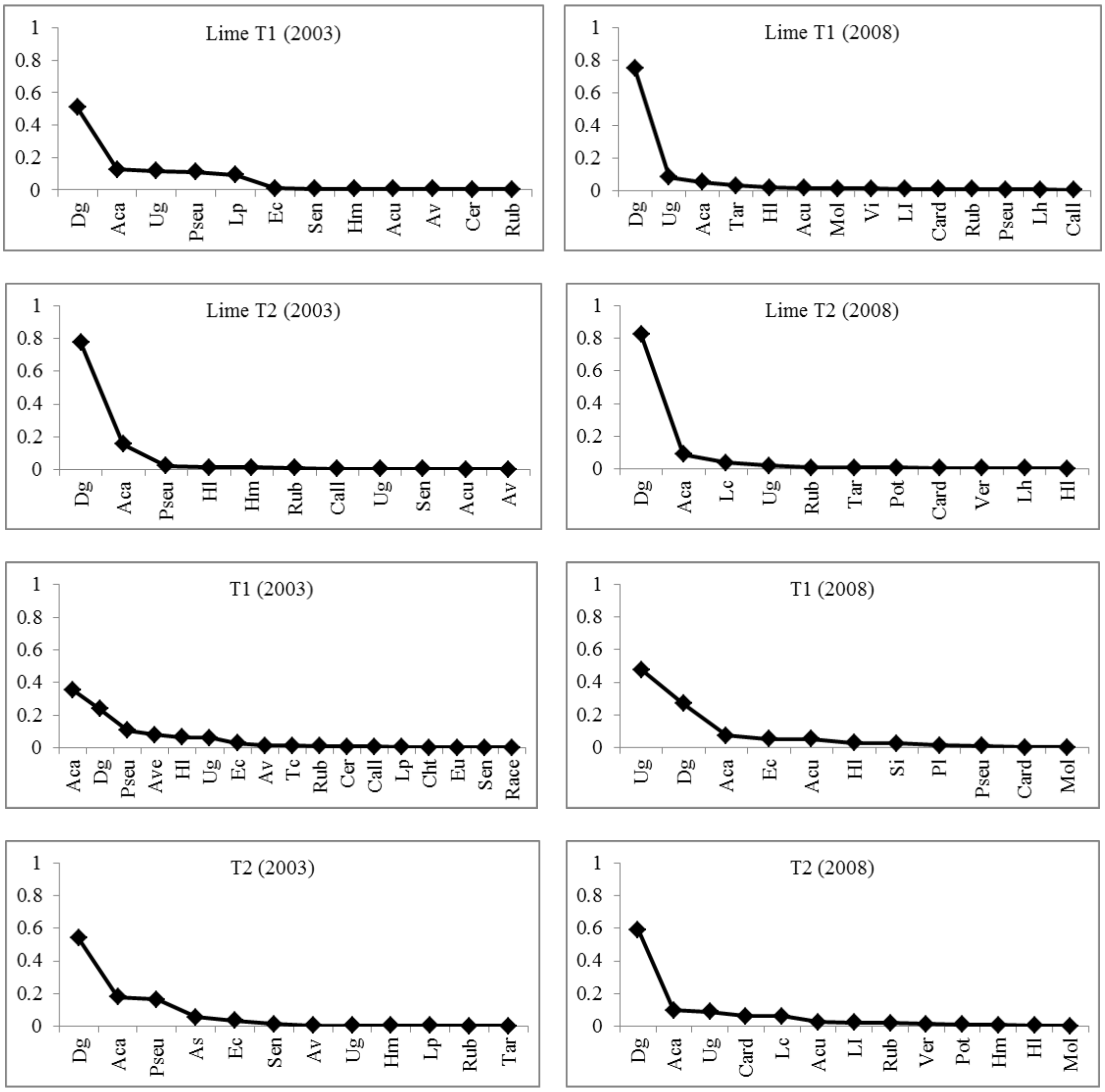


Figure 2. Species abundance diagrams for the treatments applied in 2003 and 2008. NF: no fertiliser; T1: low sewage sludge doses (50 kg total N ha^{-1}); T2: high sewage sludge doses (100 kg total N ha^{-1}). Aca: *Agrostis capillaris* L., Acu: *Agrostis curtisii* Kerguélen., As: *Agrostis stolonifera* L., Ave: *Avena* spp, Av: *Avenula sulcata* (J. Gay ex Delastre), Br: *Bromus hordeaceus* L.,Card: Carduus spp., Cer: Cerastium glomeratum Thuill, Cht: *Chamaespartum tridentatum* (L.) P.E. Gibbs., Cv: *Calluna vulgaris* (L.) Hull., Dg: *Dactylis glomerata* L., Eci: *Erica cinerea* L., Eu: *Erica umbellata* Loefl. ex L., Hl: *Holcus lanatus* L., Hm: *Holcus mollis* L., Lh: *Leontodon hispidus* L., Lt: *Lithodora prostrata* (Loisel.) D.C.Thomas., Lp: *Lolium perenne* L., Lc: Lotus corniculatus L., Mol: *Molinia caerulea* (L.) Moench., Pot: *Potentilla erecta* (L.) Raüschel., Pl: *Plantago lanceolata* L., Pseu: *Pseudoarrenatherum longifolium* (Thore) Rouy.,Race: Rumex acetosa L., Rub: *Rubus* spp., Sen: *Senecio jacobaea* L., Si: *Simethis mattiazzii* (Vand.) Sacc., Tar: *Taraxacum officinale* Weber., Tc: *Trifolium campestre* Schreber, Tr: *Trifolium repens* L., Ug: *Ulex gallii* Planch., V: *Viola* spp., Ver: *Veronica agrestis* L**.**

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