Evolution of soil organic matter in *Eucalyptus nitens* Maiden silvopastoral systems fertilised with different types of sewage sludge

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Abstract

The silvopasture has been recognized as a possible greenhouse gas mitigation strategy under the Kyoto Protocol due to the potential for carbon storage in multiple plant species and in the soil. Soil organic matter (SOM) represents the most important pool of carbon storage in terrestrial ecosystems and can be modify among other factor by the fertilisation. The objective of this experiment was to evaluate during five years the evolution of SOM in a silvopastoral system established with *Eucalyptus nitens* Maiden in Galicia (NW Spain) and fertilised with sewage sludge that has been stabilised using anaerobic digestion, composting, and pelletisation. The results showed that the SOM gradually decreased from the second year of the study probably due to the fertilisation and the ploughing of the soil but also due to a negative effect of the trees on the biological activity in the soil. Therefore, the afforestation with *Eucalyptus* not served its task to soil carbon sequestration compared with other tree species established in silvopastoral systems in the same area and it is necessary to continue our study to properly evaluate the effect of *Eucalyptus* on the SOM.

Keywords: agroforestry, afforestation, sowing, climate change, carbon sequestration

1. Introduction

The climate change is one of the most important current environmental problems which affect the whole planet (Noaa, 2016). The agroforestry practices and therefore the silvopasture (combining woody vegetation with pasture and animal production) (Mosquera-Losada *et al*., 2016b) were mentioned in the Kyoto Protocol and recently in the framework of the EU strategy on adaptation to climate change (EU 2013) and in the last IPCC (Intergovernmental Panel on Climate Change) report (IPCC 2014) as a mechanism for mitigation to climate change due to the potential for carbon storage in multiple plant species and in the soil. Soil organic matter (SOM) represents the most important pool of carbon storage in terrestrial ecosystems, accounting for about 75% of total stored carbon (Mosquera-Losada *et al*., 2011a).In Galician silvopastoral systems, the productivity (of both the understory and the trees) can be limited by low soil fertility as a result of the increased acidity (Zas and Alonso, 2002). The fertilisation with sewage sludge may increases tree and pasture production as well as reduce or increase SOM content. Moreover, in Europe, it is compulsory to stabilise sewage sludge before it is used as a fertiliser in agricultural production systems. The stabilisation processes could cause differences in the mineralisation rates (EPA, 1994), and therefore, in the fertiliser's potential, but also in the levels of SOM. Anaerobic digestion and composting are the most important types of sludge stabilisation promoted by the EU (European Directive 86/278) (EU, 1986). However, both types of waste processing candeliver sewage sludge with high proportions of water which could be reduced by 98% through the pelletisation of anaerobic sludge via a thermic treatment. Consequently, pelletisation reduces storage, transport, and spreads costs, when compared with anaerobic or composted sludge (Mosquera-Losada *et al*., 2010).The objective of this experiment was to evaluate during five years the evolution of SOM in a silvopastoral system established with *Eucalyptus nitens* Maiden in Galicia (NW Spain) and fertilised with sewage sludge that has been stabilised using anaerobic digestion, composting, and pelletisation.

2. Materials and methods

The experiment was carried out on an abandoned agricultural land in A Pastoriza (Lugo, Galicia, NW Spain, European Atlantic Biogeographic Region).At the beginning of the experiment, the soil was double ploughed to a depth of 50 cm, which is a traditional practice in this area, and 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 the autumn of 2004. After pasture sowing in February 2005, plants of *Eucalyptus nitens* Maiden were planted at a density of 1667 trees ha^{-1}, with a distance between the rows of 3 × 2 m. The experimental design was based up on a randomised block with three replicates and five treatments that were distributed in experimental units of 96 m2 with twenty five trees arranged in a frame of 5 × 5 trees. The treatments consisted of (1) no fertilisation (NF), (2) mineral fertilisation (MIN) with 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 the first harvest; (3) fertilisation with anaerobically digested sludge (ANA) with an input of 320 kg total N ha^{-1} before the pasture sowing; (4) fertilisation with composted sewage sludge (COM) with an input of 320 kg total N ha^{-1} before the pasture sowing and (5) an application of pelletised sewage sludge (PEL), which involved a contribution of 320 kg total N ha^{-1} split as 134 kg total N ha^{-1} just before the pasture sowing in 2004 and 93 kg N ha^{-1} at the end of 2005 and 2006. In all cases, the sewage sludge was superficially applied. A composite soil sample per plot was randomly taken at a depth of 25 cm every December from 2005 to 2009 as described in R.D. 1310/1990 (BOE, 1990). In the laboratory, the soil samples were air-dried, passed through a 2 mm sieve, and ground with an agate mortar. The total carbon content in the soil was estimated by oxidation of the total organic matter with potassium dicromate and sulphuric acid. The excess ofdicromate was valorated with Mohr salt (Kowalenko, 2001). The percentage of SOM was calculated by multiplying the total C content of the soil by the de Van Bemmelen factor (1.724).The data obtained were analysed using repeated measures ANOVA (proc glm procedure) The LSD test was used for subsequent pair wise comparisons if the ANOVA analysis was significant. The statistical software package SAS (2001) was used for the analyses.

3. Results and Discussion

In this study the SOM varied between 87.68 and 146.89 g kg^{-1} (Figure 1). These values were high compared to those on agronomic lands, which are considered to have high SOM levels when SOM is more than 35 g kg^{-1} (Porta *et al*., 1999), but in grassland, the SOM mean is usually between 50 and 80 g kg^{-1} (Domínguez-Vivancos 1997). However, in this study, the SOM gradually decreased from 2006 ($p < 0.01$). The reduction of SOM over time could be explained by several factors such as: i) the fertilisation because the N supplied with the fertilisers could improve the mineralisation rate by the subsequent reduction of the C/N relationship, ii) the ploughing of the soil carried out at the beginning of the experiment which could increase the aeration of the soil and therefore the mineralization rate of the SOM and iii) the effect of the trees. It is well known that the *Eucalyptus* litter quality leads to a low biological activity in the soil (Bernhard-Reversat *et al*., 2001) and results in a low organic matter decomposition rate from the litter and the sludge in *Eucalyptus* plantations which can prevent SOM accumulation. Therefore, the afforestation with *Eucalyptus* not served its task to soil carbon sequestration compared with other tree species as *Pinus radiata* D. Don (Mosquera-Losada *et al*., 2015) or *Prunus avium* L. (Ferreiro-Domínguez *et al*., 2016) also established in silvopastoral systems in the same area.

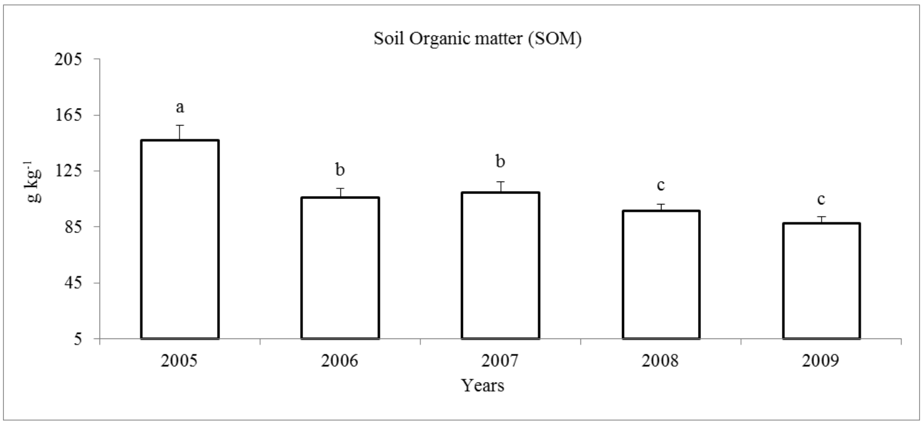
On the other hand, in 2005, the SOM was lower when the COM and PEL sludges were applied to the soil compared with the NF and MIN treatments ($p < 0.05$). The negative effect of the COM and PEL treatments on SOM could be explained by the higher Ca supplies to the soil with COM and PEL than with NF and MIN treatments. The inputs of Ca to the soil from COM and PEL sludges probably activated the mineralisation, thus reducing the SOM (Wild 1992). Similar results were previously described by Rigueiro-Rodríguez *et al*. (2011) in a *Pinus radiata* D. Don silvopastoral system also fertilized with mineral and anaerobic sewage sludge. Moreover, the dose of the PEL sludge was split several times, thus facilitating the incorporation of the sludge into the soil, and subsequently, the liberation of nutrients such as Ca which could have also favoured the increase of the mineralisation rate of the SOM. In any case, under Galician conditions, when the soil pH is improved due to the inputs of Ca to the soil from organic fertilisers it is not easy to find an increment of SOM because the SOM mineralization rate is high due to the adequate temperature and precipitation rate. Finally, in 2007, a contrary effect of the COM sludge on the SOM was found because the COM treatment increased more the SOM than the NF, MIN, and ANA treatments ($p < 0.05$). This result could be due to the higher pasture production in the COM treatment when compared with the NF and the ANA treatments (Mosquera-Losada *et al*., 2016a), because it can be assumed that the increase in the SOM depended upon the incorporation of pasture litter into the soil (Mosquera-Losada *et al*., 2011b).

4. Conclusion

The SOM gradually decreased over time probably due to the fertilisation and the ploughing of the soil but also due to a negative effect of the trees on the biological activity in the soil. Therefore, the afforestation with *Eucalyptus* not served its task to soil carbon sequestration compared with other tree species established in silvopastoral systems in the same area and it is necessary to continue our study to properly evaluate the effect of *Eucalyptus* on the SOM in the silvopastoral systems.

Acknowledgements

We are grateful to FEDER, CICYT and XUNTA DE GALICIA (Consolidation funds and Consellería de Cultura, Educación e Ordenación Universitaria ("Programa de axudas á etapa posdoutoral DOG nº122, 29/06/2016 p.27443, exp: ED481B 2016/071-0")) for financial assistance and to Escuela Politécnica Superior for their facilities. We also acknowledge José Javier Santiago-Freijanes, Divina Vázquez-Varela, Pablo Fernández-Paradela and Teresa Piñeiro-López for their help with sample processing both in the laboratory and in the field.



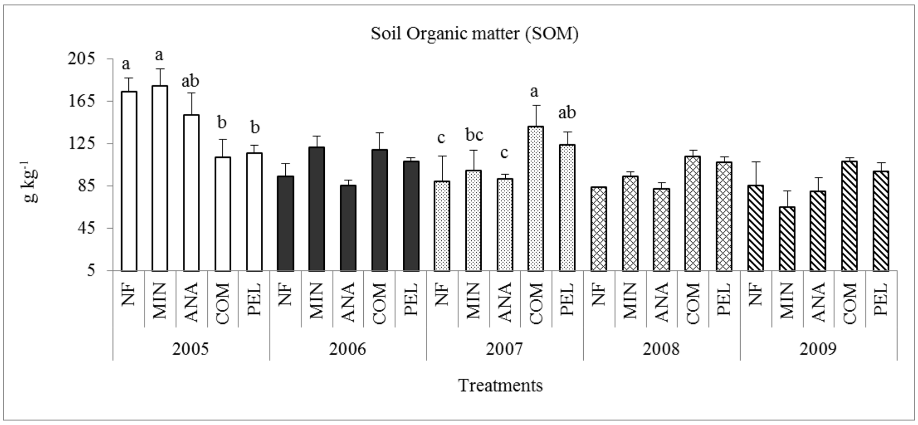


Figure 1: Evolution of soil organic matter (SOM) (g kg^{-1}) over time and soil organic matter (g kg^{-1}) under each treatment from 2005 to 2009. NF: no fertilisation, MIN: mineral; ANA: anaerobic sludge; COM: composted sludge and PEL: pelletised sludge. Different letters indicate significant differences between treatments within the same year and treatments are no significantly different if no letters are shown. Bars in each column indicate the standard error of the mean.

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