Effect of liming and organic fertilisation on soil organic matter in a silvopastoral system under Populus x canadensis Moench

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Abstract: Agroforestry systems are believed to have a higher potential to sequester C than pastures or field crops. This conjecture is based on the notion that tree incorporation in croplands and pastures would result in greater net aboveground as well as below ground C sequestration. In terrestrial ecosystems, soil organic matter is considered the most important store of C. The objective of this study was to evaluate the effect of two doses of lime (0 and 2.5 t CaCO3 ha^{-1}) and three sewage sludge treatments (0, 200, and 400 kg total N ha^{-1} $year^{-1}$ applied in two consecutive years) on soil organic matter at four soil depths (0–25, 25–50, 50–75, and 75–100 cm) in a silvopastoral system under *Populus x canadensis* Moench in Galicia (Spain) eight years after establishment. The results showed a predominance of soil organic matter in upper horizons mainly due to the superficial litter deposition and the differences in root distribution. Moreover, the application of lime and sewage sludge to the soil surface implied that organic matter was modified by the treatments in the first centimetres of the soil. In general, the liming and the fertilisation with medium doses of sewage sludge (200 kg N total ha^{-1}) reduced soil organic matter probably due to the increase of the mineralization rate associated with these treatments.

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

Introduction

Global climate change caused by rising levels of CO_2 and other greenhouse gases is currently recognized as a serious environmental issue of the twenty-first century. Nowadays, finding ecological and low-cost methods with which to sequester C is emerging as a major international policy (Montagnini & Nair, 2004). In recent years, the significance of agroforestry systems with regards to climate change mitigation has been recognized under the Kyoto Protocol due to their capacity to increase the above and below ground carbon sequestration rate and reduce emission of greenhouse gases from agricultural sector (Branca et al., 2013).

Soil organic matter (SOM) is considered the most important pool of C storage in terrestrial ecosystems, accounting for about 75% of total stored C and plays a major role in determining atmospheric concentrations of CO_2 (Mosquera-Losada et al., 2011a). The main sources of organic matter in soils are the litter deposition and the roots of pasture and trees (Fernández-Núñez et al., 2010). In the agroforestry systems, SOM varies depending on soil characteristics, climatic and other environmental conditions, management practices, and tree species and density (Howlett et al., 2011).

In Europe, it is common the use of *Populus* spp. to establish agroforestry systems, mainly because poplars are characterized by their deciduous nature, fast growth, short rotation and high industrial requirement (Savill, 1992). One of the most common hybrid poplars used in European agroforestry plantations is *Populus × canadensis* Moench (Eichhorn et al., 2006). In general, the deciduous species as *Populus* spp. tend to accumulate and store more C in the soil than the conifers, due to the rapid integration of tree leaves and roots of the former into the soil (Fernández-

Núñez et al., 2010). However, this difference is partially off-set by the higher accumulation of C in the tree in the case of pine plantations (Palma et al., 2006).

On the other hand, the silvopastoral systems are the oldest agroforestry systems used in the temperate regions of the world which are characterized by integrating trees with pasture and livestock production (Mosquera-Losada et al., 2008). In the Galician silvopastoral systems (NW Spain) the productivity (of both understory and trees) can be limited by low soil fertility as a result of increased acidity (Zas & Alonso, 2002). Liming and fertilisation using inorganic or organic fertilisers such as sewage sludge could improve both soil fertility and tree and understory vegetation productivity and therefore modify the extent of C sequestration in the soil. In general, the effect of liming and fertilisation on soil C varies with the nature of the fertiliser, as well as with the climate and other site-specific factors (Nair, 2012). Authors including Mosquera-Losada et al. (2010) have reported that fertilisation of acidic soils with sewage sludge increases the amount of soil C, although this effect was not observed at other sites also treated with nitrogen fertilisers (Tripathi al., 2008).

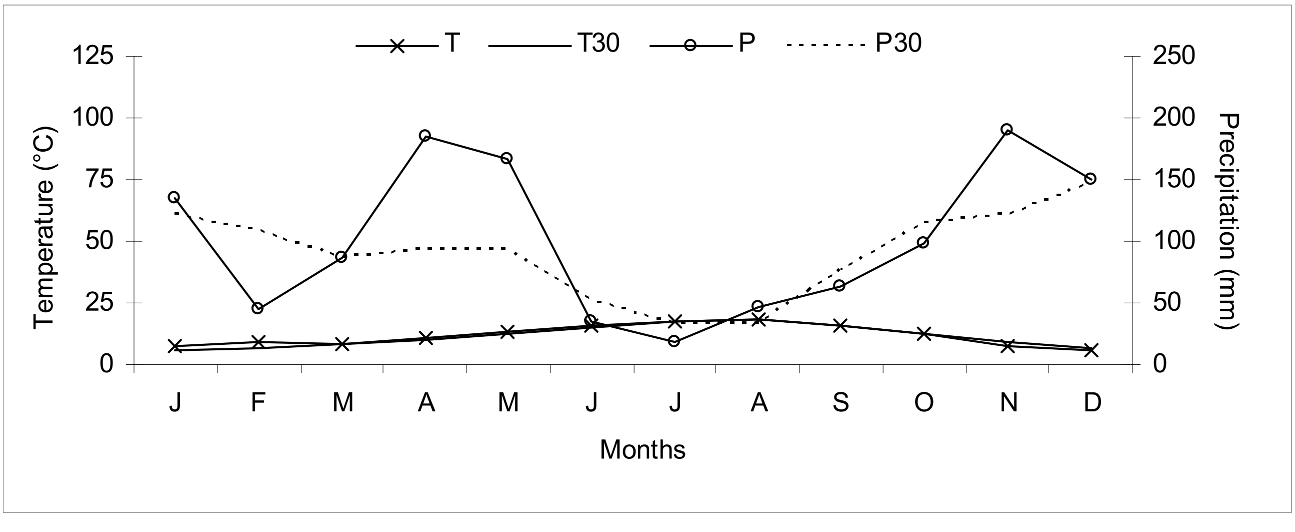
The objective of this study was to evaluate the effect of two doses of lime (0 and 2.5 t CaCO3 ha^{-1}) and three sewage sludge treatments (0, 200, and 400 kg total N ha^{-1} $year^{-1}$ applied in two consecutive years) on SOM at four soil depths (0–25, 25–50, 50–75, and 75–100 cm) in a silvopastoral system under *Populus x canadensis* Moench in Galicia (Spain) eight years after establishment.

Materials and methods

Characteristics of the study site

The experiment was conducted in A Pastoriza (Lugo, Galicia, NW Spain, European Atlantic Biogeographic Region) at an altitude of 460m above sea level. Figure 1 shows the monthly precipitation and mean temperatures for 2008 as well as the mean for the previous 30 years. In general, 2008 was a wet year with a total annual rainfall (1222.3 mm) higher than the mean rainfall registered in the previous 30 years (1083 mm). However, June and August were dry months which limited pasture production and tree growth. The annual mean temperature was mild (12 ºC) with low temperatures at the end of the year under study.

Figure 1: Monthly precipitation and mean temperatures for the study area in 2008 and mean data for the last 30 years. T: mean monthly temperature (ºC), T30: mean temperature over the last 30 years (ºC), P: monthly precipitation (mm) and P30: mean precipitation over the last 30 years (mm).



The experiment was carried out on abandoned agricultural land. The soil texture at the beginning of the experiment was sandy loam (57.3% sand, 36.54% silt and 6.16% clay) with a moderately acidic pH (H_2O) around 5.2 as well as high levels of soil organic matter and total N (80 g kg^{-1} and 3.9 g kg^{-1}, respectively). At the beginning of the experiment, all of the heavy metal concentrations in the soil (Table 1) were below the maximum threshold for using sewage sludge fertiliser as specified by the European Union Directive 86/278/CEE (EU, 1986) and Spanish legislation under R.D. 1310/1990 (BOE, 1990).

Table 1: Heavy metal concentrations in the soil at the beginning of the experiment and the legal limits established by European Directive 86/278 (EU, 1986) and Spain R.D. 1310/1990 (BOE, 1990). Limits depend on soil pH (minimum: soil pH< 7; maximum: soil pH> 7). A dash (–) signifies an element concentration below the detection limit of the technique used for its determination.

	Heavy metal concentrations (mg kg^{-1})					
	Zn	Cu	Cr	Cd	Ni	Pb
Initial soil	20.6	5.8	4.1	-	2.1	-
Spanish legal limits	150-450	50-210	100-150	1-3	30-112	50-300

Experimental design

A plantation of *Populus × canadensis* Moench (cultivar *I-214*) was established in April 2001 at a density of 434 trees ha^{-1} (4.8 m × 4.8 m). Tree density was chosen based on what is usually done in that specific area with *Populus* spp. species to ensure that tree–pasture competition is not too strong allowing adequate pasture production. Following plowing and clearing, a pasture mixture (12.5 kg ha^{-1} of *Dactylis glomerata* L. cv. Artabro, 12.5 kg ha^{-1} of *Lolium perenne* L. cv. Brigantia, and 4 kg ha^{-1} *Trifolium repens* L. cv. Huia) was sown in November 2001. A split plot design with six treatments and three replicates was used. The main plots consisted of lime treatments, and the subplots were fertiliser treatments. Each subplot was made up of 25 trees, arranged in a perfect square (368 m^2) of 5 × 5 trees. Treatments consisted of a combination of two liming doses (0 and 2.5 Mg $CaCO_3$ ha^{-1}) applied in autumn of 2001, and three sewage-sludge doses (0, 200, and 400 kg total N ha^{-1}) applied superficially in April 2002 and again in April 2003.

Sewage sludge

The anaerobically digested sludge came from a municipal waste treatment plant in Lugo. Following the U.S. Environmental Protection Agency (EPA) recommendations, the doses were based on the percentage of total N and the dry matter content of the sewage sludge (Table 2) (EPA, 1994). The EPA established that approximately 25% of the total applied N is mineralised during the first year, when sewage sludge is anaerobically digested. The EU Directive 86/278/CEE (EU, 1986) and the Spanish regulation R.D. 1310/1990 (BOE, 1990) regarding heavy metal concentrations in the application of sewage sludge to soil were also considered. The composition of the sewage sludge applied in 2002 and 2003 is summarised in Table 2.

Table 2: Chemical properties of the sewage sludge and the legal limits established by European Directive 86/278 (EU, 1986) and Spanish R.D. 1310/1990 (BOE, 1990). Limits depend on soil pH (minimum: soil pH <7; maximum: soil pH >7).

Parameters	Mean concentration in the sludge (2002)	Mean concentration in the sludge (2003)	Spanish legal limits
Dry matter, %	22.86	26.08	
pH	6.59	6.82	
N, g kg^{-1}	19.5	22.5	
P, g kg^{-1}	20.2	18.2	
K, g kg^{-1}	3.1	4.4	
Ca, g kg^{-1}	2.3	3.2	
Mg, g kg^{-1}	5.5	6.8	
Na, g kg^{-1}	0.7	0.9	
Fe, g kg^{-1}	27.8	17.7	
Mn, mg kg^{-1}	302.30	202.58	
Zn, mg kg^{-1}	1955.6	148.68	2500-4000
Cu, mg kg^{-1}	225.8	119.25	1000-1750
Cr, mg kg^{-1}	72.9	42.28	1000–1500
Cd, mg kg^{-1}	7.4	6.8	20-40
Ni, mg kg^{-1}	80.5	71.3	300-400
Pb, mg kg^{-1}	146.4	86.45	750-1200

Field samplings and laboratory analyses

To estimate the amount of SOM, in February 2009 a composite soil sample per plot was collected at a depth of 1 m and divided in the field into four subsamples corresponding to different sampling depth classes of 0–25, 25–50, 50–75 and 75–100 cm (Moreno et al., 2005). In the laboratory, the soil samples were air-dried, passed through a 2 mm sieve and ground with an agate mortar. The SOM was determined by using the Saverlandt method (Guitián and Carballás, 1976).

Statistical analysis

The SOM data obtained in each soil depth were analysed by ANOVA (proc glm procedure) using this model $Y_{ijk} = \mu + L_i + F_j + B_k + LF_{ij} + LB_{ik} + FB_{jk} + \varepsilon ijk$, where Y_{ijk} is the dependent variable, μ is the variable mean, L_i is the lime effect i, F_j is the fertilisation effect j, B_k is the block k, LF_{ij} is the lime–fertilisation interaction (lime×fertilisation), LB_{ik} is the lime–block interaction, FB_{jk} is the fertilisation–block interaction and ε_{ijk} is the error.

Moreover it was also studied the effect of the soil depth on the SOM in each treatment with ANOVA (proc glm procedure) and following the model $Y_{ij} = \mu + D_i + B_j + DB_{ij} + \varepsilon_{ij}$, where Y_{ij} is the dependent variable, μ is the variable mean, D_i is the soil depth effect i, B_k is the block k, DB_{ij} is the soil depth–block interaction and ε_{ij} is the error.

The LSD test was used for subsequent pairwise comparisons ($p < 0.05$; a = 0.05) if the ANOVA was significant. The statistical software package SAS (2001) was used for all analyses.

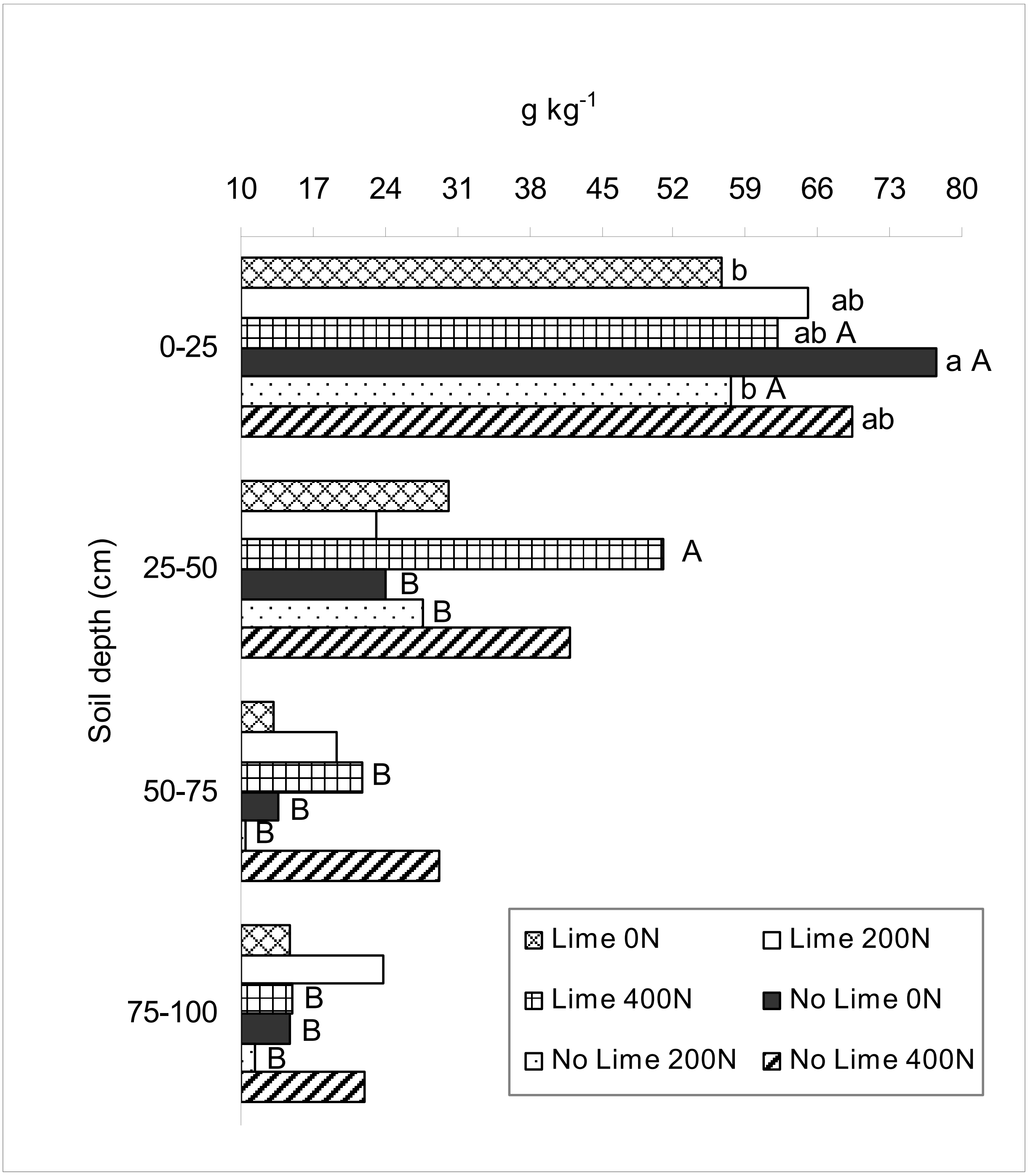
Results and discussion

In this experiment, the SOM levels in the first centimeters of the soil were similar to the SOM values observed usually in grassland (50-80 g kg^{-1}) (Domínguez-Vivancos, 1997). However, the SOM levels found in our study were low compared with the values established by other authors as Rigueiro-Rodríguez et al. (2011) in silvopastoral systems carried out in forest soils of Galicia under *Pinus radiata* D. Don (122.5-173 g kg^{-1}). In general, the high SOM in woodlands of the Galicia region is explained by the low pH, which limits soil microbial activity and therefore the rate of SOM mineralization.

As shown in Figure 2, the SOM significantly decreased with the soil depth in the Lime 200N, No Lime 0N and No Lime 100N treatments ($p<0.01$). The same trend was also observed in the rest of the treatments and could be explained in part by the vertical SOM gradient resulting from superficial litter deposition but also by the greater amount of fine root material in the topsoils than in the deeper soil layers. Several authors, including Mosquera-Losada et al. (2011a), have shown that fine roots located in the upper few centimeters of soil are the main source of organic matter within a soil carbon pool. However, it is also important to be aware of the SOM found in deeper soil layers, which may reflect inputs from tree roots (Howlett et al., 2011). Indeed, the role of deep root systems in the storage of carbon in deeper soil layers is one of the main premises on which the carbon sequestration potential of agroforestry is based compared with traditional agricultural systems (Howlett et al., 2011; Mosquera-Losada et al., 2011a).

On the other hand, in the first centimeters of the soil the SOM was significantly modified by the interaction lime*fertilisation ($p<0.05$). However it was not observed significant differences between treatments in the other soil depths ($p>0.05$) probably due to the superficial application of lime and sewage sludge. In the 0-25 cm soil depth, it was found a negative effect of lime on SOM when low doses of sewage sludge were applied (0N). Moreover, in the unlimed plots, the fertilisation with medium doses of sewage sludge (No Lime 200N) implied lower levels of SOM than the low doses (No Lime 0N). The reduction of the SOM due to the liming and the application of medium doses of sewage sludge could come from the increment of the SOM mineralization rate as a result of the inputs of Ca to the soil caused by both practices (Wild 1992) which could therefore reduce the soil capacity to sequester carbon. Similar results were previously observed by other authors as Rigueiro-Rodríguez et al. (2011) in silvopastoral systems established in the same area with *Pinus radiata* D. Don in which the combination of lime and high doses of sewage sludge (480 kg N total ha^{-1}) reduced the SOM. Finally, in the unlimed plots, it should be noted that the SOM levels in the No Lime 400N treatment were similar to the levels observed in the other treatments (No Lime 0N and No Lime 200N) probably due to the higher growth rate of trees in the No Lime 400N treatment compared with the other doses of sewage sludge without liming (Mosquera-Losada et al., 2011b) which could have masked the effect of the fertilization with high doses of sewage sludge (400N) on the SOM.

Figure 2: Soil organic matter (SOM) (g kg^{-1}) under each treatment at four soil depths (0–25, 25-50, 50-75 and 75–100 cm). Lime: 2.5 Mg $CaCO_3$ ha^{-1}; No lime: 0 Mg $CaCO_3$ ha^{-1}; 0N: low sewage sludge dose (0 kg N total ha^{-1}); 200N: medium sewage sludge dose (200 kg total N ha^{-1}); 400N: high sewage sludge dose (400 kg total N ha^{-1}). Different lowercase letters indicate significant differences between treatments within the same soil depth and different uppercase letters indicate significant differences between soil depths within the same treatment.



Conclusion

The superficial litter deposition and the differences in root distribution implied a predominance of the SOM in the soil upper horizons. Moreover, the SOM was modified by the treatments in the first centimetres of the soil due to the application of lime and sewage sludge to the soil surface. In general, the liming and the fertilisation with medium doses of sewage sludge (200 kg N total ha^{-1})

reduced the SOM probably due to the increase of the mineralization rate associated with these treatments which could reduce the soil capacity to sequester C.

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