EFFECTS OF SEWAGE SLUDGE APPLICATION ON N DYNAMICS IN FOREST SOILS: A FIELD STUDY

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ABSTRACT

The feasibility of applying municipal sewage sludge to soils as a method of its disposal increases with both the amount applied and the number of applications. The objective of this research was to study NO_3 and NH_4 leaching after repeated application of sewage sludge to soils under pine stands. The biosolid was applied at four different loading rates (0, 2.4, 17, 60 Mg ha^{-1} y^{-1}, DW sludge equivalent) in two consecutive autumns (days 0 and 371). The soils under study have low pH (<4.4), low CEC, and low base saturation. Ammonium levels were highest during the first 400 d of the experiment, and peaked on days 66-266 (maximum 48.7 NH_4-N mg L^{-1} for the 60 Mg ha^{-1} treatment). This pattern was the same at both depths at which leachates were collected, although concentrations of NH_4-N at 50 cm were generally lower. Nitrate-N levels were initially below 10 mg L^{-1}, but started to increase by the time NH_4 started to decrease, peaking in autumn, by day 386 (73.2 mg L^{-1} for the 60 Mg ha^{-1} treatment, at 25 cm depth). By this time, levels of NH_4-N were below 7 mg L^{-1}. Thereafter, NO_3-N concentrations levelled off until the following spring, peaking again in autumn, by day 774 (104.2 mg L^{-1} for the 60 Mg ha^{-1} treatment), whereas levels of NH_4-N remained low. Both NO_3 peaks appeared after peaks in temperature. The results obtained indicate that addition of municipal sewage sludge to forested plots at a rate of 2.4 Mg ha^{-1} y^{-1} in two consecutive years did not result in significant NO_3 and NH_4 leaching and subsequent ground water contamination.
Keywords: *leachate, nitrogen, sewage sludge, Pinus radiata.*

INTRODUCTION

The European Directive concerning the treatment of urban wastewaters (91/271/EEC) is intended to protect inland and coastal waters by controlling the discharge of wastewater from centres of population and from certain industries. Sewage sludge is a potentially valuable agricultural fertiliser as it is a good source of P and N, organic matter, and micronutrients (Sommers, 1977; Ferrier et al., 1996; Bramryd, 2002). However, recommended application rates should be considered to avoid (i) excessive leaching of NO_3 to groundwater (European Directive 91/676/EEC), and (ii) excessive loading of heavy metals, organic pollutants, and undesirable microorganisms to soils (European Directive 86/278/EEC).

The productivity of forest sites has been shown to be responsive to the addition of sewage sludges (Zasoski et al., 1983; Marx et al., 1995; Bramryd, 2001). Advantages of application on forest soils are, (i) low chances of human contact with the bioresidue, (ii) elimination of pollutants from the human food chain, (iii) flexibility in the time of application associated with perennial crops, and (iv) alleviation of the impacts associated with mechanical logging (e.g. soil compaction, removal of organic matter). These factors make sewage sludge application an attractive fertilizing method, especially in areas such as the Basque Country (N Spain), were most of the land is dedicated to forest use. History of prior sewage sludge application has been shown to affect the potential for NO_3 leaching, as greater NO_3 leaching losses have been observed following reapplication than in sites where sludge has not previously been applied (Burton et al.,

1990, Mitchell et al. 2000). More information is therefore needed on the effect of repeated application of sewage sludge on the fate of N in forest soils, to be able to estimate the amount of NO_3 leaching following application to forest land. The objective of this research was to study NO_3 and NH_4 leaching after repeated sewage sludge application to soils under *Pinus radiata* D. Don. stands.

MATERIAL AND METHODS

Study area and experimental design

The study area is located at Lezama (Bizkaia, Spain) at 320 m altitude (UTM coordinates: 30T 510369 4793364). The soil is a fine-textured Dystric Cambisol (FAO-ISRIC-ISSS, 1998), (Table 1) and drainage is slow. Vegetation consists of a four year old *Pinus radiata* D. Don. plantation. The mean annual air temperature in the study area is 14ºC and the mean total annual precipitation is 1210 mm.

***Table 1**. Physicochemical characteristics of the soil pit studied.*

Hor.	depth	pH	Org. C	N	P_{Olsen}	CEC†	BS†	Coarse Sand	Fine sand	Silt	Clay
	cm	H_2O	g kg^{-1}	g kg^{-1}	mg kg^{-1}	cmol(+) kg^{-1}	%	%	%	%	%
A_1	0-4	4.14	54.3	3.7	3.71	12.7	44	21.6	33.7	18.1	26.6
A_2	4-22	4.32	16.9	1.5	0.21	7.7	9	24.6	33.8	16.7	24.9
Bw	22-48	4.38	7.9	0.8	6.18	6.5	14	23.7	31.4	17.9	27.1
C	48-68	4.40	3.3	0.5	2.32	8.2	5	16.0	26.5	18.0	40.0

†CEC= Cation Exchange Capacity; BS = Base Saturation.

A randomized block design was used for the study. Sludge was applied to 9 of the 12 plots at three different loading rates (2.4, 17, and 60 Mg ha^{-1} y^{-1}, DW sludge equivalent). The municipal sludge (DW ~ 20%) was manually added on top of the soil on two dates: Oct. 2001 (day 0) and Oct. 2002 (day 371). The study was part of a project investigating the presence of heavy metals in leachates, and high doses of sludges were applied so that cumulative metal loading in the soil could be attained to simulate long-term applications. Because of these choices, the N loads greatly exceeded agronomic rates and the rates recommended by the European Directive (91/676/EEC). Chemical characteristics of the sludge applied to the plots are shown in Table 2.

***Table 2**. Mean composition of the sludges applied.*

PH	Org C	N_T	C/N	Ca	Mg	K	Na	P_{Olsen}	Cu	Zn	Cd	Pb	Cr	Ni
	g kg^{-1}		g g^{-1}		g kg^{-1}			mg kg^{-1}						
7.7	157.8	42.4	3.7	34.9	3.1	2.0	1.4	496	605	8488	<3	155	803	167

Sampling and analysis

Leachates were sampled at depths of 25 and 50 cm, using soil water samplers 24-h, after a significant rainy episode (~ once a month). Leachates were sampled by applying vacuum to the samplers, and were then taken to the laboratory in polyethylene bottles and stored in the refrigerator (<4ºC). Ammonium and NO_3 present in the leachates were determined following the methodologies described by Kandeler and Gerber (1988) and Cawse (1967), respectively, and using a spectrophotometer. The pH of the leachates was also measured.

RESULTS AND DISCUSSION

Effect of the addition of sludge on levels of NO_3-N and NH_4-N in leachates

Levels of NO_3-N and NH_4-N in leachates followed inverse patterns (Fig. 1). Ammonium-N levels at the two depths studied were highest between days 66 and 266 (Dec-2001 to Jul-2002), and decreased sharply thereafter. Values were especially high for the 60 Mg ha^{-1} treatment, with a maximum of 49 mg L^{-1} at 25 cm depth, and of 11 mg L^{-1} at 50 cm depth (Fig. 1A-C). No increase in NH_4 levels was observed after the second sludge application, possibly because of the existence of a high population of nitrifiers in soils induced by the previous sludge application. Similar results were obtained by Burton et al. (1990) investigating the effect of repeated sludge application on the fate of N.

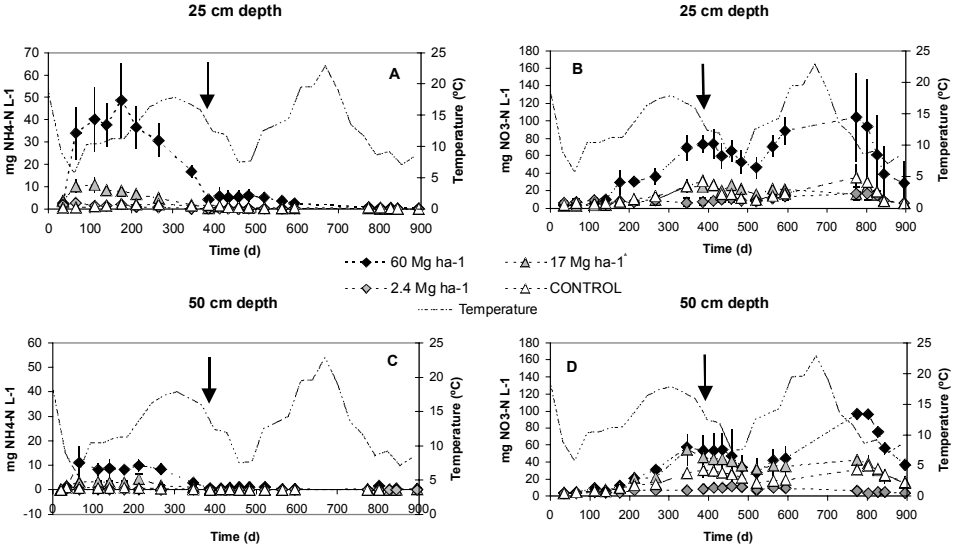

Figure 1. *(A) NH_4-N and (B) NO_3-N concentrations in the leachates at 25 cm depth. (C) NH_4-N and (D) NO_3-N concentrations in the leachates at 50 cm depth. Bars represent standard error. The arrow indicates the time at which the second sludge addition was carried out. Monthly mean temperatures are also represented.*

Levels of NO_3-N in the leachates were initially below 10 mg L^{-1}, but started to increase by the time NH_4-N levels started to decrease, peaking by day 386 (Nov-2002). At 25 cm depth, there was a sharp increase in NO_3-N levels in the leachates with the 60 Mg ha^{-1} y^{-1} treatment, with a maximum of 73 mg L^{-1} at 25 cm depth, and a more gradual increase with the other treatments (Fig. 1B). In contrast, at 50 cm depth, differences between treatments were less accentuated (Fig. 1D), possibly because of subsurface lateral flow. This may also explain the higher values of NO_3-N observed in the control plots than in plots corresponding to the 2.4 Mg ha^{-1} y^{-1} treatment, and in some cases, the 17 Mg ha^{-1} y^{-1} treatment (Fig. 1B-D). Concentrations of NO_3-N levelled off thereafter until the following spring (by day 563), peaking again in November (day 774) (Fig. 1B-D). Both NO_3-N peaks (Nov-2002 and Nov-2003) appeared after peaks in temperature (Fig. 1B-D). Nitrification rates may have increased with the rise in temperature, with the NO_3 produced being leached thereafter. Other authors have observed a lag period bet-

ween maximum rates of nitrification and the peaks in NO_3 concentrations in leachates (Medalie et al., 1994; Hallett et al., 1999). Moreover, increases in concentrations of NO_3-N were concomitant with decreases in pH, as expected, starting on days 266 (summer-2002) and 563 (spring-2003) (data not shown). Finally, the low concentrations of NO_3-N observed at the beginning of the experiment (winter 2001-2002), and the relative minimum attained during winter 2002-2003 (days 434 to 521), are attributed to a negative effect of low temperatures on both N mineralization and nitrification.

CONCLUSIONS

The results obtained indicate that addition of municipal sewage sludge at a rate of 2.4 Mg ha^{-1} y^{-1} in two consecutive years to forested plots did not result in significant NO_3-N and NH_4-N leaching, and subsequent ground water contamination. At this rate of sludge addition, concentrations of NO_3-N in leachates at 50 cm depth were always below 10 mg L^{-1} (except two sampling times), and those of NH_4-N below 0.3 mg L^{-1}, although an increasing trend in NO_3-N concentrations was observed after the second sludge application. The higher sludge doses (17 and 60 Mg ha^{-1} y^{-1}) did result in NO_3-N and NH_4-N ground water contamination, as expected. We are currently investigating the distribution and mobility of sludge-applied metals at the different doses applied.

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