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Role of amendments on N cycling in Mediterranean abandoned semiarid soils

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ABSTRACT

Soils found in semiarid areas of the Mediterranean Basin are particularly prone to degradation due to adverse climatic conditions with annual rainfall <300 mm and high temperatures being responsible for the scant vegetal growth and the consequent lack of organic matter. A three-year field experiment was conducted to test the potential of two organic amendments (sludge and compost) to improve soil quality and plant growth in a semiarid degraded Mediterranean ecosystem. Since little is known about N dynamics in such assisted ecosystems, we investigated the effects of this practice on key processes of the global N cycle. Besides soil chemical and biological parameters and vegetation cover, we measured absolute and specific potential nitrification and denitrification rates and quantified the size of the ammonia oxidising and denitrifying bacterial populations via quantitative PCR (*amoA* and *nirS* genes). At the end of the experiment soil fertility, microbial activity and plant growth had improved in treated plots. Amendments increased the amount of ammonia oxidisers and denitrifiers in soil, but the relative proportion of these groups varied in relation to the total microbial community, being higher in the case of ammonia oxidisers but not in the case of denitrifiers. As a consequence, significantly higher potential nitrification and denitrification rates were measured on a global basis in amended soils. Yet specific activities (potential rate/gene copy numbers) were lower for ammonia oxidisers in amended soils and for denitrifiers in sludge treated soils than those observed in control plots. Organic amendments influenced resource availability, the size and the activity patterns of microbial populations involved in long-term N dynamics. Therefore N cycling processes may play a key role to assist sustainable restoration practices in semiarid degraded areas.

1. Introduction

Soils found in semiarid areas of the Mediterranean Basin are particularly prone to erosion due to high climatic variability (long dry periods with significant fire risk and very low precipitation arriving as irregular torrential rainfall events) (Van Lynden, 1995; De Paz et al., 2006). Additionally inappropriate agricultural practices, land use and construction activities can result in loss of soil organic matter and essential nutrients (Yassoglou et al., 1998). As a consequence of soil quality declines, vegetation development is constrained and soil erosion risk increases (García et al., 1998; Xie and Steinberger, 2005; Bastida et al., 2007a).

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Several studies have shown that the incorporation of organic amendments into semiarid soils can reverse this trend by improving aggregate stability, nutrient cycling and plant colonization (Ros et al., 2003; Pérez de Mora et al., 2006). Recycling of organic residues as amendments is a cost-effective and sustainable alternative to improve the organic matter content of soils. However, their application must be adequately controlled since some of these amendments contain heavy metals, pathogens and unwanted odours. To minimize risks it has been suggested that organic wastes should be previously composted or stabilized (Pascual et al., 1997; Burton and Turner, 2003).

Since organic C content is a critical criterion to evaluate the degree of desertification, most studies in semiarid areas have dealt with C-related processes. In contrast, N dynamics have received less attention, although nitrogen (N) is the only essential nutrient that is not released by the weathering of minerals and is a primary limiting nutrient for vegetation development in Mediterranean type ecosystems (Arianoutsou-Faraggitaki and Margaris, 1982; Schulten and Schnitzer, 1998). External N sources such as organic amendments can therefore ameliorate the N pool of such soils and consequently improve plant growth. In addition to ammonium (NH_4^+) and nitrate (NO_3^-), organic amendments incorporate degradable organic compounds into the soil, which can in turn affect key steps of the N cycling such as nitrification and denitrification (De Wever et al., 2002). The main factors affecting these processes have largely been studied in agricultural systems (Vallejo et al., 2006), but little is known about the effects of incorporating amendments into highly degraded soils from semiarid areas.

Biochemical and microbiological properties have traditionally been used to monitor changes in soil quality and quantify restoration activities in degraded semiarid soils (García et al., 1998; Pérez de Mora et al., 2005). Recently, the development of culture independent techniques such as quantitative PCR has significantly improved the ability to study of microbial populations and microbial processes in soils. Nitrogen-related transformations are particularly good examples because there are many genes involved in the N cycle and the activity of the microorganisms responsible for such processes can be monitored (Ferguson, 1998; Bothe et al., 2000; Francis et al., 2007). The combination of measuring activity and using molecular tools can therefore provide quantitative and qualitative information essential for understanding ecosystem dynamics and for improving land management. In the present study, an experiment was set up to test the potential of organic amendments under field conditions to improve the soil status and vegetation cover in a semiarid degraded area. As little is known about N dynamics in "seminatural" managed ecosystems in arid or semiarid environments, our aim was to evaluate the impact of incorporating stabilized sludge and biosolid compost on key processes of the N cycle (nitrification and denitrification) three years after addition. Furthermore, we were interested to know whether amendments have a durable effect on the genetic potential of such soils and hence affect the population size and the activity patterns of the main players involved in these two processes (ammonia oxidising and denitrifying bacteria) to improve our current understanding of N dynamics in managed semiarid soils and the sustainability of assisted restoration practices in such areas. We hypothesised that a single amendment application of sludge or biosolid compost would improve soil fertility and plant growth. The synergistic interaction of amendments and plants would in turn stimulate microbial biomass and activity in soil, resulting in enhanced nitrification and denitrification potentials. We also predicted that there would be differences in the magnitude and pattern of the above responses in the long-term, restoration practices changing the physical environment, the availability of nutrients and the genetic pool of the soil.

2. Materials and methods

2.1. Study site

The study was carried out in an experimental area agriculturally abandoned 10 years ago and largely eroded, situated in the province of Murcia (Southeastern Spain, 38°1′N 1°12′W). The climate is semiarid Mediterranean (mean annual rainfall of 333.2 mm and a mean annual temperature of 17.2 °C) with mild rainy winters and very hot, dry summers. The soil was classified as loam, Aridic calcisol (FAO-ISRIC-ISSS, 1998). The vegetation is characterised by open matorral species such as *Asphodelus fistulosus* L., *Salsola genistoides* Juss. ex Poir. and *Rosmarinum officinalis* L.

2.2. Materials and experimental design

Experimental plots (4 m × 5 m) were arranged in a complete randomised block design with two amended treatments and one control (unamended). Each treatment was replicated three times. The amendments tested were: sewage sludge (S) from a wastewater treatment plant (Murcia, SE, Spain), digested anaerobically and stabilized through the removal of ammonia and methane, and a biosolid compost (CM) made from the same material with straw as bulking agent. Amendments were incorporated into the topsoil (15 cm) at a

Table 1 – Characteristics of organic materials (values on dry weight basis).

	Sludge	Compost
pH	6.6	6.8
EC[a]	2.85	2.46
Total organic C[b]	378	406
Total N[c]	43000	30300
Total P[c]	1600	1700
Total K[c]	3900	4000
Total Cd[c]	<2.5	<2.5
Total Cr[c]	14.0	11.0
Total Cu[c]	247	187
Total Ni[c]	14.8	11.9
Total Pb[c]	80.8	54.9
Total Zn[c]	718	510
C/N ratio	8.73	13.5

[a] $dS\ m^{-1}$.
[b] $g\ kg^{-1}$.
[c] $mg\ kg^{-1}$.