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Saline soils in Italy: distribution, ecological processes and socioeconomic issues

Soils are crucial for crop production and for the major ecosystem services. They preserve and sustain life. Salinity is one of the main soil threats that reduce soil fertility and affect the crop production. In recent times, a great attention has been paid to the general shortage of arable land, and to the increasing demand for ecological restoration of areas affected by secondary salinization processes. Microorganisms in these habitats may share a strategy, may have developed multiple adaptations for maintaining populations, and cope eventually with extreme conditions by altruistic or cooperative behavior for maintaining their population active. The understanding and the knowledge of the composition and distribution of microorganisms in natural habitats can be interesting for ecological reasons and it is important to develop new restoration strategy of salt-affected soils.

Keywords: saline soils, Italy, soil microorganisms, soil spatial variability, molecular analytical tool

JEL Code: Q15, Q24

1. Introduction

Soil is a complex dynamic biological system recognized crucial for crop production (Kennedy and Smith, 1995) and for the major ecosystem services (Bennet *et al.*, 2010; Keesstra *et al.*, 2012; Berendse *et al.*, 2015; Decock *et al.*, 2015; Brevik *et al.*, 2015; Smith *et al.*, 2015; Keesstra *et al.*, 2016), which preserve and sustain life. Soils are the essential substrate to provide the Earth's primary renewable resources, serving as interface between the biosphere, hydrosphere, lithosphere, and atmosphere. The soil's role as a reserve of biodiversity has been well established providing a wealth of new insight into diversity of microbial species found in soil habitats. However, population and human growth, climate change, urbanization, agricultural practices, erosion and compaction, nutrient depletion, loss of soil organic carbon, changed demand for food and other threats, lead to reduced function of soil ecosystem services and result in the loss of biodiversity and pedodiversity (Lo Papa and Dazzi, 2013; Dazzi and Lo Papa, 2016).

Salinization is one of the most known and widespread soil degradation process. All the soils naturally contain a mix of salts more or less soluble in water, and some of them are essential for crops development (Francois and

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Maas, 1994) however, when salts accumulate in soil to such a level to compromise seed germination and/or the crop development and to determine undesired effects on the environment, soils are called "saline" or "salt affected". Consequently, saline soils can be defined as soils containing enough soluble salts to reduce the overall soil fertility to interfere with crop growth (FAO, 1988) and limit the growth of organisms (Canfora *et al.*, 2014, 2015, 2016; Dion and Nautiyal, 2008). According to Amoozegar *et al.* (2003) soils are considered saline when the concentration of salt is higher than 0.2% (w:v), and when the electrical conductivity (EC_e) of a saturated paste is greater than 4 dS m^{-1}, (Richards, 1954). The two most diffused soil classification systems introduced thresholds of EC_e to classify a soil horizon as saline: the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014) considers the reference value 15 dS m^{-1} of EC_e in defining the salic horizon, while the USDA Soil Taxonomy (Soil Survey Staff, 2014) fixed the threshold at 30 dS m^{-1}.

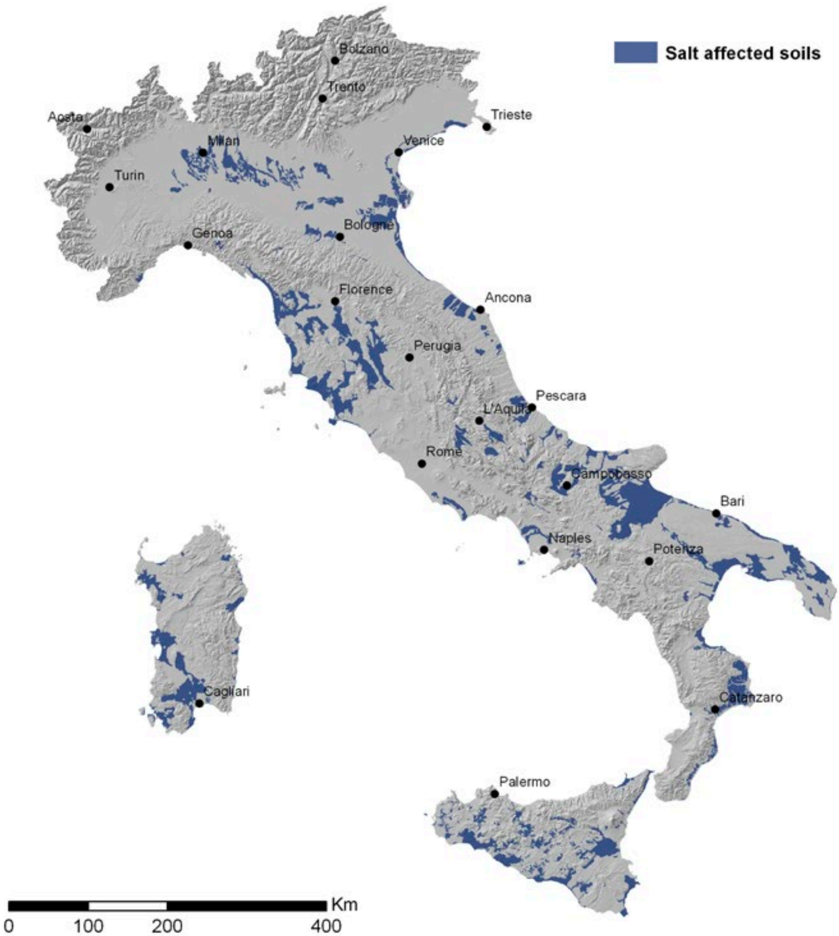
A basic distinction must be made between primary and secondary salinization processes (Canfora *et al.*, 2014; Mavi *et al.*, 2012; Ahmad *et al.*, 2013; Singh *et al.*, 2016a, 2016b), based on whether salt accumulates in soil by natural phenomena or as a consequence of the soil management. Seawater intrusion or natural salt intrusion from saline water bodies is a typical process of primary salinization in coastal lagoons (de Wit *et al.*, 2011). Secondary salinization is usually caused by human interventions such as inappropriate irrigation practices, i.e. after the use of salt-rich irrigation water, insufficient drainage, inappropriate fertilization practices (i.e. massive use of waste water, of animal slurries). A natural secondary soil salinization mechanism is represented by the long-term effects of catastrophic damage caused by tsunami waves, which can deposit salty seawater on large flooded areas with dramatic consequences for agriculture (Tóth *et al.*, 2008; Argaman *et al.*, 2012; de la Paix *et al.*, 2013; Mao *et al.*, 2014). Nearly 831 Mha land show saline soils worldwide (Martinez-Beltran and Manzur, 2005) while, human-induced salinity affects an estimated 76 Mha of land worldwide – an area larger than the whole arable land in Brazil (FAO, 2015).

2. Assessing soil salinization in Italy

In Italy, one of the salt-affected countries in Europe (Salvati & Ferrara, 2015), soil salinization accounts for 3.2 Mha (Dazzi & Lo Papa, 2013). They are more or less present in almost all the Italian regions with different incidence (Figures 1 and 2).

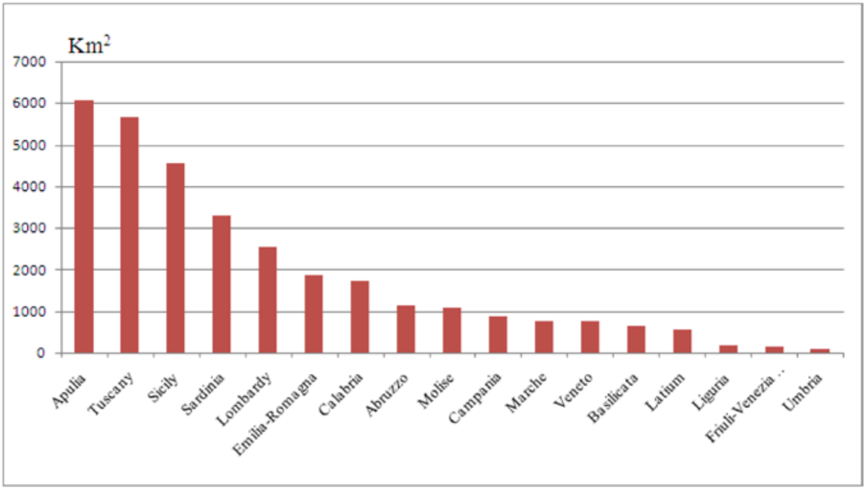
The multifaceted association of soil salinization risk with the socioeconomic local context is difficult to define and assess objectively because soils

Fig. 1. In blue those Italian areas where it is possible to find salt affected soils (from Dazzi and Lo Papa, 2013)



are inherently variable over space and susceptible to multiple uses (Montanarella, 2007). Since there are limited and localized field data quantifying these processes, proxies are generally used for the definition of areas exposed to salinization risk (Perini *et al.*, 2008). Given the lack of data capable of representing the phenomenon on a national scale, Costantini *et al.* (2009) proposed a modelling approach that can define the areas potentially saline, or where excessive water pumping can lead to a progressive salinization of the soil. This

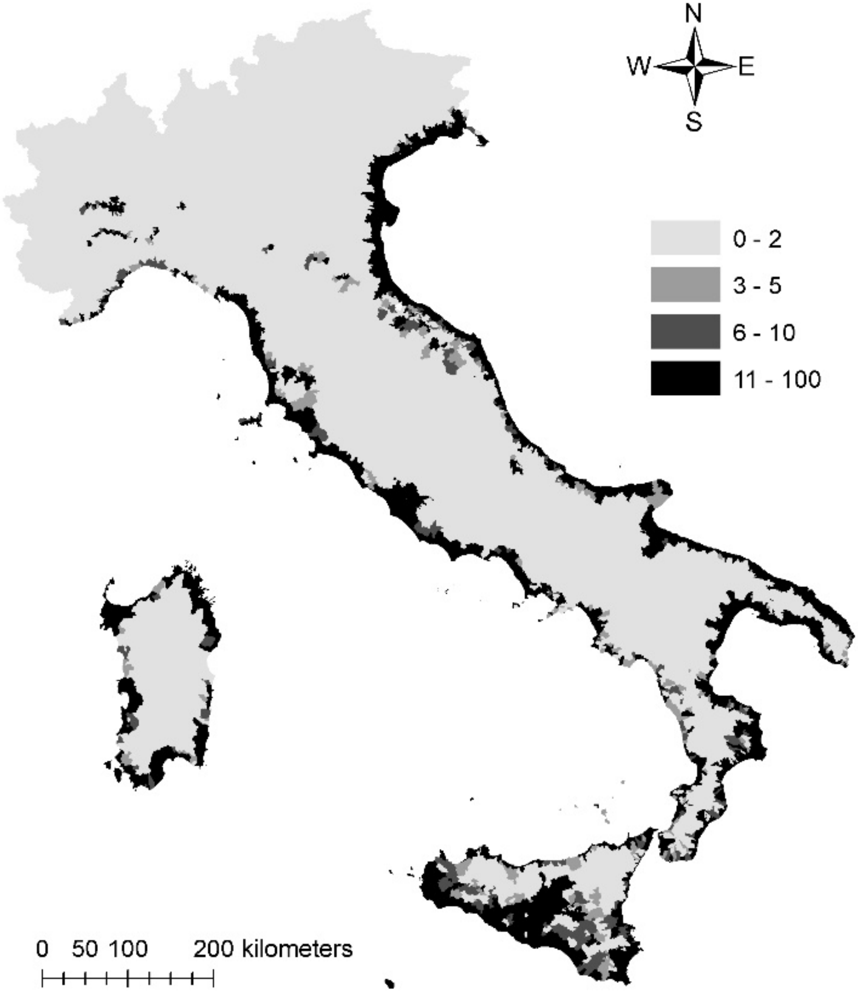
Fig. 2. Distribution of salt affected soil in the Italian administrative regions (from Dazzi and Lo Papa, 2013)



indicator was constructed by overlapping a 'buffer' strip of land within six miles of the coastline (considered as potentially vulnerable to soil degradation processes due to salinization), with areas characterized by a share of less than 10 meters above sea level and the presence of salt rock types. The resulting areas were classified as at risk of primary salinization. Based on this approach, Perini *et al.* (2008) proposed an improved assessment methodology. In this sense, the spatial distribution of a soil salinization risk index in Italy was mapped in Figure 2 and shows a rather homogeneous spatial pattern with municipalities at risk concentrated along the coastal areas of the country and in specific flat areas close to the sea.

Based on empirical results presented in Perini *et al.* (2008), a total of 1269 municipalities was identified at risk of soil salinization (i.e. with at least 1% of the administered land classified as risky) covering 24.3% of the country surface area and hosting 37.5% of Italian resident population (Table 1). Population density in the 1269 municipalities classified at risk was found remarkably higher (292 inhabitants/km^2) than that observed in the remaining 6831 municipalities (156 inhabitants/km^2). Only 8% of northern Italian municipalities were found at risk but the percentage increased in central Italy (25%) and especially in southern Italy (39%). Municipalities with > 10% of land exposed to soil salinization risk are primarily distributed along the Italian coasts and in Sicily and Sardinia lowlands (see Figure 3).

Fig. 3. Distribution and percentage of land at risk of soil salinization in Italy



3. Ecological aspects

Ecological processes connected with salinization are the product of complex time scale interaction in soils where microorganism mediated processes (i.e. carbon sequestration, nutrient cycling) are under the influence of the root system (Berg and Smalla 2009).

Tab. 1. Socioeconomic attributes of municipalities showing no salinization risk and a low-to-high soil salinization risk in Italy

Variable	No risk	Low-to-high risk
Resident population (inhabitants)	35,642,295	21,351,182
% distribution in Italy	*62.5*	*37.5*
Population density (inhabitants/km^2)	156	292
Total surface area (km^2)	228,260	73,074
% distribution in Italy	*75.7*	*24.3*
% distribution in northern Italy	*91.8*	*8.2*
% distribution in central Italy	*74.5*	*25.5*
% distribution in southern Italy	*60.7*	*39.3*
Number of municipalities	6,831	1,269

Microorganisms in these habitats may share a strategy, may have developed multiple adaptations for maintaining populations, and cope eventually to extreme conditions by altruistic or cooperative behavior (Agarwal *et al.*, 2014) for maintaining their population active. From the genetic point of view, these species display an under- or over-expression of peculiar genes and metabolites, which confer them the capability of coping with an osmotic stress (Dion and Nautiyal, 2008). Many studies have been focused on the isolation and characterization of halophilic Bacteria and Archaea communities in saline and hypersaline soils (Quesada *et al.*, 1982; Ventosa *et al.*, 1998) and biotechnological applications are under investigation (Ghazanfar *et al.*, 2010; Keshri *et al.*, 2013; Arora *et al.*, 2014; Canfora *et al.*, 2014). Notwithstanding, data on the ecology, structure, diversity, and functionality of organisms occurring in natural saline soils remains still elusive. Naturally salt-affected soils have a biotechnological potential in their microbial communities, representing not only a gene reserve for potential biotechnological applications in the improvement and conservation of saline environments, but they can serve as model systems for exploring relationships between diversity and activity at the soil level. The rapid and comprehensive methodologies to assess soil microbial communities have rapidly transformed the understanding of microbial biodiversity over the past decade. However, the researcher's perception of environmentally variability and the scale at which specific properties like salinity are measured, can misrepresent the spatial scale at which microbial groups shape their structure and function. Space and scale in population, community, and ecosystem processes are increasingly recognized as fundamental factors affecting soil microbial functions and activities (Ettema and Wardle, 2002). There is a large degree of uncertainty involved in measuring the extreme complexity of the soil ecosystem. For this reason, understanding the spatial pattern in the abundance and structure of microbial communities occurring in saline soils represents a crucial target in ecology (Parkin, 1993; Pereira *et al.*, 2012; Locey and Lennon 2015) as it sheds light on the selection mechanisms exerted by the environment on bacterial groups with specific functions and properties.

In this framework, attention has been focused on a series of surveys in "extreme" environments as model systems for exploring the relationships between diversity and activity at the soil level in selective/limiting situations.

Very few studies succeeded in addressing the microbial ecology of the microbial species in soils, according to the different salt concentrations and, at a different scale, to bacterial taxa distribution in relation to salinity gradients. In the field of naturally salt-affected soil, the paper of Canfora *et al.* (2014, 2015, 2016) provided specific information on the type of distribution of different microbial communities as a function of spatial gradients in salinity and pH. Canfora *et al.* (2014) analyzed the 16SrRNA genes from soil samples showing a strong correlation between the variability of the considered site properties and certain heterogeneity of the topsoil in saline soils from the south coastal belt of Sicily (Italy) at the working scale adopted. Sampling sites differed for vegetation cover and chemical-physical parameters, which was apparently independent from soil microbial community diversity. This first study provided specific information on the type of distribution of different bacterial groups as a function of spatial gradients in salinity and pH. The analysis of bacterial 16S rRNA-based datasets revealed significant differences in bacterial community composition and diversity, along an increasing salinity level, which underlies a multi-scale spatial variability with respect to the macro-scale environmental scheme in terms of geography and soil and sheds light on the key role of soil salinity as driver in shaping the distribution and diversity of the microbial community. What is more, the soil studied showed a patchy distribution of the vegetation structure and of chemical properties, which coincided with a heterogeneous distribution of many bacterial groups. The variability of soil texture among sites is explained by the alluvial genesis of the soil as highlighted by the pedological survey. Thus, the textural variability of the upper horizons is a direct consequence of the variability of fluvial deposition processes in space and time. Other different factors linked to spatial variability, physical and chemical characteristics and microbial diversity are the percentage of vegetation and salt crust cover. TRFs numbers estimation from bacterial and archaeal communities, based on T-RFLP profiles, showed as well a high level of variability between sites. Archaea exhibited a large heterogeneity with salinity gradient, whereas bacterial seems to follow an opposite trend, and their abundance was positively correlated with salt concentrations. Archaea are historically and phylogenetically more closely associated with extreme habitats than bacteria, more heterogeneous and gain the ecological niches (Ventosa *et al.*, 1982; Ventosa *et al.*, 1998; Walsh *et al.*, 2005; Petrova *et al.*, 2010). According to some authors (Setia *et al.*, 2011; Asghar *et al.*, 2012), salinity may reduce soil respiration and, just because of this reason, strongly affects microbial community composition favoring Archaea (Rousk *et al.*, 2011) and halophilic Bacteria. Hence, the fact that abundance, composition and diversity of the microbial community shift to Archaea is obvious. Moreover, results obtained by plotting the soil chemical and physical factors with the clusters of Bacteria and Archaea showed a positive relationship between Archaea composition, distribution and organic C, suggesting that the presence of high contents in organic matter in the soil favors the diversity of these microorganisms. The discriminant analysis for Archaea community underlines the influence of texture linked to lower crust cover percentage in their distribution. Bacterial community seems to show a different behavior in terms of diversity, suggesting that the soil spatial variability favors Archaea rather than Bacteria. The high increase of both diversity and richness of archaeal community could be likely consistent with a strategy of multiple adaptations for resisting high salt concentrations. It was possible to make two assumptions that paved the way to a depth further study (Canfora *et al.*, 2016). The first assumptions is that a spatial autocorrelation in terms of microbial diversity can hardly be found at the soil scales used for physical-chemical studies. The second assumption is that an environment in which some limiting factors favour some microbial groups and not others is in fact compared to a set of islands that allow the formation of different communities, separated for the physical and chemical factors and by the availability of nutrients. This study revealed that in spite of the salinity as "noise", the spatial discontinuity allows the formation of more possible microbial assortments, considering that not a single microbial community but association of efficient communities do better adjust their physiology in specific environments. For example, a recent study showed the presence of cyanobacteria and salt crust cover, describing the interface between biological and geochemical components in the crust where the occurrence of the gypsum crystals, their shapes and compartimentalization suggested that they separated NaCl from the immediate microenvironment of the cyanobacteria. Microbial communities associated to gypsum-halite crusts have been described in several countries but only few studies focused on the processes occurring between organisms and minerals at the microscale, like the present paper does. Data obtained by SEM, EDS, soil chemistry and 454 sequencing data, documented the formation of a protective envelope onto cyanobacterial filaments made of calcium and sulfur-based compounds, and that this compartmentalization might have a role to overcome salt stress.

It appears evident the role of salt concentration in defining the diversity of the bacterial community in a saline soil. On the one hand, it appears evident the robust adaptation and the plasticity of bacterial community that, as a matter of fact, changed between soil sites according to difference in soil salt content. On the other hand certain genera and species possess different adaptation level showing different sensitivity to salinity, more or less dependent on other factors, such as the presence of organic matter, plant cover, plant roots at different scales. In any case it is evident the existence of different scales in the distribution of some major environmental factors, just as the salinity factor, that seem to be a necessary condition for the proliferation of the species belongings to specialized groupings of bacteria.

In the study on the effect of lagoon salinity, soil type and different land uses on both inland soil and groundwater quality, and soil microbial community structure, diversity and gene abundance (data not shown), we shed light on the unexplored relation between soil salinization in coastal system and soil microbial communities. The results of this study suggested that soil microbial community structure and diversity seem to be affected primarily by soil type (texture, soil organic matter) and groundwater salinity, and depends also on soil depth and land-use (as showed in previous study by Ventosa *et al.*, 1998). Further investigation in the field of soil science with the aim of assessing multiple impacts of land-use and management practices on soil variables in extreme ecological conditions or along specific biophysical gradients provides a relevant information base to formulation of new indicators of environmental sustainability.

4. Soil salinization and socioeconomic issues in Italy

An exploratory analysis of the spatial distribution of an index of soil salinization risk in relation with a number of socioeconomic and territorial indicators in Italy, a Mediterranean country experiencing increased risk of soil salinization in the last decades was proposed by Salvati (2014). In this study, the local-scale analysis covering the entire country (301,330 km^2) at the spatial level of municipalities - intended as spatial units suitable to describe local communities and the related territorial context - offers an original, joint contribution to soil science, geography and planning disciplines. A multi-dimensional approach based on a comprehensive set of socioeconomic and territorial indicators analyzed through descriptive, inferential and multivariate statistics was thus developed with the aim to identify the attributes that better characterize the Italian municipalities exposed to salinization risk. Indicators have been calculated from the collected variables for each Italian municipality and classified into six research dimensions (Population dynamics and human settlements, Population structure and territorial characteristics, Labour market and education/human capital, Economic specialization and competitiveness, Quality of life, Agriculture and rural development, Environment). The indicator's set is aimed at providing a comprehensive analysis of the socioeconomic, cultural and political profile of Italian municipalities.

The empirical results presented by Salvati (2014) indicate that territorial contexts characterized by soil vulnerability to salinization are associated with high human pressure due to crop intensification, population density and dispersed urban settlements coupled with a defined socioeconomic profile with high unemployment rate and family size, high crime intensity index but medium-high wealth conditions and a younger population structure. Although density of water reservoirs decreases rapidly with the percentage of areas exposed to soil salinization, the share of agricultural land applying more sustainable irrigation practices to the total cultivated land follows the reverse pattern possibly indicating farmers' adaptation to specific environmental conditions. This may reduce the risk of soil degradation in sensitive and ecologically-fragile areas.

These findings do not corroborate the hypothesis of a latent nexus between rural poverty and soil degradation illustrated in earlier studies (Salvati, 2014; but see also Wilson and Juntti, 2005; Salvati and Carlucci, 2011; Imeson, 2012), indicating instead the specificity of each soil degradation process in terms of socio-ecological relationships (Boardman *et al.*, 2003; Iosifides and Politidis, 2005; Patel *et al.*, 2007). Improving the effectiveness of local communities responses to soil salinization cannot be achieved without a thorough comprehension of the different socioeconomic and territorial contexts existing at the local scale (Corbelle-Rico *et al.*, 2011). Policies should consider more tightly the intrinsic ability shown by local communities to adapt to potentially worse environmental conditions dealing with specific soil degradation processes, as this study highlights. Measures supporting the spread of sustainable irrigation practices may be more effective in territorial contexts where awareness of local environmental problems, endogenous knowledge and skills and practical solutions were already developed due to the long-term human-nature interaction. Only an in-depth knowledge of the influence of the local socioeconomic context on soil attributes (and possible conservation measures) may inform effective sustainable land management policies targeting specific soil degradation processes (Iosifides and Politidis, 2005).

5. Conclusions

Italy is considered a hotspot for land degradation and desertification in the Mediterranean region and salinization constitutes an important cause of soil degradation in the area. Recently, well documented case-studies evidenced that soil salinization increased especially in south Italy, where crop intensification has led, over the past twenty years, to an unsustainable use of groundwater for irrigation. The increasing world's population, climate change with extreme weather events, considered also as cause of salinization, require new strategies in a framework where legislation demands for lower inputs and sound management agricultural practices. Although the role of anthropogenic factors as key drivers of soil degradation has been occasionally studied, soil degradation cannot be convincingly explained as a phenomenon depending on changes in few biophysical factors alone. Very little information exists regarding the diversity of microorganisms isolated by hypersaline soil, and very few studies address the diversity of microbial species structure, distribution, and diversity according to the different salt concentration and, at a spatial scale in relation to salinity gradient. Improving the effectiveness of resident microbial communities responses to soil salinization cannot be achieved without a thorough comprehension of the different socioeconomic and territorial contexts existing at the local scale. The assortment and distribution of microorganisms in a heavily fragmented environment depend on very complex dynamics of colonization and dispersion. The analysis of the correlation between the population of microorganisms and environmental parameters, such as the organic matter, pH, and salinity, adds important information that can help to unravel the mechanisms of formation and structure of the bacterial communities. It should be noted, that these data are of pivotal importance because they reflect abilities required by certain genera and species in their natural environments. This represents a new wave of research reinforcing the claim for a microbial-based strategy using microbial ecology approach, which analyses the diversity and functioning of microbial communities that can help in evaluating the impact of environmental stressors, such as salinity. In microbial ecology, the knowledge of the composition and distribution of microorganisms in natural habitats can be interesting for ecological reasons. A number of strategies have been proposed to reshape the microbial composition in soil and redirect microbial activity. Natural environments can serve as model systems for exploring the relationships between diversity and activity at the soil level in selective/limiting situations, assuming that microorganisms, occurring in natural or extreme environments, could be used in some kind of restoration or conservation techniques of saline environments. Naturally salt-affected soils have a biotechnological potential in their microbial communities, which represent a source of beneficial microorganism and a gene reserve for future biotechnological application. The soil plays a pivotal role in maintaining ecosystem environmental quality, and in this way microbial community represents an important key to understanding the impacts of environmental and anthropogenic factors on ecosystems. The use of molecular tools, such as gene probes, are essential for further scientific advances in microbial ecology, providing a wealth of new insight into the diversity of microbial species found in soil habitats. Studying soil using an ecological approach is a necessary prerequisite for improving the understanding of its structure (biodiversity) and functioning (Bardgett, 2002; Widinga *et al.*,2005), encouraging through a microbial-based strategy the bio augmentation and the involvement of the resident community in both the problem analysis and solving.

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