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Remediation of saline soils by a two-step process: Washing and amendment with sludge

Isabel Sastre-Conde [a], M. Carmen Lobo [b], R. Icela Beltrán-Hernández [c], Héctor M. Poggi-Varaldo [d,*]

[a] SEMILLA, SAU, Govern Balears, Palma de Mallorca, Illes Balears, Spain
[b] Instituto Madrileño de Investigación Agraria y Desarrollo Rural, Agrario y Alimentario IMIDRA, Apdo. 127, 28800 Alcalá de Henares, Madrid, Spain
[c] UAEH-Centro de Investigaciones Químicas, Carr. Pachuca-Tulancingo km. 4.5, Cd. Universitaria, CP, 42067 Pachuca, Hgo, Mexico
[d] CINVESTAV-IPN, Dept. Biotechnology and Bioengineering, Environmental Biotechnology and Renewable Energies R&D Group, P.O. Box 14-740, Mexico D.F. 07000, Mexico

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Soil salinization is a serious land-degradation problem that affects soil, plants and groundwater within ecosystems. In this work, the effect of washing saline–sodic soils with $CaCl_2$ at 2% (w/v) and amendment with composted and dry sewage sludge was evaluated in a remediation assay. The effectiveness of amendments to improve the soil fertility was investigated with seed germination assays of *Raphanus sativus* L. Two different organic wastes were used: sewage sludge composted with pruning wastes (CP) and thermally dried sewage sludge (T) at rates of 1 and 2% (w/v) on organic matter basis. In general, there was an increase of germination percentage in the amended washed soils. The best indices were obtained at the 1% amendment dose with CP. The low exchangeable sodium percentage (ESP) in washed–amended soil (3 to 6 times lower than that of saline–sodic soil) could partially explain the increase in seed germination percentage of *R. sativus* L. The incorporation of organic amendments to washed soil also seemed to be beneficial as a step in the restoration process according to the chemical characteristics, especially by increasing the level of nutrients such as carbon, nitrogen, and phosphorus. A significant multiple linear regression of radish germination index in terms of pH values, sodium adsorption ratio of soil (SAR), and different forms of nitrogen (NH_4^+ and NO_2^-) was found.
Overall, saline–sodic soil washing with $CaCl_2$ followed by addition of organic amendments seems to be a promising strategy for restoration of such soils with simultaneous improvements of cation balance and nutrient/organic matter contents.

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1. Introduction

The urgency and seriousness of the problem of the saline–sodic soils have been recognized at various national and international forums. For instance, the United Nations Conference on Desertification held in Nairobi in 1977 recommended the prevention of soil salinity and sodicity (Abrol et al., 1988).

Among the different practices of saline–sodic restoration reported so far, the partial reclamation of salt land productivity through revegetation with salt tolerant plants (halophytes) has been shown to slow down the process of salt accumulation in the soil (Barrett-Lennard, 2002). The recovery of uncultivated agricultural areas affected by salinity was also made possible using over-irrigation and drainage systems (Cabrera and Cervera, 1996; Castellanos et al., 1996). Biological techniques and the use of organic matter sources such as farmyard manure, compost and green manure have long been known to facilitate the reclamation of saline/sodic soils (Ouni et al., 2013; Yu et al., 2010; Lakhdar et al., 2009; Tejada et al., 2006; United Nations, 1977; Richards, 1973). Among the methods mentioned the most widely used and likely the fastest has been washing of soils to remove salts from the growth roots through irrigation strategies (Yu et al., 2010; Sahin and Anapali, 2005; Minhas et al., 1999).

Seed tolerance to high saline concentration in soils has been evaluated in diverse research experiments. It is known that salt concentration in soils, especially NaCl is one of the factors that could negatively affect germination (Pathak and Rao, 1998). In general, seed germination was more sensitive to salinity stress than fully-grown established plants (Freeman, 1973; Catalán et al., 1994). For instance, certain authors such as Villagra (1997) found that salinity negatively affected the germination in seeds of *Prosopis argentina* and *Prosopis alpataco* (decrease of both the germination rate and final germination percentages).

The Lake of Texcoco is located in central Mexico; originally, it was one of the five lakes in the region of Anáhuac, or the Valley of Mexico. The Lake of Texcoco has been drained via channels and a tunnel to the Pánuco River since the early 17th century, and nowadays it only occupies a small area surrounded by salt marshes (4 km) East of Mexico City. The lake desiccation has promoted a series of changes, whose major effects were erosion and soil salinization, water shortages, dust storms, sinking ground, poor water quality and decreased biological

* Corresponding author at: CINVESTAV-IPN, Dept. Biotechnology and Bioengineering, Environmental Biotechnology R&D Group, P.O. Box 14-740, México D.F. 07000, Mexico.
E-mail addresses: misastre@semilla-sau.es, isabelsastre2003@yahoo.es (I. Sastre-Conde), r4cepe@yahoo.com (H.M. Poggi-Varaldo).

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Table 1
Chemical characteristics of the amendments used in this work.

Organic wastes	Chemical characteristics					Exchangeable cations				Heavy metals					
	pH	EC[a]	N[b]	OM[c]	P[d]	Ca	Mg	Na	K	Ni	Pb	Cd	Cu	Cr	Zn
		mS/cm	%	%	mg kg^{-1}	mg kg^{-1}				mg kg^{-1}					
CP[e]	6.07	915	1.81	19.8	287	17,606	2339	703	2640	125	503	4.77	505	593	1602
T[f]	6.64	320	3.94	40.4	400	6359	1455	531	1564	175	398	3.08	409	243	1118

Notes: Maximum allowed concentrations of total metals according to the 3 Draft of the EC (April, 2000) are the following: Ni < 300 mg kg^{-1}, Pb < 750 mg kg^{-1}; Cd < 10 mg kg^{-1}; Cu < 1000 mg kg^{-1}; Cr < 1000 mg kg^{-1}; Zn < 2500 mg kg^{-1}.
[a] Electrolytic conductivity (mS/cm).
[b] Total nitrogen (%).
[c] Organic matter (%).
[d] Total phosphorus (mg kg^{-1}).
[e] Composted sludge.
[f] Thermally-dried sewage sludge.

resources (Alcocer and Williams, 1996). Thereby, in Mexico, the desiccated clayish sediments of the former Lake of Texcoco adjacent to Mexico City have become around 10,000 ha of extreme saline–sodic soils. They are practically useless for agriculture and animal growth (Tarín Vázquez and Veláquez, 1986). Furthermore, during the dry season, it is a source of heavy "tolvaneras" (winds that drag soil particulates) that sweep the boundaries of Mexico City with any sort of visibility impairment, respiration hazards to population, and possibility of infectious disease transmission (Codd, 2000; Chow et al., 2002).

Furthermore, soils from the former Lake of Texcoco have special characteristics such as a clay type 2:1 (smectite) matrix (associated to changes of swelling and shrinking according to the water content), as well as the presence of amorphous silica in the form of gel and opal spheres within the clay fraction (López-Avila et al., 2004). This fraction exhibits a high cationic exchangeable capacity that along with the strongly alkaline pH promotes a soluble state. It was observed the presence of naturally cemented layers hardened by calcium carbonate and amorphous silica on the banks of the former Lake of Texcoco, forming sodium silicate crystals. Furthermore, Gutiérrez-Castorena et al. (1998) reported that the carbonate accumulations had a lacustrine origin, which are suffering diagenetic processes forming secondary carbonates; calcic and petrocalcic horizons have developed on the clayish soils. On the other hand, this formation as calcium silicate presents a chemical composition similar in oxides of Si, Al, Fe, Mg, K and Na to and different in oxides of calcium and silica from the cementitious layers. These particular characteristics allow the cracking ("jaboncillo") of the soil with input of calcium carbonate and cementation of distinct material types. Therefore, this leads to soils with a poor structure and high content of dissolved particles associated to high salt content that do not provide a healthy environment to plant and animal life.

Thus, environmental and sanitary Mexican authorities have expressed the need to reclaim the soils of the former Lake of Texcoco. On the other hand, Mexico has signed the agreements under the Agenda 21 in order to adopt regulations leading to the "sustainable development" particularly as applied to agriculture practices (Galaviz-Villa et al., 2010).

Therefore, the aim of this work was to assess the effectiveness of the restoration of saline–sodic soil from former Lake Texcoco (Mexico), using a process that consisted of washing with a $CaCl_2$ solution followed by organic amendment. For this purpose, the response was evaluated by a seed germination assay of *Raphanus sativus* seeds and by appraising changes of physico-chemical characteristics of soils and extracts.

2. Materials and methods

2.1. Materials

2.1.1. Sampling site

The former Lake of Texcoco (19°30′20″N 98°52′55″W) lies in the valley of Mexico at an altitude of 2240 m above sea level, with 16 °C and 705 mm of mean annual temperature and precipitation respectively. The soil consists of volcanic ash deposited in situ in a lacustrine environment and recently covered by colluvial materials (Beltrán-Hernández et al., 1999).

2.1.2. Soil and organic amendment characteristics

2.1.2.1. Soil. The experiment was performed using saline–sodic soils (SS) from the former Lake of Texcoco (Mexico) with high salt concentrations (NaCl and Na_2CO_3), pH 10.4, high electrolytic conductivity (*EC*) of 21.87 dS m$^{-1,}$ (25 °C) and exchangeable sodium percentage values (*ESP*) between 60 and 80%. Furthermore, the main nutrients of this soil had a content of 2.6% of organic matter (O.M.), a 0.091% of total nitrogen and a 51 mg kg^{-1} of available phosphorus. This soil (SS) was classified considering the USDA classification as a sandy–loam soil (8% clay, 12% loam and 80% sandy).

Afterwards, when saline–sodic soil was washed, we obtained a washing soil (WS) with the following characteristics: a pH of 8.56, an EC of 1.32 dS m^{-1}, a percentage of O.M. and N at 2.55% and 0.091% respectively, and 25 mg kg^{-1} of available phosphorus. The texture of WS was classified like loam–sandy soil.

2.1.2.2. Organic amendments. Two types of amendments based on sewage sludge were added to *SS* and WS. The first one consisted of sludge composted with pruning residues (*CP*), whereas the second was sewage sludge treated by thermal drying (*T*). Properties of amendments are displayed in Table 1 (whose values are expressed in dry weight, dw). Both amendments were slightly acidic, whereas *T* contained almost twice-organic matter and nitrogen than *CP*. On the other hand, *CP* had an *EC* and exchangeable calcium contents three times higher than *T*. The *CP* exhibited the highest levels of heavy metals analyzed (Pb, Ca, Cu, Cr and Zn), although these values were lower than those included in the Spanish Regulation Directive 1310/1990 (RD, 1990) and the European Directive 86/278/CEE (ED, 1986).

2.1.2.3. Vegetal bioindicator used in the process remediation. We have used seeds of *Raphanus raphanistrum* var. *sativus* (L.) G. in the germination test.

2.1.3. Experimental design

The design was divided into two parts; in the first step soil washing and in the second test the input of organic matter both in the washing soil as in the saline–sodic soil. Thus, both, saline–sodic soil and washing soil were tested with application of organic matter, from organic waste, at different doses. Following it is drawn a scheme, that below is developed in the points: Sections 2.1.3.1 and 2.1.3.2.

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