Chemical and biological characteristics of alkaline saline soils from the former Lake Texcoco as affected by artificial drainage

Abstract Soils from the former Lake Texcoco are alkaline saline and were artificially drained and irrigated with sewage effluents since the late 1980s. Undrained soil and soil drained for 1, 5 and 8 years were sampled, characterized and incubated aerobically for 90 days at 22°C while production of CO₂, available P and concentrations of NH₄⁺, NO₂⁻ and NO₃⁻ were monitored. Artificial drainage decreased pH, water holding capacity, organic C, total N, and Na⁺, K⁺, Mg²⁺, Ca²⁺, Cl⁻ and SO₄²⁻ concentrations, increased inorganic C and Ca²⁺ concentrations more than 5-fold while total P was not affected. Microbial biomass C decreased with increased length of drainage but bacteria, actinomycetes, denitrifiers and cellulose-utilizing bacteria tended to show opposite trends. CO₂ production was less in soils drained 6 years compared to undrained soil but more than in soils drained for 1 year. Emission of NH₃ was negligible and concentrations of NH₄⁺ remained constant over time in each soil. Nitrification, as witnessed by increases in NO₃⁻ concentrations, occurred in soil drained for 8 years. NO₂⁻ concentrations decreased in soils drained ≤1 year in the first 7 days of the incubation and remained constant thereafter. It was found that artificial drainage of soils from the former Lake Texcoco profoundly affected soil characteristics. Decreases in pH and Na⁺, K⁺, Cl⁻ and SO₄²⁻ concentrations made conditions more favourable for plant growth, although low concentrations of inorganic N and available P might be limiting factors.

Key words Alkaline saline soils · Micro-organisms · Characteristics · C and N mineralization

Introduction

The former Lake Texcoco is in the valley of Mexico City at an altitude of 2,240 m above sea level, and has a mean annual temperature of 16°C and precipitation of 705 mm. The soils in the area are formed from volcanic ash deposited in the former lake and covered recently by colluvium. The water table is near the surface (80–150 cm) and the groundwater is highly saline, NaCl and Na₂CO₃ being dominant. The undrained soils are saline-sodic, with a pH between 9.8 and 10.4, electrical conductivities in saturation extracts between 22 and 150 mS dm⁻¹ and large exchangeable sodium percentages (60–80). The soil texture is loamy to clayey, the structure is granular in the topsoil and prismatic in the subsoil and the organic matter contents range from 20 to 50 g kg⁻¹ (dry soil). Natural drainage is poor and roots are restricted by a compact ash layer 5–20 cm thick to depths of 16–40 cm.

The mineralogy of the soil is dominated by amorphous silica, smectites, kaolinite and cristobalite (Gutiérrez-Castorela 1997). These amorphous materials give the soil a very large water-retention capacity (2,400–5,000 g kg⁻¹), which decreases irreversibly upon drying. Drainage of the area has created cracks 1 m deep and up to 10 cm wide. The amorphous material also increases P fixation; retention is especially high...
(80%) in the moist subsoil, but in the topsoil it ranges from 26% to 31% (INEGI 1994).

The soils have partly been drained to remove the excess salt and irrigated with sewage effluents. *Distichlis spicata*, an indigenous grass with a high salt and Na tolerance, and *tamarix* (*Tamarix* spp.) have been introduced since the early 1970s to control erosion and now cover much of the area.

We investigated how duration of artificial drainage and irrigation with sewage effluents affected soil characteristics. Soil was sampled from a site that had not been drained and from sites drained for 1, 5 and 8 years, and characterized.

**Materials and methods**

**Site characteristics**

Topsoil (0–15 cm) was sampled on 15 March 1998 at random by augering 30 times four plots drained for different lengths of time (Table 1). Eight years ago, concrete tubes (15 cm Φ) were installed as drains at a depth of 2 m and a distance of 60 m (referred to as the soil drained for 8 years). The drains installed 5 years ago at a depth of 1.5 and a distance of 30 m were PVC tubes (15 cm Φ) (referred to as the soil drained for 5 years), while 1 year ago they were installed at a depth of 1.8 and a distance of 50 m (referred to as the soil drained for 1 year).

Cruciferae (*Eruca sativa*, *Brassica campestris*), compositae, gramineae [*Distichlis spicata*, *Eragrostis obtusiflora* (zacahuistle), *Tamarix*, *Bouteloua*, *Muhlenbergia*, *Hordeum* and *Cynodon*) can be found in the sites drained for 5 and 8 years. In the undrained soil and soil drained for 1 year only, *Distichlis spicata*, *Suadera nigra* (romerito) and some Cruciferae can be found. The undrained site was 80% covered with vegetation, the site drained for 1 year was 25% covered, while the sites drained for 5 and 8 years were completely covered.

The soils were partially drained in order to remove excess salt and were irrigated with sewage effluents. The effluents used to drain the soils originated from two different canals but the differences in characteristics were small (Table 2).

**Chemical characterization**

Total C and total N were determined by Leco combustion analyser while inorganic C was determined by adding 20 ml 1 M HCl solution to 1 g air-dried soil and trapping the CO₂ evolved in 20 ml 1 M NaOH. The NaOH was titrated with appropriate concentrations of H₂SO₄ to determine the CO₂ trapped. Total P was measured by aqua regia digestion with sodium carbonate fusion (Crosland et al. 1995) and Fe²⁺, Mn²⁺, Al³⁺ and Si⁴⁺ in amorphous oxyhydroxides were measured by extraction with ammonium oxalate and measured on an atomic absorption spectrophotometer (Tamm 1922; Schwertmann 1964), and total anions (Cl⁻ and SO₄²⁻) and cations (Ca²⁺, Na⁺, K⁺, Mg²⁺) and B by methods described in APHA, AWWA and WPCF (1989).

**Biological characterization**

Soil microbial biomass C was determined by fumigation extraction as described by Vance et al. (1987). The ammonifiers (*Rodina* 1972), denitrifiers (*Tiedje* 1982), NH₄⁺ and NO₃⁻ oxidizers (Schmidt and Belser 1982), free-living N₂ fixators (*Rodina* 1972) and cellulose-utilizing bacteria (*Hendricks* et al. 1995) were determined in a culture medium.

Bacteria, actinomyces and fungi, defined as the total number of colony forming units (cfu), were determined by serial dilution with a sterilized 1/4-strength Ringer’s solution and plating on general and selective media (Clark 1965a,b; Menzies 1965). Soil extract nutrient agar amended with 5 mg cyclohexamide ml⁻¹ was used to enumerate bacteria, Czapek agar for actinomyces, while Rose-bengal agar amended with 0.1 mg streptomycin-sulphate ml⁻¹ was used for fungi. The plates were inoculated with 0.1 ml⁻¹ soil suspension (three plates per suspension kept at 25°C for 4–7 days).

**Aerobic incubation**

The four soil samples, approximately 12 kg for each soil, were passed through a 5 mm sieve, adjusted to 40% of water-holding capacity (WHC) and conditioned for 7 days in drums to which 100 ml of distilled H₂O was added to avoid desiccation of the soil. Each drum also contained a beaker with 100 ml of 1 M NaOH to trap the CO₂ evolved. The drums were aired every 7 days to avoid anaerobicity.

From each site, 21 subsamples of 40 g of soil were added to 120 ml glass flasks for measurement of inorganic N and 21 subsamples of 10 g to 20 ml plastic beakers for measurement of inorganic P. Three plastic beakers were chosen at random from each treatment and soil was extracted for inorganic N with 160 ml of 0.5 M K₂SO₄ solution; they were shaken for 30 min, filtered through Whatman No 42 paper and inorganic P concentration was determined by adding 20 ml 1 M HCl solution to 1 g air-dried soil and trapping the CO₂ evolved. Total P was measured by distillation with MgO (Bremner and Keeney 1966) and NO₃⁻ and NO₂⁻ with a sterilized 1/4-strength Ringer’s solution and plating on general and selective media (Clark 1965a,b; Menzies 1965). Soil extract nutrient agar amended with 5 mg cyclohexamide ml⁻¹ was used for fungi. The plates were inoculated with 0.1 ml⁻¹ soil suspension (three plates per suspension kept at 25°C for 4–7 days).

**Table 1** Characteristics of soils from the former Lake Texcoco characterized by different length of drainage time

<table>
<thead>
<tr>
<th>Drainage</th>
<th>Conductivity (mS cm⁻¹)</th>
<th>pH</th>
<th>Carbon</th>
<th>Total</th>
<th>Nitrogen Phosphorus¹</th>
<th>Particle size distribution</th>
<th>USDA textural classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>WHC²</td>
<td>Organic Inorganic</td>
<td>Clay</td>
<td>Silt</td>
<td>Sand</td>
</tr>
<tr>
<td>Undrained</td>
<td>399</td>
<td>9.9</td>
<td>1016</td>
<td>6.0</td>
<td>0.398</td>
<td>444</td>
<td>167</td>
</tr>
<tr>
<td>1 year</td>
<td>799</td>
<td>10.2</td>
<td>912</td>
<td>19.13</td>
<td>7.4</td>
<td>3.57</td>
<td>0.390</td>
</tr>
<tr>
<td>5 years</td>
<td>98</td>
<td>9.2</td>
<td>717</td>
<td>15.94</td>
<td>33.2</td>
<td>1.36</td>
<td>0.409</td>
</tr>
<tr>
<td>8 years</td>
<td>126</td>
<td>8.3</td>
<td>572</td>
<td>14.60</td>
<td>35.1</td>
<td>0.92</td>
<td>0.379</td>
</tr>
</tbody>
</table>

¹ Water-holding capacity
² Total P was measured by aqua regia digestion with sodium carbonate fusion (Crosland et al. 1995)