

## Supplementary information

### pH and conductivity

For the determination of pH and conductivity, a portable multiparameter was used (HACH HQ40D) calibrated using pH standards of 4.01, 7.00 and 10.01, and of conductivity NaCl 1000  $\mu\text{S}/\text{cm}$ . A 20 g soil sample was treated by the addition of 50 mL of water and mechanical stirring for 5 minutes, proceeded to leave the contents of the beaker at rest and after an hour, measured the pH and conductivity values, introducing the respective electrode in the supernatant (Rice, Baird, & Eaton, 2017; US EPA. Method 9045D, 2004).

### Texture

The texture was determined by a qualitative method to touch and sight, established by the FAO, for which the amount of soil that the hand was capable of containing, without stones, branches or other elements that hinder its handling, the sample was moistened with water while it was kneaded until reach the point where the soil did not adhere to the hands, this procedure over three minutes and finally the soil was classified according to as indicated in the cited standard (FAO, 2006).

### Porosity

Porosity was determined by the difference in density between the water and the contaminated soil, it began with the tare of a 100 mL test tube that was later filled with soil to a volume of 90 mL, the content of the test tube was weighed and water was added, once the liquid was filtered through the sample in its totality, the corresponding capacity was completed and it was weighed again, with the data, the pertinent calculations are made in accordance with what is described below (ASTM C830-00, 2016).

$$\text{Porosity (\%)} = \frac{\text{soil volume}}{\text{water volume}} \times 100$$

### Granulometry

The granulometry method allowed to determine the classification of the soil contaminated through the particle size distribution. For the test, used a pretreated sample by saturation with deionized water and rest for the disintegration of the lumps present, the soil was transferred to the sieves previously tared and sorted ascending (75, 150, 250, 300, 500, 1000, 2000 and 4000  $\mu\text{m}$ ) the sample was washed and sieved for 15 minutes, then, the sieves with the respective fractions were dried and weighed to calculate the percentage of sample contained in each of them. The size distribution less than 75  $\mu\text{m}$  was determined using the method of sedimentation whose principle is based on the settling speed of the particles. The resulting washing liquid was transferred to a 1000 mL test tube, it was made up to its total volume with deionized water and 1 g of pyrophosphate of sodium was added to prevent soil particles from coagulating, the content of the test tube was shaken and subsequently the fractions <63, <20, <6.3 and <2  $\mu\text{m}$  were collected in tared Petri dishes, at different times and depths, according to described in the method (ASTM C136 / C136M - 19, 2019), then dried and determined the percentage of the fractions by weight difference.

## Humidity

The water content in the contaminated soil was quantified taking as reference the gravimetric method for which a soil sample of 10 g contained in a tared crucible was subjected to drying in an oven at a temperature of 105 °C for a period of 24 hours, cooled to room temperature in a desiccator and for the determination of the humidity percentage, the calculations detailed below, based on the difference in weight (ASTM D2216 -98, 1998).

$$\text{Humidity (\%)} = \frac{\text{soil weight} - \text{dry soil weight}}{\text{soil weight}} \times 100$$

## Organic matter

The presence of organic carbon was analyzed using the gravimetric method based on the volatilization of all forms of organic carbon present in the sample of contaminated soil to be treated. Initially, a sample of 10 g of soil was dried at 105 °C in a tared crucible for 24 hours, after removing the soil moisture, it was calcined using a muffle at a 700 °C temperature for 4 hours, the percentage of organic matter was determined by the equation set forth below (ASTM F1647 - 11, 2018).

$$\text{Organic matter (\%)} = \frac{\text{dry soil weight} - \text{calcined soil weight}}{\text{dry soil weight}} \times 100$$

## Cation exchange capacity

The analysis of the cation exchange capacity was carried out starting from the saturation of the soil with an index cation, in this case ammonium, by adding ammonium acetate, subsequently, the excess of ammonium was removed by vacuum filtration and washing with sodium chloride, which allowed to determine the exchangeable amount of ammonium and finally cation exchange capacity using volumetry, sodium hydroxide was used for the titration of the sample and an analysis blank, and phenolphthalein as indicator, the calculations for the quantification are described below (US EPA. Method 9080, 1986).

$$CEC \text{ (meq/100)} = \frac{(V1 - V2). N. 100}{P}$$

Where:

V1: Volume of NaOH used in the titration of the sample

V2: Volume of NaOH used in the blank titration

N: Normality of sodium hydroxide

P: Weight of dry soil sample

## Humic acids and fulvic acids

Humic acids were determined gravimetrically, the test was started with an alkaline extraction by addition of sodium hydroxide on the soil sample, the extraction was assisted by mechanical agitation, followed by centrifugation. The supernatant was acidified with hydrochloric acid and centrifuged again, the sediment contains humic acid present in the sample, the supernatant was

reserved for the determination of fulvic acids, finally this fraction was dried and the analyte was determined by weight difference according to what is indicated in the following equation (ISO 19822:2018, 2018). The supernatant resulting from the previous extraction was used for the determination of fulvic acids by UV-VIS spectrophotometry, the value was read at a wavelength of 465 nm (Jarukas et al., 2021).

$$\text{Humic acid (\%)} = \frac{\text{dry precipitate weight}}{\text{soil weight}} \cdot 100$$

#### Heavy metals

The analysis technique used for the determination of heavy metals present in soil was Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The acid digestion was performed using nitric acid and hydrogen peroxide, with this the organic matter is oxidized and the interferences are reduced. The sample was refluxed again with hydrochloric acid and finally remnants of digestion were removed by filtration (US EPA. Method 6020B, 2014).

#### Nitrogen

The concentration of nitrogen in the soil was determined using the method HACH 8038 (2017). Sulfuric acid and hydrogen peroxide were used for the acid digestion and oxidation of the sample, by this the organic nitrogen was converted to its ammoniacal form and TKN, finally, the nitrogen concentration was measured by colorimetry.

#### Total Petroleum Hydrocarbons (TPHs) TPH 1

The TPHs were identified by gas chromatography with a flame ionization detector (FID) (U.S. EPA Method 8015D, 2003). The extraction was performed adding 10 mL of acetone on 10 g of soil, stirred for 30 minutes at high speed on an orbital shaker, after this 10 mL of the extraction solvent of TPHs (hexane with surrogate O-terphenyl) was added and stirred again under the same conditions. Sample was centrifuged at 1500 rpm for 3 minutes, finally 10 mL of deionized water were added and the organic phase was transferred to 2 mL amber vials. A sample blank and a fortified blank were performed. The chromatographic conditions are described in Table 1. The fraction analyzed by this method is the comprised between C<sub>8</sub> to C<sub>40</sub>.

Parameter	Value
Instrument model	Agilent Technologies 7890A GC System
Inlet	280 °C pulsed splitless
Injection volume	2 µL
Column	Fused Silica, Agilent 123.1632: DB-TPH (-10 °C – 320 °C (320°C): 30 m x 320 µm x 0.25 µm)
Column temperature program	Ramp 1: 270 °C (30°C/min), 0 min Ramp 2: 300 °C (7°C/min), 19 min

**Table S1.** TPHs analysis GC conditions

## Total Petroleum Hydrocarbons (TPHs) TPH 2

An additional analysis of TPHs was performed in order to obtain the total concentration of TPHs by the gravimetric method, for which 5 mL of the extract were placed in a previously tared balloon, the contents of the flask were allowed to evaporate overnight at room temperature, and the evaporation of the rest of the solvent was completed in an oven at 60 °C for 3 hours. Finally, the concentration of the contaminants was calculated by weight difference (US EPA. Method 1664, 2010).

$$TPHs (mg/kg) = \frac{(final\ weight - initial\ weight\ (1000))1000}{soil\ weight}$$

## Polycyclic Aromatic Hydrocarbons

For the analysis of PAHs, Liquid Chromatography was used as an analytical technique. High Efficiency Fluorescence Detector (HPLC-FLD), the extraction and detection of the analytes were carried out based on the method (AOAC. Method 2007.01, 2005).

## Soil respiration

The respiratory activity of the soil was determined based on the quantification of the production of carbon dioxide (CO<sub>2</sub>). A soil sample was left in incubation at 28°C for 5 days with ammonium nitrate. The released CO<sub>2</sub> was captured with sodium hydroxide and subsequently titrated with hydrochloric acid in the presence of barium chloride. The following equation was used for the calculation of the amount of dioxide of carbon:

$$mg\ de\ CO_2 = (B - V)NE$$

Where:

B: Volume (mL) of HCl used in the titration of the control NaOH

V: Volume (mL) of HCl used in the NaOH titration of the studied soil

N: Normality of hydrochloric acid

E: Equivalent weight (E=22)

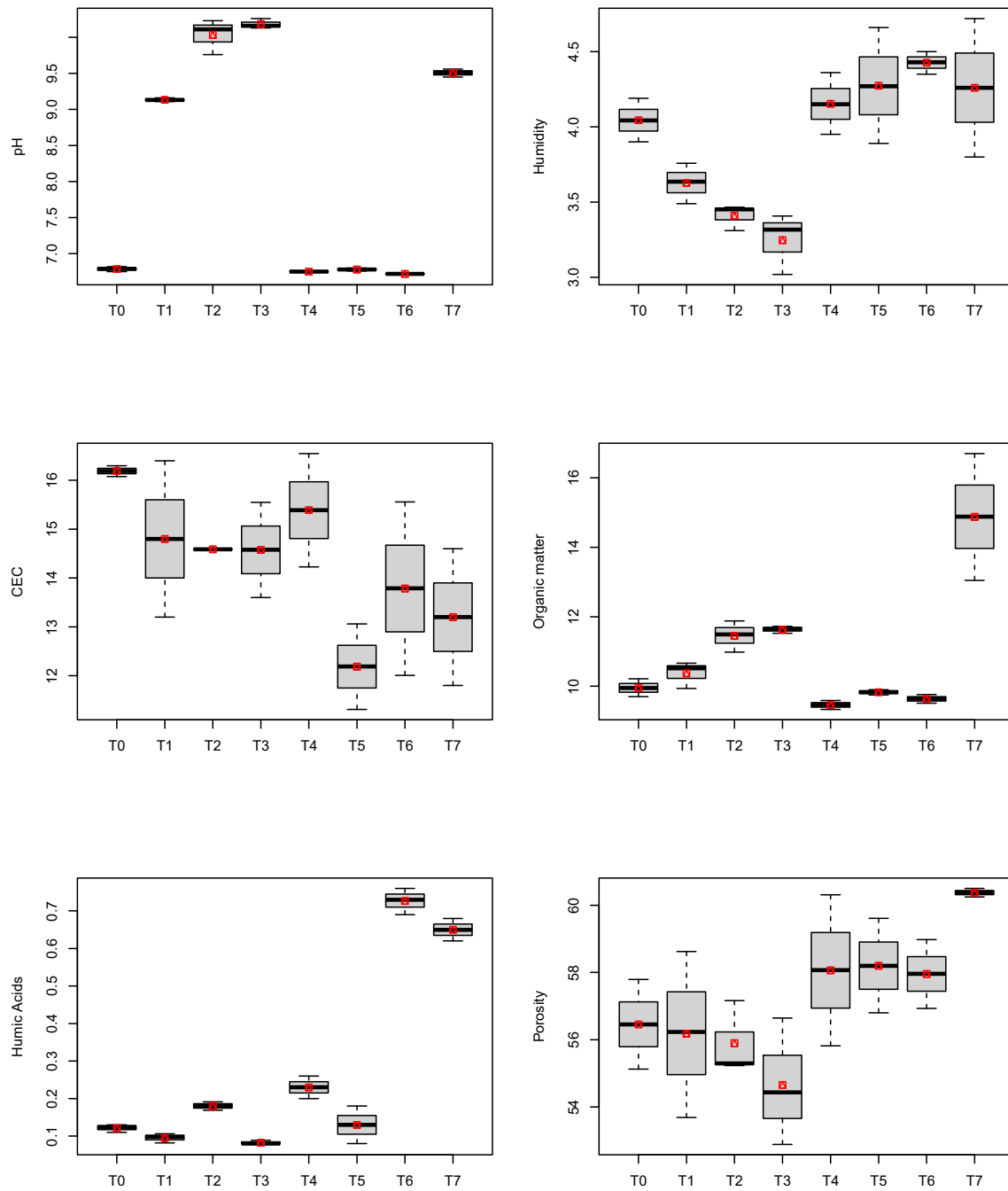


Figure S1. Boxplot of the Physical and chemical characteristics after the first month applied the treatments. Mean is shown in red. T0: Soil without treatment; T1, T2 and T3 soils treated with lime at 1, 2 and 3 % respectively; T4, T5 and T6 soils treated with 40 nm silica nanoparticles at 0.5, 1 and 2 % respectively; T7 soil treated with 0.5 % of nano silica and 2 % of lime.

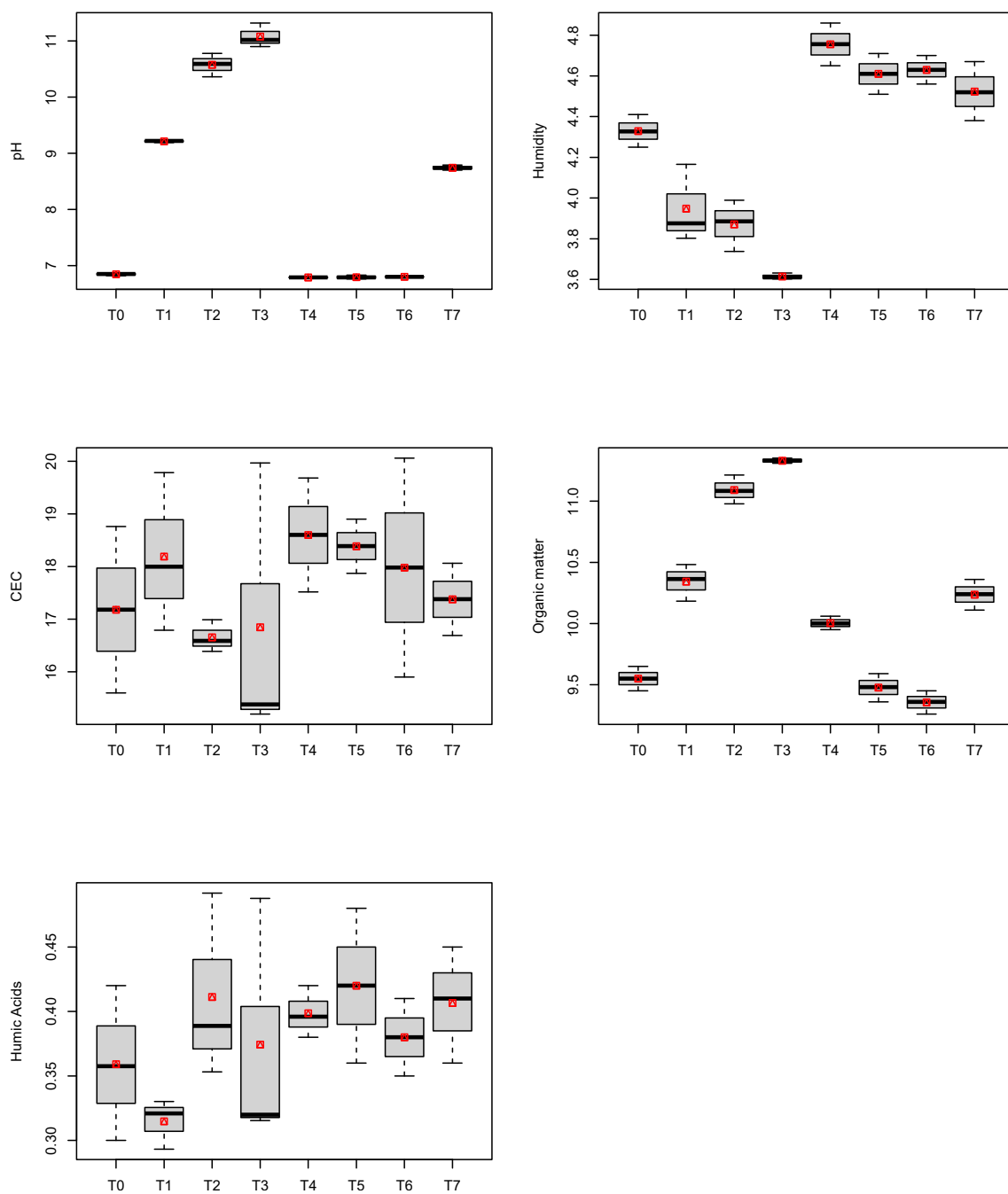


Figure S2. Boxplot of the Physical and chemical characteristics after the second month applied the treatments. Mean is shown in red. T0: Soil without treatment; T1, T2 and T3 soils treated with lime at 1, 2 and 3 % respectively; T4, T5 and T6 soils treated with 40 nm silica nanoparticles at 0.5, 1 and 2 % respectively; T7 soil treated with 0.5 % of nano silica and 2 % of lime.

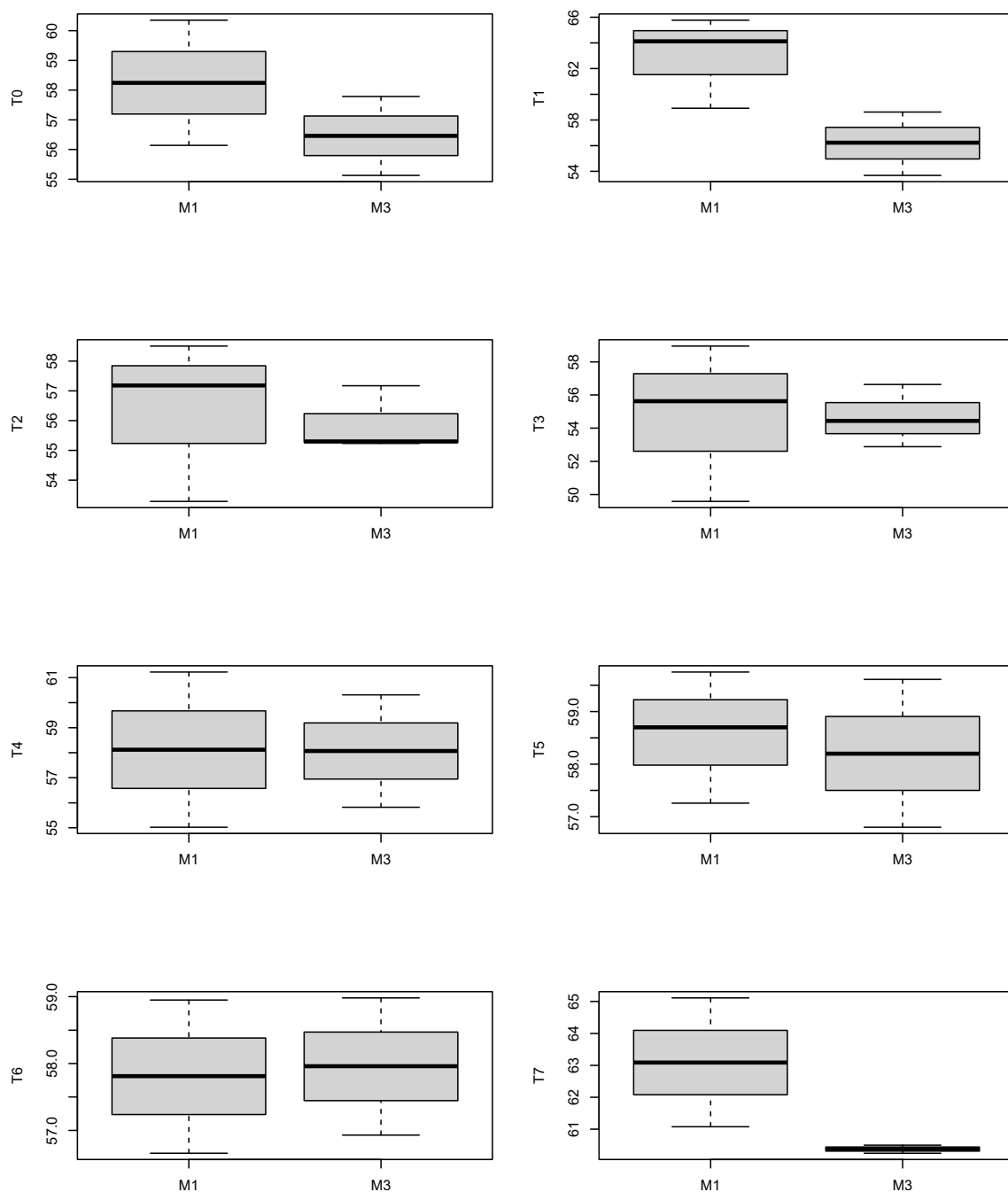


Figure S3. Boxplot by treatment for porosity. T0: Soil without treatment; T1, T2 and T3 soils treated with lime at 1, 2 and 3 % respectively; T4, T5 and T6 soils treated with 40 nm silica nanoparticles at 0.5, 1 and 2 % respectively; T7 soil treated with 0.5 % of nano silica and 2 % of lime. M is for month (1, 2 or 3).

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