Catena 172 (2019) 11–20

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Repetitive land application of urban sewage sludge: Effect of amendment rates and soil texture on fertility and degradation parameters

Helmi Hamdi[a,*], Sarra Hechmi[a], Mohamed Naceur Khelil[b], Inès Rahma Zoghlami[a], Saoussen Benzarti[c], Sonia Mokni-Tlili[a], Abdennaceur Hassen[a], Naceur Jedidi[a]

[a] Water Research and Technology Center, University of Carthage, P.O. Box 273, Soliman 8020, Tunisia
[b] National Institute for Research in Rural Engineering, Water and Forestry, P.O. Box 10, Ariana 2080, Tunisia
[c] Higher School of Agriculture at Mograne, 1121 Mograne, Tunisia

ARTICLE INFO

Keywords:
Sewage sludge
Soil texture
XRD analysis
Fertility
Biological properties
Degradation

ABSTRACT

The agricultural reuse of urban sewage sludge in degraded croplands has seen a wide acceptance for biowaste recycling and for the improvement of soil fertility. However, soil degradation and health issues may arise from the fact that sludge addition causes chemical and biological contamination if mismanaged. To closely monitor the long term soil-sludge interactions, a field study was conducted over a three-year period under a semi-arid climate. More precisely, changes in topsoil properties were assessed in 4-m^2 uncropped plots amended with sludge rates equivalent to 0, 40, 80 and 120 $t\,ha^{-1}\,year^{-1}$ for two soil textures: soil A (sandy loam) and soil S (sandy). Results showed that all studied parameters changed significantly in a dose-dependent manner for both soils as compared to untreated controls. As such, sludge addition improved consistently TOC, N, P and K content up to soils treated with 120 $t\,ha^{-1}\,year^{-1}$. The enhancement of soil nutrient status impacted positively on biological properties, including microbial biomass and soil enzyme activities (dehydrogenase, protease and phosphatase). However, the variation of soil properties was more important in soil A characterized by a higher fine fraction thus stronger retention capacity. Accordingly, XRD analysis of soil A revealed several identifiable peaks representing kaolinite and illite clays in contrast to soil S. Unexpectedly, high to excessive sludge doses of 80 and 120 $t\,ha^{-1}\,year^{-1}$ did not provoke soil degradation after three repeated annual amendments. In fact, pH values in both soils remained within neutral to alkaline range (7.76–8.63); total heavy metals (Cu, Zn, Ni and Pb), soil salinity and fecal coliforms were all below threshold values for contaminated soils.

1. Introduction

The Mediterranean region and its adjacent areas have been consistently facing irregular rainfall, prolonged droughts and inadequate cropland management that have led to sustained soil depletion and degradation (Lakhdar et al., 2010; Kelessidis and Stasinakis, 2012; Zoghlami et al., 2016a). Consequently, the land application of organic amendments provides a management strategy that compensates the nutrient deficiency and improves soil properties (Hueso-González et al., 2014). For instance, sewage sludge reuse (including direct land application and composting) seems to be the predominant choice for biosolids management in EU-15 countries, mainly in Spain, France, Germany, Italy and UK (Kelessidis and Stasinakis, 2012). For instance in Italy and Spain, respectively 31% and 65% of the generated sludge are annually recycled through agricultural soils (Roig et al., 2012; Mininni and Sagnotti, 2014). Suleiman et al. (2010) reported that changes in Jordanian regulations have created the opportunity for beneficial use of biosolids through land application. In Tunisia, farm manure has traditionally been the principal organic amendment used by farmers to restore soil fertility and improve soil physico-chemical parameters (Lakhdar et al., 2010). Because manure supply has become expensive and often deficient, the recourse to unconventional biowastes such as municipal solid waste composts and urban sewage sludge has been proposed as an alternative solution for their recycling and for the improvement of soil quality at lower costs (Benzarti et al., 2007; Lakhdar et al., 2010; Zoghlami et al., 2016b). In countries where sludge agricultural reuse has seen an increasing interest, several research studies have shown that the rational land application improves soil fertility, biological activities as well as crop yield (Roig et al., 2012; Özyazici, 2013; Poulsen et al., 2013).

As a biowaste with complex composition, undesirable changes may also occur in agricultural soils after sludge addition depending on

* Corresponding author.
E-mail address: helmi.hamdi@certe.rnrt.tn (H. Hamdi).

https://doi.org/10.1016/j.catena.2018.08.015
Received 21 March 2018; Received in revised form 4 August 2018; Accepted 13 August 2018
0341-8162/

sludge quality, amendment rate and frequency as well as the soil type (Hamdi et al., 2007a; Latare et al., 2014; Zoghlami et al., 2016a). These changes include chemical and biological contamination in addition to soil physical degradation (Hamdi et al., 2007a; Singh and Agrawal, 2008). For example, the presence of heavy metals in sewage sludge may cause soil contamination and have adverse effects on plant growth and soil microorganisms after amendment, depending on metal toxicity, concentration and bioavailability (Ben Achiba et al., 2009, 2010; Roig et al., 2012). Soluble salts in the urban wastewater stream are mostly adsorbed onto the sludge phase after treatment and can eventually cause soil salinization in case of inappropriate reuse or under water stress conditions (Hamdi et al., 2007a).

Soil biology is also a major component of soil quality and responsible for many ecological processes (Gonzalez-Quiñones et al., 2011). Soil microbial biomass is essential for carbon mineralization and organic matter stabilization by catalyzing many enzymatic reactions. For instance, the activities of protease, dehydrogenase and phosphatase in soil have critical relations with nitrogen, carbon, and phosphorus recycling, respectively (Cenciani et al., 2011; Nannipieri et al., 2011; Zoghlami et al., 2016b). According to Tarrasòn et al. (2010), soil microbiological properties such as microbial biomass and enzyme activities are good and sensitive indicators for soil health or degradation and can be used to predict short- and long-term trends in soil quality. In this regard, soil texture has an influence on turnover rates of soil nutrients and biomass activity (Bouajila et al., 2014; Mohammad, 2015). These authors indicated also that the presence of a higher fine fraction in soil namely, clay and/or loam particles enhanced organic carbon content, positively affected nutrient equilibrium and consequently microbial growth.

In view of the fact that the nutritional contribution of sludge to croplands is now confirmed, recent research studies have been more directed to monitor changes in amended soil properties (Topcuoğlu, 2005; Tarrasòn et al., 2010; Antille et al., 2013; Lassoued et al., 2013). In general, these investigations consist of short-term amendment trials with different sludge doses using cropping systems. However, a very few studies have closely assessed the long-term interactions between sludge and the soil compartment as a reservoir for sludge-borne chemicals and microorganisms without the influence of plant rhizosphere. In this regard, soil texture plays a critical role in the mobility (accumulation and losses) of chemicals after amendments. The current long-term field study aims to investigate the type of these interactions and the intrinsic capacity of agricultural soils to cope with moderate to excessive loads of sewage sludge. Accordingly, changes in physico-chemical and biological properties were monitored after three successive annual amendments in two light-textured agricultural soils. These two soils have low yet different fine fraction content that may influence soil parameters after amendments. In addition, amendment rates were increased up to 80 and 120 t ha^{-1} year^{-1} to highlight soil-sludge interactions in case of abusive reuse. These interactions were made more obvious by the consistent absence of a vegetal cover under direct influence of semi-arid conditions.

2. Materials and methods

The field-scale experiment has been underway since 2012 at the agricultural experiment station of the National Institute for Research in Rural Engineering, Water and Forestry (INRGREF) in the coastal city of Nabeul (north-east Tunisia). The site is characterized by light-textured soils and a superior semi-arid climate with mean annual precipitation of 400–450 mm and average temperature of 18 °C. Sewage sludge trials were conducted simultaneously on a sandy loam soil (soil A) and a sandy soil (soil S) within the same station. Soil texture was determined using the Robinson pipette method (Beretta et al., 2014). A mineralogical analysis was also performed by means of X-Ray diffraction (XRD) of powdered samples from both soils. XRD analysis was carried out with an X'Pert Pro diffractometer (PANalytical) and a Cu Kα source (λ = 1.54 Å).

Table 1
Physico-chemical and microbial properties of experimental soils and sewage sludge.

	Soil S	Soil A	Sewage sludge
Sand (%)	83.3	70.9	–
Clay (%)	5.2	11.9	–
Loam (%)	11.5	16.2	–
pH (1:2.5)	7.24	7.72	7.7
EC (μS/cm) (1:5)	119.1	154.7	1702
TOC (%)	0.67	0.76	18.5
N (%)	0.1	0.071	1.18
C/N	7	10.7	15.7
P Olsen (mg kg^{-1})	17.5	14.1	220
K (mg kg^{-1})	8.44	58.8	9.54
Ca (mg kg^{-1})	1540	9560	113.54
Na (mg kg^{-1})	80	196	1231
Cd (mg kg^{-1})	0.36	0.74	4.04
Pb (mg kg^{-1})	16.2	16.5	35
Ni (mg kg^{-1})	0.58	0.44	22.2
Zn (mg kg^{-1})	5.88	2.48	342
Cu (mg kg^{-1})	1.37	0.1	174.4
Bacteria (CFU g^{-1})	$103 \cdot 10^5$	$122 \cdot 10^5$	$125 \cdot 10^7$
Fungi (CFU g^{-1})	$52 \cdot 10^2$	$58 \cdot 10^2$	$3 \cdot 10^7$

All values for soil or sewage sludge are given on dry weight basis.

The urban sewage sludge was collected annually from a wastewater treatment plant in the vicinity of the experimental site. It was generated by an activated sludge treatment process as secondary treatment followed by dewatering using drying beds (Zoghlami et al., 2016b). Table 1 summarizes some physico-chemical properties of the experimental soils and the urban sewage sludge used for this study.

2.1. Experimental design

As mentioned above, fertilization trials were carried out into two close agricultural parcels with different soil types (A and S) located at the same station. Each parcel was divided in four completely randomized blocks containing four treatments each. These treatments were: control soil (C) and sewage sludge added annually at three increasing rates equivalent to: 40 t ha^{-1} year^{-1} (SS-40), 80 t ha^{-1} year^{-1} (SS-80) and 120 t ha^{-1} year^{-1} (SS-120). In all there were four replicate treatments for each soil type. These treatments were carried out in 4-m^2 plots (2 m × 2 m) separated from each neighboring plot by a 2-m path.

Sludge was added yearly during the fall season (October–November) and incorporated into the top soil by hand digging up to 10–15 cm depth. Physico-chemical and microbiological analysis revealed that sewage sludge properties did not vary significantly at each annual amendment. Added amounts were converted to kg/m^2 based on plot surfaces of 4 m^2. Throughout this field study, weeds were removed manually when needed to keep uncropped plots consistently unvegetated. Consequently, changes in soil properties were only influenced by edapho-climatic factors and sludge doses. Prior to every annual sludge amendment, three soil subsamples are collected from each replicate plot at 0–20 cm and 20–40 cm depth using a manual auger. These sub-samples are composited to one single sample per replicate treatment then taken to the laboratory for characterization. The outcomes described in this study represent changes in topsoil properties (0–20 cm) sampled in fall 2015. Consequently, all plots had already received three successive sludge amendments as mentioned above (in 2012, 2013 and 2014).

2.2. Physical and chemical investigation

Soil physico-chemical parameters were investigated using air-dried soil samples sieved through 2 mm mesh and stored at 4 °C in the dark. Soil pH and electrical conductivity (EC) were measured in soil-water