Science of the Total Environment 627 (2018) 681–688

Contents lists available at ScienceDirect

Science of the Total Environment

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

Sewage sludge used as organic manure in Moroccan sunflower culture: Effects on certain soil properties, growth and yield components

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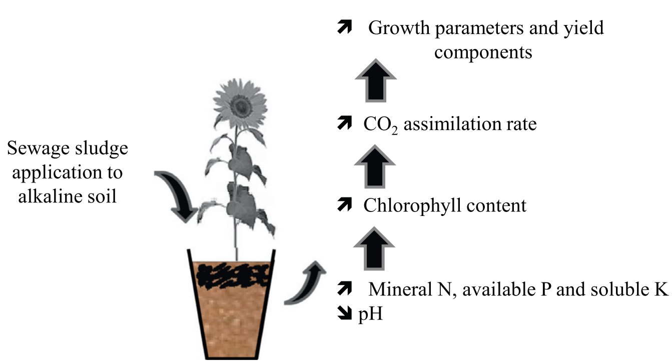
HIGHLIGHTS

- In Morocco, no management strategy for sewage sludge has been implemented.
- Sewage sludge application to soils increased mineral N, available P and soluble K.
- High N and P levels in sludge explain beneficial effect on sunflower growth.
- Sunflower plants treated with sewage sludge showed best grain yield.
- Higher yield was associated with grain number and grain weight increase.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 28 December 2017
Received in revised form 25 January 2018
Accepted 25 January 2018
Available online 3 February 2018

Editor: D. Barcelo

Keywords:
Sewage sludge
Helianthus annuus L.
Agricultural application
Soil fertility
Yield components

ABSTRACT

The wastewater treatment and sludge production sectors in Morocco are recent. Considered as waste, no management strategy for sewage sludge (SS) has been implemented. Thus, its disposal definitely represents a major environmental problem since sludge is either incinerated, used as landfill or simply deposited near wastewater treatment plants. The objective of this study was to determine the effects of dehydrated SS on certain soil properties (pH, electrical conductivity (EC), Mineral nitrogen, available phosphate P_2O_5, and soluble potassium K_2O), and also on growth and yield components of the sunflower (*Helianthus annuus* L.). An experiment was conducted using six treatment rates (0; 0 + NPK; 15; 30; 60 and 120 t ha^{-1}). The results showed that soil pH was significantly affected by SS, becoming less alkaline compared to the control, while electrical conductivity increased significantly when the applied doses were above 30 t ha^{-1}. Also, a significant enrichment in mineral N and available phosphorus was detected in amended soil. However, no differences were found between pots having received the mineral fertilization and the SS at 15 t ha^{-1}. Stem height growth of the sunflower seedlings receiving SS increased significantly compared to the two controls. For both the aerial and root parts, significant increases in dry biomass accumulation were observed compared to the unamended plants. Net CO_2 assimilation (A_n) increased, while stomatal conductance (g_{sw}) and transpiration rates (T_r) decreased with increasing SS rates. SS application at 15 t ha^{-1} presented similar values of the yield components compared to plants fertilized chemically. However, grain yield (in quintals ha^{-1}) was noted to be 2.4, 5 and 8 times higher in treatments receiving SS respectively at the rate of 30, 60 and 120 t ha^{-1}.

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https://doi.org/10.1016/j.scitotenv.2018.01.258
0048-9697/

1. Introduction

Management and preservation of water resources is one of the cornerstones of environmental protection. Wastewater treatment plants thus play a fundamental role in the water cycle, producing a liquid effluent of a quality suitable to be returned to natural surface waters with minimal impact on the environment or on public health. However, this process generates a significant by-product called sludge, or more precisely bio-solids. In Morocco, sludge is considered as waste and is therefore managed as such. As in other developing countries, the wastewater treatment and sludge production sectors are recent. Consequently, no management strategy for this organic residue has been implemented and sludge disposal definitely represents a major environmental problem since it is either incinerated, used as landfill or simply deposited on lands near wastewater treatment plants.

Sustainability requires sewage sludge to be managed as a valuable resource, rather than as a burden. Agriculture offers one empirical use: large amounts of SS are spread on agricultural lands throughout the world (Lavado, 2006). For example, in the European Union, 37% of the SS produced is applied to agricultural lands compared to 44% in China, 60–65% in the United States and 85% in Egypt (Ghazy et al., 2009; European Commission, 2010; Spinosa, 2011; Bourioug et al., 2017, 2018). Land application of sewage sludge may have many beneficial effects on soil fertility, enriching it with its nitrogen, phosphorus and micronutrient contents and improving the soil's physico-chemical, microbiological and enzymatic properties, all of which present advantages for crop production (Singh and Agrawal, 2008; Kumar and Chopra, 2013; Bourioug et al., 2015). Public acceptance of this practice is closely related to environmental concerns about SS landfilling and incineration (Kidd et al., 2007). In addition, SS re-use may partially or completely reduce dependence on chemical fertilizers and thus become economically profitable. However, the presence in sludge of hazardous components such as trace metals (TMs), organic compounds (Harrison et al., 2006), emerging contaminants such as pharmaceutical products (Bourioug et al., 2017) and pathogens presents potential contamination risks for soils and plants (Epstein, 1998; Lewis and Gattie, 2002), though the levels of these toxic substances in SS depend on sludge origin. In order to evaluate both their benefits and their risks, many studies have focused on the SS effects on several agronomic crops such as rice (Singh and Agrawal, 2010), corn (Rodríguez et al., 2003) and beans (Kumar and Chopra, 2013).

Potential contaminants in SS spread on agricultural soil, which may be transferred into the human food chain directly via uptake into food crops, should be avoided or at least be limited to tolerable levels in the biomass used for energy, biofuel or in the manufacture of feedstock (Andersson-Sköld et al., 2013; Zabaniotou et al., 2008). The sunflower (*Helianthus annuus* L.) is an annual crop of the Asteraceae family, native to North America, specifically from the southwestern United States and northern Canada. It can be grown in many semi-arid regions with limited water availability. In addition to its use as animal feed, it is one of the leading oilseed crops, producing an oil of excellent quality for human consumption. Widely used in phytoremediation, pollutant accumulation was highest in stems and leaves instead of the seeds which are the edible part, suggesting that sunflowers are safe for both people and animals (carbofuran: Teerakun and Reungsang, 2005; trace metals: De Maria and Rivelli, 2013). Sunflowers are also an important crop for biodiesel production, particularly in southern European countries (Zabaniotou et al., 2008).

The objective of this study was to determine the effects of dehydrated activated sludge on certain soil properties (pH, electrical conductivity (EC), Mineral nitrogen, available phosphate P_2O_5, and soluble potassium K_2O), and on the growth and yield components of sunflowers.

2. Materials and methods

2.1. SS and soil characterizations

A loamy soil collected from the experimental farm at the National School of Agriculture (ENA, Meknès-Morocco), (33°50′34″ N Latitude, 5°28′31″ W Longitude) was used in this experiment. Taken from within the top 30 cm of the soil layer, it was sieved through a 1 cm mesh. Dehydrated SS from a new domestic wastewater treatment plant in the non-industrial city of Ifrane (Morocco) (33°31′59″ N Latitude, 5°06′00″ W Longitude), and produced with activated sludge process, was also used. The physico-chemical characteristics of the soil and SS are provided in Table 1.

2.2. Plant material, growth conditions and experimental setup

The experiment was carried out under a rain shelter at ENA (Meknès-Saïs Region, Morocco). Certified seeds of the *H. annuus* var. Leila, registered in the official Moroccan catalogue in 2005 (ONSSA, 2017), were purchased from a local seed dealer and planted in pots 27 cm in height with bottom and top diameters of 21.5 and 26 cm, respectively. The pots were filled with a layer (1 kg) of gravel at the bottom to improve drainage and 8.5 kg of dried soil. After sludge application, 1 kg of additional soil was added to homogenize the seedbed. On March 7, 2017, three seeds were planted in each pot. The plants were allowed to grow under natural conditions and were later thinned to one healthy plant per pot. Seedlings were irrigated with distilled water to 70% of field capacity three times a week or twice a day in warm weather. The experiment consisted of six treatments:

- 0: unamended soil used as a negative control (NC).
- 0 + NPK: without sludge and with recommended fertilizers (NPK: 180; 100; 400 kg ha^{-1}). NPK (90; 100; 400 kg ha^{-1}) were provided as a basic fertilizer before sowing and the rest of the nitrogen (90 kg ha^{-1}) was fractioned into two applications administered at the two and four leaf stages. This treatment was used as a positive control (PC).

Table 1
Physico-chemical characterization of soil and sewage sludge used in the experiment (Mean ± SD, $n = 5$).

Parameters (unit)	Soil	Sewage sludge (SS)	Soil limits[a]	SS limits[a]
Cd (μg g^{-1}DW)	0.22 ± 0.1	1.15 ± 0.2	2	10
Cu (μg g^{-1}DW)	1.6 ± 0.7	17.9 ± 1.2	100	1000
Pb (μg g^{-1}DW)	16.2 ± 0.8	81 ± 4.5	100	800
Zn (μg g^{-1}DW)	3.1 ± 0.2	215 ± 12.4	300	3000
Al (mg g^{-1}DW)	44 ± 1.3	10.8 ± 0.2		
Cr (μg g^{-1}DW)	57.5 ± 3.5	32.8 ± 2.4		
As (μg g^{-1}DW)	6.7 ± 0.0	< 5.00		
Hg (μg g^{-1}DW)	< 0.10	0.44 ± 0.1		
Ni (μg g^{-1}DW)	21.5 ± 1.9	20.9 ± 1.7		
Se (μg g^{-1}DW)	< 5.00	< 5.00		
Co (μg g^{-1}DW)	11.4 ± 1.1	< 5.00		
Mg (meq 100 g^{-1})	2.6 ± 0.2	12.9 ± 0.7		
Ca (meq 100 g^{-1})	29.5 ± 2.1	26.1 ± 1.4		
Na (meq 100 g^{-1})	0.3 ± 0.1	1.4 ± 0.1		
Mn (meq 100 g^{-1})	19.7 ± 3.4	65.9 ± 9.7		
Fe (meq 100 g^{-1})	6.1 ± 0.5	130 ± 17.0		
Total N %	0.07 ± 0.0	5.22 ± 0.2		
Mineral N (μg g^{-1}DW)	18.7 ± 2.5	513.3 ± 32.2		
P olsen (μg g^{-1}DW)	<9.8	586 ± 17.8		
K (μg g^{-1}DW)	271 ± 13.4	920 ± 21.1		
OM total %	0.98 ± 0.1	83.2 ± 5.4		
Ratio C:N	–	9.27		
pH water (2:5)	8.2 ± 0.3	6.1 ± 0.1		
EC (dS m^{-1})	0.10 ± 0.01	2.83 ± 0.23		
Clay %	23.5 ± 0.6	–		
Loam %	46.9 ± 0.7	–		
Sand %	29.6 ± 0.4	–		

[a] French regulatory limits (08/01/98) for concentration of TMs in SS for agricultural use.