The effect of incorporating biosolids on soil quality after cotton crop management

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Abstract A pilot sewage sludge (also known as "biosolids", BS) application of 7,000 kg/ha (dry weight) was performed in the area of Lamia prefecture, central Greece, in two fields cultivated with Cotton. BS was very rich in organic matter (75%) and had high concentrations of nutrients, with all heavy metals below the limits set for use in agricultural soils. Soil samplings before BS applications and after cotton cultivation for 1 and 2 years for the first and second pilot respectively, revealed the positive effect of BS use to soil quality. Soil organic matter increased from 0.9 and 0.8% to 3.8 and 3.3% respectively. Soil P content increased only to the pilot sampled one year after BS applications. BS increased significant the concentration of Mg, Mn and Fe at both pilots farms. Heavy metals in the soil was kept in acceptable levels at both pilots after BS use except Cr that exceeds the upper limits set by Common Ministerial Decision at both pilots. In conclusion, the results of the study underline the positive effect of BS in soil quality if we could control toxic heavy metals concentrations in the soils by analyzing and organizing proper application rates for each soil case separately.

Keywords: Sewage Sludge, soil organic matter, heavy metals, soil quality

1. Introduction

The use of biosolids in agriculture constitutes a considerable incentive given the fertilising and soil conditioning properties of sludge (Giannakopoulos *et al.*, 2017). The uncontrolled disposal of BS onto the land however may contaminate surface and ground waters, which impacts upon the biosystem balance with negative impacts on the ecosystem (Sharma *et al.*, 2017). The land application of BS has nowadays acquired popularity in view of its potential to recycle valuable components of BS, such as organic matter, N, P, and other plant nutrients (Martinez *et al.*, 2002; Singh and Agrawal, 2009) and especially for soils that are deficient in organic matter such as the Mediterranean soils characterized by high organic matter mineralization rates (Koutroubas *et al.*, 2014). BS applications also alter the physicochemical and biological properties of soils, leading to decrease of soil pH (Epstein *et al.*, 1976; Singh *et al.*, 2011) and increase in electrical conductivity (Lloret *et al.*, 2016). Agricultural soils treated with organic wastes exhibited significant improvement in soil properties such as enhanced storage capacity for soil organic carbon, water-holding capacity, formation of stable aggregates, cation exchange capacity and soil aeration (Mattana *et al.*, 2014). Moreover, Parat *et al.*, (2007) revealed that repeated BS application had significant effects on the soil's physical properties due to the positive effect on macro-aggregates formation.
The purpose of this study was to determine the temporal evolution of soil properties following the incorporation of BS in two cotton cultivation fields exploring potential risk of heavy metal contamination and overall effect on soil quality.

2. Materials and methods

2.1. Study area

A pilot BS application was performed in the area of Lamia prefecture, central Greece, in two fields cultivated with Cotton (*Gossypium hirsutum L,)*, Moschochori (38° 49′50′′N, 22°27′36′′E) and Heraclia (38°48′37′′ N, 22°27′10′′E). BS was collected from the wastewater treatment plant of the city of Lamia. Lamia is a city in central Greece (population 52,000), which has a unit of municipal sewage sludge procession, with a daily mean waste supply about 11,500 m^3. The waste procession unit serves a total of 66,700 citizens from Lamia and other nearby areas, and has a system of active sewage sludge process operating in two aeration tanks for humidity reduction.
BS samples were analyzed according to the Standard Methods for the Examination of Water and Wastewater of the American Public Health Association and AWWA (APHA, 2012). BS had very high concentrations of organic matter, and essential nutrient for cotton cultivations, while all heavy metal concentrations were significant below the upper limits of BS applications in agricultural soils set by the Common Ministerial Decision 80568/4225/1991 (Table 1). BS contained very high concentrations of

inorganic nitrogen forms of NH_4-N and NO_3-N suggesting special caution for an appropriate application rate to minimize the risk of waters contaminations by inorganic nitrogen. It is widely accepted that large amounts of nitrates can be leached from BS applications under certain circumstances (Shepherd, 1996). BS was applied in both pilot fields at a rate of 7,000kg/ha (dry matter).

Table 1. Physicochemical properties of BS used and heavy metals limited values of BS for use in agricultural soils

Property	**BS**	**[PTE]$_{max}$**
pH	7.95 ± 0.01	6.5-8.7
Moisture,%	67.5 ± 0.5	40-55
EC (μS/cm)	(1,686-3,400) ± 0.001	
Org, matter, %	75.85 ± 0.05	
Total N, %	1.8 ± 0.1	
Total P, %	0.35 ± 0.02	
B, mg/kg	2.05 ± 0.05	
Ca, %	10.15 ± 0.05	
NH_4 - N	250 ± 5	
NH_3-N	91 ± 2	
Ni,mg/kg	50.5 ± 0.5	300-400
Zn, mg/kg	355 ± 5	2,500-4,000
Cd, mg/kg	1.35 ± 0.05	20-40
Cu, mg/kg	300.0 ± 0.5	1,000-1,750
Pb, mg/kg	20.0 ± 0.1	750-1,200
Hg, mg/kg	0.55 ± 0.05	16-25
Cr, mg/kg	25.5 ± 0.1	500
Mn, mg/kg	60 ± 2	
Fe, mg/kg	3.5 ± 0.5	
As, mg/kg	< 1	
Co, mg/kg	< 2	
Mo, mg/kg	< 1	

[PTE]max=maximum permissible concentration of potentially toxic elements in biosolid batches used for agricultural purposes in the EU (Giannakopoulos *et al.*, 2021)

Soil samplings before BS applications in the 2 pilots was performed on May 2017 at Moschochori pilot and August 2018 at Heraclia pilot. The second soil sampling was performed on May 2020 for the both pilots. Before the second samplings at Moschochori the field was cultivated for 2 growing seasons with cotton and the last winter with wheats, and at Heraclia with cotton and wheats in the following winter. At both pilots pre-plant fertilization before cotton sowing was performed with 225kg/ha of a N-P-K:11-22-22 type fertilizer. Soil samplings were conducted from a depth of 0-30 cm. At both pilots samples were collected randomly in the center of the field. Eight to ten (8-10) subsamples were collected and then aggregated to a composite sample. Three composite samples per pilot field were collected before and after BS applications. The soil samples were air dried, crushed and sieved with a 2 mm sieve and soil physicochemical analysis was performed according to Allison *et al*., (1965a; 1965b), the essential nutrients such as Nitrogen, Phosphorus, and Potassium were determined following Hutchinson and Meema (1987) methods. Total metal (Cd, Pb, and Zn) concentrations were analyzed according to the the EPA 3050 method (determination of pseudo-total heavy metals in soil samples) using an atomic absorption spectrophotometer (Thermo Scientific, iCE 3000 Series) according to Hutchinson and Meema's (1987). Statistical analysis performed with SPSS (ver.11 for windows). T test was used to compare soil properties before and after disposal.

3. Results and discussion

In the end of monitoring period soil pH were lower at both pilot farms with greater reduction to observed at Moschochori. Similar results on soil pH reduction and electrical conductivity were obtained after application of BS by Evangelou *et al*., (2020) in soils of the same region and by Tsadilas *et al*., (2014) in other type of soils in Greece. PH reduction after BS applications could be attributed to the soil organic matter decomposition that produces a variety of acid compounds as described by Carrido *et al*. (2005). BS in this study contains very high concentration of organic matter (75%), significantly higher than other BS that have been applied in similar studies. Evangelou *et al*. (2020) reports organic matter concentrations in BS of 45 %, while Shahen and Tsadilas (2013) concentrations up to 55%. As a result of this very high organic matter concentration in BS, the soil organic matter content significantly increased by the application of BS at both pilots from 0.9% and 0.8% to 3.8% and 3.3% for Moscochori and Heraclia respectively. This soil organic matter increase is significantly greater in regards to other studies, and is considered very important for over all soil quality improvement as soil organic matter is the most important soil quality index that influence a number of physical chemical and biological soil properties (Nieder and Biendi, 2008). Especially in Mediterranean environments where most agricultural soils characterized by low soil organic matter concentrations, BS applications in agricultural lands could be an effective way for the overall soil quality improvement.

Lower increases of soil organic matter by BS application was found by other researchers (Evangelou *et al*. 2020, Shaheen and Tsadilas 2013). Although soil available P concentrations have been reported to increase significantly by the BS applications (Guedes *et al*., 2014; Shaheen *et al*., 2012), in this study this happened only to Heraclia pilot, probably because in Moshchochori pilot P from BS utilized by the cultivated plants two years after the applications. Especially for P, that is almost exclusively obtained from phosphate rock, which is not a renewable source and it is expected to be depleted in about 100 years (Smil 2000), BS has to be treated as a precious P source. No influence was recorded by BS application on K at both pilots. Evangelou *et al*. (2020) and Tsadilas *et al*. (2014), have also reported no significant difference of K soil concentrations after BS application to agricultural soils. Ca and Na significant decreased by BS applications at both pilots (Table 2).

BS increased significant the concentration of Mg, Mn and Fe at both pilots. Especially the Mg concentrations increased from 78 to 257 and from 93 to 972 mg/kg at Moschochori and Heraclia respectively indicating the need of understanding Mg availability after applications of this type of BS in order to avoid any risk of potential negative effects on plant nutrition and soil quality.

Table 2. Influence of BS application on selected soil parameters. The values represent the mean of three determinations (N per mean = 3) ± standard deviation from the mean. Different letters in parameter values of each site indicate significant difference according to t-test for $p<0.05$

Parameter	**Moschochori Pilot**		**Herakleia Pilot**	
	Before disposal	After disposal	Before disposal	After disposal
Sand,%	37.0 ± 0.5^a	33.6 ± 0.5^a	36.0 ± 0.5^a	36.8 ± 0.5^a
Clay,%	46.0 ± 0.5^a	26.7 ± 0.5^a	42.0 ± 0.5^a	30.6 ± 0.5^a
Silt%	17.0 ± 0.5^a	39.7 ± 0.5^a	22.0 ± 0.5^a	32.6 ± 0.5^a
EC,	0.43 ± 0.10^b	0.21 ± 0.08^a	0.12 ± 0.4^b	0.14 ± 0.03^c
pH	8.0 ± 0.1^a	7.2 ± 0.1^a	7.7 ± 0.1^a	7.4 ± 0.1^a
Soil org. ma,%	0.9 ± 0.2^b	3.8 ± 0.4^a	0.8 ± 0.2^b	3.3 ± 0.2^c
Total $CaCO_3$	18.4 ± 0.6^a	4.0 ± 0.2^b	2.1 ± 0.3^a	12.6 ± 0.2^b
P, mg/kg	19.0 ± 0.5^a	12.0 ± 0.5^a	10.0 ± 0.3^a	17.0 ± 0.6^b
K,mg/kg	140.0 ± 0.5a	153.0 ± 0.4^c	110.0 ± 0.5^a	151.0 ± 0.6^c
Na,mg/kg	190.0 ± 0.8^a	48.0 ± 0.2^c	160.0 ± 0.7^a	17.0 ± 0.2^b
Ca,mg/kg	140.0 ± 0.2^a	18.4 ± 0.1^b	110.0 ± 0.8^a	55.7 ± 0.5^c
Mg,mg/kg	78.0 ± 0.3^a	257.0 ± 0.9^b	93.0 ± 0.5a	972.0 ± 0.5^b
Mn,mg/kg	1.1 ± 0.2^a	98.0 ± 0.6^b	1.0 ± 0.2^b	73.0 ± 0.4^a
Fe,mg/kg	8.9 ± 0.4^a	59.0 ± 0.3^c	7.2 ± 0.4^c	57.0 ± 0.3^b

All heavy studied metal concentrations, except Cr were within the desirable values imposed by the Common Ministerial Decision 80568/4225/1991. Cu tended to increase after BS application, probably due to the organic matter increase. Organic matter content and Cu have been reported by several authors to positively correlate (Siplova *et al*., 2014; Tsadilas *et al*., 2014). Soil Cu after BS applications has been also reported by Evangelou *et al*. 2020 in the study area. Ni, and Zn also increased after BS applications at both pilots.
Cr concentrations however increased significant at levels above the upper levels set by Common Ministerial Decision 80568/4225/1991, although the Cr concentration of BS was not very high and below the allowed limits for this element (Table 3).

Table 3. Influence of BS application on heavy metals soil concentrations. The values represent the mean of three determinations (N per mean = 3) ± standard deviation from the mean. Different letters in parameter values of each site indicate significant difference according to t-test for $p<0.05$

Parameter	Moschochori Pilot		Herakleia Pilot		Limited values of Heavy metals concentrations in soils*
	Before disposal	After disposal	Before disposal	After disposal	
Cd, mg/kg	0.8 ± 0.1^a	< 0.13	0.2 ± 0.1^a	0.14 ± 0.02^a	1 to 3
Cu, mg/kg	19.0 ± 0.2^a	24.0 ± 0.2^b	21.0 ± 0.1^a	32.0 ± 0.3^b	50 to 140
Ni, mg/kg	59.0 ± 0.2^a	49.0 ± 0.4^c	29.0 ± 0.3^a	46.0 ± 0.5^b	30 to 75
Pb, mg/kg	19.0 ± 0.1^a	10.0 ± 0.3^b	14.0 ± 0.4^b	8.3 ± 0.4^c	50 to 300
Zn, mg/kg	36.0 ± 0.3^a	62.0 ± 0.2^a	36.0 ± 0.2^a	59.0 ± 0.3^a	150 to 300
Hg, mg/kg	< 0.1	< 0.5	< 0.1	0.93 ± 0.04^b	1 to 1.5
Cr, mg/kg	2.2 ± 0.2^a	53.0 ± 0.5^c	2.2 ± 0.2^a	220.0 ± 0.8^c	1 to 3

*Common Ministerial Decision 80568/4225/1991

Conclusions

From the results of this study it is concluded that BS application at 7000kg/ha affects positively soil quality in the area of central Greece as soil organic matter increase, soil pH decreases and many of essential nutrients increases. Available forms of Zn and Cu concentrations tend to increase, but soil Cr increased above statutory limits. It seems therefore that if we use BS in the proper amounts, in order to keep the toxic heavy metal at acceptable levels, we could get benefits from their application to soil.

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