Sewage Sludge application on cotton cultivations: Soil properties interactions

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Abstract Application of sewage sludge (SS) to agricultural soils is a current practice in EU. European legislation permits its use in agriculture when concentrations of metals in soil do not exceed the maximum permissible limits. In a soil classified as Typic Xerochrepts located in Lamia area, central Greece, a field experiment was conducted for two consecutive years, to study the influence of municipal SS application on cotton yield and soil properties. The experimental design was complete randomized blocks with four treatments: 1. Control, 2.inorganic fertilization, 3.Sewage sludge 6000 dry SS kg/ha, and 4.Sewage Sludge10000kg dry SS/ha, each replicated 4 times. The results showed that SS application on both rates, and inorganic fertilization did not cause significant difference in cotton yield. Soil properties, at the end of the second year of SS application, significantly affected by SS application to a positive direction i.e. pH decreased slightly, organic matter increased, available phosphorus increased significantly, as well as total nitrogen concentration, exchangeable potassium and available zinc. The potentially toxic elements like lead, chromium, and nickel were not significantly affected by SS application for both rates. Available Cu and Zn concentrations, however, increased significantly at both SS applications rates compared to the control.

Keywords: Sewage sludge, cotton, fertilization, heavy metals

1. Introduction

Worldwide, the management of the produced municipal sewage sludge (SS) is an issue of major importance. The quantity of produced waste is continuously increasing and it is required to find ways for environmentally effective and economically feasible management.

In Greece, the usual practice which was being followed for this purpose included the deposition of sludge in landfills, creating serious environmental and economic problems in sewage treatment establishments, as new areas were continually required for the deposition of these wastes. However, recently, this practice of deposition to landfills or discharge into the sea was banned by the European Union, creating thus a need to find alternative methods of municipal sewage sludge management (Kelessidis and Stasinakis, 2012).

Another rather interesting management practice, which is commonly used in other countries, is drying and incineration of the sludge and its use in agriculture. Since SS contains components which are useful or necessary for plant growth and can improve soil properties, its use as a fertilizer or/and as a soil amendment can be both environmentally and economically beneficial (Kacprzak *et al*., 2017, Tsadilas *et al*., 2014). These components are a number of nutrients such as nitrogen (N), phosphorus (P) and metals (iron-Fe, Zn-zinc, copper-Cu), as well as organic matter, which substantially improves soil quality. Nowadays, at European level, about 40% of the produced SS is directed to agriculture (Smith, 1996), while in Greece this practice has just recently started to be applied.

However, since SS often contains high concentrations of heavy metals such as nickel (Ni), lead (Pb) and cadmium (Cd), its use in agriculture for consecutive years requires special caution because there is a risk of phytotoxicity symptoms occurrence due to metals accumulation, but also a possibility of metals' transfer to the food chain and a threat to human and animal health (McGrath and Cegarra, 1992). For this reason, regulations in the form of legal compliances have been enacted for the use of SS application in agriculture.

In 2013, the Municipal Water and Sewerage Company of Lamia (DEYAL) in central Greece, in the aims of municipal waste management, decided to investigate the possibility of the use of sewage sludge in the agriculture of the area. For this purpose, experiments were conducted by the Institute of Soil Mapping and Classification (Larisa, Greece) in experimental fields, but also in local farms, as well, according to the regulations 86/278 of the European Union (Fytili and Zabaniotou, 2008), which in Greece is the respective CMD 80568/4225/91. Experiments were conducted for two consecutive years (2013-2014), in the same cotton (*Gossypium hirsutum* L.) cultivated field.The aim of this study was to investigate the effect of municipal sewage sludge application on cotton yield and characteristics, as well as on soil properties.

2 Materials and Methods

Table 1. Selected properties of the Soil and the SS used in the study

Property	Soil	SS
pH, H_2O (1:1)	8,07	6,4
EC, µS/cm	376	3400
SOM , %	1,30	45
Total N (Kjeldahl), %.	0,09	5,9
P (Olsen), mg/kg	2,50	600
Ni, mg/kg	355	57
Cr, mg/kg	274.67	73
Pb, mg/kg	13.00	42
Hg, μg/kg	< 20	690
Cu ,mg/kg	32.33	411
Cd, mg/kg	< 0.78	<0,78

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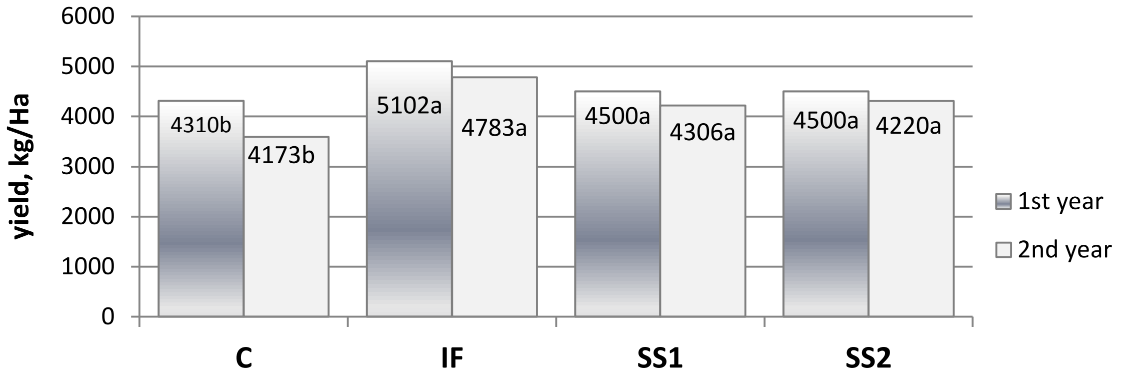

Figure 1. Influence of SS application on seed cotton yield. Numbers in the columns with the same letter do not differ significantly according to LSD test at the probability level of $p<0.05$.

Table 2. Influence of two years of SS application on soil properties

	Control	IF	SS1	SS2
pH	8,55 a*	8,50ab	8,32 b	8,25ab
EC, μS/cm	523,7a	476,5 a	718,7 a	838,0 a
SOM, %	1,47 a	1,45 a	1,62 a	1,60a
P,mg/kg	7,07b	8,8 b	23,3 a	19,5 a
N total, %	0,104 a	0,107 a	0,110 a	0,123 a
K, cmol+/kg	0,41 a	0,40 a	0,41a	0,44 a
Mg,cmol+/kg	9,65 a	9,60 a	10,05 a	8,77 a
Cu(DTPA), mg/kg	0,83b	1,22 a	1,40 a	1,83 a
Zn(DTPA), mg/kg	0,42c	0,30c	1,30b	2,05 a
B, mg/kg	0,77 a	0,77a	0,85a	0,82a
Pb, mg/kg	7.02 a	7.50 a	6.90 a	8.47 a
Cu, mg/kg	31.00 a	32.00 a	33.00 a	35.50 a
Cr, mg/kg	246.7 a	246.7 a	249.2 a	251.0 a
Ni, mg/kg	337.2 a	337.7 a	333.5 a	335.2 a
NO_3-N,mg/kg	3,26b	4,12b	28,75ab	51,00a

*Different letter in the same row indicate significant difference according to LSD test for $p<0.5$

A field experiment was conducted in the area of Lamia prefecture, central Greece, with Cotton (*Gossypium hirsutum L.)* grown on a soil classified as Typic Xerochrepts with 30% Clay, 39% Silt 39% Sand, and 10% $CaCO_3$ that was not cultivated the last 5 years. SS 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 supplies about 11.500m^3. The waste procession unit serves a total of 66.700 citizens from Lamia and other smaller nearby areas, and has a system of active sewage sludge process which takes place in two aeration tanks for humidity reduction. The basic characteristics of the soil and the amendments used are shown in Table 1. The experimental design was complete randomized blocks with the following treatments: control (C), included only soil without inorganic fertilizer and SS; Inorganic Fertilization (IF), included fertilization with 6 units of N; SS1 included SS at a rate of 6000kg/ha dry and SS2 included 10000kg/ha dry. Each treatment was replicated four times. The dimensions of the plots were 10m ×5 m. The fertilizer was composite in the form of 11–15–15 and it was incorporated into the soil in a depth 10 cm the same day of SS incorporation, 10 days before cotton sowing. In March before sowing, as well as at the end of September, soil samplings were conducted from a depth of 0–30 cm. The samples were air dried, crushed and sieved with a 2 mm sieve and analyzed for the properties referred below. PH and electrical conductivity in a suspension 1:1 water:-soil, exchangeable K and Mg with the ammonium acetate

method, organic matter with the wet oxidation procedure with the potassium dichromate method, available P with the sodium bicarbonate method, total N with the Kjeldahl method, available B with the hot calcium chloride extraction method, available metals with the DTPA method, and total heavy metals were determined according to the procedures referred by Page *et al.* (1982). SS were analyzed by the same methods used for soils (Table 1). Cotton harvest was performed at the end of September by hand and seed cotton samples were weighted for yield determinations. Statistical analysis was performed by SPSS and includes one way analysis of variance and LSD post hoc test.

2. .Results and discussion

Application of SS at both rates increased cotton yield compared to Control in a similar way to inorganic fertilizers, at both years of applications. Control treatments however revealed high yields, which could be attributed to high soil fertility, because of the non-cultivation for the last 5 years. From the results it is obvious that SS may replace inorganic fertilization without reducing cotton yield. The different rates of SS applications have not any significant difference suggesting that 6000kg SS dry/ ha is satisfactory for the cotton cultivation in the study area. Similar results of the influence of SS application on cotton yield were reported by Antoniadis *et al*, 2010 and Tsadilas *et al*, 2014. SS significantly influenced most of the soil properties studied after 2 years of applications (Table 2). Soil pH tended to decrease due to inorganic fertilizer application but the decrease was more profound by the SS application. PH decreased from 8,55 to 8,25 for SS2 treatment. As expected, electrical conductivity was significantly increased in all SS treatments included, due to their high soluble salts content. Most of EC increase could be attributed to soil NO_3-N increase with the SS application (Figure 2).

This increase of EC, however, is not at harmful level

for crops like cotton (Bernstein 1955). Similar results on soil pH and electrical conductivity were obtained after application of SS by Tsadilas *et al*. (2014). Organic matter content significantly increased by the application of SS from 1,47% in the control up to 1,62 % and 1,60 % in the treatment SS1 and SS2, respectively.

This contribution of SS is considered important especially in Mediterranean environments where soils are poor in organic matter. Similar results were found for the influence of SS on soil organic matter content by other researchers (Shaheen andTsadilas 2013). A similar trend to organic matter content was recorded also for total N content, since they are closely related. From 0,101 % in the C it was increased to 0,110 % in the treatment SS1 and to 0,123% in the SS2. Another noteworthy effect of the application of SS was found for soil P.It is noticed that phosphate 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). Consequently, to avoid P shortage, any source of P like the SS (Guedes *et al*. 2014), should be utilized. In the present study it was found that application of SS increased available soil P from 7,07 mg/kg soil up to about 20, i.e., almost three times more than in C (Table 2). Similar results on the influence of SS on the available soil P were reported by Shaheen *et al*.(2012). No other influence was recorded by SS application on K or Mg. Tsadilas *et al*, 2014, has also reported no significant influence of K and Mg soil concentrations after SS application to agricultural soils. SS increased available soil B. In the treatments without SS, (control and IF) available soil B increased from 0,77 mg/kg to 0,85 and 0,82mg/kg in the treatment SS1 and SS2 respectively. $Cu_{(DTPA)}$ tended to increase after SS application, probably due to the organic matter increase. Organic matter content and $Cu_{(DTPA)}$ have been reported by several authors to positively correlate (Siplova *et al*., 2014, Tsadilas *et al*., 2014). Zinc also significantly increased in the treatments of SS applications, from 0.42mg/kg $Zn(_{DTPA})$ in the control treatment to 2,05kg/kg when 10000kg/ha SS were applied. Soil concentrations of Pb, Cu, Cr, and Ni did not affected significant by SS applications in both rates. Contrary, mineral nitrogen was increased significantly by SS applications. NO_3-N increased by 3,26mg/kg to the control to 51mg/kg by the application of 10000kg/ha SS, in the end of the cultivation period. Such mineral nitrogen concentrations could lead to nitrogen leaching below the active soil layer if there is no biomass to utilize it. It is widely accepted that large amounts of nitrates can be leached from SS applications under certain circumstances (Shepherd, 1996). Special caution has to be given in the application rate of sewage sludge to land that must be determined on the basis of crop N requirement to avoid potential hazards associated with excessive NO_3-N in soil (Navarro Pedre~no *et al*., 1996), taking in to account mineralization rates of organic nitrogen in the SS.

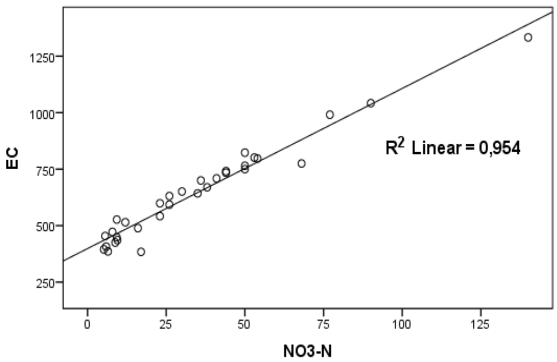

Figure 2. Relationship of Soil Electrical Conductivity and soil NO_3-N.

3. Conclusions

From the results of this study it is concluded that SS application at 6000kg/ha affects positively cotton yield in the area of central Greece. Soil organic matter increases, soil pH decreases and electrical conductivity increases but at levels no harmful to cotton crops. In addition, significant increase is obtained in available soil P and B. Available forms of Zn and Cu concentrations tend to increase, and available mineral nitrogen also increases It seems therefore that if we use SS in the proper amounts, so that to keep the toxic heavy metal at acceptable levels, and control nitrogen mineralization, we could

get benefits from their application to soil.

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