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Municipal sewage sludge application on cotton cultivations. Effect on yields soil chemical properties and heavy metal concentrations

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Abstract

Application of municipal sewage sludge (MSS) 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 order to study the influence of MSS on cotton yield and soil properties, a filed experiment was conducted in a soil classified as Typic Xerochrepts located in Lamia area, central Greece, for two consecutive years. The experimental design was complete randomized blocks with four treatments: Control (C), inorganic fertilization (IF), application of 6000 dry kg ha^{-1} MSS, and 10000 dry SS kg ha^{-1}, each replicated 4 times. The results showed that MSS application in both rates, increased significantly cotton yield compared to control equally to inorganic fertilization. Soil properties, at the end of the second year of MSS application, were significantly affected by MSS application in a positive way i.e. pH decreased slightly, but organic matter content, available phosphorus, total nitrogen concentrations exchangeable potassium and available zinc and copper increased significantly. The potentially toxic elements lead, chromium, and nickel were not significantly affected by MSS application in both application rates compared to control.

Keywords: Municipal sewage sludge, cotton, fertilization, organic matter, heavy metals.

1. Introduction

Worldwide, the management of the produced municipal sewage sludge (MSS) 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 than Greece countries, is drying and incinerating of the sludge and then its use in agriculture. Since MSS contains components useful or necessary for plant growth and can improve soil properties, like soil organic matter concentrations which substantially improves soil quality, 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). MSS contains significant quantities of macronutrients as phosphorus nitrogen, and micro nutrients (Fe, Mn, Zn, B, Cu, Mo, Co, and Se). These nutrients can be utilized for the needs of cultivated plants, decreasing thus of chemical fertilizers needs. Moreover, MSS application has a positive effect on physical soil properties. Tsadilas *et al.* (2005) reported for example a significant increase of available water capacity, wilting point, final infiltration rate, and soil aggregate stability with MSS application on cotton cultivation. Twenty years ago, at European level, about 40% of the produced MSS was directed to agriculture (Smith, 1996), while in Greece this practice has recently started to be adopted.

Municipal sewage sludge however, contains several heavy metal contaminants in trace amounts and its use in agriculture for consecutive years requires special caution because of the a risk due to heavy metal accumulation of causing phytotoxicity and heavy metals transferring into food chain threating thus human and animal health (McGrath and Cegarra, 1992). Certain heavy metals, such as copper (Cu), zinc (Zn) and nickel (Ni) can cause toxicity to plants. Cadmium (Cd) can cause important hazards to public health, due to its low soil absorbability and the fact that it is possible to have its accumulation in plant mass, resulting to its entry in to the food chain (Alloway, 1995). For this reason heavy metals are limited by threshold values set out in regulations, ensuring that MSS can be used safely in agriculture (EEC, 1986).

In 2013, the Municipal Water and Sewerage Company of Lamia in central Greece, in decided to investigate the possibility of the use of municipal sewage sludge by encouraging the farmers to apply it in agricultural crops grown in 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, according to the regulations 86/278 of the European Union (EEC, 1986; Fytili and Zabaniotou, 2008), enacted in Greece through the respective Common Ministerial Decision 80568/4225/91. The aim of this study was to investigate the effect of MSS application on cotton yield and soil properties with emphasis on heavy metal concentrations with an experiment conducted for two consecutive years, in the same cotton (Gossypium hirsutum L.) cultivated field.

2. Materials and methods

A field experiment was conducted in the area of Lamia prefecture, central Greece. The soil was calcareous clay loam ($CaCO_3$ 10%, clay 30%, silt 39%, and sand 39%) Typic Xerochrept, with soil organic matter 1,30%. The field was divided into 50 m^2 plots (5 m × 10 m each) with 2 m spacing between them. There were four different sludge treatments: Two rates of sewage sludge (6000 and 10000 kg dry matter ha^{-1}, referred to as “SS1” and “SS2”, respectively, thereafter) one with inorganic fertilizer with 150 kgN ha^{-1} and 70 kg P ha^{-1} referred to as “IF” and one unamended “control” (no MSS, no fertilizer). These rates of application were repeated every year for 2 years 2013 and 2014 in the same plots. In this complete randomized block experimental design with four replicates, resulted in a total of 16 plots. Municipal sewage sludge was obtained from the sewage 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 processing, with a daily mean waste supplies of about 11.500 m^3. The waste processing unit serves a total of 66.700 citizens from Lamia and other smaller nearby areas, and has a system of active sewage sludge processing which takes place in two aeration tanks for humidity reduction. The moisture content was pre-determined by heating at 105 °C overnight, in order to apply sewage sludge on a dry matter basis. Sludge was applied uniformly manually and incorporated to a depth of 15 cm by rotovation 2 weeks before sowing, the same day of inorganic fertilizer application, in April each year. Cotton seeds, selected so that they may have the characteristics of early maturity and high yield potential, were planted at a rate of 22 kg ha^{-1}. During the growing season the field was irrigated with ‘‘travelling gun’’c. 4000 m^3 water ha^{-1}. Leaf samples were taken at full bloom stage (end of July) from the middle rows of each plot. At the harvest day composite soil samples (obtained from five different sub-samples within each plot) were also taken from a depth of 0–25 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). MSS were analyzed by the same methods used for soils. Cotton harvest was performed at the end of September by hand and seed cotton samples were weighted for yield determinations. Statistical analysis performed by SPSS included one way analysis of variance and LSD post hoc test.

3. Results and discussion

The basic characteristics of the soil and the amendments used are shown in Table 1. In comparison to unamended soil, MSS is more acidic with significant higher concentrations of organic, matter, total nitrogen, and phosphorus. Electrical conductivity is almost 10 times higher than soil. Although most commonly, the background levels of heavy metals in soils are often lower than the heavy metals present in sludge (Sloan *et al.*, 1998), in this study unamended soil contains higher Ni, Cr, and Cu concentrations than MSS used. Moreover Cd concentrations were below detectable levels (Table 1). Application of MSS at both rates increased cotton yield compared to control in a similar way to inorganic fertilization (IF), at both years of applications although control treatments revealed high yields, which could be attributed to high soil fertility, because the soil was not cultivated for the last 5 years. From the results it is obvious that MSS may replace inorganic fertilization without reducing cotton yield. The different rates of MSS applications have not any significant difference suggesting that the lowest rate of 6000 kg^{-1} SS dry is satisfactory for the cotton cultivation in the study area (Figure 1). Similar results of the influence of MSS application on cotton yield in Greece were reported by Antoniadis *et al.* (2010) and Tsadilas *et al.* (2014). MSS 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 MSS application. pH decreased from 8,55 to 8,25 for SS2 treatment. Organic matter content significantly increased by the application of MSS from 1,47% in the control up to 1,62 % and 1,60 % in the treatment SS1 and SS2, respectively. This contribution of MSS is considered important particularly for Mediterranean environments where soils are very poor in organic matter. Similar results were found for the influence of MSS on soil organic matter content by other researchers (Shaheen and Tsadilas, 2013). A similar trend to organic matter content was recorded also for total N content, obviously because they are closely related. From 0,101 % in the control, it increased to 0,110 % in the treatment SS1 and to 0,123% in the SS2. Another noteworthy effect of the application of MSS 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 MSS (Guedes *et al.*, 2014), should be utilized. In the present study it was found that application of MSS increased available soil P from 7,07 mg/kg soil up to about 20, i.e., almost three times more than in control treatment (Table 2). Similar results on the influence of MSS on the available soil P were reported by Shaheen *et al.* (2012). MSS increased also available soil B from 0,77 mg/kg to 0,85 and 0,82 mg/kg in the treatment SS1 and SS2, respectively. No significant influence, however, was recorded by MSS application on K or Mg. Tsadilas *et al.* (2014), has also reported no significant influence of K and Mg soil concentrations after MSS application to agricultural soils. 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 MSS application as suggested from the significant correlation of soil EC and NO_3-N (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 MSS by Tsadilas *et al.* (2014). Mineral nitrogen increased significantly by SS applications. NO_3-N increased by 3,3 mg/kg in the control to 51 mg/kg in the treatment SS2, at the end of the cultivation period. Such mineral nitrogen concentrations could lead to nitrogen leaching below the active soil layer if there is no plant biomass to utilize it. It is widely accepted that large amounts of nitrates can be leached from MSS applications under certain circumstances (Shepherd, 1996). Special caution has to be given in the application rate of municipal 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 Pedreno *et al.*, 1996), taking in to account mineralization rates of organic nitrogen in the sewage sludge.

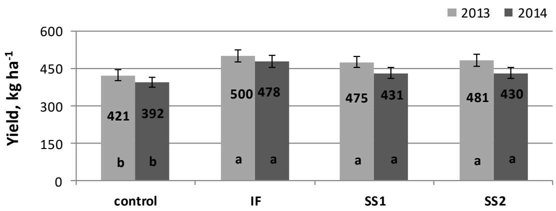

Figure 1. Influence of MSS application on cotton yield (for each year, different letters indicate statistically significant difference at probability level p < 0.05 according to the LSD test)

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

Soil chemical property	Soil	SS	Soil heavy metal conc.	Soil	SS
pH, H_2O (1:1)	8,07	6,4	Ni, mg/kg	355	57
EC, µS/cm	376	3400	Cr, mg/kg	274,6	73
SOM, %	1,30	45	Pb, mg/kg	13,00	42
Total $N_{(Kjeldahl)}$, %.	0,09	5,9	Hg, µg/kg	< 20	690
$P_{(Olsen)}$, mg/kg	2,50	600	Cu, mg/kg	32,33	411
			Cd, mg/kg	< 0,78	<0,78

Table 2. Influence of two years of MSS application on selected soil chemical properties and nutrients

Soil properties	Control	IF	SS1	SS2
pH	8,55 a*	8,50 ab	8,32 b	8,25 ab
EC, µS/cm	524 a	476 a	719 a	838 a
SOM, %	1,47 a	1,45 a	1,62 a	1,60 a
P_{Olsen}, mg/kg	7,07 b	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	0,41 a	0,44 a
Mg, cmol+/kg	9,65 a	9,60 a	10,05 a	8,77 a
B, mg/kg	0,77 a	0,77 a	0,85 a	0,82 a
NO_3-N,mg/kg	3,3 b	4,1 b	28,7 ab	51,0 a

Within rows, means followed by different letters are significantly different according to LSD test at P < 0.05

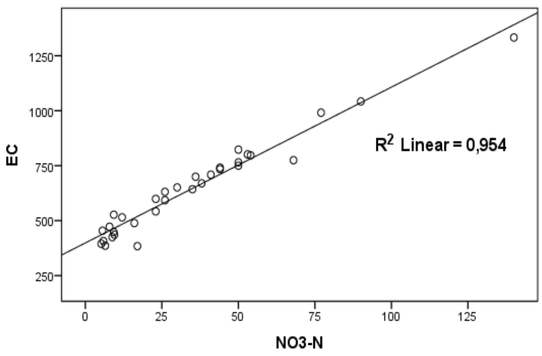

Figure 2. Relationship of soil electrical conductivity and soil NO_3-N

In regards to heavy metals concentrations, $Cu_{(DTPA)}$ tended to increase after MSS application, probably due to the organic matter increase. Organic matter content and $Cu_{(DTPA)}$ have been reported by several authors to be positively correlated (Siplova *et al.*, 2014; Tsadilas *et al.*, 2014). Zinc also significantly increased in the treatments of MSS applications, from 0,42 mg/kg $Zn_{(DTPA)}$ in the control treatment to 2,05 kg/kg in the treatment SS1 which is in agreement with Oliveira and Mattiazzo (2001) findings after 2 years of MSS applications. On the contrary, to Oliveira and Mattiazzo findings for soil Pb, Cu, Cr, and Ni concentrations, those metals did not affected significant by MSS applications in both rates (Table 3).

Table 3. Influence of two years of MSS application on soil heavy metals concentrations

	Control	IF	SS1	SS2
$Cu_{(DTPA)}$, mg/kg	0,83 b**	1,22 a	1,40 a	1,83 a
$Zn_{(DTPA)}$, mg/kg	0,42 c	0,30 c	1,30 b	2,05 a
B, mg/kg	0,77 a	0,77 a	0,85 a	0,82 a
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

**Total concentrations*

***Within rows, means followed by different letters are significantly different according to LSD test at P < 0.05*

However, MSS applications must be treated carefully, as MSS amended soils may change in their ability to sorb heavy metals over time at high metal concentrations (Antoniadis *et al.*, 2007). Basic nutrients in cotton leaves shown in Table 4. Zn concentrations in cotton leaves although they did not show a significant change, a trend of Zn decreases with the high rate of MSS application that had led to higher Zn soil concentration suggest that as sludge rates increase, metal availability is not necessarily increased proportionally, as also similarly stated by Antoniadis *et al.* (2008). MSS application rates increase, enhanced quantities of sludge-added organic matter tend to bind proportionally higher metal concentrations than at lower sludge additions, and this tends to reduce metal availability, although total metal concentrations in soil may increase with added sludge (Luo and Christie, 1998). Moreover the control soil of this study had an alkaline pH value of 8,5 which reduces metal availability by enhancing the ability of soil colloids to sorb cations (Sigh *et al.*, 1995). On the contrary, for values of pH below 6, a disengagement of heavy metals is observed leading to increased absorption by the plants (Selim and Sparks, 2001) and must be seriously considered when SS applications is going to be applied in acidic soils. All other nutrients in cotton leaves suggest that MSS applications in both rates have a similar with inorganic fertilization effect on cotton nutrition (Table 4).

Table 4. Nutrient concentrations in cotton leaves

	Control	IF	SS1	SS2
N, %	3,76 b	4,15 ab	4,21 a	4,31 a
P, mg/kg	3295 a	2899 b	3006 ab	3069 ab
K, %	1,54 a	1,42 a	1,46 a	1,49 a
Mg, %	1,30 a	1,27 a	1,24 a	1,32 a
Zn, mg/kg	91,5 a	89,7 a	152,0 a	140,2 a
B, mg/kg	55,2 a	52,7 a	51,00 a	51,2 a

Within rows, means followed by different letters are significantly different according to LSD test at P < 0.05

4. Conclusions

From the results of this study it is concluded that MSS application at 6000 dry kg ha^{-1} 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 and nitrogen concentrations tend to increase. Total heavy metal concentrations were not significantly increased particularly Ni and Cr which were quite lower in municipal sewage sludge used compared to soil. It seems therefore that if we use MSS 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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