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AGRICULTURAL UTILIZATION OF SEWAGE SLUDGE - APPLICATION TO WHEAT

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Abstract

In a soil classified as Typic Xerochrept located in Larissa area, central Greece a field experiment was conducted to study the influence of municipal sewage sludge application on wheat yield and soil quality. The experimental design was complete randomized blocks with five treatments (control, no sewage sludge, no inorganic fertilizers-C; inorganic fertilization, no sewage sludge-IF; sewage sludge application at a rate 10 ton dry SS/ha-SS1; and 15 ton/ha-SS2) each replicated 3 times. Sewage sludge was applied at the middle of November 2009 by using an appropriate spreader. In the treatment with inorganic fertilization the conventional rates of N and P were applied (100 kg N/ha and 80 kg P_2O_5/ha respectively). Sewage sludge and fertilizers were incorporated in a depth 25 cm with ploughing. Wheat (Triticum vulgare, var. Mavragani) showing (180 kg/ha) became ten days after SS application. Wheat germination started 18 days after showing. Wheat was harvested at the middle of June, next year. Soil sampling was carried out at the showing date and at the end of July next year. The results showed that SS application increased wheat yield compared to control (from 3.78 ton/ha to 44.93 and 4.78 ton/ha in the treatments SS1 and SS2 respectively). The treatment included inorganic fertilization obtained the highest yield (5.75 ton/ha). Soil pH decreased significantly (from 8.23 in the C to 8.02 in the treatment SS2). Available P was significantly increased in the treatment SS2 (from 9.7 in C to 16 mg/kg in the SS2) but exchangeable K was not significantly affected. Nitrates concentration after the harvest was higher in the treatment SS2. No significant differences were observed in total concentrations of Zn, Pb, Ni, and Cr. It was concluded that SS application at rates 10 or 15 ton/ha may completely substitute inorganic fertilization.

Key words: Sewage sludge, wheat, soil quality

Introduction

Management of sewage sludge (SS) produced by the municipal wastewater treatment plants is a serious issue for the societies. Among the various alternatives, application to agricultural land seems to be the most effective way of SS management from both economic and environmental point of view. Sewage sludge contains significant amounts of organic matter and a number of essential elements to plant growth. However at the same time SS contains also some potentially toxic substances both organic and inorganic that should be controlled in order to avoid detrimental effects to the environment if SS will be applied to the land. At European Union level about 50 % is disposed, 37% is used in agriculture, 11% is incinerated and the remaining amount is managed in various other beneficial ways (Smith, 1996). For Mediterranean environments, agricultural use of SS besides the benefit of nutrient application to the soils has an additional advantage related to organic matter enrichment of the soils that is at very low level due to several factors including climate, intensive soil cultivation and mismanagement.

To ensure the safe and beneficial use of SS in agriculture the European Union Council has adopted the directive 86/278/EEC on the protection of the environment and in particular the soil when SS is applied in agriculture (EEC, 1986) which was put in force implemented in each EU member as a relevant law. In addition, every country has each own Code of Good Agricultural

Practices through which the rules of the directive are implemented. Concerning the benefits from the agricultural use of SS, it is related mostly to the contained appreciable amount of the basic nutrients nitrogen (N) and phosphorus (P). A typical N and P content of SS is 7.5 and 3.9% respectively from which 15 and 50% respectively are considered available in the first cropping year (Smith, 1996). The availability of N is dependent on the carbon:nitrogen (C:N) ratio. The smaller the value of ratio, the higher the amount of available N. Usually, the amount of P content in SS compared to its N content is higher than that required for balanced nutrition of plants. In general, P requirement of agricultural crops is 10-25% of the N removed by the plants from soil (Cooke, 1982). So, if we estimate the amount of SS required according to the N needs of the plants we would apply considerably higher amount of P needs and we will create environmental problem. Therefore, it is better to estimate the amount of SS based on P rather than N content in order to avoid the risk of nitrate nitrogen leaching. Another important issue that should be taken into account when we apply SS to soil, is the possible harmful effects of the potentially toxic elements contained in SS. Several studies have shown that SS contain appreciable amounts of potentially toxic elements that could be uptaken by the plants (Vigerust and Selmer-Olsen, 1986). These metals may cause toxic effects to plants the sensitivity of which to each metal varies considerably. Davis and Beckett (1978) in experiments with nutrient solutions determined the upper critical concentrations of metals to barley plants above which the yield of biomass production is significantly reduced. From all those referred above, it is obvious that, if the rules imposed for SS utilization are implemented, the use of SS in agriculture may be useful. However, in order this practice to be adopted by the farmers they should become aware about the benefits of the SS use since they are usually very reservative to apply SS in their field. So far, in Greece very small amount of the municipal SS produced by the wastewater treatment plants is used in agriculture, the most important reason being for that the lack of awareness of the farmers about the benefits of the SS utilization. So, the purpose of the present study was to organize an experiment to demonstrate the people the beneficial results of the sound SS utilization in agriculture.

Materials and Methods

In a field located near Larissa, central Greece an experiment was conducted in 2009 with the following characteristics: experimental design complete randomized blocks; treatments: control-C, no sewage sludge (SS), no inorganic fertilizers; inorganic fertilization- (IF), application of 90 kg N/ha; application of 10 ton dry SS/ha-SS1; application of 15 ton dry SS/ha-SS2; replications of each one treatment 3; plot area 0,175 ha, total area of the experiment 2,1 ha; crop wheat (Triticum durum, var. Mavragani); date of showing 11/2/2009. The soil of the experimental field was a Typic Xerochrept, with pH 8,3, and organic matter content 1,2-2,1%. Before showing the soil was cultivated in a depth 25 cm, sewage sludge at the rates referred above was incorporated in the plough depth and after one week the wheat was shown in a quantity of 180 kg/ha. Eighteen days after showing the emergence of the wheat plants was happened regularly in the whole showed area. Inorganic fertilizers (ammonium nitrate) was applied in the soil surface at the middle of next February. The properties of the SS applied, that came from the wastewater treatment plant of the city of Larissa, are shown in Table 1. In the same table the permissible upper of the potentially toxic heavy metals imposed by the EU are referred. Three soil samplings from each one experimental plot were done as follows: the first one just before SS application, the second at the next May and the last one next September about two months after harvest. In the samples of the first sampling the basic soil chemicals properties were determined (i.e. pH and electrical conductivity in an extract soil:water 1:1, exchangeable K^+ (ammonium acetate method), NO_3-N (potassium chloride extraction mathod), available P (sodium bicarbonate extraction method) and the “available” amounts of the metals Pb, Ni, Cd, Cr, Zn, Cu και Fe (DTPA extraction method). In the samples of the second sampling the concentration of NO_3-N was determined to monitor its evolution. Lastly in the third sampling samples, the same determinations were performed as in the samples of the first sampling, to follow the level of heavy metals due to SS application. All the methods used are referred by Page et al. (1982). Wheat harvesting was done in the middle of the next June by an appropriate harvesting machine. Statistical analysis of the results obtained included analysis of variance performed by SPSS statistical package by using the LSD test.

Table 1. Selected properties of the sewage sludge applied (in parenthesis the upper limit values permitted by the legislation, EC 1986)

Property	Value	Property	Value, mg/kg d.w.
Organic carbon, %	28,4	Cr	65,4
Total N, %	5,02	Pb	214 (750-1200)
pH (1:10 SS:water)	6,5	Hg	4,1 (16-25)
Total P, % d.w.	2,6	Cu	264 (1000-1750)
Cd, mg/kg d.w.	1,8 (20-40)	Zn	1369 (2500-4000)
Ni, mg/kg d.w.	32,5 (300-400)	Fe	5153

Results and Discussion

The emergence of weed seeds was started 18 days after showing and completed in few days. It was uniform in the whole experimental area. Later, a better growth compared to control was observed to the treatments received SS or inorganic fertilization, expressed as higher height of the plants and better tillering. The color of the plants in control was lighter green than in all the rest treatments indicating inadequate nitrogen nutrition. In most replications the order of plants height was C<IF<SS1<SS2.

Influence of sewage sludge on wheat yield

Sewage sludge and inorganic fertilizer application increased wheat yield significantly compared to control (Fig. 1). Sewage sludge at both rates resulted in lower yield compared to inorganic fertilization. This was expectable for the first year of SS application since the mineralization of organic matter needs considerable time to release available N compared to inorganic fertilizer that provides available to plants N forms very quickly. In any case it can be claimed that SS may replace inorganic fertilizers. Similar results on the influence of SS on wheat yield was reported by several investigators (Qioing et al., 2012; Motta and Maggiore, 2013)

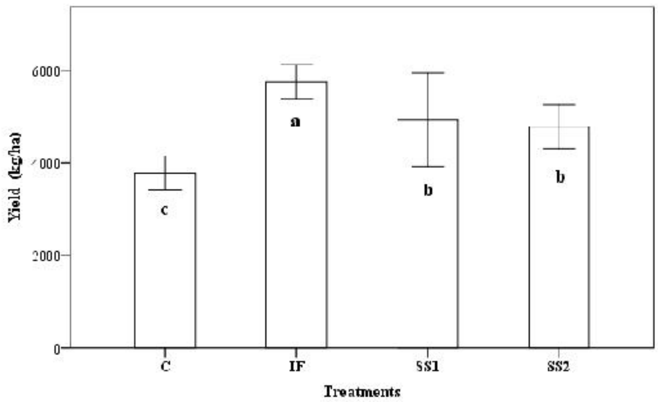

Figure 1. Influence of sewage sludge application on wheat yield (Columns with different letters differ significantly at the probability level p<0.005 according to the LSD test. The bars show the SE of the means)

Influence of sewage sludge on soil properties

Table 2 shows the influence of SS on selected soil properties. Application of SS had limited but significant effect on soil properties studied.

Soil pH decreased by 0.2 units in the treatment received the higher SS rate. Sewage sludge may cause a decrease of soil pH due to organic matter mineralization (Tsadilas et al., 1995).

Organic matter also significantly increased in the treatment received the higher SS rate (SS2). This is important for soils with low organic matter content like the Mediterranean soils.

Available P was significantly affected by the SS application (Table 2, Fig. 2). Before its application the value of available P was around 10 mg/kg in all the experimental plots. After harvesting however, its concentration was found to be significantly higher in the treatments received SS. In the treatment SS1 its was found about 14 mg/kg and in the treatment SS2 16 mg/kg i.e it increased about 60%.

Table 2. Influence of sewage sludge application on selected soil properties and soil heavy metal content

Treatments						
	pH (soil:water 1:1)	Organic matter, % mg/kg	Available P, mg/kg	Exch. K, cmol/kg	Electrical Conductivity, µmhos/cm	NO_3^-, mg/kg
C	8,22a	1,29b	9,66b	0,40a	362	5,7b
IF	8,18a	1,54b	10,33b	0,33a	373	8,3b
SS1	8,15a	1,60ab	13,66ab	0,37a	404	9,7b
SS2	8,02b	1,87a	16,00a	0,36a	477	23,6a
	Cu, mg/kg	Zn, mg/kg	Pb, mg/kg	Cd, mg/kg	Total Ni, mg/kg	Total Cr, mg/kg
C	19,33a	40,66a	17,66a	1,03a	100,3a	97,3a
IF	20,67a	45,00a	18,33a	1,26a	104,0a	111,3a
SS1	20,33a	43,33a	16,33a	1,00a	98,00a	101,3a
SS2	20,66a	45,66a	20,00a	1,16a	106,0a	106,0a

Numbers in the same column followed by different letters differ significantly at probability level p<0.05 according to the LSD test.

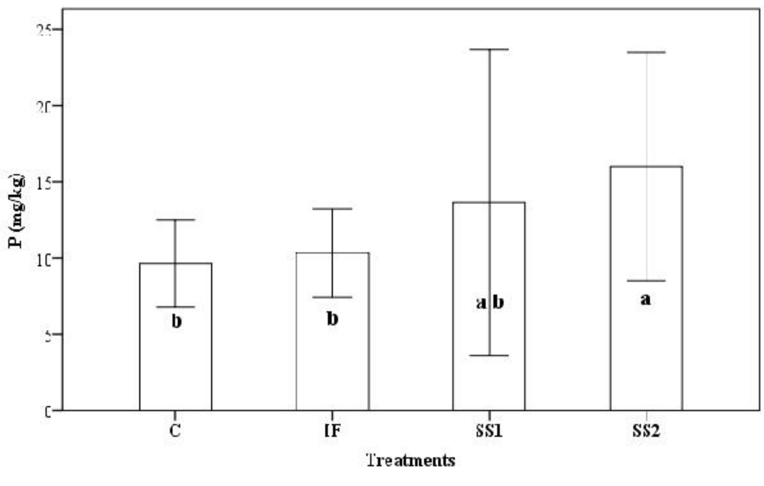

Figure 2. Diagrammatic presentation of sewage sludge application on the concentration of available soil P (Columns with different letters differ significantly at the probability level p<0.005 according to the LSD test. The bars show the SE of the means)

Concentrations of P_{Olsen} higher than 10 mg/kg are considered adequate for wheat crop (Olsen and Sommers, 1982). The contribution of SS in P is very significant since P is a non-renewable element and supplies are becoming increasingly scarce. It is estimated that the reserves of P will cover the P needs of agricultural production by 2033 and after then will face a serious shortage in P inputs (SSA, 2010). So, any possible P source such SS should be seriously considered.

Electrical conductivity (EC) slightly increased, remaining however at levels that are considered low and no restrictive for most of the crops (Marx et al. 1999).

No influence of SS application was recorded on exchangeable K as it was expected since K content of SS is low since it follows the liquid phase in the wastewater treatment process. In all treatments K concentration was fond ≤ 4.0 cmol/kg which is considered low (Marx et al. 1999).

Nitrates concentration after harvesting date was found to be significantly higher in the treatment received the higher SS rate although it was at low level. Nitrates concentration was in close correlation with EC which shows that a significant part of the EC is due to nitrates ions (R^2 = 0.79***, data not shown).

No one of the metals studied was significantly influenced by the SS application. This is due the low content of heavy metals of the SS used (Table 1). What is worthy to mention, is that soil Ni is quite high and according to relative directive (EEC, 1986) in soils like that application of SS is not permitted. A number of data (unpublished data of the authors) show a noticeable high concentration in Greek soils that should be examined to reveal the reasons and the possible measures to be taken.

Conclusions

Sewage sludge from the wastewater treatment plant of the city of Larissa, central Greece is suitable properties and it can be used for substituting mineral fertilizers for wheat crop. It increases yield, enriches soil in available P and has no significant effect on soil heavy metals concentration.

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