

The effect of municipal sewage sludge on properties physicochemical and microbial agricultural soil

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Abstract

The organic matter content of sludge can improve the physical, chemical and biological properties of the soil ensuring better cultivation and good agricultural productivity. The objective of this study is to evaluate the effect of sewage sludge on the main physicochemical and biological properties of the soil. The sludge was spread in an agricultural field in Ain defla (Algeria) cultivated with a tomato crop ('Panikra') in four treatments: (T): soil without sewage sludge and without mineral fertilization, (B): soil with sewage sludge, (E): soil with mineral fertilization, (B + E): soil with sewage sludge and mineral fertilization. For this, several physical, chemical and microbiological properties were analyzed on the residual sludge used and the soils collected in the studied plots. The results show that the sludge used does not exhibit any toxicity and that the treatment with the sewage sludge with the fertilizer used on the agricultural soil forms a better compost for improving the physicochemical quality of the soil compared to the other treatments. The application of sewage sludge also can accelerate microbial activity by increasing the number of bacteria, fungi and azotobacter.

Keywords: fertilization; organic matter; major elements; soil properties; tomato

Introduction

The beginning of the 21st century has been marked by notable developments that continue to transform world agriculture and rural economies due to the continued growth of the world population, the demands to feed and improve the quality of life of this population so we are particularly concerned. Internationally interested in developments in agriculture that could directly address growing concerns about future food security, productivity and sustainability (FAO, 2015). The recovery of urban sludge in agriculture is a major sector in wastewater management. Each year, 70% of sewage sludge is recovered by composting or agricultural spreading, and more than 80% in the sanitation services managed by water companies. Although sewage sludge

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is considered as waste, it is nevertheless of agronomic interest because of its richness in organic matter, nitrogen, phosphorus and a favourable carbon / nitrogen ratio (Becerra-Castro *et al.*, 2015).

Sewage sludge is composed of organic compounds, macronutrients, a wide range of micronutrients, non-essential trace metals, organic micropollutants and microorganisms (Kulling *et al.*, 2001). The land application technique, as fertilizing resource, is one of the methods considered to be very effective and efficient. Sludge may be applied to agriculture lands, forest, disturbed land (Tchobanoglous and Burton, 2003). This method has the following advantages: harness important quantities of nutrients – organic matter, nitrogen, phosphorus, potassium, trace elements, reduced chemical fertilizers consumption, uses organic matter mineralization and the decontamination capacity of soil (Mosoarca and Negrea, 2012). The study of the state of purification in Algeria and more particularly in western Algeria has shown that our 156 purification stations annually produce significant quantities of sludge estimated at around 225,000 tonnes of dry matter (Sahnoun, 2019).

The use of sludge has a beneficial effect on the improvement of soil fertility; it contributes to the dynamic growth of the content of organic substances, which are rapidly transformed into soil humus. This is particularly important for degraded soils, as well as light soils, easily permeable, the physicochemical fertility of which by the sewage sludge is radically improved by contributing to increased agricultural productivity. In addition, it was found that the beneficial effect of sludge fertilization is visible only in the second and third year of sludge application (Antolín *et al.*, 2005; Fernández *et al.*, 2009) However, it has been shown that sewage sludge application at recommended rates increased microbial activity in soil and tied up the heavy metals making them unavailable to plant and soil (Sastre *et al.*, 1996). Sewage sludge contains pathogenic bacteria, viruses and protozoa along with other parasitic helminths, which can give rise potential health hazards to human, animals and plants. Salmonella and Taenia, were identified as the greatest concern and risk to health from microbes in sewage sludge applied to land (World Health Organization, 1981.)

The objective of this study was to determine the effect of sewage sludge on the quality of agricultural soils and their effectiveness as a compost for the restoration of the physicochemical and biological properties of soils cultivated with tomato (Panikra) in a possibility of recovery of residual sludge and wastewater from the Ain Defla province WWTP and the suitability of tomato cultivation in the soil spread by the sludge by performing different analyzes according to the types of treatment used on the soil.

Materials and Methods

This study was performed out in an open area in the agricultural domain of SAADI Djilali in Arib Ain defla Algeria. There were 12 plots distributed over 3 blocks, each plot of 9 m² (3m x 3m), these plots were divided into three rows by 1m buffer zone and amended with either 3 kg/m² sewage sludge (Soulignac, 2000). The experimental design includes four treatments with three repetitions: T: soil without Sewage sludge and without mineral fertilization. B: soil with Sewage sludge. E: soil with mineral fertilization. B + E: soil with sewage sludge and mineral fertilization. The quantities of sewage sludge for the treatment B and B + E are equal to 3 kg/m². The composition of NPK fertilizer of treatment E and B + E was 130 units of N / ha; 120 units of P / ha and 150 units of K / ha. The field experimental plots were set up in a randomized block design as shown in Figure 1.

Soil analysis

Physicochemical analysis

Soil samples before and after harvesting were collected from each site in all plots from a depth of 20 cm (Zouidi *et al.*, 2019). The samples were air dried, sieved through 2-mm sieve and kept in plastic bags. Texture evaluation was performed as described by Robinson Khon; total nitrogen content was determined by the Kjeldhal method, Electrical Conductivity (EC) and pH were measured using pH and EC electrodes (JENWAY 3510 pH metre; AD 331 EC metre), water content was expressed by weight as the ratio of the mass between

wet and dry samples. The criterion for a dry sample was a weight of sample after drying in oven at temperature between 100 and 110 °C. Organic matter was determined by calcination at 550 °C for 16 h, Total Organic Carbon (TOC) was determined by oxidation sulfochromique. Major elements contents were determined by X-ray fluorescence in oxidized form on a solid solution sample called lozengé. This procedure is related to the practical instrumental method of basic soil analysis by X-ray fluorescence spectrophotometry and concentrations of heavy metals and microbiological parameters were determined. Soil had texture clay loam; alkaline pH and low organic matter content as summarized in Table 1.

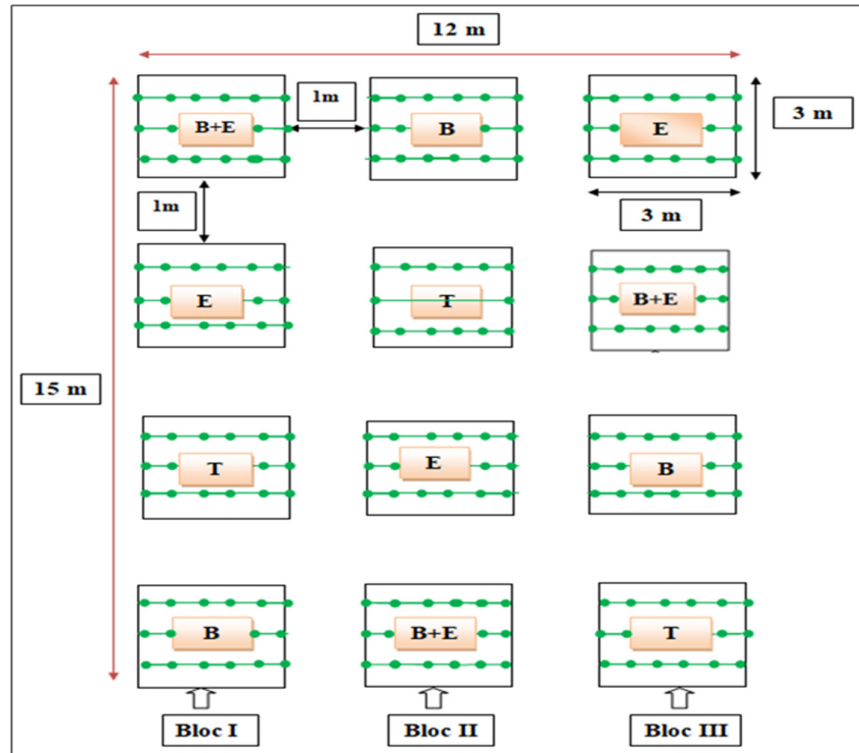


Figure 1. Representative schema of experimental field

Table 1. Physicochemical parameters of soil before application of sewage sludge

Parameters	Water content (ww)%	pH	EC mS/cm	O.M (%)	TOC %	Na meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	P meq/100g
Concentrations	4.69	8.4	0.13	1.36	0.25	0.12	7.17	1.52	2.15	37.88

Microbiological analysis

The soil sample was mixed, and a suspension of 1 g (dry weight equivalent) in 10 ml of sterile water was prepared. One ml of the soil suspension was then diluted serially (ten-fold) and used in the estimation of aerobic heterotrophic bacterial and fungal populations by standard spread-plate dilution method described by Seeley and Van Demark (1981), in triplicate.

The fungi are grown on the nutrient OGA medium with decimal dilutions of the soil at the rate of 3 drops of each dilution (10^{-1} to 10^{-6}) or 0.2 ml are placed on each box and incubation was at 28 °C for 7 days. (Bedjadj, 2011). The dilutions of the soil have been added on the nutrient agar favouring the cultivation of azotobacters; the colonies developed after incubation at 28 °C for 7 days (Zouidi, 2019). Bacterial counts were in the order of 10^5 - 10^7 cfu/g of soil, while fungal counts were in the order of 10^3 - 10^5 cfu/g of soil.

Collection of sludge

The sludge for the experiment was taken on 12/03/2017, from wastewater treatment located in the territory of Ain Defla province (Algeria). The sludge was collected from randomly on drying beds (on both ends of the beds and at the center) where the mixed sludge subjected to dehydration. The principle is based on filtration and evaporation of the natural sludge in the drying zone in order to reduce the water content of the sludge for the physicochemical and microbiological analysis of this sludge.

Physicochemical parameters of sewage

The physicochemical parameters of the sludge are recorded in Table 2, Based on the measurement of pH and electrical conductivity, the sewage sludge is neutral (7.21) and salty (3.81 ms/cm) and significantly higher organic matter content, carbon content and key nutrients. Mean concentrations of heavy metals were present at low concentrations, not exceeding allowable levels according to the AFNOR NA 17671 norm for the trace element contents of the sludge sample. The different elements are organized in the following order: Zn> Co> Pb> Cr> Ni> Cd> Hg.

Table 2. Physicochemical parameters of sewage sludge used in the experiment

Physicochemical parameters	Sewage sludge
pH	7.21
Electrical conductivity EC (ms/cm)	3.81
Water content (ww)%	56.1
Volatile matter (M.V)	39.91
Organic Matter (O.M) %	76.54
Carbon %	15.17
Azote (g/kg)	38
Chrome (mg/kg)	48
Nickel(mg/kg)	09
Copper(mg/kg)	105
Cadmium(mg/kg)	01
Zinc(mg/kg)	474
Plomb(mg/kg)	75
Mercury(mg/kg)	0.1

Sludge microbiological analysis

Microbiological properties sewage sludge used in the experiment was determined in the hygiene laboratory of Tipasa province and in the laboratory to the production of culture nutrients IMEN LAB; The NPP method was used to determine the total coliforms, fecal coliforms and fecal streptococci.

Table 3. Microbiological parameters of sewage sludge used in the experiment

Sludge samples	Coliform total		Coliform fecal		<i>Clostridium</i>		Streptococcus fecal		<i>Salmonella</i>		Vibrio		Helminth egg		<i>Staphylococcus aureus</i>	
	R	N	R	N	R	N	R	N	R	N	R	N	R	N	R	N
S1	160	*	26	2x10 ⁶	IND	-	92	-	-	<8-10g MS	-	-	+	<3-10g MS	+	-
S2	160	*	40	2x10 ⁶	IND	-	160	-	-	<8-10g MS	-	-	+	<3-10g MS	+	-
S3	+240	*	60	2x10 ⁶	IND	-	160	-	-	<8-10g MS	-	-	+	<3-10g MS	+	-
S4	160	*	23	2x10 ⁶	IND	-	160	-	-	<8-10g MS	-	-	+	<3-10g MS	+	-

S: Sample, R: Results, * Norms OMS, N: norms, + Indicate presence, - Indicate absence

According to the table, the studied sludge contains a significant number of pathogens such as total coliforms, fecal coliforms, clostridia, faecal streptococcus, *Staphylococcus aureus* and *helminth eggs*. We note that sample S3 is the sample most loaded with pathogenic microorganisms. The results also show that the

residual sludge used in the spreading tests complied with the French norm NF U 44-095 (JO 26 March 2004) and the Tunisian norms NT 106-20 (2002) (Raïs *et al.*, 2016). According to Duchene (1990), the very specific living conditions (temperature, humidity, richness of the environment) necessary for the good development of pathogenic germs are not encountered during the biological treatment of wastewater, neither during the treatment of sludge nor of the spreading which means that most of the germs are totally destroyed.

Results and Discussion

Soil control

Table 4 showed that the soil texture was determined as clay loam, it composed of 38.4% silt, 31.6% clay and 30% sand. The soil samples are characterized by a low organic matter content and an alkaline pH (8.36) a slight increase in pH was recorded after harvest (8.52), the statistical study shows that this difference in pH was and weakly significant ($p < 0.05$).

The statistical analysis of variance indicated that electrical conductivity (EC) was strongly significant ($p < 0.001$), the values ranged between 0.13 and 0.48 ms/cm.

The determination of the total organic matter (O. M) and carbon contents revealed low values before the application of sewage sludge (1.26% for O. M and 0.32% for carbon) and after harvest (1.28% for O. M: 0.30% for carbon), statistical analysis of variance indicated that this difference is not significant. A slight increase was recorded after the application of these sewage sludge. The determination of the total major element content before harvest revealed low values for P, Mg and Na and high values for K and Ca, then an increase in the values of P and Na observed during the experiment as we shown in Table 4.

Table 4. Mean values of physicochemical parameters of soil control before and after harvesting

Treatment T	Before application of sewage sludge	After 2-month application of sewage sludge	After harvesting	Standard deviation
pH	8.36	8.53	8.52	0.147
EC (ms/cm)	0.13	0.17	0.48	0.071
Silt (%)	38.40	26.40	27.20	6.272
Clay (%)	31.60	30.80	36.40	3.917
Sand (%)	30	41.90	37.20	8.125
O.M (%)	1.26	1.45	1.28	0.672
C (%)	0.32	0.93	0.30	0.689
K (mg/l)	106.4	12.34	9.36	30.762
Na (mg/l)	2.59	2.33	4.42	0.457
Mg (mg/l)	18.73	13.84	12.82	1.273
Ca (mg/l)	146.62	170.5	132.71	25.816
P (mg/l)	1.90	1.79	2.30	0.601

Soil with sewage sludge

Based in table 5, it has been observed an increase of soil pH and EC for sites which were amended with sewage sludge but they were low than the sites which were not amended with sewage sludge (Tsadilas *et al.*, 2002). Mihalache *et al.* (2007), reported also an increase in soil pH in soils treated with sewage sludge. The changes in soil pH have been correlated with the calcium carbonate content of sludge (Sommers, 1977).

ANOVA analysis of pH variance shows that the change in soil pH is weakly significant ($p < 0.05$), but it is highly significant ($p < 0.001$) for CE electrical conductivity, according to Benmouffok *et al.* (2005), soils treated with residual sludge tend to have a neutral pH and become enriched in phosphorus and organic matter. The spreading of sewage sludge can induce a salinity effect in agricultural soils (Morisot and Tournier, 1986), the organic matter in the sites which have been amended by the sewage sludge is 1.34%, which is higher than

organic matter and carbon in soil samples that were not modified by sewage sludge. The determination of the total content of major elements before harvest shows an increase in Na values; Ca and P; and the values decrease for K and Mg. Therefore, statistical analysis of total major element content (ANOVA) in soil samples amended by sewage sludge shows a significant difference ($p < 0.05$) as summarized in Table 5.

Table 5. Mean values of physicochemical parameters of soil with sewage sludge before application of sewage sludge and after harvesting

Treatment B	Before application of sewage sludge	After 2-month application of sewage sludge	After harvesting	Standard deviation
pH	8.42	8.45	8.45	0.067
EC (ms/cm)	0.12	0.13	0.51	0.112
Silt (%)	38.70	25.20	27.20	6.239
Clay (%)	27.90	31.60	34.80	5.865
Sand (%)	34.10	41.60	37.20	9.761
O.M (%)	1.39	0.92	1.34	0.475
C (%)	0.16	1.34	0.36	1.706
K (mg/l)	73.9	11.89	8.97	38.270
Na (mg/l)	2.87	1.84	5.48	0.736
Mg (mg/l)	17.79	14.4	13.7	1.496
Ca (mg/l)	141.65	178.3	135.17	24.087
P (mg/l)	1.78	1.68	2.65	0.612

Soil with fertilizer

In this case the values of pH and Electrical conductivity EC varied significantly with NPK fertilizer as indicated in table 6. Analysis of ANOVA for the O.M in the sites which were amended by NPK fertilizer ($P < 0.001$) demonstrated lowest values than O.M in soil amended by sewage sludge, these results prove good fertilizing and soil improvement qualities of sludge.

As shown in Table 6, the average organic carbon contents in the soil samples amended with NPK fertilizer are lower compared to the soil samples amended with sewage sludge. This observation is consistent with the results of Singh and Agrawal (2011) and Mi *et al.* (2016) which showed that the application of organic fertilizers leads to an increase in organic carbon values compared to NPK fertilizers. It has been observed too an increase of the Na average and decrease of K; Mg; Ca; P average.

Table 6. Mean values of physicochemical parameters of soil with fertilizer before fertilization and after harvesting

Treatment E	Before application of sewage sludge	After 2-month application of sewage sludge	After harvesting	Standard deviation
pH	8.40	8.47	8.46	0.062
EC (ms/cm)	0.13	0.13	0.56	0.080
Silt (%)	38	30.80	28	7.327
Clay (%)	30.40	31.60	36.80	5.158
Sand (%)	30.40	37.60	34.80	8.671
O.M (%)	1.32	0.94	0.97	0.166
C (%)	0.22	0.35	0.24	0.207
K (mg/l)	90.4	10.82	9.05	33.110
Na (mg/l)	2.62	2.12	4.89	0.738
Mg (mg/l)	18.34	13.79	12.43	0.842
Ca (mg/l)	140.83	144.3	133.21	34.355
P (mg/l)	2.03	1.59	1.90	0.394

Soil with sewage sludge and fertilizer

Table 7 noted an increase in soil pH and electrical conductivity EC. So, pH increases from 7.81 units before application of sewage sludge and NPK fertilizer till 8.46 units after harvesting, and the values of EC ranged between 0.12 and 0.76 ms/cm. The amount of O.M in the sites which were amended with sewage sludge and NPK fertilizer is 2.63%, which is higher than organic matter to all treatments. Soil samples with sewage sludge and fertilizer show a higher TOC value than all the other treatments; compared with the soil samples amended by NPK fertilizer; the soil samples amended by sewage sludge and the soil control., the average TOC is 3.25% after harvesting.

The determination of the total content of major elements before harvesting shows increase values for Na, Mg and P; and decrease values for K and Ca. The results showed that the pH, electrical conductivity EC, TOC, organic matter, and total content of major elements (Na, Mg, P) increased when the soil was amended with sewage sludge and fertilizer compared to all treatments.

This experiment showed that sewage sludge and fertilizer create good environment for physicochemical parameters of soil as compared to all the treatments, so the organization of the different treatments in the following order: EE+B > EB > EE > ET according to their efficiency.

Table 7. Mean values of physicochemical parameters of soil with sewage sludge and fertilizer before application of sewage sludge and after harvesting.

Treatment E+B	Before application of sewage sludge	After 2-month application of sewage sludge	After harvesting	Standard deviation
pH	7.81	8.46	8.46	1.124
EC (ms/cm)	0.12	0.14	0.76	0.198
Silt (%)	38.40	25.20	28	6.992
Clay (%)	29.20	31.20	33.20	5.952
Sand (%)	31.60	40.80	37.60	9.072
O.M (%)	1.30	1.03	2.63	1.261
C (%)	0.28	2.12	3.25	3.875
K (mg/l)	101.6	11.26	9.31	36.549
Na (mg/l)	2.64	2.14	5.53	0.722
Mg (mg/l)	18.39	13.72	18.39	1.886
Ca (mg/l)	143.51	181.9	136.76	28.152
P (mg/l)	1.85	1.60	3.49	1.598

Microbiological analysis

In the count of the microflora we have compared the bacteria, fungi and azotobacters in the control soil and soil with the sewage sludge in the 3 blocs.

The total bacterial counts (TBC)

The mean total bacterial counts (TBC) of soil sample before application of sewage sludge ranged between 10.40×10^4 UFC/g s.s and 54.54×10^4 UFC/g s.s. The values of total bacterial counts (TBC) were at 15.50×10^4 UFC/g s.s and 75.59×10^4 UFC/g s.s after application of sewage sludge as shown in Figure 2. Although highest counts were observed in soil sample bloc I, and lowest count was observed in soil sample bloc III. We observed that the bacteria were the most microorganism's dominant in soil, this predominance of bacteria could be attributed to the ubiquity of bacteria who can colonize different media and they can be activated for great areas of temperature, acidity, alkalinity, pressure and salinity (Dommergues, 1962).

The effect of acidity of the soil, when the acidity of soil is higher, when the microbial biomass is low. Bacteria are more favoured by environments close to neutrality (Boullard and Morceau, 1962).

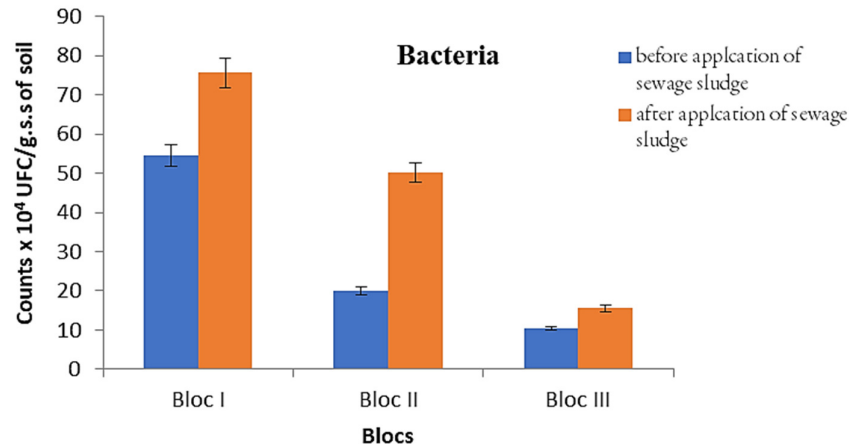


Figure 2. The average total bacterial count of the soil before and after application of Sewage sludge

Total fungi count (TFC)

Fungi play a role in recycling waste, chemical secretions and excretions from the roots of plants, animals and microorganisms (Zouidi, 2019). The fungal counts in the soil samples before the application of sewage sludge were in the order of 8.78×10^2 g/g. s. s and 15.78×10^2 g/g. s. s, followed by the values of the total number of mushrooms between 15.20×10^2 g/g. s. s and 23.20×10^2 g/g. s. s after application of sewage sludge, as shown in Figure 3. Fungi are not the most common soil microorganisms, but their weight is very important due to their large size compared to bacteria (Huber and Schaub, 2011). They are low in our soil due to the alkaline pH effect because fungi generally support acidic pH; under such conditions, they are more competitive than bacteria for the exploitation of a substrate (Karabi, 2016).

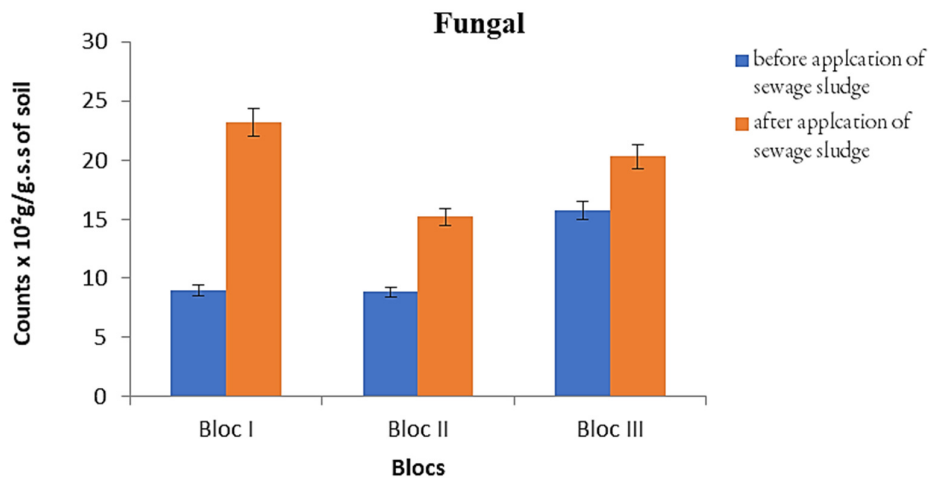


Figure 3. The average total fungi count (TFC) of the soil before and after application of sewage sludge

Total *Azotobacter* count

The determination of the *Azotobacter* showed that are relatively low. The values of the azotobacter varied between 60.45×10^3 UFC/g s.s before application of sewage sludge and 90.78×10^3 UFC/g s.s after application of sewage sludge (Figure 4). This variation is due to the richness of minerals and organic matter in the soil. This increase of the total aerobic mesophilic flora could be explained by the enrichment of the medium in mineral nitrogen by the aerobic of nitrogen that are also activated after the application of wastewater.

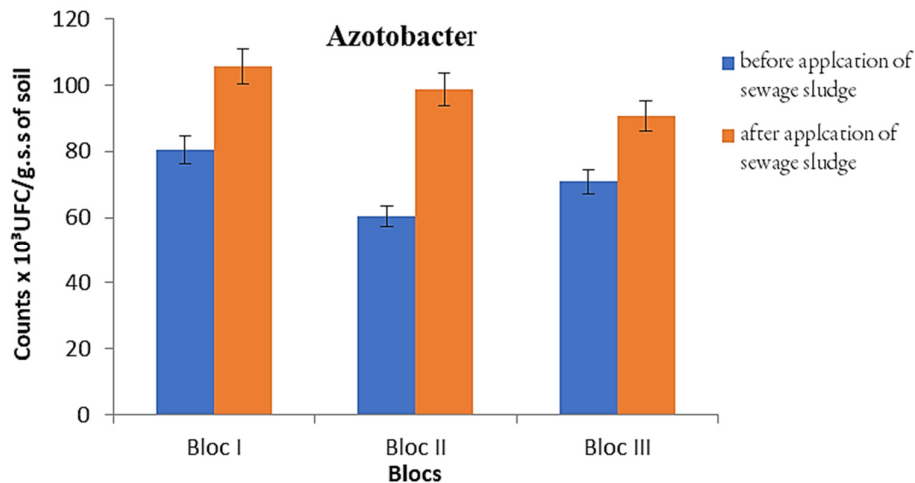


Figure 4. The average of total *Azotobacter* count of the soil before and after application of sewage sludge

Conclusions

The application of sewage sludge is a widely used agricultural practice that serves several purposes primarily to improve soil quality. They can also be valued by spreading on agricultural soils. The application makes it possible to recycle part of the sludge and to take advantage of its fertilizing properties since they are rich in organic matter and certain fertilizing elements urban waste are potentially interesting to ensure the biological fertility of soils. Sludge analyses confirm the presence of heavy metals and the various germs which remain below the threshold of international toxicity norms.

The results of this study showed that soil mixed with sewage sludge and fertilizer creates a good support for the physicochemical and biological parameters of agricultural soils in relation to all the treatments used. In physicochemical terms, the greatest impact caused by the application of sludge on the soil was the increased pH, EC electrical conductivity, carbon, organic matter and total content of major elements (Na, Mg, P). From a biological point of view this treatment improved the microbial activity mainly by a growth of bacteria, fungi and azotobacter whereas bacteria were the most dominant microorganisms in the soil which can colonize different environmental media by function of variation of temperature, acidity, alkalinity, pressure and salinity.

Finally, the application of sludge changed the physicochemical and biological properties of the soil, so we concluded that the sludge can be used as a natural fertilizer on the soil.

Authors' Contributions

DN, WH and DA designed and performed the experiments and also wrote the manuscript. ZM and MM performed the statistical analysis. ZM and DA reviewed the manuscript. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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