RECOVERY OF RESIDUAL SLUDGE FROM A WASTEWATER TREATMENT PLANT. IMPACT OF SLUGE-SOIL MIXTURE ON THE GROWTH OF TOMATO SOLANUM *LYCOPERSICUM* L.

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استرداد الحمأة الناتجة من محطة معالجة مياه الصرف الصحي. تأثير مزيج التربة والحمأة على نمو الطماطم SOLANUM *LYCOPERSICUM* L.

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ABSTRACT

Sewage sludge is used as a fertilizer in agriculture to rehabilitate deteriorated soils and replace artificial fertilizers. Sludge can be utilized to improve soil characteristics, promote microbial life, and increase plant production where it includes the primary nutrients and organic matter. The current study investigated the impact of the treatment of sewage sludge on the physico-chemical characteristics of the soil, and also on the growth of tomato (Solanum lycopersicum). The experiment consists of using a sludge-soil mixture, with different fractions of sewage sludge: soil control (0% sludge) and 20%, 40%, 60%, 100% of sludge. Biometric measurements (height, stem diameter and number of leaves) were performed on the tomato. The results showed good fertilizing properties of a sludge/soil mixture with the 60% sludge fraction. However, the tomato that grew on the 40% fraction had better growth and high foliage compared to the plants on the other fractions. The spreading of sludge provides a soil amendment and an additional supply of nutrients for tomatoes. The use of 40% fraction of sludge spreading for the cultivation of this plant can maintain better soil fertility while reducing the risk of heavy metal accumulation. Indeed, the 40% fraction of sludge has concentrations which are: 86±0.40 mg/kg for copper, 294 ±0.40 mg/kg for zinc and 50±5.9 mg/kg for lead, lower than the limits recommended by the European directives.

ملخص

الكلمات المفتاحية: حمأة الصرف الصحي ، الخصائص الفيزيائية والكيميائية للتربة ، نسبة 40٪ ، نمو الطماطم ، المعادن الثقيلة ، المخاطر

تستخدم حمأة الصرف الصحي كسماد في الزراعة لإعادة تأهيل التربة المتدهورة واستبدال الأسمدة الصناعية. يمكن استخدام الحمأة لتحسين خصائص التربة، وتعزيز حياة الكائنات الحية المتواجدة في التربة، و كذا زيادة المحصول النباتي للإحتوائها على العناصر الغذائية الأولية والمواد العضوية. تهدف الدراسة الحالية إلى دراسة تأثير معالجة حمأة الصرف الصحي على الخصائص الفيزيائية والكيميائية للتربة، وكذلك على نمو الطماطم (*Solanum lycopersicum L.*). تتمثل التجربة في استخدام خليط التربة مع الحمأة بنسب مختلفة من الحمأة، حيث استعملنا التربة الخالصة (أي 0٪ الحمأة) و 20٪ من الحمأة ، 40٪ ، 60٪ ، 100٪ من نسب الحمأة. تم إجراء القياسات الحيوية (الطول وقطر الساق وعدد الأوراق) على الطماطم. أظهرت النتائج خصائص تسميد جيدة لخليط الحمأة / التربة بنسبة 60٪ من الحمأة. ومع ذلك ، فإن الطماطم التي نمت على الجزء 40٪ كان لديها نمو أفضل وأوراق شجر عالية مقارنة بالنباتات في الأجزاء الأخرى. يوفر انتشار الحمأة تعديلًا للتربة وإمدادًا إضافيًا بالمواد المغذية لنمو للطماطم. يمكن أن يؤدي استخدام نسبة 40٪ من انتشار الحمأة لزراعة هذا النبات إلى الحفاظ على خصوبة التربة بشكل أفضل مع تقليل مخاطر تراكم المعادن الثقيلة. في الواقع ، يحتوي جزء 40٪ من الحمأة على تركيزات هي: 86 ± 0.40 مجم / كجم للنحاس ، 294 ± 0.40 مجم / كجم للزنك و 50 ± 5.9 مجم / كجم للوزن ، أقل من الحدود الموصي بها من قبل المعايير الأوروبية.

INTRODUCTION

The disposal of sewage sludge, a primary product of wastewater treatment plants, is a challenge. On the one hand, sewage sludge is environmentally harmful, but on the other side, it can be used as a fertilizer in organic farming *(Jarde, 2002; Soudani et al., 2017).*

The sludge treatment and disposal account for around half of the expenses of running sewage treatment plants. Traditional sludge disposal techniques, such as landfill, incineration, and ocean disposal, have a number of drawbacks. Sludge landfilling and incineration both have significant environmental consequences due to groundwater contamination and the creation of global warming gases *(Scholz, 2016; Eid et al., 2017).*

The use of treated sludge in agriculture can greatly reduce the cost of disposal, protect the environment, cut prices when compared to commercial fertilizers, offer critical plant nutrients, and increase soil fertility *(Zhao et al., 2012).*

Organic additions are required to improve soil fertility and productivity in arid land due to the low organic matter concentration *(Hussein, 2009; Eid et al., 2017).* For that it is hypothesized that urban sludge can improve organic matter in agricultural soil, hence enhancing plant growth and reducing the volume of sewage sludge produced. The content of the added sludge, including the organic matter and soil physio-chemical parameters, are related to the observed changes in soil chemical properties after the addition of the sludge *(Kidd et al., 2007; Tejada et al., 2016; Eid et al., 2017).*

De Sousa et al (2022) evaluated the impact of sewage sludge on soil fertility, nutrition and yield of sugarcane in three successive crops. Results showed that waste sludge increased pH and base sum, reduced exchangeable aluminum and improved soil chemical conditions. Sugarcane yield increased after SS rates and decreased with each crop cycle.

However, *Sabbahi et al (2022)* examined the presence of helminth eggs and protozoan cysts in samples of dried sewage sludge collected from ten sewage treatment plants (WWTPs) located in eight governorates of Tunisia. Based on morphological criteria, protozoan cysts were detected in all composite samples of dried sludge (N = 116) from the treatment plants studied; the content of all the dried sewage sludge samples examined was below WHO (2006) and US EPA (2003) recommendations and therefore the sludge could potentially be reused in agriculture. Sludge samples were taken from five municipal sewage treatment plants located in the largest industrial area in southern Poland to determine the ecological risk from heavy metals in sludge. This risk was assessed by calculating the potential ecological risk factor (ER), the risk index (RI), the risk assessment code (RAC), the individual contamination factor (ICF), the global risk (GRI) as well as the Individual Ecological Risk (IER) and Global Ecological Risk (GER).

The results found showed that the highest ecological risk was posed by Zn, Cd and Ni, while in the case of their total concentrations, by Cd and Hg. The results obtained confirm that the quantitative determination of the total content of heavy metals in sewage sludge is not a sufficient criterion in the assessment of the ecological risk that these elements pose to the natural environment and living organisms *(Tytla, 2020*).

The purpose of this study is to determine the impact of the application of various fractions of urban sludge from the Tiaret wastewater treatment plant on the properties of the soil, and on the development of tomato cultivation in a mixture of sludge-ground.

MATERIALS AND METHODS

In this experiment, soil samples were taken from a 25 cm layer. On the other hand, a dried sewage sludge was collected from the wastewater treatment plants of Bouchekif (Wilaya of Tiaret, Algeria).

The ground sludge was mixed with agricultural soil in proportions of 0% sludge for control soil, fraction of 20% sludge, 40% sludge, 60% sludge and 100% (0% soil). The different fractions were cultured in registered pots. Note that the residual sludge from this treatment plant does not have any treatment before its use in agricultural spreading.

Tomato seeds were grown on these pots in semi-controlled culture conduction (daytime temperature of 25°C, nighttime temperature of 10°C, and 60% humidity). During germination of tomato seeds, operations of depressing the young plants were carried out in order to reduce the density of the plants in the pot. The pot experiment was conducted in a completely random block design with 60 replicates for each treatment. Plants were watered manually daily with tap water. For additional investigation, soil mixture samples were air-dried, powdered, and sieved at 2 mm. The pH was measured in soil-water extracts *(Jackson, 1958).* The texture examination was carried out according to Robinson Khon's instructions. The wet oxidation method was used to determine organic matter in the soil mixture, while the micro-Kjeldahl method was used to determine total Kjeldahl nitrogen and the Drouineau method was used to determine active lime; the procedure involved reacting the soil with ammonium oxalate and then determining unreacted oxalate by back-titration with potassium permanganate. Trace metals (Cu, Zn, and Pb) were analyzed using an Atomic Absorption Spectrophotometry after being digested with a nitric acid mixture *(Carter et Gregorich, 2008*). The number of tomato leaves was recorded, the height growth, and circumference were measured once per month.

RESULTS AND DISCUSSION

Soil/sludge mixture physico-chemical properties

One of the main goals of this study is to determine the impact of sewage sludge on the physico-chemical properties of the soil. The current study found that the application of sewage sludge changed the parameters of agricultural soil. The chemical characteristics of the soil were dramatically improved by increasing the sludge application rates (Tab 1, 2).

Table 1

Physico-chemical characterization of the different sludge fractions (Mean ± SD)

Level of Factor	N	pH	Total limestone (%)	Active limestone (%)	C%	Organic matter (%)	EC (mS/cm)	CEC (cmol/kg)	N (%)	C/N
Sludg 100% (B)	60	8.24±0.06	37.12±0.08	23.16±0.05	12.03±0.02	20.70±0.04	5.20±0.08	26.67±0.44	1.30±0.02	9.27±80.17
Sludg 20% (B1)	60	7.18±0.06	22.13±0.08	14.07±0.05	2.30±0.07	3.96±0.12	1.36±0.04	19.16±0.18	0.24±0.01	9.74±0.52
Sludg 40% (B2)	60	7.82±0.02	24.45±0.05	16.35±0.05	5.88±0.07	10.12±0.13	2.21±0.04	19.16±0.18	0.62±0.01	9.56±0.16
Sludg 60% (B3)	60	7.61±0.02	27.46±0.05	20.84±0.07	9.16±0.10	15.76±0.17	3.56±0.06	24.10±0.03	0.96±0.02	9.52±0.16
Ordi Soil (T)	60	7.36±0.39	26.15±0.06	19.14±0.09	0.63±0.05	1.09±0.09	0.92±0.03	18.34±0.38	0.06±0.01	11.03±10.62

The physico-chemical properties obtained for the mixtures show that the pH value is the same. In this respect, *Parkpain et al., (2000),* found that acidic soils had a higher pH than neutral soils after the addition of sludge, whereas neutral soils had no change.

According to the findings of other researchers, the electrical conductivity increases when the dose is increased *(Dridi et Toumi, 1999; Pisson, 2000; Korboulewsky et al. 2001; Boutmedjet, 2004; Bipfubusa et al, 2006; Amadou, 2007; Bahri et al. Annabi, 2011; Guerf, 2012).*

In modified substrates, the CEC appears to be increasing. *Epstein et al. (1976)* discovered that adding sludge compost raises CEC and that this increase is proportional to the dose given. An increase in the CEC of the soil increases the potential pool of nutrients available to plants (cations) while decreasing the loss of ETM, which are preferentially fixed on the adsorbing complex rather than transferred to the soil solution *(Mazen et al 2010; Eid et al., 2017).*

The addition of residual sludge has also aided in the improvement of maximum values in organic matter, which has increased from 1.09± 0.09 % in T (100% soil) to 3.96±0.12%, 10.12 ± 0.13% and 15.76±0.17 % in B1, B2, and B3 respectively (Tab 1), and thus in organic carbon. This is in line with findings from earlier investigations *(Hussein, 2009; Mazen et al., 2010; Soudani et al., 2017; Eid et al., 2017).*

Several authors had also discovered that the sludge had significantly increased the amount of organic carbon in the soil as well as the amount of azote in the soil *(Dridi et Toumi, 1998; Korboulewsky et al, 2001; Bipfubusa et al., 2006; Bahri et Annabi, 2011; Guerf, 2012).*

The B3 substrate, which contains 60% sludge, is particularly rich in organic matter, according to *Baize (1988)* categorization. The compost enhanced the organic matter content and cation exchange capacity of the soil substantially. *Guerrero et al. (2001)* discovered that when sewage sludge was added to the soil, total soil organic carbon rose.

Organic matter is a source of plant nutrients, and the progressive mineralization of organic matter provides plants with bioavailable ions. The C/N ratio in all substrates is close to 10, which has a non-depressive effect on the plants since it operates directly on the soil biology and does not generate mineral nitrogen blockages *(Glemas, 1980).*

Houot, (2009), Annabi et Bahri, (2011), noted that the C/N ratio here implies strong biological activity. The addition of sludge tends to raise trace element concentrations; however, they were present in low concentrations in the various substrates and do not exceed the AFNOR standard's permissible levels (1985).

The quantities of zinc, lead, and copper measured in the altered substrates are similar to those found in sludge, indicating that the soil has a significant fixing potential. These findings are comparable to those of *(Antolin et al., 2005; Mazen et al., 2010; Nogueira et al., 2013; Soudani et al., 2017; Eid et al., 2017)*, who found that soil levels of Zn, Pb, and Cu are directly proportional to sludge spread dosages.

These high Cu and Zn concentrations are similar to those reported by *Eid et al. (2017)*, although they are greater than *Gattullo et al. (2017)* 's average values of 128 mg/kg (Cu) and 302 mg/kg (Zn). The zinc values in our study were sharply increased and are now given with non-toxic values. Zn is less linked to organic matter than other ETM, according to *Bhogal et al. (2003)* and *Moffett et al. (2003)*, and thus would be less influenced by sludge decomposition (Fig. 1).

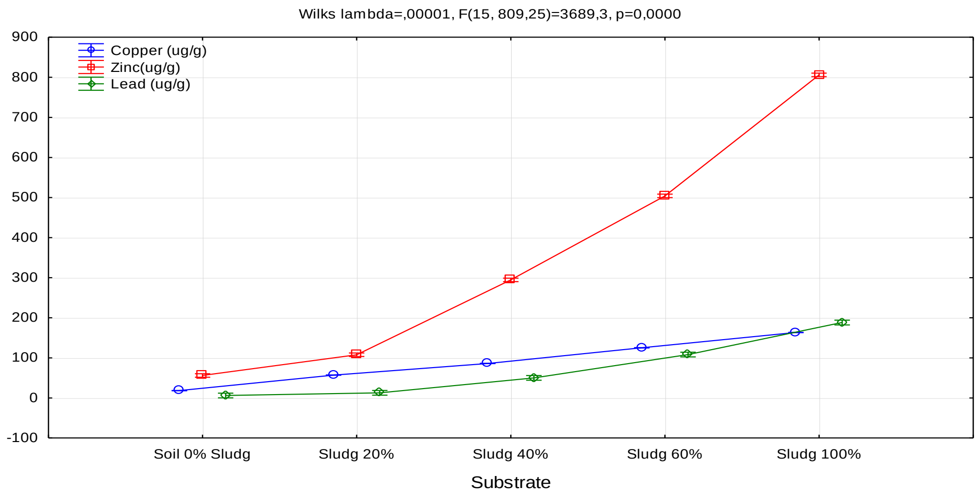

Fig. 1 - Evolution of heavy metals Pb, Zn, Cu as a function of different substrate fractions

Indeed, the 40% fraction of sludge has concentrations which are: 86±0.40 mg/kg for copper, 294 ±0.40 mg/kg for zinc and 50±5.9 mg/kg for lead, lower than the limits recommended by the European directives, which are respectively: 50-140 mg/kg, 150-300 mg/kg and 50-300 mg/kg Pb.

Texture has a direct relationship with hydrodynamic parameters in particular permeability, water storage capacity and porosity as well as cation exchange capacity. The samples analyzed are composed of several fractions dominated much more by silts and sands. It can be concluded that the samples used in this experiment have a sandy silty texture which favors the dynamics and the entrainment of heavy metals at depth. The comparison between the different textures shows that there are no significant differences between the size fractions and the doses of sludge applied, which is in agreement with the work of *Gallardo et al., (1987)*, or they report that changes in physical properties are only obtained for high dose applications.

The sludge used in this experiment consists of the following fractions in order of decrease: the silty fractions then the sandy fractions and lastly the clay fractions. In conclusion, this sludge has a sandy loam texture (Table 2).

Table 2

Characterization of the particle size distribution in the different sludge fractions (Mean ± SD)

Substrate	N	Clay (%)	Fine silt (%)	Coarse silts (%)	Fine sands (%)	Coarse sands (%)
fraction1 (100% raw sludge)	60	11.95±0.09	41.06±0.09	14.49±0.09	22.72±0.09	9.79±0.08
fraction 2 (20% sludge)	60	8.53±0.22	31.75±0.29	26.09±0.24	15.82±0.30	17.80±0.55
fraction 3 (40% sludge)	60	9.93±0.19	38.70±3.86	23.82±0.08	17.49±0.20	9.56±0.13
fraction 4 (60% sludge)	60	11.12±0.05	40.40±0.11	18.82±0.18	20.89±0.14	8.77±0.10
fraction 5 (100% raw soil)	60	2.19±0.11	6.22±0.09	59.15±0.39	6.85±0.30	25.58±0.36

Growth and productivity of Solanum lycopersicum tomato in sludge-soil mixture

Biometric measurements of *Solanum lycopersicum* plants in soil mixed with sewage sludge at a proportion of 0 (control), 20, 40 and 60% (60 replicates for each) are shown in table 3.

After two months of growing, the survival rate of tomato plants was around 85%. In general, biometric measurements had increased with increasing proportion of sludge in mixtures. The results compared to a control based on agricultural soil, show that the tomato grows very significantly in the three mixtures, however this growth is very remarkable in the mixture with 40% sludge (Table 3).

Plants grown on the 40% mud mix had a maximum final height of 78.50 cm, a maximum leaf count of 32.00 and a maximum stem diameter of 6.00 cm. In the case of plants grown on the control soil, much lower maximum results were recorded: 36.20 cm for the height, 12.00 for the number of leaves and 2.30 cm for stem diameter.

The impacts of sludge on improving soil aggregation and the contribution of organic matter in improving soil chemical characteristics, increasing soil water retention, and, as a result, providing vital nutrients for plant growth, could explain why sludge application increases plant productivity *(Antolin et al., 2005; Hussein, 2009; Soudani et al., 2017).*

Moreover, *Mendoza et al., (2006),* found that the agricultural use of sewage sludge increased the morphological characteristic of sorghum plants.

Al-Saikhan et al., (2020), had demonstrated good growth of lettuce and cucumbers on arid soil fertilized with municipal sludge, considered as a source of fertilizer due to its high contents of organic matter and available nitrogen and phosphorus; he had also found limited absorption of the heavy metals.

Table 3

Biometric parameters of tomatoes grown in different sludge fractions (Mean±SD)

Biometric parameters of Tomato	N	Mean±SD	Min	Max
TH Stem_Soil (cm)	60	35.73±0.32	35.00	36.20
TH Stem_ Sludg (cm)	60	64.50±0.86	63.00	65.70
TH Stem_ Sludg 20% (cm)	60	49.49±5.85	5.00	50.80
TH Stem_ Sludg 40% (cm)	60	77.58±0.50	76.50	78.50
TH Stem_ Sludg60% (cm)	60	68.04±0.63	66.80	69.00
Diam COL_ soil (cm)	60	1.99±0.19	1.60	2.30
Diam COL_ Sludg (cm)	60	6.59±0.27	6.00	7.10
Diam COL_ Sludg20% (cm)	60	3.17±0.22	2.70	3.50
Diam COL_ Sludg40% (cm)	60	5.74±0.19	5.30	6.00
Diam COL_ Sludg 60%(cm)	60	4.26±0.21	3.80	4.60
Nbr Leav_soil	60	9.87±1.61	5.00	12.00
Nbr Leav_Sludg	60	20.65±1.38	17.00	23.00
Nbr Leav_Sludg20%	60	13.28±1.17	11.00	15.00
Nbr Leav_Sludg 40%	60	28.93±1.53	27.00	32.00
Nbr Leav_Sludg 60%	60	20.57±12.84	17.00	118.00

Interaction: Waste sludge – Soil – Tomato

In order to study the effect of the supply of residual sludge, from a wastewater treatment plant of the Ain Bouchekif station, on the physico-chemical characteristics of the soil, on the one hand and on the physiology of the tomato on the other hand; a canonical correspondence analysis (CCA) was performed, taking these parameters into account. The result of this CCA is shown in Figure 2.

Two dimensions can be interpreted:

- F1 which represents 95.03% of the point clouds (95.03% of the information can be explained in this dimension).

- F2 which represents 4.7% of the point clouds can be explained in this axis.

On the positive side of the F1, one can find: Pure sludge and the 40% sludge fraction correspond with better growth of the tomato. This mixture: soil-sludge is rich in organic matter, in nitrogen with good electrical conductivity. This explains why sewage sludge has high fertilizing values for tomato (phosphorus, nitrogen and calcium oxide) and organic matter. A rapid enrichment in mineral nitrogen is observed in the 60% fraction favoring the rapid growth of the plant.

Indeed, the solid fraction of the effluents constitutes a potential of fertilizing organic and mineral matter. However, this potential undergoes notable spatio-temporal variations *(Bahri et al, 1987).* In the young *Eucalyptus camaldulensis Dehnh* plants grown in three fractions of soil-sludge mixtures (20%, 40% and 60%), the biometric values (heights and diameters of the stems, number of leaves) of the plants in all the sludge mixtures were higher than those of control plants (100% soil). The mixture, which contained 60% sludge, gave the best result *(Soudani et al, 2017).* For tomato, the 40% fraction is best.

Also on this side, an interaction between the rate of silt and pure sludge fractions and 60% is observed. The higher the percentage of mud, the greater the quantity of silt.

However, the 60% mixture presents a risk of pollution by heavy metals, in particular the Pb, which requires monitoring before any use of these soils in agriculture.

Akintola et al., (2019), showed the efficiency and ability of *Adansonia digitata L* to accumulate and distribute heavy metals in its tissue parts. Thus, a difference in the concentrations in mg/Kg of Pb (28.22; 19.58), Zn (76.22; 48.06) and Cu (55.68; 26.45) in the soil, before and after planting *Adansonia digitata L*, clearly significant was observed. Along the same axis, on the negative side, one can find: ordinary soil and the 20% sludge fraction correspond to a fairly high pH and mineralization of organic matter (a fairly high C/N ratio due to the drop in mineral nitrogen in this section). In fact, the electrical exchange capacity CEC is related to the pH, it is the nutrient retention capacity of the soil at alkaline pH. The texture of the soil is loamy and the rate of limestone (total and active) is high.

Also on this side, an interaction between the rate of silt, pure sludge fractions and 40% is observed. Indeed, the higher the percentage of sludge, the greater the amount of silt.

In the F2 axis, positive side, the projection of the information on this axis makes it possible to define the correspondence of the 40% fraction and the rate of clays and silt (fine and coarse). It should be noted that the texture of the soil-sludge mixture is strongly influenced by the condition of the environment, in particular the long-term climate factor. *Fahd-Rachid (1993)* showed that an increase in the organic matter content, in certain mineral elements (P and Ca), in the cation exchange capacity and in the pH were observed in a field of stony sandy soil mixed with the incorporation of sewage sludge or urban compost and grown in temperate regions, after 18 years of experimentation. On a practical level, the use of composts and sludge helps maintain the stock of humus in the soil. Isohumic coefficients are between 0.08 and 0.20 for sludge and between 0.28 and 0.33 for composts.

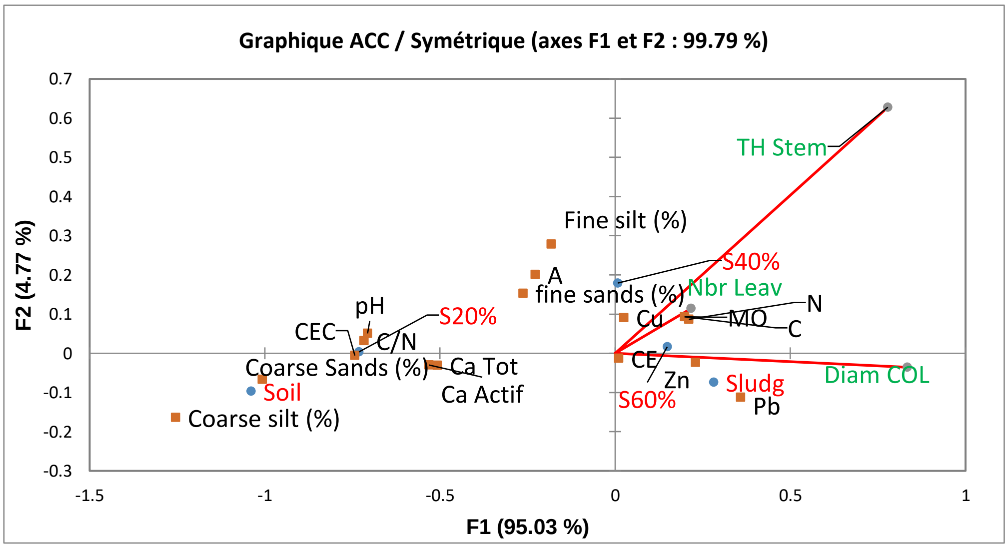

Fig. 2 - Relation: sludge-soil-plant by Canonical Correspondence Analysis (CCA)

CONCLUSIONS

The agricultural benefits of sewage sludge application are enormous, especially when added to low-organic-matter soils like those in Tiaret, Algeria. The effects of varied sewage sludge application rates (0, 20, 40, and 60%) on selected soil parameters and tomato plant growth were explored in this study.

The current study's findings show that using sewage sludge in agriculture can improve soil properties/fertility, provide critical plant nutrients, and increase crop productivity. In this study, sewage sludge was applied to agricultural soil and resulted in a significant increase in soil organic matter content and, as a result, crop output. Sludge at a 60% rate is useful in increasing soil characteristics and fertility. In the 40% mixture, tomato plants treated with sludge exhibited superior development and a high number of leaves. Plant development was improved by the mud, yet there were no negative effects on plant health.

The CCA has made it possible to define the beneficial aspect of the spreading of residual sludge from urban treatment plants for tomatoes. An increase in the growth in height and in diameter of the seedlings is remarkable in the 40% sludge fraction, compared to the seedlings grown in the ordinary soil and the substrate of 20% sludge. This means that the addition of sludge constitutes a satisfactory fertilization in nitrogen and organic matter. However, the residual load of nitrogen and heavy metals can present a risk of contamination of the water table by nitrates and also a risk of soil pollution by heavy metals. The cultivation of plants that bio-accumulate these pollutants is strongly recommended before any use of these soils for other crops.

Agricultural land application of sewage sludge would be an environmentally benign solution to traditional disposal issues, reducing the requirement for commercial fertilizers and, as a result, protecting our environment. Proper environmental protection management, concentrating on the potential dangers of heavy metal pollution, can sustain the benefits of wastewater for soil fertility and sludge spreading. More research is needed to track the accumulation of heavy metals in soil and to look into the pre-treatment of sewage sludge before it is applied to agricultural land. Additionally, future research should investigate the use of sludge spreading rates (40%) to maintain better soil fertility while reducing the risk of sludge buildup and heavy metal pollution of soils. Additionally, trace metals in fruits and vegetables should be carefully monitored.

It should be noted that Algerian (Executive Decree No. 2006-138), European and World Health Organization (86/278/EEC) directives have been established relating to the use of sewage sludge by farmers as fertilizer, in order to avoid harmful effects on the environment and human health, by ensuring that the nutritional needs of plants are taken into account and that the quality of the soil and surface and ground water is not compromised.

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