The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 30, Pages 72-77

ICBAST 2024: International Conference on Basic Sciences and Technology

Chemical Properties of Agricultural Soils after Applications of Municipal Sewage Sludge

Rabia Cherfouh
Mouloud Mammeri University

Khaled Ouali
Mouloud Mammeri University

Si Ammar Kadi
Mouloud Mammeri University

Azeddine Mouhous
Mouloud Mammeri University

Ali Bouzouren
Mouloud Mammeri University

Zahia Dorbane
Mouloud Mammeri University

Nacima Zimbri-Zirmi
Mouloud Mammeri University

Houci Guermah
Mohamed Boudiaf University

Farid Djellal
Ferhat Abbas University

Idir Moualek
Mouloud Mammeri University

Dahia Saidj
Saad Dehleb University

Abstract: An alternative technique for disposing and managing municipal sewage sludge is its application to soils associated with crop production. The aim of the present study was to evaluate the suitability of the existing sludge application routes in terms of the fertility of the soil and the accumulation of heavy metals. A chemical analysis was carried out on four agricultural soils located in the north-central region of Algeria, which had been subjected to an irregular application of sewage sludge for more than ten years. Results showed high levels of organic matter, nitrogen, phosphorus and potassium in the sludge samples. The amended soils are characterised by an increased content of organic matter and an improved availability of nutrients, including nitrogen, potassium and phosphorus. In addition, the pH of the soil solution is close to neutral, there is an increase in the cation exchange capacity and there is no change in the electrical conductivity. The total concentrations of cadmium, copper, nickel and zinc were found to be consistently low and below the acceptable limit values for soil. Copper accumulation in P3 soil was slightly above standard (122.4 mg.kg-1). However, amended soils

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

showed remarkable Cu (+167%) and Ni (+84%) accumulation. Whereas the total concentration of Cd is slightly lower than in the control soil, its speciation indicates a very high bioavailability. The results show that sewage sludge application has a positive effect on the availability of essential elements and the improvement of soil properties. However, inappropriate use and/or inaccurate application rates can lead to soil contamination with potentially toxic heavy metals.

Keywords: Municipal sewage sludge, Nutrients, Heavy metals, soil, Chemical properties.

Introduction

The objectives of land production, the search for the reduction of mineral fertilisers and for a circular economy are driving the agricultural use of sewage sludge (SS). In Algeria, the amount of SS currently produced by urban wastewater treatment plants is about 450,000 tons per year (Cherfouh et al., 2018; Hannachi et al., 2014). The weakness of soil fertility has increasingly promoted agricultural use, as this practice helps to avoid its uncontrolled disposal, recycles nutrients and minimizes soil pollution in terms of direct discharge into the natural environment (Montes et al., 2023; Rehman et al., 2013).

It is established that sewage sludge is a rich source of nutrients, including nitrogen and phosphorus, as well as organic matter and trace elements that are beneficial for plant growth and yield (Cherfouh et al., 2022; Kautale et al., 2005; Wong et al., 1995). Furthermore, sewage sludge is regarded as a viable alternative to commercial fertilisers. Sewage sludge has the potential to enrich soil with macronutrients, including phosphorus, potassium, sulphur, calcium and magnesium, as well as micro-nutrients (Cherfouh et al., 2018).

The dearth of experimental data on the effects of SS on soil properties gives rise to concerns regarding the potential damage caused in terms of soil quality, environmental pollution and human health problems. The necessity to consider the environmental hazards has prompted a multitude of studies and has prompted the authorities of numerous countries to establish regulations for the utilisation of SS in accordance with its heavy metal content and soil characteristics (Merdy et al., 2024; Mishalli et al., 2014).

The objectives of this work are to determine the effect of sewage sludge amendment on agronomic soil properties and to assess the potential contamination with heavy metals. In the absence of regulatory requirements, and as the agricultural use of SS started empirically, our objective is to find indications that the existing use routes for sewage sludge are sustainable in the long term.

Materials and Methods

Soil Sampling

The sampling was conducted in April 2021 to allow for the inclusion of pedological turnover processes. The study area is situated in the Tizi-Ouzou district of northern Algeria. Three representative vineyard soils receiving sewage sludge (S-SS) and a reference soil (RS) that did not receive either SS were sampled. At each site, five soil cores were sampled at the corners and at the centre at a depth of 0 to 10 cm. The five samples were thoroughly mixed together to create a composite soil sample. The samples were then air-dried and sieved at 2 mm. Aliquots of the < 2 mm soil fraction were ground in an agate mortar and stored in polyethylene containers at 4 °C until analysis.

Analysis

The soil texture was determined using the Robinson pipette method. All solutions were prepared using high-purity water and analytical-grade chemicals (Merck). For the sludge and soil samples, the pH and electrical conductivity (EC) were determined using a 1:5 soil-to-water ratio. The organic carbon and total nitrogen content of the solid samples (soils and SS) were determined using a CHNS apparatus (Shimadzu, Flash 2000) following H3PO4 pre-treatment (Pastor et al., 2011). For the liquid samples (water extracts), the dissolved organic carbon was determined using a TOC (total organic carbon) analyser (TOC-V CSH, Shimadzu). The cation exchange capacity (CEC) was determined for the sludge and soil samples by the cobaltihexamine procedure (Tarchouna et al., 2010). The metal contents were quantified by ICP-AES (inductively coupled plasma atomic emission spectrophotometry), while the ion concentrations in solution (nutrients and other major species).

Results and Discussion

Main Agronomical Characteristics of the Studied Soils, Sludge, and Wastewater

Tables 1 present the principal agronomical characteristics of the soils and SS. With regard to the soils, the values indicated in Table 1 pertain to the 0-10 cm soil layer. The SS exhibited elevated concentrations of soil organic matter (SOM) and total nitrogen, accompanied by a low C/N ratio (6.3). The water extract of the SS exhibited elevated concentrations of both dissolved organic carbon (WEOC) (1455 mg L^{-1}) and total nutrients. The given values for nutrients confirm the potentially positive agronomical effect of spreading sludge. The SS had high amounts of leachable Ca^{2+}, Mg^{2+}, K+, and SO_4^{2-} and lower, but non-negligible, concentrations for the sum of nitrogen species and PO_4^{3-}. Its high SO_4^{2-} value may be related to the possible use of sulphate compounds during the wastewater treatment process, as expected due to their high solubility. These attributes are likely associated with the elevated K^+, Ca^{++}, NO_3^- and SO_4^{2-} values observed in the studied soils (S1, S2 and S3) when compared to the reference soil (RS), which has not been amended.

Granulometry and Dry Bulk Density.

The three studied soils showed similar mineral particles size distribution. According to the texture triangle, S1 is loam, S2, S3 and RS are silt-loam, this variability being consistent with the natural variability of the parental material. The Values of dry bulk density are in the range expected for the surface soil layer, between 1.1 and 1.3g.cm^{-3}.

Soil pH

All soils exhibited a neutral to slightly alkaline pH (USDA, 1993). With regard to the reference soil, the application of SS resulted in a slight but significant increase in the average soil pH from 7.05, 7.69, 7.78, and 7.88 respectively (Table 1). The majority of studies have demonstrated that the application of sludge results in a reduction in pH soil. Here the elevated levels of potassium, calcium, and magnesium cations from the SS, when combined with the low organic matter content of the soil, are likely to result in an increase in soil alkalinity and subsequently in soil pH (figure 1).

Cation Exchange Capacity (CEC), Electrical Conductivity (EC) and SOM

The CEC values are within the typical range observed for this soil type, they were higher in amended soils than in the RS. This shows the improvement in the soil's ability to fix nutrients after sludge spreading (figure 2.).The EC values in soil extracts remained below 55.4 µS.cm^{-1}, despite the SS extract exhibiting significant conductivity (946.5 µS.cm^{-1}). The low EC values in soils indicate sufficient leaching by annual deep drainage of soluble chemical species, indicating a very low risk of injury to all cultivated crops. The soil organic matter (SOM) content of the upper horizon is low (0.94%) in the RS, which is consistent with the characteristics of a Mediterranean soil. The application of sewage sludge resulted in a notable increase in SOM content, with values rising from 1.45, 2.41 and 2.98, respectively.

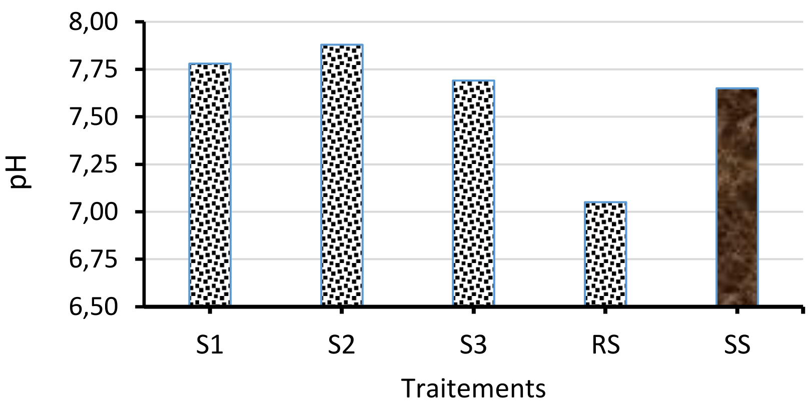

Figure 1. pH of the soil solution in amended soils

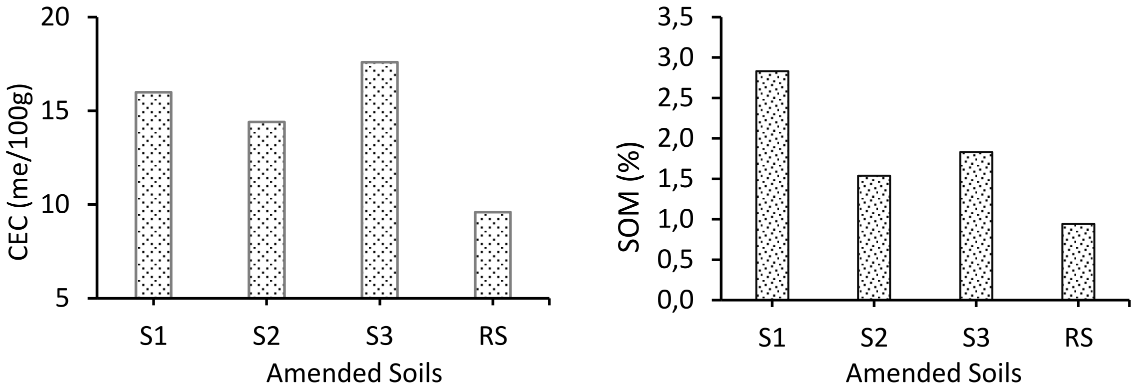

Figure 2. Cation exchange capacity and soil organic matter in amended soils

Water Extractable Nutrients

The sewage sludge exhibited elevated levels of leachable nutrients, including calcium, magnesium, potassium, and sulphate. These attributes are likely associated with the elevated values observed for the S1, S2, and S3 soils when compared to the RS soil. The findings demonstrated that SS amendment enhanced nutrient availability, particularly for potassium and phosphorus, in alignment with previous research.

Total Content of the Heavy Metals in Soils and Sewage Sludge

The sludge SS gave about 0.5, 119.6, 107.1 and 365.6 mg kg-1 for Cd, Cu, Ni and Zn respectively. These heavy metal concentrations remain below the standard value for agricultural purposes. The sludge application leads to higher metal contamination on the soils. The metal accumulation index shows considerable variation among different soil types, with values ranging from 0.8 to 5.2 for copper, from 2.0 to 2.7 for nickel and from 2.2 to 4.1 for zinc. The concentration of Cd was found to be lower than that of the reference soil. This is probably due to the increased mobility of Cd in the studied soils.

Table1. Agronomic parameters for sludge (SS) and studied soils (S1, S2 and S3). Average values for the 0–10 cm soil layer.

Parameter	Unit	S1	S2	S3	RS	SS
CEC	$me.100g^{-1}$	16.00	14.4	17.6	9.6	38.5
SOM	%, w/w	2.83	1.54	1.83	0.94	22.78
N total	%, w/w	0.25	0.11	0.14	0.09	3.61
C/N	#	11.52	14.11	13.01	10.38	6.31
WEOC	$mg.L^{-1}$	129.8	62.04	65.39	172.42	14550
pH	#	7.78	7.88	7.69	7.05	7.65
CE	$\mu S.cm^{-1}$	55.4	45.2	43	78.2	946.5
Ca^{++}	mg.L-1	28.77	21.98	23.97	14.4	1057.6
Mg^{++}	mg.L-1	2.85	3.16	3	10.03	198.1
K^{+}	mg.L-1	10.66	6.43	4.63	1.57	2487.4
Na^{+}	mg.L-1	2.01	1.76	2.21	1.59	553.6
Cl-	mg.L-1	2.01	1.87	1.76	0.87	784.6
F-	mg.L-1	0.07	0.26	0.27	14.72	nd
NO_3^{-}	mg.L-1	2.07	1.54	0.91	0.45	nd
NO_2^{-}	mg.L-1	0.77	0.36	0.53	5.55	nd
PO_4^{---}	mg.L-1	9.68	0.55	nd	3.59	900.9
SO_4^{--}	mg.L-1	4.12	6.92	2.96	3.72	5595.4
Cd	mg.kg-1	0,17	nd	0,05	0,21	0,49
Cu	mg.kg-1	42,27	122,36	20,99	25,07	119,66
Ni	mg.kg-1	31,53	23,11	29,76	11,81	107,15
Zn	mg.kg-1	123,87	68,34	87,02	30,49	365,57

Furthermore, the concentration of Cd was found to be well below the ceiling value (2 mg kg-1). The pH value recorded in the soil solution is indicative of alkalinity, suggesting that the solubility of ETMs is relatively low. The concentration of metals in the soil has a strong influence on the uptake by plants and on the biological life dependent on the soil (wong et al., 1995). The bioavailability regimes of metals vary with total content, leading to differences in the rates of soil processes such as SOM decomposition and soil chemistry. It's essential to determine the chemical speciation of heavy metals in the soil to get the best view of bioavailability. Recently, Merdy et al (2024) found that the Time to Critical Content Index (TCCI) for metals to reach the critical threshold was very different depending on whether the analysis was based on total content or on readily bioavailable fractions of metals.

Conclusion

The application of sludge has been demonstrated to result in elevated nutrient levels and a marked enhancement in soil fertility. These findings demonstrate the potential of urban sewage sludge application as a means of improving soil quality, even in the absence of data on the specific doses and frequencies employed. From an environmental perspective, however, the potential for soil contamination by heavy metals requires assessment.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements

* We would like to thank the Algerian Ministry of Higher Education and Scientific Research (MESRS) and the Mouloud Mammeri University of Tizi-Ouzou for the facilities that made it possible to carry out this work and to present it as a poster at the International Conference on Basic Sciences and Technology (ICBAST2024).

* This article was presented as a poster presentation at the International Conference on Basic Sciences and Technology (www.icbast.net) held in Antalya/Turkey on November 14-17, 2024.

References

Cherfouh, R., Lucas, Y., Derridj, A., & Merdy, P. (2018). Long-term, low technicality sewage sludge amendment and irrigation with treated wastewater under Mediterranean climate: impact on agronomical soil quality. *Environmental Science and Pollution Research*, *25*(35), 35571-35581.

Cherfouh, R., Lucas, Y., Derridj, A., & Merdy, P. (2022). Metal speciation in sludges: A tool to evaluate risks of land application and to track heavy metal contamination in sewage network. *Environmental Science and Pollution Research*, *29*(46), 70396-70407.

Hannachi A, Gharzouli R, Djellouli Tabet Y (2014) Gestion et valorisation des eaux usées en Algérie. *Larhyss J 19*, 51–62.

Kauthale, V. K., Takawale, P. S., Kulkarni, P. K., & Daniel, L. N. (2005). Influence of flyash and sewage sludge application on growth and yield of annual crops. *International Journal of Tropical Agriculture*, *23*(1-4), 49-54.

Merdy, P., Cherfouh, R., & Lucas, Y. (2024). Long-term agricultural reuse of treated wastewater and sewage sludge: developing a Time to Critical Content Index for metal species. *Environmental Monitoring and Assessment*, *196*(9), 1-14.

Montes, R., Méndez, S., Carro, N., Cobas, J., Alves, N., Neuparth, T., ... & Rodil, R. (2022). Screening of contaminants of emerging concern in surface water and wastewater effluents, assisted by the persistency-mobility-toxicity criteria. *Molecules*, *27*(12), 3915.

Mtshali, J. S., Tiruneh, A. T., & Fadiran, A. O. (2014). Characterization of sewage sludge generated from wastewater treatment plants in Swaziland in relation to agricultural uses. *Resources and Environment*, *4*(4), 190-199.

Ramdani, N., Hamou, A., Lousdad, A., & Al-Douri, Y. (2015). Physicochemical characterization of sewage sludge and green waste for agricultural utilization. *Environmental Technology*, *36*(12), 1594-1604.

Ramdani, N., Hamou, A., Lousdad, A., & Al-Douri, Y. (2015). Physicochemical characterization of sewage sludge and green waste for agricultural utilization. *Environmental Technology*, *36*(12), 1594-1604.

Soil Survey Division Staff. (1993). Soil survey manual. Soil conservation service. *United State Department of Agriculture Handb. 18*.

Tarchouna, L. G., Merdy, P., Raynaud, M., Pfeifer, H. R., & Lucas, Y. (2010). Effects of long-term irrigation with treated wastewater. Part I: Evolution of soil physico-chemical properties. *Applied Geochemistry*, *25*(11), 1703-1710.

Author Information

Rabia Cherfouh
Mouloud Mammeri University
17 RP, Tizi-Ouzou Algeria
Contact e-mail:rabiacherfouh@yahoo.fr

Khaled Ouali
Mouloud Mammeri University
17 RP, Tizi-Ouzou Algeria

Si Ammar Kadi
Mouloud Mammeri University
17 RP, Tizi-Ouzou Algeria

Azeddine Mouhous
Mouloud Mammeri University
17 RP, Tizi-Ouzou Algeria

Ali Bouzouren
Mouloud Mammeri University
17 RP, Tizi-Ouzou Algeria

Zahia Dorbane
Mouloud Mammeri University
17 RP, Tizi-Ouzou Algeria

Nacima Zimbri-Zirmi
Mouloud Mammeri University
17 RP, Tizi-Ouzou Algeria

Houci Guermah
Mohamed Boudiaf University
M'sila, Algeria

Farid Djellal
Ferhat Abbas University
Setif, Algeria

Idir Moualek
Mouloud Mammeri University
17 RP, Tizi-Ouzou Algeria

Dahia Saidj
I. S. V. ,Saad Dehleb University,
Blida, Algeria

To cite this article:

Cherfouh, R., Ouali, K., Kadi, S.A. Mouhous, A., Bouzourene, A., Dorbane, Z., Zirmi-Zembri, N., Guermah H. Djellal, F., Moualek, I. & Saidj, D. (2024). Chemical properties of agricultural soils after applications of municipal sewage sludge. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 30,* 72-77.