Research Article
P-ISSN: 3070-9296
E-ISSN: 3070-930X

Crystal Journal of Environmental Science, Innovation & Green Development

Developing the Fertilizer Potential of Biochar Produced from Sewage Sludge

Amil A. Ibadov*

Hacettepe University, Türkiye

Corresponding Author: Amil A. Ibadov, Hacettepe University, Türkiye

Cite: Ibadov, A. A. (2026). Developing the fertilizer potential of biochar produced from sewage sludge. Crystal Journal of Environmental Science, Innovation & Green Development, 2(3), 01-06.

Received: February 28, 2026; **Accepted:** April 09 2026; **Published:** May 01, 2026

Abstract
One of the most serious problems humanity faces is the increasing pollution of soils over time, leading to a reduction in the area where fruits, vegetables, and agricultural products are grown due to the escalating soil contamination. One of the most effective methods to prevent soil crisis could be the reprocessing of anthropogenic waste that harms nature to some extent. The reprocessing of human-generated wastes, such as sewage sludge (SS), plays a critically important role in eliminating soil pollution. Currently, sewage sludge management is a significant issue in environmental engineering. Sewage sludge is a residue similar to mud originating from wastewater treatment. This sewage waste contains attractive levels of nitrogen (N) and phosphorus (P) from an agricultural perspective, and its use as a soil improver in agriculture has been observed. However, since sewage sludge contains various harmful substances such as heavy metals, pharmaceuticals, certain pathogens, and toxic organic compounds, applying untreated sewage sludge can pose a threat to human health and the environment. Therefore, proper processing and disposal of sewage waste are crucial to minimize potential risks to human health and the environment. Pyrolysis, a thermal treatment, can be employed to address environmental issues like these.

Keywords
Sewage Sludge, Biochar, Soil Pollution, Fertilizer, Eco-Friendly

Introduction

Currently, inappropriate farming techniques, indiscriminate use of fertilizers and pesticides lead to soil degradation, a decrease in soil organic matter, and adverse effects on plant growth. Among the methods contributing to soil improvement, the use of sewage sludge has become increasingly popular in recent years [1, 2]. Sewage sludge, a waste product derived from sewage treatment in wastewater treatment plants, has agriculturally suitable levels of N (%1.5-4.0), P (%0.3-1.2), and organic carbon, making it a soil conditioner that has been used for centuries to sustain productivity in agricultural soils [3].

However, sewage sludges have diverse sources, and their contents vary. The quantity of sewage sludge depends on the degree and characteristics of wastewater pollution, the processes applied in the treatment plant (physical, physiochemical, biological, etc.), and the quality of the treatment. Nevertheless, the processes applied for the treatment and disposal of sewage sludge in treatment plants are often inadequate. This inadequacy may arise from either the failure to construct the units envisaged during the planning stage or the unhealthy operation of existing units [4]. Additionally, the application of untreated sewage sludge, along with pathogens, raises health concerns due to organic and inorganic pollutants [3]. Various studies have identified that such sludge containing heavy metals like lead (Pb), arsenic (As), and chromium (Cr) pose a carcinogenic risk, especially for children [5]. Due to these reasons, the direct use of sewage sludge as a soil conditioner in agriculture is an insufficient and not recommended solution.

While sewage sludge is hardly used for agricultural purposes in Belgium, the Netherlands, and Sweden, in Germany, the United

Kingdom, France, and Portugal, 30-70% of the produced sludge is used for agricultural purposes. As of the end of 2018, the number of wastewater treatment plants serving approximately 83% of the Turkish population, equivalent to 54,484 tons of dry sludge daily, has reached 991 [4].

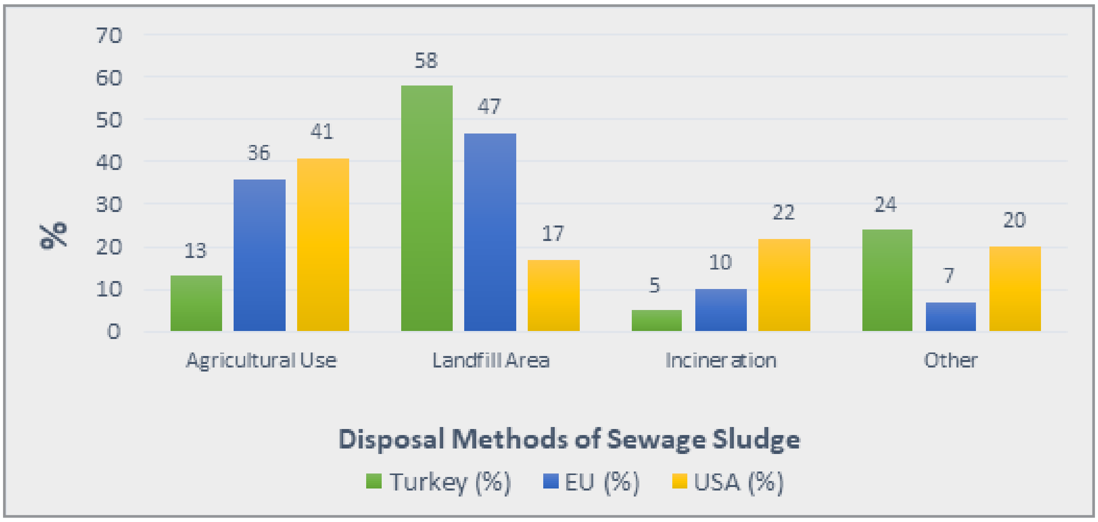

Figure 1: Disposal Methods of Sewage Sludge in Turkey, EU and USA

Newly emerging pollutants such as pharmaceuticals, personal care products, flame retardants, and micro-plastics have further heightened concerns regarding the agricultural use of sewage. Processes like composting and anaerobic digestion can, at best, only partially address the associated health issues [6].

The pyrolysis method allows the conversion of sewage sludge into biochar. The biochar obtained captures toxic elements such as copper (Cu), cadmium (Cd), and chromium (Cr) that were present in the sewage sludge, rendering them inert and preventing them from mixing with the soil. One issue with the material obtained through pyrolysis is its low potassium (K) content. The addition of potassium is necessary to enhance the absorption of phosphorus into the soil. One of the crucial features of the project is to increase the amount of potassium in biochar, thereby enhancing its effectiveness as a fertilizer. For this purpose, potassium acetate salt is used in the project. The soil-improving properties of the biochar obtained are supported by laboratory analyses.

Utilizing biochar derived from sewage sludge that would otherwise poison the soil can significantly contribute to solving environmental problems. The goal of the project is not only to use the final product as a fertilizer in agriculture but also to clean soils affected by human-made wastes. This report will highlight the severity of soil and sewage waste problems and explain how the solution addresses these issues. Additionally, you can find detailed information about the innovative aspects and applicability of the method. After providing estimated cost for the project, the target audience is discussed. Factors that could negatively impact the project are also identified, and a bibliography of literature used is included.

Solution

In response to the serious attention given to this issue by the government in recent times, I envision contributing by transforming sewage sludge accumulated in sewer systems and septic tanks into biochar. This biochar can then be utilized as soil fertilizer in agricultural lands.

Thermal processes, incineration, and pyrolysis are alternative treatment methods. Pyrolysis is a method that breaks down a substance into products under high temperatures and anaerobic (oxygen-free) conditions. It sterilizes the material and reduces the concentration of organic toxins (e.g., poly-cyclic aromatic hydrocarbons (PAHs), poly-chlorinated biphenyls (PCBs), and dioxins), pharmaceuticals (e.g., hormones), and other micro-components (plastics, surfactant). Additionally, it passive immobilizes potentially toxic elements like Cu, Cd, and Cr found in the raw material, reducing the risk of leakage and plant uptake. Unlike incineration, pyrolysis retains most of the carbon in the sewage sludge [5-7].

Contrary to additives like calcium (Ca), iron (Fe), and magnesium (Mg) in pristine biochar, which have been shown to reduce the presence of P, I believe using potassium (K) as a pre-pyrolysis additive can reverse the situation. Potassium phosphate salts exhibit very high solubilities, and the hypothesis suggests that if K is abundantly present, pyrolysis could result in the preferred formation of potassium phosphate, thereby increasing the presence of P in biochar. I used potassium acetate as a pre-pyrolysis additive due to its widespread use and low cost ($25 per ton) for general applications like de-icing [8]. The aim is to produce a more complete carbon-sequestering fertilizer with well-balanced nutrient availability.

Considering both financial and feasibility aspects, I believe this solution, which I find highly effective and practical, also supports recycling or reuse, which are fundamental initiatives of the modern approach. If pyrolysis vapors and liquids are used to feed the process or renewable energies, atmospheric carbon removal, storage, and environmental impact-wise, pyrolysis for sewage sludge can be considered the most sustainable solution [5].

Method

Sewage sludge was obtained from AzerSu, a state institution in Azerbaijan dealing with the distribution of drinking and general-use water, as well as the recovery of sewage water. The sludge was delivered in containers and primarily consisted of solid sediment and a relatively clear liquid on top (Figure 3). The excess liquid was drained off (Figure 4), and the remaining wet residue was filtered through a vacuum filter (Figure 5).

Figure 2:

Figure 3:

Figure 4:

To facilitate the transfer of dried solids onto the polymer filter, filter paper was placed on top of the polymer filter. Due to the limited size of the vacuum filter, this drying process was repeated several times. The obtained solids were left to air-dry for a day. Subsequently, they were carefully scraped off and placed into an hourglass, and the total wet weight of the sample was measured. This sample was then placed in an oven heated above 100°C. The solid was allowed to dry in the oven for 30 minutes and then removed for cooling. Afterward, an appropriate amount of 1 normal N potassium acetate solution was added to moisten the dried sample, increasing the potassium content to approximately 5% of the initial wet weight.

Figure 5:

Figure 6:

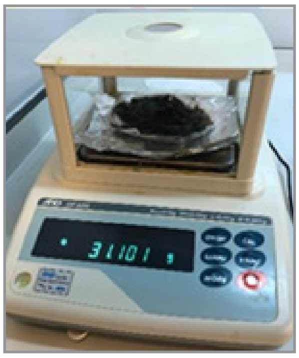

Figure 7:

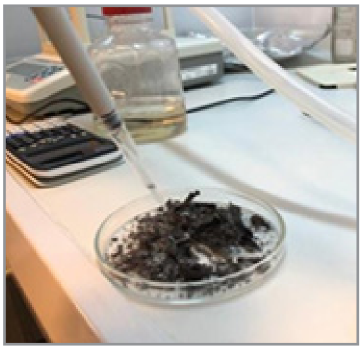

Figure 8:

Figure 9:

Figure 10:

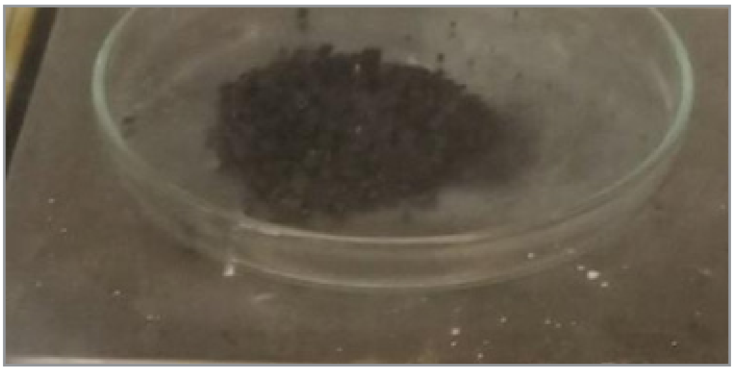

Figure 11: Final Product

Finally, the sample was placed into the pyrolysis reactor and gradually heated to 700°C under a continuous flow of nitrogen gas. Pyrolysis was maintained at 700°C for 21.5 minutes, and then the final product was removed from the reactor. This led to the breakdown of organic toxins such as polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pharmaceuticals, surfactants, etc. During the pyrolysis process, the mass of the sample decreased from 6.4 g to 2.0 g, indicating a yield of 31.25%.

In terms of the product analysis, the electrical conductivity of the biochar dissolved in deionized water at a ratio of 1:20 by mass was found to be 6.04 mS, and the pH level was 10.64. Unlike soil, which contains other elements such as Ca and N, the absence of these substances in the used water means that the figures are considered above standard. For example, studies have shown that the presence of calcium increases phosphorus absorption and lowers the pH below 8.5. Therefore, pH values around 10 are not typically expected in agricultural applications [9-14].

Phosphorus (P) extraction analysis on the samples was utilized to investigate the impact of added potassium on how well phosphorus could be extracted from biochar in the soil. The percentage of extractable P was calculated as 0.807 by dividing the amount of P in the solution formed after extraction (determined using Optical Emission Spectroscopy) by the amount of P present in the biochar (determined using Elemental Analysis). This was done to examine the effectiveness of potassium in facilitating the extraction of phosphorus from biochar in the soil.

$$P_{extractable}\ (\%) = \frac{P_{solution}}{P_{bioc\ har}} = 0.807\%$$

When compared to the value of potassium in pristine biochar (%0.047) as reported in studies by Buss and others, the obtained value is 17 times larger, demonstrating a significant improvement [5]. According to the results of elemental analysis, the concentration of cadmium in the biochar was reported to be less than 0.08 mg/kg, indicating that the harmful element is virtually negligible. As for zinc, its concentration of 1890 mg/kg is below the limit value specified in the Regulation on the Use of Municipal and Urban Treatment Sludges in Soil (Appendix 1-B), which is 2500 mg/kg, making it harmless [14]. The potassium content was determined to be 3.57%.

Innovative Aspect

Biochar is a type of fertilizer that has gained increasing attention and priority in recent years, offering many advantages over mineral and organic fertilizer types. In a brief overview, mineral fertilizers provide the nutrients needed for strong plant growth in high quantities, while organic sources contain organic carbon, a fundamental component of healthy soil. However, various applications have revealed that mineral fertilizers have short-term beneficial effects on measured variables such as plant growth, pH, base saturation, cation exchange capacity (CEC), and many other nutrients. These effects are often limited and may result in toxicity to plants and significant damage to growth due to high pH values. Additionally, the addition of mineral fertilizers to sandy soil under high rainfall is futile, as most nutrients are rapidly washed away, causing serious negative effects on the economy and water pollution.

As for organic fertilizers, compost with high nutrient content (Ca and Mg) in plants and higher CEC and pH values (only in the initial growth period) yields better short-term results. However, compost fertilizer is not universally available and, due to its weight and volume, cannot be transported over long distances, making it a costly option. Furthermore, composting is a technology-intensive process, requiring heavy equipment for processing raw materials and transporting compost to fields.

Innovation takes center stage as an ideal solution for longer-term and sustainable approaches – biochar stands out as a unique solution that can positively impact plant yield, soil fertility, nitrogen dynamics, phosphorus retention, and carbon sequestration, whether used alone or in combination with mineral and organic fertilizers.

The key innovation lies in leveraging the pre-pyrolysis contribution of potassium, in contrast to elements like Ca, Fe, and Mg in biochar, to increase the presence of phosphorus in biochar. Utilizing potassium acetate salts with high solubility, which are widely available and economical, makes the project technically sound and addresses potential feasibility issues.

Applicability

Biochar is a lightweight black residue consisting of carbon and ash left after the pyrolysis of biomass. It is used to reduce soil pollution and improve soil fertility.

According to the "Global Biochar Market Forecast" report, it is estimated that the global biochar market will experience an increase in revenue by 13.57% and in volume by 11.22% CAGR (Compound Annual Growth Rate) from 2020 to 2028. The market is expected to reach a volume of approximately 980.26 kilo tons and generate revenue of 4064.50 million dollars by 2028. The growth of the global biochar market is dependent on various factors, including the easy availability of diverse and inexpensive raw materials, reliable and continuous workflow, the carbon sequestration ability of biochar, and, finally, enhanced environmental regulations. Environmental regulations are a major driving force for the biochar market. The soil improvement and carbon sequestration properties of biochar positively contribute to the environment by reducing greenhouse gases. Thanks to these features, biochar has become an increasingly produced product over time.

In Turkey, it was reported in 2015 that the potential for agricultural and animal production waste to be converted into biochar was 3,942,654 tons. Animal wastes account for a large portion of the biochar conversion potential, ranking first with a rate of 77%, followed by garden pruning waste at 22.5%, and field agricultural waste covering only 0.6% of biochar production [12].

Considering the chemical methods for obtaining biochar from sewage sludge taken from water treatment plants, it is anticipated that since sewage sludge is waste, it will have no cost. Moreover, considering the environmentally friendly nature of biochar and the growth potential of the market in Turkey, the project is likely to be successful.

Table 1: Total expenses of project

EXPENSES				
No	**Work Package Name**	**Description**	**Need/Materials**	**Cost**
1	Sewage Sludge Collection	Raw material of biochar is supplied by the government institution.	1 L sludge	Available
2	Filtration	Solid particles are filtered from sewage sludge using a vacuum filtration system. Liquid-solid particles are separated by filter material.	Vacuum Pump, Vacuum Filter, Filter Paper	Available
3	Drying	The sludge quantity is minimized, and the product quality is enhanced by drying.	Drying Oven	Available
4	Material Transfer	Materials are transferred in a safe and proper process for use in other stages.	Watch Glass	Available
5	Increasing Potassium Amount	Potassium acetate is used to increase phosphorus absorption in soil, and the potassium content is adjusted.	125 g of Potassium Acetate	3 USD
6	Pyrolysis	The sludge is converted into biochar by pyrolysis at high temperature and low oxygen.	pyrolysis reactor pyrolysis heater rubber pipe quartz glass shards	Available
7	Laboratory Analysis	The substance obtained is tested for soil enhancement. Biochar that passes the test is used to improve soil fertility.	Tests conducted at "Caspian Ecology Laboratory."	40 USD

The Situation Regarding the Project's Feasibility with the Least Cost

As the sewage sludge waste, which is used in biochar production, falls into a low-cost category, it incurs no expenses. Potassium acetate, an additional substance used, is a low-cost and readily available material. Consequently, if the production of the soil improver/fertilizer transitions to mass production, it is anticipated that the project will result in a cost-effective product in the end.

Target Audience of the Project Idea (USERS)

The project appeals to a wide range of people. The priority is two main groups: farmers and urban residents. Unfortunately, soil degradation is not limited to physical occupation alone. Harmful accumulation of organic and inorganic pollutants occurs in the soil due to excessive fertilization and pesticide use. Additionally, industrial activities contribute to soil pollution as chemical pollutants from water and air pollution mix with the soil. Among the inorganic substances causing soil pollution, heavy metals are prominent. Farmers and rural residents are most affected by this type of soil pollution. In cases of high accumulation, heavy metals can exhibit carcinogenic and lethal properties. On the other hand, atmospheric discharges and waste materials generated during industrial activities contain heavy metals. Especially in large cities like Istanbul, Izmir, and Ankara, toxic gases released into the air lead to acid rain, significantly polluting the soil. Urban residents are the most affected by this pollution [13].

Through the project, the soil will be cleansed of harmful substances, resulting in more efficient and beneficial soil in both urban and agricultural areas.

References

1. Oden, M. K., Özer, İ., & Horasan, B. Y. (2019). Investigation of usage samples of treatment sludges in agricultural areas. Turkish Journal of Agriculture – Food Science and Technology, 743–749. Accessed December 14, 2022.
2. Kominko, H., Gorazda, K., & Wzorek, Z. (2017). The possibility of organo-mineral fertilizer production from sewage sludge. Waste Biomass Valorization, 8, 1781–1791. Accessed December 10, 2022.

3. Sewage sludge problem in Turkey. (n.d.). Literature research. Chapter 5.1, p. 217. Accessed December 11, 2022.
4. Yakamercan, E., Ari, A., & Aygun, A. (2021). Land application of municipal sewage sludge: Human health risk assessment of heavy metals. Cleaner Production, p. 8. Accessed December 19, 2022.
5. Buss, W., Bogush, A., Ignatyev, K., & Masek, O. (2020). Unlocking the fertilizer potential of waste-derived biochar. ACS Sustainable Chemistry & Engineering, 8, 12295–12303. Accessed October 13, 2022.
6. Potassium acetate – Acetic acid potassium salt. (n.d.). Retrieved February 2, 2023, from https://www.alibaba.com/product-detail/Potassium-Acetate-Acetic-acid-potassium-salt_11000006699183.html
7. Buss, W., et al. (2018). Biochar phosphorus release is limited by high pH and excess calcium. Journal of Environmental Quality, 47(5), 1298–1303. Retrieved January 20, 2023, from https://doi.org/10.2134/jeq2018.05.0181
8. Yasal mevzuat (İP 4). (2010). Regulation on the use of domestic and urban treatment sludges in soil (Official Gazette No: 27661 dated 03.08.2010). Chapter 4.1.1, p. 128, Table 4.2. Retrieved from https://webdosya.csb.gov.tr/db/destek/icerikler/ek4-20191127123641.pdf
9. Üstündağ, Ö. (2022). Investigation of the adsorption properties of biogas plant wastewater and the possibilities of its use in agriculture (Doctoral thesis). Soil Science and Plant Nutrition Doctoral Program, Adnan Menderes University, p. 13. Accessed December 6, 2022.
10. Karaca, A., & Turgay, O. (2012). Toprak kirliliği (Soil pollution). Toprak Bilimi ve Bitki Besleme Dergisi (Journal of Soil Science and Plant Nutrition), 1(1), 13–19. Accessed December 15, 2022.
11. Bilen, S., & Kızıloğlu Algan, F. T. (2003). Toprak Kirlenmesi ve Biyolojik Çevre (Soil Pollution and Biological Environment). Retrieved February 1, 2023, from https://dergipark.org.tr/tr/download/articlefile/34208
12. Xiao, R., Wang, J. J., Gaston, L. A., Zhou, B., Park, J. H., Li, R., Dodla, S. K., & Zhang, Z. (2018). Biochar produced from mineral salt-impregnated chicken manure: Fertility properties and potential for carbon sequestration. Waste Management, 78, 802–810. Accessed January 20, 2023.
13. Schulz, H., & Glaser, B. (2012). Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. Journal of Plant Nutrition and Soil Science, 175, 410–422. Accessed January 29, 2023.
14. Grand, A., & Michel, V. (n.d.). Compost: Advantages and disadvantages. Accessed February 1, 2023.