Assessment of heavy metal content and agricultural reuse potential of municipal solid waste incineration ash

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Abstract
Municipal solid waste incineration ash presents a significant environmental challenge globally. In Vietnam, the utilization of ash from waste incineration remains limited, posing potential risks to both the environment and public health. This study aims to analyze the heavy metal content and assess the potential reuse of ash from municipal solid waste incinerators in agriculture. Through sampling and analysis methods, the nutrient composition, including N, P, K, along with heavy metal residues (As, Hg, Pb, Cd), were determined to evaluate its reuse potential. The results indicate that both ash and slag contain high nutrient levels, and the heavy metal content falls within safe limits for agricultural applications. The study proposes solutions for the sustainable reuse of ash, reducing reliance on chemical fertilizers and contributing to the circular economy through effective waste management.
Keywords: *ash; coal ash; heavy metals; municipal solid waste incinerator; slag; reuse.*
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1. INTRODUCTION

Vietnam's population is rapidly increasing, positioning the country as the 14th most populous nation worldwide. This population growth exacerbates waste management challenges, as household waste generation rises significantly. Current landfill sites are overloaded, negatively impacting nearby communities. Waste-to-energy incineration plants are considered an advanced solution, widely implemented in countries like Japan, China, and several European nations (Tun et al., 2020). In Vietnam, facilities such as the Dan Phuong Waste Treatment Plant, the Soc Son Waste-to-Energy Plant, and the Can Tho Waste-to-Energy Plant have adopted this technology. However, the management of ash residue from incineration facilities remains a pressing concern.

Although composting technology for organic waste is known, it still faces challenges in Vietnam. For instance, compost from facilities like Vietstar and Tan Sinh Nghia struggles with high costs and low quality due to inadequate waste sorting, leading to compost backlogs. The use of incineration ash in agriculture is limited compared to its application in construction materials, partly due to concerns about potential hazards like toxins, radioactive substances, explosion risks, and corrosion or toxicity (Van, 2019). Ash can directly impact human health or interact with other elements to pose indirect risks (Ngo & Bui, 2015).

Research indicates that incineration ash can be utilized to improve agricultural soil, in building materials, and in environmental restoration of limestone quarries (Ngo & Bui, 2015). Ash holds substantial potential in agriculture due to its effectiveness in enhancing soil quality and crop yields. High levels of elements like potassium, sodium, zinc, calcium, magnesium, and iron in ash can increase the productivity of various crops (Hafeez et al., 2023). Its alkalinity and high mineral content make ash a viable option for use as fertilizer or soil amendment. Additionally, ash enhances soil structure, increasing porosity, water retention, and drainage capacity (Rashid et al., 2023). This has been shown to benefit the growth of leafy greens, roses, and water spinach, especially for urban households with limited space. Inexpensive and readily available, ash allows for the creation of mini vegetable or flower gardens with minimal effort and cost. Moreover, ash serves as an effective water filtration material, absorbing dissolved organic compounds and maintaining water clarity, which is advantageous for ornamental fish farming (Lavane et al., 2018).

Given the environmental challenges posed by waste incineration and the promising potential of ash reuse in agriculture, this study is crucial in evaluating its feasibility. The research aims to analyze the heavy metal content and assess the reuse potential of incineration ash from municipal solid waste incinerators in agriculture. By understanding the composition of bottom ash, the study seeks to determine its applicability in agricultural settings. The novelty of this study lies in its comprehensive assessment of incineration ash, focusing on its chemical composition and the potential risks and benefits of soil application. This research is significant for environmental sustainability, exploring innovative methods for waste management while enhancing agricultural productivity. Furthermore, the findings have broader implications for sustainable development and socio-economic growth, as using incineration ash in agriculture can reduce dependency on chemical fertilizers, lower agricultural costs, and mitigate the environmental impact of waste management practices. This aligns with promoting a circular economy, where waste materials are repurposed to create value-added products, contributing to environmental protection and economic development.

2. MATERIALS AND METHODS

2.1. Research materials

The ash and charcoal samples were collected from the incinerator 15 minutes after the combustion process began to ensure uniformity and represent the quality of ash at a stable temperature and chemical reaction phase. These samples were provided by Nam Long Xanh Joint Stock Company, a leading entity in solid waste incineration technology located in Binh Chanh district, Ho Chi Minh city, Vietnam. Sampling was conducted in August 2023 to ensure that the data accurately reflect the conditions and characteristics of the incineration process during the study period.

2.2. Sampling and analysis methods

For ash obtained from the incineration of homogeneous solid waste, three representative samples were randomly collected from various points within the waste mass to ensure representative distribution for comparison against hazardous waste thresholds.

The samples underwent leaching analysis following the ASTM D5233-92 standard (Nguyen et al., 2023), a standardized method for single-batch extraction for waste materials. Cadmium (Cd), Copper (Cu), Lead (Pb), and Nickel (Ni) concentrations were subsequently determined using EPA SW-846 Method 3050B and TCVN 647:2007. Atomic Absorption Spectroscopy (AAS) was applied to analyze Iron (Fe) according to ACIAR-AAS 008-2007, Magnesium (Mg) as per ACIAR-AAS 011-2007, Manganese (Mn) in line with ACIAR-AAS 012-2007, Zinc (Zn) according to ACIAR-AAS 019-2007, Mercury (Hg) following ACIAR-AAS 009-2007, and Arsenic (As) based on ACIAR-AAS 001-2007 (García & Báez, 2012).

To provide a comprehensive perspective and suggest effective solutions, the study also included an analysis of charcoal. This comparison aimed to evaluate the specific differences between these two by-products, thereby clarifying the application potential of each within different contexts. The inclusion of both ash and charcoal in the analysis not only broadens the research scope but also enables more detailed recommendations aligned with sustainable agricultural and waste management objectives. Data collection were statistically processed and analyzed using Microsoft Excel 2016 and SPSS 20..

2.3.Evaluation methods for reuse purposes

The evaluation methods and legal framework for the reuse of ash and charcoal are based on the following standards and regulations:

National Technical Regulation on Hazardous Waste Thresholds – Vietnam Standards (QCVN) 07:2009/BTNMT: This standard defines hazardous waste thresholds, covering both inorganic and organic hazardous components. It also specifies technical

▲ *Figure 1. Ash (A) and coal (B) samples used in the experiment* requirements for sampling, analysis, identification, and classification of hazardous waste (QCVN 07:2009/BTNMT, 2009) (Huyen & Tram, 2019).

QCVN: 2018/BNNPTNT – National Technical Regulation on Fertilizer Quality: This regulation establishes quality standards, limiting factors, testing methods, and management requirements for fertilizers during production, import and distribution in Vietnam.

Government Decree No.108/2017/ND-CP on Fertilizer Management: This decree provides guidelines for state management of fertilizers, including recognition, testing, production, trade, export, import, quality management, labeling, advertising, workshops, and use of fertilizers in Vietnam.

Decision No.100/2008/QD-BNN on Production, Trading and Use of Fertilizers: This decision specifies allowable quantitative deviations and mandatory quantitative criteria for various types of fertilizers.

3. RESULTS AND DISCUSSION

3.1. Evaluation of nutritional components in ash and charcoal from municipal solid waste incineration

Table 1 provides information on the N, K, and P content in ash and charcoal derived from the incineration of municipal solid waste. The presented data highlight the primary chemical components that could impact plant growth when these materials are added to soil.

Both ash and charcoal exhibit relatively high alkalinity, with pH values of 9.8 and 9.4, respectively. This alkalinity can be advantageous for agricultural applications, as it may raise soil pH and neutralize acidic soils. Studies have shown that increasing the amount of fly ash can enhance soil pH (Kishor et al., 2010). However, an excessively high pH range, from 11 to 12, can severely inhibit bacterial respiration, impacting enzyme activity and disrupting the nitrogen cycle in soil.

Plants grow best under high humidity, above 90%, as increased respiration intensity promotes rapid germination. For sandy soils, the application of fly ash can alter soil structure, improve micronutrient availability, and enhance water retention (Page et al., 1979). Despite the relatively low moisture content of ash and charcoal, fly ash has a water-holding capacity of 49–66% by weight. Adding up to 46% fly ash can reduce soil bulk density. Increasing fly ash concentration in agricultural soils has been shown to improve soil porosity and water retention, benefiting plant growth (Khan & Wajid, 1996). High soil moisture, when supplemented with incineration ash, creates an ideal environment for seed germination.

The nitrogen content in ash and charcoal is 0.5% and 0.83%, respectively. Nitrogen is an essential nutrient for plant growth, supporting robust development. The phosphorus content (as P_2O_5) is 1.12% in ash and 0.32% in charcoal, playing a vital role in root and flower development, which are crucial for plant growth.

Table 1. N, K, P composition of ash after burning household waste

Parameter	Unit	Ash sample	Coal sample
pH		9.8	9.4
Moisture	%	8.2	10.6
Total N	%	0.5	0.83
Total P as P_2O_5	%	1.12	0.32
Total K as K_2O	%	3.07	1.05

The potassium content (as K_2O) in ash is 3.07%, meeting the QCVN 01-189:2019/BNNPTNT standard, which requires a minimum of 3.0% K_2O in compound fertilizers. This indicates that ash can be an effective potassium source for crops. Although the potassium content in charcoal is 1.05%, lower than the QCVN requirement, it can still contribute potassium to the soil.

In conclusion, the levels of N, K, and P in ash and charcoal from municipal solid waste incineration indicate potential for soil quality enhancement (QCVN 01-189:2019/BNNPTNT, 2019). With their water retention capabilities and essential nutrients, ash and charcoal can support plant growth, reduce fertilizer costs, and promote sustainable agriculture. Utilizing ash and charcoal as viable fertilizer sources not only offers economic benefits but also contributes to environmental protection and sustainable agricultural practices.

3.2. Evaluation of heavy metal residues in ash and charcoal from incinerators

The four micronutrients - Nickel (Ni), Manganese (Mn), Titanium (Ti), and Copper (Cu) - listed in Table 2 may benefit soil and plants at low concentrations. However, excessive nickel can adversely affect plants by slowing germination, inhibiting shoot and root growth, reducing biomass, limiting nutrient uptake from roots, and suppressing photosynthesis and transpiration. At low concentrations, nickel plays an essential role in plants, bacteria, and fungi; thus, nickel deficiency can result in stunted growth, leaf and meristematic tissue infections, altered nitrogen metabolism, and reduced iron uptake (Ahmad & Ashraf, 2012). The nickel content in ash (16.4 ppm) is 2.8 times higher than in charcoal (5.78 ppm).

Manganese is an important mineral nutrient for plants, playing a significant role in various physiological processes, particularly photosynthesis (Rashed et al., 2019). Manganese deficiency commonly occurs in soils with a pH above 6 and in highly weathered tropical soils. It is crucial in enhancing stress tolerance. The deficiency threshold for manganese is generally below 20 ppm in the dry weight of young leaves. The manganese content in ash (557 ppm) is 2.9 times higher than in charcoal (189 ppm).

Titanium is considered beneficial for plant growth. It is absorbed through roots and leaves and is known to improve crop yield by stimulating enzyme activity, increasing chlorophyll content and photosynthesis, enhancing nutrient uptake, strengthening stress tolerance, and improving crop yield and quality. Titanium is beneficial at low concentrations but can become harmful at high levels (Lyu et al., 2017).

Finally, copper is an essential nutrient for plants, yet excessive copper can negatively affect plant growth. The copper content in ash (32.4 ppm) is 2.4 times higher than in charcoal (13.4 ppm). Although copper is a necessary micronutrient for plants, an excess is toxic to most plant species (Shabbir et al., 2020).

According to the data, the metal content in ash and charcoal from municipal solid waste incineration remains below the absolute threshold limits set by QCVN 07:2009/BTNMT (National Technical Regulation on Hazardous Waste Thresholds). Therefore, the ash and charcoal samples can be considered non-hazardous to humans and the environment (QCVN 07:2009/BTNMT, 2009). After screening, the ratio of ash to charcoal was determined to be 12% ash and 88% charcoal. However, the concentration of heavy metals in ash is significantly higher than in charcoal. The results indicate that metal accumulation in ash is approximately 2.5 to 3 times greater than in charcoal.

3.3. Evaluation of toxic heavy metal content and their impact on plant growth

Metals such as arsenic (As), mercury (Hg), cadmium (Cd), cobalt (Co), antimony (Sb), and tin (Sn) are generally harmful to plants upon exposure. These metals adversely affect the physiological and biochemical functions of plants, leading to growth inhibition, chlorosis, necrosis, leaf curling, altered stomatal activity, membrane dysfunction, inhibition of photosynthesis and respiration, and disruptions in metabolism and the activity of essential enzymes (Ashfaque et al., 2016). The study by Farha Ashfaque and colleagues highlights the impact of heavy metals on plants, as detailed in Table 3.

However, results from Table 2 indicate that neither ash nor charcoal contains detectable levels of arsenic (As), mercury (Hg), cadmium (Cd), cobalt (Co), antimony (Sb), or tin (Sn). This absence is advantageous when considering the use of ash and charcoal in products to support plant growth. The lead content in ash and charcoal is 13.1 ppm and 3.95 ppm, respectively. Chromium levels are 29.9 ppm in ash and 11.6 ppm in charcoal. Although the concentrations of lead and chromium in both ash and charcoal are significantly lower than regulatory standards, these metals are harmful to both humans and organisms and should be carefully considered for agricultural applications (Pratush et al., 2018).

Table 2. Metal content from ash and coal

Metal	Unit	Ash sample	Coal sample	Hazardous waste threshold QCVN 07:2009/BTNMT
As	mg/kg	ND	ND	36.88
Hg	mg/kg	ND	ND	3.69
Pb	mg/kg	13.1	3.95	276.6
Cd	mg/kg	ND	ND	9.22
Ni	mg/kg	16.4	5.78	1291
Co	mg/kg	Lower 3.0	ND	1475
Sb	mg/kg	ND	ND	18.44
Cr	mg/kg	29.9	11.6	-
Sn	mg/kg	ND	ND	-
Mn	mg/kg	557	189	-
Ti	mg/kg	444	147	-
Cu	mg/kg	32.4	13.4	-

** Note: ND – Not Detected*

Table 3. Evaluation of toxic heavy metal content and their impact on plant growth (Ashfaque et al., 2016)

Metal	Dosage	Physiological, metabolic and crop yield effects
Cd	200 mg $CdCl_2$/kg soil	Decreased net photosynthesis, RuBisCo activity, increased lipid peroxidation and H_2O_2 content.
	25, 50, 100 and 150 mg $CdCl_2$/kg soil	Decreased dry weight, leaf area, net photosynthetic rate, chlorophyll content and grain yield
	25 and 50 µM/l $CdCl_2$	Decreased photosynthesis, growth, chlorophyll fluorescence, leaf area, dry weight and increased antioxidant enzyme activities.
Pb	150 – 1500 µM of $Pb(C_2H_3O_2)_2$	Decreased growth, chlorophyll content, carotenoids and proline levels.
As	5 – 50 µM Na_2AsO_4	Inhibited seed germination and stunted plant growth.
	25 µM Na_3AsO=	Reduced root and shoot development.
Cu	5 – 50 µM $CuSO_4.5H_2O$	Reduced seed germination, inhibited plant growth and reduced root and shoot length.
Ni	200 µM $NiSO_4$/kg soil	Reduced photosynthesis, chlorophyll content, stomatal conductance, nitrogen content and activities of enzymes such as RuBisCo and nitrate reductase.

The analysis data show that lead levels in ash are approximately three times higher than in charcoal, suggesting a higher risk associated with ash compared to charcoal if added to soil in the same quantity. Similarly, the chromium content in ash is about 2.5 times greater than in charcoal. While chromium can have both beneficial and harmful effects, proper supplementation can promote plant growth.

3.4. Evaluation of the reuse potential of ash and charcoal from municipal solid waste incinerators for agricultural purposes

Beyond comparing with hazardous waste standards, considering the mandatory quantitative criteria for fertilizers - including organic, organic-mineral, microbial, and bio-organic fertilizers produced from municipal waste, industrial processing waste, food waste, livestock waste, and organic foliar fertilizers - as outlined in Decision No.100/2008/QD-BNN by the Ministry of Agriculture and Rural Development on "Regulations on Fertilizer Production, Trading, and Use," the heavy metal content in both ash and charcoal does not exceed the mandatory quantitative limits. Therefore, they hold potential for agricultural use, provided they meet regulatory requirements for commercialization and undergo trial production testing.

Table 4. Mandatory quantitative criteria for fertilizers

Heavy metal	Limit threshold (100/2008/QD-BNN)
As	≤ 2.0 mg/kg or ppm
Cd	≤ 2.5 mg/kg or ppm
Pb	≤ 250.0 mg/kg or ppm

This assessment indicates that, although heavy metals are present in ash and charcoal, their concentrations remain within permissible limits. Therefore, ash and charcoal can be considered for agricultural applications, offering a sustainable approach to recycling waste materials into valuable soil amendments (Campos et al., 2020; Ukwattage et al., 2013).

Ash, rich in elements such as potassium (K), phosphorus (P), and nitrogen (N), is suitable for crops with high nutrient demands, such as rice, corn, soybeans, and fruit trees (e.g., banana, mango, orange), to improve yields. Meanwhile, charcoal, with its porous structure and good water retention, is ideal for crops grown in sandy or fast-draining soils, such as leafy vegetables (lettuce, mustard greens), flowers (roses, chrysanthemums), and ornamental plants.

Additionally, the alkalinity of ash aids in neutralizing acidic soils, which is particularly beneficial in areas with low pH. This makes ash useful in the cultivation of industrial crops such as coffee, tea, and rubber, helping to maintain stable pH levels while supplying essential nutrients. By enhancing soil structure and increasing water retention capacity, charcoal can support the growth of short-cycle crops and greenhouse vegetables, optimizing water and nutrient use.

To expand and widely implement these new technologies, various approaches need consideration. From a policy perspective, appropriate policies from government agencies or organizations and individuals interested in utilizing ash and charcoal are essential (Munawar et al., 2021). Policies should initially support businesses toward green development and environmental waste management. These policies should align with the national "Green Growth" agenda (Lorek & Spangenberg, 2014), leveraging the potential of individuals or groups interested in using this type of ash and charcoal waste.

To maximize the reusable amount of ash and charcoal, support from businesses or government is necessary. Additionally, policies promoting waste sorting at the source should be strengthened. The primary limitation of this process lies in properly collecting waste according to its composition to ensure a stable input source, avoiding harmful elements in the final product. Lessons should be drawn from previous policies and programs implemented in Vietnam to avoid pitfalls that led to unsatisfactory results, such as the "3R Project" (Mohammed et al., 2020).

4. CONCLUSION

Analysis of ash and charcoal from municipal solid waste incineration using gasification technology indicates that both materials contain high levels of N, P, and K, which are beneficial for enhancing soil fertility. However, ash exhibits a higher concentration of heavy metals compared to charcoal, with a sample composition ratio of 12% ash and 88% charcoal. Despite the presence of heavy metals, these concentrations remain within permissible limits under QCVN 07:2009/BTNMT, classifying ash and charcoal as non-hazardous waste with potential for agricultural reuse if managed appropriately. This application not only reduces reliance on chemical fertilizers and lowers production costs but also mitigates the negative impacts of waste management. The study highlights the potential for sustainable circular economy development by transforming waste into resources, which promises positive contributions to agriculture and environmental protection in the future.

While the study provides detailed data on nutrient and heavy metal content in ash and charcoal from municipal solid waste incineration, some limitations remain. First, the sample collection was restricted to a specific location and time, which may not fully represent variations over time and across different locations. Second, the study focuses on chemical composition analysis without in-depth evaluation of the long-term impacts of ash and charcoal on soil ecosystems and crop productivity over multiple growing seasons. Additionally, large-scale field trials to verify the effectiveness and safety of using ash and charcoal have yet to be conducted, limiting immediate practical applications. Based on the study results, future directions could focus on long-term assessments of ash and charcoal impacts on various crops and soil environments over multiple seasons. Expanding the research to explore the combination of ash and charcoal with organic and microbial fertilizers could also optimize usage efficiency. Developing supplementary treatment processes for ash and charcoal to further minimize heavy metal residues is another essential area of focus. Further investigation into integrating ash and charcoal within closed-loop farming systems or high-tech agriculture holds promise for creating new value while contributing to sustainable circular economy models.

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REFERENCES

1. Ahmad, M. S. A., & Ashraf, M. (2012). Essential roles and hazardous effects of nickel in plants. Reviews of environmental contamination and toxicology, 125-167.

2. Ashfaque, F., Inam, A., Sahay, S., & Iqbal, S. (2016). Influence of heavy metal toxicity on plant growth, metabolism and its alleviation by phytoremediation - a promising technology. Journal of Agriculture and Ecology Research International, 1-19.

3. Campos, P., Miller, A. Z., Knicker, H., Costa-Pereira, M. F., Merino, A., & De la Rosa, J. M. (2020). Chemical, physical and morphological properties of biochars produced from agricultural residues: Implications for their use as soil amendment. Waste management, 105, 256-267.

4. García, R., & Báez, A. (2012). Atomic absorption spectrometry (AAS). Atomic absorption spectroscopy, 1, 1-13.

5. Hafeez, A., Rasheed, R., Ashraf, M. A., Qureshi, F. F., Hussain, I., & Iqbal, M. (2023). Effect of heavy metals on growth, physiological and biochemical responses of plants. In Plants and their interaction to environmental pollution (pp. 139-159). Elsevier.

6. Huyen, D. T. T., & Tram, L. T. B. (2019). Development of a procedure for evaluating the impacts of the accidental emission of hazardous chemicals, case study in Ho Chi Minh City, Vietnam. Environmental Management, 63(4), 486-494.

7. Khan, M. R., & Wajid, M. (1996). The effect of fly ash on plant growth and yield of tomato. Environmental Pollution, 92(2), 105-111.

8. Kishor, P., Ghosh, A., & Kumar, D. (2010). Use of fly ash in agriculture: A way to improve soil fertility and its productivity. Asian Journal of Agricultural Research, 4(1), 1-14.

9. Lavane, K., Minh, T. N. N., Thu, D. T. C., Le, N. T. T., & Ngan, N. T. C. (2018). Reusing honeycomb coal slag as buffer material in the biological filtration system to treat household domestic wastewater (Vietnamese version). Journal of Agricultural Science and Technology 2, 693-704.

10. Lorek, S., & Spangenberg, J. H. (2014). Sustainable consumption within a sustainable economy - beyond green growth and green economies. Journal of Cleaner Production, 63, 33-44.

11. Lyu, S., Wei, X., Chen, J., Wang, C., Wang, X., & Pan, D. (2017). Titanium as a beneficial element for crop production. Frontiers in plant science, 8, 597.

12. Mohammed, M., Shafiq, N., Abdallah, N., Ayoub, M., & Haruna, A. (2020). A review on achieving sustainable construction waste management through application of 3R (reduction, reuse, recycling): A lifecycle approach. IOP Conference Series: Earth and Environmental Science,

13. Munawar, M. A., Khoja, A. H., Naqvi, S. R., Mehran, M. T., Hassan, M., Liaquat, R., & Dawood, U. F. (2021). Challenges and opportunities in biomass ash management and its utilization in novel applications. Renewable and sustainable energy reviews, 150, 111451.

14. Ngo, T. M., & Bui, Q. L. (2015). Study the nature, componet and proposal how to use ash form domestic waste by burner generate. Journal of hydraulic engineering and environment, 48, 50 - 56.

15. Nguyen, L. H., Tran, T. V. N., Hoang, M. G., Nguyen, H. G., Tong, T. K., Isobe, Y., Kawasaki, M., Ishigaki, T., & Kawamoto, K. (2023). Material and monetary flows of construction and demolition waste and assessment on physical and environmental properties of illegally dumped construction and demolition waste in Hanoi. Environmental Science and Pollution Research, 30(60), 125965-125976.

16. Page, A., Elseewi, A. A., & Straughan, I. (1979). Physical and chemical properties of fly ash from coal-fired power plants with reference to environmental impacts. In Residue Reviews (pp. 83-120). Springer.

17. Pratush, A., Kumar, A., & Hu, Z. (2018). Adverse effect of heavy metals (As, Pb, Hg, and Cr) on health and their bioremediation strategies: a review. International Microbiology, 21, 97-106.

18. QCVN01-189:2019/BNNPTNT. (2019). National technical regulation on fertilizer quality. Plant Protection Department, Department of Science, Technology and Environment

19. QCVN07:2009/BTNMT. (2009). National Technical Regulationon Hazardous Waste Thresholds. Vietnam Environment Administration, Department of Science and Technology, Department of Legal Affairs

20. Rashed, M., Hoque, T., Jahangir, M., & Hashem, M. (2019). Manganese as a micronutrient in agriculture: crop requirement and management. Journal of Environmental Science and Natural Resources, 12(1-2), 225-242.

21. Rashid, A., Schutte, B. J., Ulery, A., Deyholos, M. K., Sanogo, S., Lehnhoff, E. A., & Beck, L. (2023). Heavy metal contamination in agricultural soil: environmental pollutants affecting crop health. Agronomy, 13(6), 1521.

22. Shabbir, Z., Sardar, A., Shabbir, A., Abbas, G., Shamshad, S., Khalid, S., Murtaza, G., Dumat, C., & Shahid, M. (2020). Copper uptake, essentiality, toxicity, detoxification and risk assessment in soil-plant environment. Chemosphere, 259, 127436.

23. Tun, M. M., Palacky, P., Juchelkova, D., & Síťař, V. (2020). Renewable Waste-to-Energy in Southeast Asia: Status, Challenges, Opportunities, and Selection of Waste-to-Energy Technologies. Applied Sciences, 10(20), 7312.

24. Ukwattage, N. L., Ranjith, P., & Bouazza, M. (2013). The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon). Fuel, 109, 400-408.

25. Van, P. (2019). Waste treatment in the direction of burning and generating electricity (Vietnamese version) Sai Gon Giai Phong online Enviroment. View from <https://www.sggp.org.vn/xu-ly-rac-thai-theo-huong-dot-phat-dien-606816.html>.