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Palm Oil Mill Effluent: A Potential Solution for Enhancing Soil Fertility

[1]Tamuno-Boma Odinga-Israel, [1]Conquest Chivusalem Nodi,
[2]Victory Sorbari John-Amadi, [1]Prince Aruchi Chikordi Amechi and [3]Israel, Moses Israel
[1]Department of Biochemistry, Faculty of Science, Rivers State University, Rivers State, Nigeria
[2]Department of Animal and Environmental Biology, Faculty of Science, Rivers State University, Rivers States, Nigeria
[3]Institute of Geoscience and Environmental Management, Rivers State University, Rivers State, Nigeria

ABSTRACT

Background and Objective: Palm oil mill effluent (POME), a byproduct of palm oil processing, is traditionally viewed as an environmental pollutant due to its high organic content and biochemical oxygen demand. This study evaluates some properties of soil samples collected from a POME discharge site in Omerelu, Rivers State. **Materials and Methods:** Soil samples were collected from the POME polluted site and a non-POME polluted site which served as the control sample. The samples were analyzed for the physicochemical properties of the soil samples using the AOAC standards for laboratory procedures. The IBM SPSS version 25 was used for the statistical analysis, and Turkey's *post hoc* test was used for multiple comparison. Results are presented as Mean±Standard Deviation, with significance at $p \leq 0.05$. **Results:** Results showed a significant increase in soil pH from 5.1067±0.0100 in non-POME soil (Sample A) to 6.7300±0.1 in POME soil (Sample B). Organic carbon content rose substantially from 0.3767±0.1528 in Sample A to 2.9267±0.1528 in Sample B. Total nitrogen levels also increased from 1.0830±0.002 to 1.3713±0.0015 while available phosphorus improved significantly from 1.43±0.01 to 14.3267±0.251 mg/kg, reflecting enhanced nutrient availability. Visual assessments corroborated these findings, with POME soil exhibiting a darker, humus-rich appearance and denser vegetation. **Conclusion:** These results indicate that POME, when properly managed, can serve as an eco-friendly soil amendment, improving soil fertility and agricultural productivity. However, its strong odour and potential environmental risks highlight the need for treatment before application. This study advocates further large-scale trials and the development of regulatory guidelines to optimize POME's use in agriculture, promoting both environmental sustainability and enhanced crop yields.

KEYWORDS

Palm oil mill effluent, soil fertility, organic carbon, nitrogen, phosphorus, sustainable agriculture

INTRODUCTION

Nigeria, with its vast arable land, faces mounting challenges in ensuring food security for its growing population[1]. Among these challenges is declining soil fertility, which undermines sustainable agricultural productivity[2]. Although conventional inorganic fertilizers provide a potential solution, their high cost, exacerbated by reliance on imports and environmental risks, limit their widespread adoption by smallholder farmers, who form the backbone of the nation's agricultural economy[3]. This situation underscores the need for cost-effective and sustainable soil conditioners.

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Palm oil production, a major economic driver and export commodity for Nigeria, generates significant quantities of wastewater known as palm oil mill effluent (POME)[4]. Improper disposal of POME poses severe environmental risks due to its high organic content, which can contaminate water sources[5]. However, emerging research highlights POME's potential as a nutrient-rich resource for improving soil fertility when appropriately processed[6].

The POME, a byproduct of the palm oil extraction process, contains a high organic load composed of lipids, proteins, carbohydrates, and essential nutrients such as nitrogen, phosphorus, and potassium[7,8]. These attributes make it a promising candidate for transforming agricultural practices by enhancing soil organic matter, improving soil structure, and promoting nutrient availability[9,10]. When used as a bioorganic fertilizer or soil conditioner, POME can enhance soil health, boost crop yields, and reduce dependency on synthetic fertilizers, providing a sustainable alternative for small-scale farmers[11].

Several studies support the efficacy of POME in improving soil productivity. Increased growth and yield of crops such as Napier grass when treated with POME, attributing these improvements to its high nutrient content[12]. Similarly, a significant benefit in palm oil seedling growth was observed following POME application[13], as well as the positive effects of POME on soil physicochemical properties and plant development[14]. These findings suggest that POME's nutrient-rich composition and organic matter can address declining soil fertility and support sustainable agricultural practices.

Incorporating POME into agricultural systems not only improves soil fertility but also offers an environmentally friendly solution to managing palm oil industry waste. By enhancing microbial activity, nutrient cycling, and soil structure, POME contributes to better plant development and reduced reliance on inorganic fertilizers[15]. Its application as a bioorganic fertilizer aligns with global efforts to promote sustainable farming practices and reduce environmental degradation[16].

This research evaluated the properties of the POME site as a possible cost-effective and sustainable soil amendment for Nigeria's agricultural sector. By addressing both waste management challenges and declining soil fertility, POME has the potential to empower smallholder farmers, enhance agricultural productivity, and promote food security in the nation.

MATERIALS AND METHODS

Study area: The study was conducted from November, 2021 to February, 2022 on soil samples from SIAT Nigeria Limited, an agro-industry in Omerelu town, Rivers State, Nigeria. Agro-industries account for about 15% of environmental pollution[17], raising environmental concerns like pollution from palm oil mill effluent (POME) in Omerelu Town, Rivers State, Nigeria.

Physical assessment of soil sampling sites: Sample A served as the control while Sample B served as the POME sample. The sampling sites were visually inspected to observe vegetation, soil colour, odour, and texture. This method aligns with standard environmental assessment protocols[18].

Soil sampling: Topsoil samples were collected in triplicates from the study site (POME-polluted area) at a distance of 0-5 m, and control samples were collected from a non-polluted site located 100 m away. Nine samples were collected, sealed in sterile polyethylene bags, and transported to the Rivers State University, Port Harcourt laboratory for analysis. This sampling protocol was adapted from prior studies[19,20]. Some general guidelines from Soil Science Literature[21] provide approximate ranges for classifying soil organic and nutrient content concentration for soil fertility in Table 1.

Table 1: Soil classification of organic and nutrient content

	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (mg/kg)
High	>3.0	>0.5	>15.0
Moderate	1.0	0.1-0.5	5.0-15.0
Low	<1.0	<0.1	<5.0

Measurement of soil pH: The pH of the soil samples was measured using a calibrated digital pH meter following a standard procedure[22]. Twenty grams of soil were weighed into a beaker, and 20 mL of distilled water was added to form a slurry. The pH meter was inserted into the slurry, and the pH values were recorded for each of the nine samples. Soil with a pH between 6.1 and 7.3 is considered slightly acidic and neutral, optimum conditions for soil nutrients and most bacterial activity to thrive, and agriculturally favourable for crop yield[22].

Analysis of organic carbon in soil samples: The determination of organic carbon was carried out using the Walkley-Black method[23]. Approximately 1 g of sieved soil (<2 mm) was transferred into a 250 mL conical flask, and 10 mL of 1 N Potassium Dichromate ($K_2Cr_2O_2$) was added. This was followed by the careful addition of 20 mL of concentrated Sulfuric Acid (H_2SO_4) while swirling. After cooling, 200 mL of distilled water, 10 mL of Phosphoric Acid (H_3PO_4), and a few drops of ferroin indicator were added. The solution was titrated with a 0.5 N Ferrous Sulfate ($FeSO_4$) solution until the endpoint was reached, signaled by a color change to maroon red. The titre values were recorded for each sample and used to calculate the organic carbon content.

Analysis of nitrogen content in soil samples: The soil nitrogen content was determined using the Kjeldahl method[24]. Five grams of soil were weighed into a beaker, and 50 mL of Potassium Chloride (KCl) solution was added. The mixture was swirled thoroughly, and filtered through filter paper, and the clear filtrate was collected in a test tube. Two millilitres of Sulfuric Acid (H_2SO_4) and brucine reagent were added to the filtrate, and the mixture was heated for 30 min. A spectrophotometer was used to measure the absorbance at 410 nm. The absorbance values were used to calculate the nitrogen content concerning a calibration curve.

Analysis of phosphorus in soil samples: The determination of phosphorus in the soil samples was carried out using the Olsen method[25]. One gram of soil was weighed and placed in a beaker. Twenty milliliters of Sodium Bicarbonate ($NaHCO_3$) solution were added, and the mixture was shaken for 20 min. The mixture was then filtered, and half a teaspoon of Calcium Carbonate ($CaCO_3$) was added to the filtrate to improve clarity. One milliliter of ammonium molybdate solution and two drops of stannous chloride solution were added. The solution was left undisturbed for 5 min to allow for colour development, after which its absorbance was measured using a spectrophotometer at 690 nm. The phosphorus content was calculated using a calibration curve.

Data analysis: Data were analyzed using IBM SPSS (Statistical Package for Social Sciences) version 25.0. Statistical evaluations of the difference between the group mean values were tested by One-way Analysis of Variance (ANOVA) and the Turkey's *post hoc* test for multiple comparisons. The results were expressed as Mean±Standard Deviation and statistical significance was considered at $p \leq 0.05$.

RESULTS AND DISCUSSION

Physical properties of soil: Visual inspection of the soil sample shows the different visual characteristics of the two soil samples. They were characterized in terms of colour, odor, and vegetation (Table 2 and Fig. 1).

- **Colour:** Sample A was found to be brown, and the Sample B (POME) site was black with humus
- **Odour:** Sample A had no odor, Sample B (POME contaminated) had offensive odor
- **Vegetation:** Sample A had little vegetation, and Sample B (POME contaminated) was grown with trees and grasses

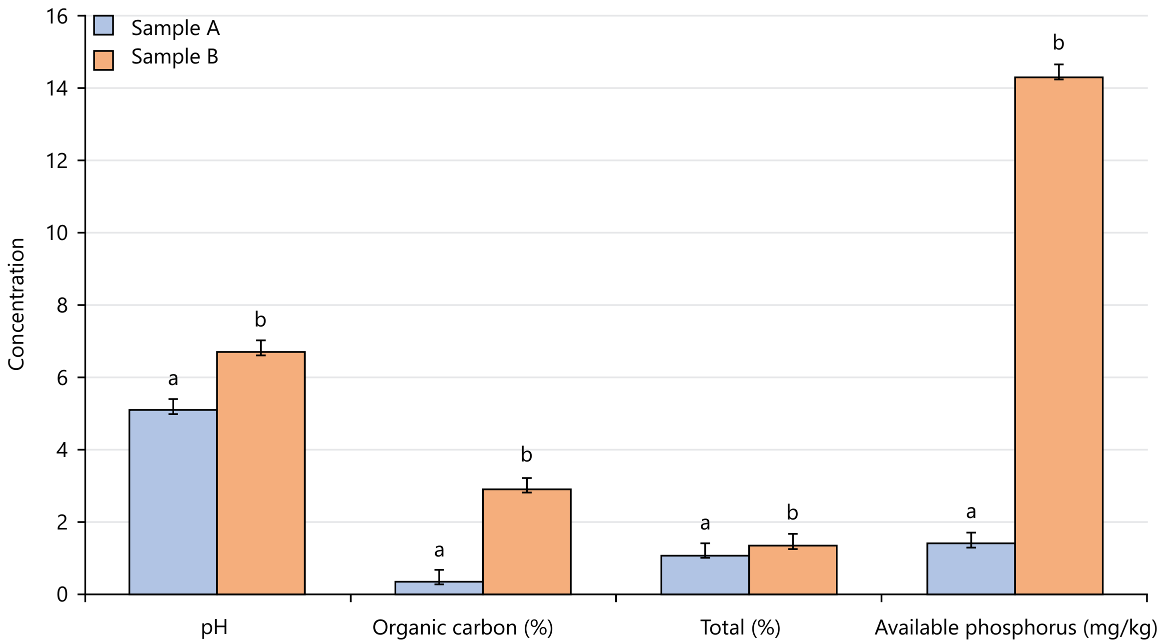

Fig. 1: Comparison of soil parameters between Sample A and B

Table 2: Visual Inspections of POME dumpsite and non-dumpsite

Sample	Colour	Odour	Vegetation
A	Brown	Free of odour	Sparse vegetation
B	Black with humus	Strong and unpleasant	Dense growth of trees and grasses

The impact of palm oil mill effluent (POME) contamination on soil properties was assessed, and the results present compelling evidence that POME could potentially serve as a panacea for improved soil fertility when properly managed.

The significant increase in pH from 5.1067±0.0100 in Sample A (non-contaminated) to 6.7300±0.1 in Sample B (POME-contaminated) suggests a shift from strongly acidic to slightly acidic/neutral conditions, which is agriculturally favourable, this aligns with FAO guidelines[21], which indicate that soils with a pH of 6.1-7.3 create optimum conditions for nutrient availability and bacterial activity crucial for soil fertility. This finding is contrary to previous studies which report a consequential decrease in soil pH when treated with POME[26], but aligns with another study by Ganapathy *et al.*[27] on soil from POME dumpsite, attributing the rise in biodegradation of organic materials to increased soil pH, and gradual neutralization of soil acidity. This adjustment to near-neutral pH enhances nutrient solubility, especially phosphorus, calcium, and potassium, which thrive in slightly acidic to neutral pH ranges.

The organic carbon content in Sample B (2.9267±0.1528%) was significantly higher than in Sample A (0.3767±0.1528%), indicating POME's potential to enrich soils with organic matter. According to the classification by FAOUN[21], this falls within the moderate range (1.0-3.0%), nearing the threshold for high organic carbon levels. The dark colouration and humus-rich appearance of Sample B further corroborate the increased organic matter content observed. This aligns with reports that POME introduces slowly decomposing organic compounds into the soil, leading to improved soil structure, water retention, and fertility[28].

Total nitrogen levels also showed a notable increase in Sample B (1.3713±0.0015%) compared to Sample A (1.0830±0.002%). Both values are categorized as high, based on FAO guidelines, and signify that POME contributes to nitrogen enrichment. The microbial activity stimulated by the organic content in POME likely mobilized nitrogen within the soil, enhancing its availability for plant uptake[29]. The dense vegetation observed in Sample B, with trees and grasses thriving, could further indicate nitrogen sufficiency, as nitrogen is a critical macronutrient for plant growth and chlorophyll production.

The significant increase in available phosphorus from 1.43±0.01 mg/kg in Sample A to 14.3267±0.251 mg/kg in Sample B underscores POME's potential to enhance phosphorus availability. Although the level in Sample B remains in the moderate range (5.0-15.0 mg/kg) according to FAO standards[21], the marked improvement could be attributed to the neutralizing effect of POME on soil pH, as phosphorus availability peaks within slightly acidic to neutral pH ranges[30]. This finding is consistent with Li *et al.*[31], that highlight the role of POME in solubilizing phosphorus in soils, which is critical for root development and energy transfer in plants.

Visual inspection further supports the chemical findings. Sample B exhibited a black, humus-rich appearance, suggesting a high organic matter content. The strong, unpleasant odor observed could be attributed to the slow decomposition of organic materials in POME, releasing volatile compounds. Additionally, the dense vegetation in Sample B compared to the sparse vegetation in Sample A underscores POME's ability to create a nutrient-rich environment conducive to plant growth. This aligns with previous findings that highlight the beneficial effects of organic amendments on soil fertility and vegetation[31,32].

The results collectively highlight the potential of POME as a soil amendment when appropriately managed. The organic carbon, nitrogen, and phosphorus enrichment observed in POME-contaminated soil indicate its ability to improve soil fertility significantly. However, the strong odor and potential environmental risks associated with untreated POME necessitate proper treatment before application to agricultural soils. Treated POME could act as a sustainable alternative to chemical fertilizers, contributing to soil health and agricultural productivity while mitigating the environmental burden of POME disposal.

CONCLUSION

This study demonstrates the potential of palm oil mill effluent (POME) as an effective soil amendment for improving soil fertility. The significant increases in pH, organic carbon, nitrogen, and phosphorus levels in POME-contaminated soil suggest that POME can enhance soil properties, creating a more favourable environment for plant growth and microbial activity. The positive visual and chemical changes observed highlight the benefits of POME in enriching soils, improving soil structure, and promoting nutrient availability. However, the strong odour and environmental risks associated with untreated POME underline the need for proper treatment before application. Treated POME can serve as a sustainable, cost-effective alternative to chemical fertilizers, contributing to both agricultural productivity and environmental sustainability.

It is recommended that further research focus on optimizing POME treatment methods to mitigate potential environmental risks, particularly regarding odour and contamination. Additionally, large-scale field trials should be conducted to assess the long-term impact of treated POME on soil fertility and crop yields. Proper management and treatment protocols should be developed to ensure the safe and effective use of POME as a sustainable soil amendment, promoting its adoption in agricultural practices.

SIGNIFICANCE STATEMENT

This study discovered the potential of palm oil mill effluent (POME) as an effective soil amendment that can be beneficial for improving soil fertility and enhancing plant growth. The significant increases in pH, organic carbon, nitrogen, and phosphorus levels in POME-treated soil suggest its ability to enhance soil properties, creating a more favorable environment for microbial activity. However, proper treatment is necessary to mitigate environmental risks associated with untreated POME. This study will help researchers uncover critical areas of sustainable soil management that many have not explored. Thus, a new theory on utilizing treated POME as an eco-friendly soil amendment may be arrived at.

REFERENCES

1. Fasoyiro, S.B. and K.A. Taiwo, 2012. Strategies for increasing food production and food security in Nigeria. J. Agric. Food Inf., 13: 338-355.
2. Bindraban, P.S., M. van der Velde, L. Ye, M. van den Berg and S. Materechera *et al*., 2012. Assessing the impact of soil degradation on food production. Curr. Opin. Environ. Sustainability, 4: 478-488.
3. Chinasa, I.J. and O.S. Alagba, 2020. Information needs of rice farmers on inorganic fertilizer use in Ebonyi State, Nigeria. J. Agric. Ext., 24: 9-21.
4. Gobi, K. and V.M. Vadivelu, 2013. By-products of palm oil mill effluent treatment plant-A step towards sustainability. Renewable Sustainable Energy Rev., 28: 788-803.
5. Kamyab, H., S. Chelliapan, M.F.M. Din, S. Rezania, T. Khademi and A. Kumar, 2018. Palm Oil Mill Effluent as an Environmental Pollutant. In: Palm Oil, Waisundara, V.Y. (Ed.), IntechOpen, London, United Kingdom, ISBN:978-1-78923-427-5, pp: 13-28.
6. Awere, E., A. Bonoli, P.A. Obeng, S. Pennellini, S. Bottausci, W.K. Amanor and E.K. Akuaku, 2022. Small-Scale Palm Oil Production in Ghana: Practices, Environmental Problems and Potential Mitigating Measures. In: Palm Oil-Current Status and Updates, Waisundara, V.Y. (Ed.), IntechOpen, London, United Kingdom, ISBN: 978-1-83768-066-5.
7. Ewelike, N.C., J.C. Orji, I.E Adieze, V.E. Ogwudire, B.U. Uzoho and A. Ukaoma, 2021. Effect of palm oil mill effluent on the growth of maize (*Zea mays*). Indian J. Agric. Res., 55: 761-764.
8. Aziz, M.M.A., K.A. Kassim, M. ElSergany, S. Anuar and M.E. Jorat *et al*., 2020. Recent advances on palm oil mill effluent (POME) pretreatment and anaerobic reactor for sustainable biogas production. Renewable Sustainable Energy Rev., Vol. 119. 10.1016/j.rser.2019.109603.
9. Supriatna, J., M.R. Setiawati, R. Sudirja and C. Suherman, 2024. Enhancing soil fertility, inorganic fertilizer efficiency, and oil palm productivity through bio-compost application in oxium biodegradable sacks on former mining land-podzols: Insights from a field study in Indonesia. J. Saudi Soc. Agric. Sci., (In Press). 10.1016/j.jssas.2024.09.006.
10. Ngone, M.A., D.M.B. Ajoacha, D.T. Achiri, G.V.T. Tchakounté, S. Ruppel, A.S. Tening and C. Ngosong, 2023. Potential of bio-organic amendment of palm oil mill effluent manure and plant growth-promoting bacteria to enhance the yield and quality of maize grains in Cameroon. Soil Secur., Vol. 11. 10.1016/j.soisec.2023.100090.
11. Manorama, K., S.K. Behera and K. Suresh, 2024. Oil Palm (*Elaeis guineensis* Jacq). In: Soil Health Management for Plantation Crops: Recent Advances and New Paradigms, Thomas, G.V. and V. Krishnakumar (Eds.), Springer, Singapore, ISBN: 978-981-97-0092-9, pp: 111-176.
12. Ako, P.A.E. and B. Anegbe, 2022. Total and available copper and zinc in soils affected by palm oil mill effluent in Oghareki, Oghara Kingdom, Delta State, Nigeria. J. Appl. Sci. Environ. Manage., 26: 1049-1055.
13. Loh, S.K., M.E. Lai and M. Ngatiman, 2019. Vegetative growth enhancement of organic fertilizer from anaerobically-treated palm oil mill effluent (POME) supplemented with chicken manure in food-energy-water nexus challenge. Food Bioprod. Process., 117: 95-104.
14. Maliki, M., E.U. Ikhuoria, S.O. Omorogbe and M.O. Ekebafe, 2020. Comparative study on nutrient availability and growth of tomato (*Lycopersicon esculentum*) seedlings in soils amended with palm oil mill effluent and rubber processing effluents. Cogent Food Agric., Vol. 6. 10.1080/23311932.2020.1738199.
15. Sanches, J.P., S.S. Costa, D.A. das Graças, A. Silva and G.C. Baião *et al*., 2024. Soil fertilization with palm oil mill effluent has a short-term effect on the bacterial diversity of an Amazonian agricultural land area. Microorganisms, Vol. 12. 10.3390/microorganisms12030507.
16. Mutsaers, H., 2019. The challenge of the oil palm: Using degraded land for its cultivation. Outlook Agric., 48: 190-197.
17. Ganesh, R.S.V., R.P. Devi, D. Ramesh, S. Karthikeyan and D. Murugananthi, 2023. A step into future fuel industrial effluents into bioethanol: A review. Int. J. Environ. Clim. Change, 13: 3633-3640.

18. Burcham, Z.M., A.D. Belk, B.B. McGivern, A. Bouslimani and P. Ghadermazi *et al*., 2024. A conserved interdomain microbial network underpins cadaver decomposition despite environmental variables. Nat. Microbiol., 9: 595-613.
19. Cline, M.G., 1944. Principles of soil sampling. Soil Sci., 58: 275-288.
20. Edwards, A.C., 2010. Soil Sampling and Sample Preparation. In: Trace Elements in Soils, Hooda, P.S. (Ed.), John Wiley & Sons, New Jersey, ISBN: 9781444319477, pp: 39-51.
21. FAOUN, 2006. Guidelines for Soil Description. 4th Edn., Food & Agriculture Org., Rome, Italy, ISBN-13: 9789251055212, Pages: 97.
22. Regassa, A., K. Kibret, Y.G. Selassie, A. Kiflu and W. Tena, 2023. Soil Properties. In: The Soils of Ethiopia, Beyene, S., A. Regassa, B.B. Mishra and M. Haile (Eds.), Springer, Cham, Switzerland, ISBN: 978-3-031-17011-9, pp: 111-156.
23. de Vos, B., S. Lettens, B. Muys and J.A. Deckers, 2007. Walkley-black analysis of forest soil organic carbon: Recovery, limitations and uncertainty. Soil Use Manage., 23: 221-229.
24. Bremner, J.M., 1960. Determination of nitrogen in soil by the Kjeldahl method. J. Agric. Sci., 55: 11-33.
25. do Carmo Horta, M. and J. Torrent, 2007. The Olsen P method as an agronomic and environmental test for predicting phosphate release from acid soils. Nutr. Cycl. Agroecosyst., 77: 283-292.
26. Cheng, Y.W., C.C. Chong, M.K. Lam, W.H. Leong and L.F. Chuah *et al*., 2021. Identification of microbial inhibitions and mitigation strategies towards cleaner bioconversions of palm oil mill effluent (POME): A review. J. Cleaner Prod., Vol. 280. 10.1016/j.jclepro.2020.124346.
27. Ganapathy, B., A. Yahya and N. Ibrahim, 2019. Bioremediation of palm oil mill effluent (POME) using indigenous *Meyerozyma guilliermondii*. Environ. Sci. Pollut. Res., 26: 11113-11125.
28. Wu, T.Y., A.W. Mohammad, J.M. Jahim and N. Anuar, 2009. A holistic approach to managing palm oil mill effluent (POME): Biotechnological advances in the sustainable reuse of POME. Biotechnol. Adv., 27: 40-52.
29. Onwusi, C.C. and C.O. Nwuche, 2017. The impact of palm oil mill effluent (POME) application on the rhizosphere heterotrophic population, nitrogen fixing bacteria and enzyme activity of an agricultural soil. Niger. J. Biotechnol., 34: 1-11.
30. Azmi, L.H.M., A. Elaissari, M.O. Fatehah, H. Abdul Aziz and Y.T. Hung, 2023. Evaluation of Coagulation-Flocculation Treatment Technologies in Palm Oil Effluent Management. In: Industrial Waste Engineering, Wang, L.K., M.H.S. Wang and Y.T. Hung (Eds.), Springer, Cham, Switzerland, ISBN: 978-3-031-46747-9, pp: 509-551.
31. Li, H., A. Lehmann, R. Rongstock, Y. Xu, E. Kunze, P. Meidl and M.C. Rillig, 2025. Diversity of organic amendments increases soil functions and plant growth. Plants People Planet, 7: 80-86.
32. Pantelides, I.S., I.A. Stringlis, O.M. Finkel and J. Mercado-Blanco, 2023. Editorial: Organic amendments: Microbial communities and their role in plant fitness and disease suppression. Front. Plant Sci., Vol. 14. 10.3389/fpls.2023.1213092.