Available online at
https://borneoakademika.uitm.edu.my

e-ISSN: 2735-2250

Volume 8(2) December 2024, 197-209

Borneo Akademika

Evaluating the Impact of Organic Compost on Soil Microbial Diversity in Sustainable Malaysian Agriculture: A Review

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ARTICLE INFO

Article history:
Received 1 October 2024
Accepted 15 November 2024
Online first
Published 20 December 2024

Keywords:
organic compost
agriculture farming
microbial diversity
soil fertility
sustainable agriculture

ABSTRACT

The excessive use of chemical fertilisers in agriculture has led to a trend of soil degradation, particularly affecting agricultural farming in Malaysia. While chemical fertilisers offer rapid, short-term increases in crop yield, their long-term detrimental effects on soil health and the environment are becoming increasingly apparent. These fertilisers disrupt vital soil microbial diversity, leading to a decrease in soil fertility over time. To counteract these issues, the practice of using organic compost has emerged as a sustainable alternative in agriculture. Organic compost not only improves soil structure but also provides vital nutrients and encourages microbial activity in plant crops. While various studies have compared the impact of different types of organic compost on crop growth, there is currently limited local research focused on the presence and diversity of soil microbial communities in sustainable crop production in Malaysia. This review aims to provide scholars and practitioners, particularly in Malaysia, with a thorough understanding of the benefits and applications of organic compost and its impact on soil microbial diversity for sustainable agriculture.

INTRODUCTION

The application of organic compost in agriculture has gained significant attention as a sustainable approach to improving soil health and crop productivity. Organic compost enhances soil structure and fertility by promoting a diverse and thriving microbial population, including bacteria, fungi, and actinomycetes, which form symbiotic relationships with plants. They break down organic matter into simpler forms so plants can readily receive the needed nutrients (Parab et al., 2023). Organic fertilisers strongly influence the soil microbiome in short- and long-term effects apart from supporting soil health by enhancing microbial activity, interactions of microbes and nutrient cycling (Lazcano et al., 2021; Wu et al., 2020). Apart from providing essential nutrients to plants and improving soil aeration and organic matter, farmyard manure could increase the population of soil microbes and accumulate excess humus content (Sindhu et al.,

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2020). These microorganisms play a critical role in nutrient cycling, making essential elements available to crops while suppressing soil-borne pathogens, thereby reducing the need for chemical pesticides. In contrast, while chemical fertilisers are effective in delivering a rapid nutrient supply, they often disrupt soil ecology over time. Their repeated use can deplete organic matter, degrade soil structure, and negatively impact beneficial microorganisms. Moreover, chemical inputs often result in nutrient leaching and runoff, contributing to water pollution. In Malaysia, where agriculture remains vital to the economy, the transition towards organic compost presents an opportunity to address long-standing environmental and agronomic challenges.

One pressing example is the overreliance on chemical fertilisers in rice cultivation in Sungai Panjang, located in the Sabak Bernam district. This practice has led to declined soil fertility, poor nutrient management, and increased vulnerability to pests and diseases, emphasising the need for more sustainable alternatives like organic compost to restore soil health and ensure long-term agricultural productivity. Other chemical inputs like pesticides, weedicides, and herbicides have become the farmers' choice in enhancing farm productivity where the usage of pesticides in Malaysia has reached 49,199 tons per year and ranks the third highest in Southeast Asia after China and India (Zainol et al., 2024). This has resulted in anthropogenic pollutants, such as the accumulation of heavy metals and pesticides, which negatively impact soil health. Furthermore, long-term chemical fertiliser usage may degrade soil health due to nutrient leaching compared to organic fertilisation. An assessment study by Liang et al. (2020) mentioned that one of the lower rivers in Johor, the Temon River, was polluted with high concentrations of heavy metals like iron (Fe), copper (Cu), and arsenic (As) from the oil palm plantation near an urban village. The study claims that high Cu concentration may be the result of fertilisation activities since it counts as one of the micronutrients needed by oil palm but is the main composition of chemical fertiliser. Meanwhile, arsenical herbicides and insecticides might be the cause of high concentration. Kiran et al. (2022) agreed that a prominent portion of heavy metals are toxic and lead to environmental pollution. They affect the physico-chemical properties of soil, such as pH, organic matter, ion exchange capacity, texture, and growth and density of microbes. (Ali et al., 2022).

To address the issues impacting sustainable agriculture in Malaysia, chemical fertilisers can be replaced with more eco-friendly options such as organic compost. Other than providing soil nutrients, improving soil structures, increasing soil moisture content, and improving crop yields, organic compost significantly accelerates the composition of the soil microbial community (Zhou et al., 2022). Despite the benefits, chemical fertilisers are still being used in Malaysian agriculture. Tan et al. (2020) reported that Malaysia consumed 1.97 million tonnes of N, P, and K fertilisers in 2014. Due to this, the awareness of reducing the reliance on chemical fertilisers among communities in Malaysia should be increased by providing them with scholarly knowledge, especially about the important roles of soil microbes in crop production through organic compost application. In the literature survey, we systematically searched electronic databases such as Web of Science, Scopus, ScienceDirect, Springer Link, ProQuest, and Google Scholar for published papers from 2019 to 2024. Additionally, we explored papers cited in previous reviews related to the focus of interest for this review. This review aims to provide scholars and practitioners, particularly in Malaysia, with a thorough understanding of the benefits and applications of organic compost and its impact on soil microbial diversity for sustainable agriculture.

Articles selection

The initial step in developing the basis of knowledge and understanding the importance of incorporating microbial knowledge into sustainable farming practices was to analyse related papers and try to associate any identified relationships between the impacts of organic compost

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and soil microbial diversity. Within this process, relevant articles were searched through online databases or electronic resources subscribed by Perpustakaan Tun Abdul Razak (UiTM Library), such as Web of Science, Scopus, ScienceDirect, Springer Link, ProQuest, and other freely accessible search engines like Google Scholar. Keywords such as 'organic compost impacts on soil microbial diversity', 'importance of organic compost in agriculture farming', and 'inorganic fertiliser impacts on soil fertility' were used in this process, which resulted in the identification of 127 articles. However, only 47 remained after the second screening process. 68% of the articles are related to the association between organic compost and soil microbial communities, the roles of organic compost in sustainable agriculture, and the impacts of organic compost on soil microbial diversity, while the remainder is linked to the consequences of harmful chemical inputs usage in Malaysian agriculture farming. Most of the selected articles highlighted the study of organic compost and its impact on soil microbial diversity conducted in other countries, while only a few articles from local researchers in Malaysia call attention to exploring soil microbial diversity in organic compost studies.

The role of organic compost in sustainable agriculture

Composting is a sustainable approach to waste management by recycling organic waste, which improves soil properties, enhances soil quality, and increases soil organic matter content, which has declined because of anthropogenic activities (Sayara et al., 2020). It may originate from plants, animals, or humans, decomposed by millions of microorganisms in various groups under aerobic conditions (Ho et al., 2022). In research from Supriatna et al. (2023), oil palm seedlings that were applied with co-composed of empty fruit bunch (EFB) and palm oil mill effluent (POME) in the nursery have higher yields, better plant health, and increased nutrient uptake while organic amendment which contained straw, manure, green manure, and combined green manure with straw has improved the quality of topsoil and increased wheat and maize yields (Zhao et al., 2024). Other composts, such as vermicompost, could promote the growth of vegetable crops by increasing plant height, flowering, fruiting, and developing pod and leaf formation (Manzoor et al., 2024). Liu et al. (2024) said biochar increases high-oleic peanut production through biological nitrogen fixation (BNF) activity. In a study by Supian et al. (2024), organic fertiliser made from leaf mould and fresh green grass was applied to mango trees *(Mangifera indica)* at Lake G3 Universiti Tun Hussein Onn Malaysia (UTHM). The findings showed that the organic fertiliser used provided acceptable levels of NPK content, which increased soil health and yield for the trees. It may be an alternative strategy for reducing chemical fertiliser usage. Ma'mor et al. (2023) utilised food waste such as eggshells and fruit peel, which can be used as soil amendment and organic fertiliser in improving soil fertility due to their mineral content to enhance the growth of maize. This study was carried out in Felda Chemplak, Labis, Johor, and revealed that the combination of both organic wastes improved soil properties and produced higher maize yield compared to a single application of eggshell powder and fruit peel. In a study by Tan et al. (2021) conducted in Agricultural Park Universiti Tunku Abdul Rahman, Perak Campus in Kampar, the manures from broiler and layer chickens have positively impacted the dry weight, plant height and root length of choy sum *(Brassica chinensis L. var. parachinensis)*. The findings concluded that chicken manure could be a sustainable agriculture option through proper management due to less leaching of nitrate detected in the treated soil as well as reducing erosion, diversifying agroecosystem, and improving water holding capacity with better infiltration. Table 1 shows the use of different types of organic compost and their benefits on crop growth in Malaysia.

Table 1. The use of different types of organic compost and their benefits on crop growth

Region	Organic compost types	Benefits	Crop type	References
UTHM	Mixed food waste, vegetable waste, and fruit waste	- Develop good growth - Promising a chemical-free fertiliser	*Azolla Pinnata*	Hissham et al. (2024)

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Farm Management Unit, UiTM Sarawak Branch, Samarahan Campus	EFB compost, *Trichoderma* biofertilisers	- Improve soil pH and soil moisture - Increase NPK content	Chili *(Capsicum annuum L. Var. Kulai)*	Tangga et al. (2022)
MARDI Serdang, Selangor	Poultry manure	- Boosts nutrients - Protect the environment	Moringa *(Moringa oleifera L.)*	Farahzety et al. (2024)
Universiti Putra Malaysia, Bintulu Campus, Sarawak	*Leucaena*, forest litter, chicken manure, and cow dung co-composted with chicken litter biochar	- Improve crop productivity - Reduction of environmental pollutions to forest like residue slash pile burning - Facilities suitable disposal of animal wastes - Improve mineral acid soil	Rice *(Oryza sativa L.)*	Maru et al. (2023)
Universiti Putra Malaysia	Rice husk biochar, poultry litter composted and co-composted biochar	- Increased macronutrients - Reduced heavy metal uptake by crop	Maize *(Zea mays)*	Ahmed et al. (2021)
UiTM Jasin	Pineapple peel compost, pineapple core compost	- Boosts plant growth - Both increase soil pH and exchangeable K and Ca	Okra *(Abelmoschus esculentus L.)*	Kamaruddin et al. (2023)
Agrotechnopark Universiti Malaysia Kelantan (Jeli Campus)	Forest litter (FL), chicken manure (CM), insect frass (IF) and empty fruit bunch mixed with Azolla sp. (EFBA)	- Increased plant height has responded to CM, IF, and EFBA - All organic amendments with different sources played significant role in the plant's resource allocation during the saplings stage	Gaharu *(Aquilaria malaccensis)*	(A S Mohamad Amir Hamzah et al., 2021)

Impact of organic compost on soil microbial diversity

Microorganisms play an important role in the soil ecosystem (Li et al., 2024). They maintain the health of agroforestry ecosystems through the decomposition of residue and nutrient cycling (Deqiang et al., 2023). Soil microbial diversity simultaneously supports and stabilises multiple ecosystem functions (Wagg et al., 2021). Ray et al. (2020) noted that microorganisms promote plant growth, supply nutrients, and balance fertiliser inputs such as nitrogen and phosphorous. He added that groups of microbes with specific roles adhere and desorb inorganic nutrients to physical surfaces and break down organic residues. He also remarked that microbes maintain a sustainable rhizosphere community by protecting plants, receiving nutrients, and overcoming biotic and abiotic stress responses. Besides, arbuscular microbes like mycorrhizal fungi are known as early symbiotic partners among all land plant species. Other mycorrhizal systems vary in nutritional benefits and costs that are useful for the serendipitous system. Meanwhile, high organic content compost increases microbial activity in high-salinity soils. Hence enhancing the availability of nutrients and minerals for plants, which resulted in crop growth and productivity (Ho et al., 2022). The utilisation of agricultural byproducts could boost soil carbon sequestration and soil diversity, as well as the fertility of soil and plant growth, which promotes sustainable agriculture systems and food security. For example, compost application enhances beneficial microorganisms that provide essential nutrients in barley plantations, which helps in suppressing pathogens and improving productivity as well as disease resistance to the crop Ghouili et al. (2023). The addition of compost to soil has positively contributed to physical, chemical, and biological properties, which may lead to better productivity and quality of crops (Ho et al., 2022). In a study by Li et al. (2024), bacterial and fungal communities are very responsive to organic fertiliser due to their high sensitivity. Organic fertilisation not only enhances protists diversity but also increases the relative abundance of phagocytic protists, which may remarkably change the ecological association between protists and bacteria or fungi. The abundance of heterotrophic

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protists, which are involved in the breaking down of organic matter and consumption of bacteria and fungi, will result in a good corporation of protists and soil organic matter.

Association between organic compost and soil microbial communities

In a study by Yang et al. (2020), addification of organic composts such as biochar (B) and bean dregs (BD) were applied in pig manure (PM) composting. They aimed to investigate the impacts on degradation and humification of organic matter, and the dynamics and metabolic functioning of bacterial communities in PM-composting after both B and BD were added. BD + B treatment promoted organic matter degradation, humic acid content and influenced the microbial community structure of compost. During composting, the changes in the bacterial communities at the genus level were mainly *Firmicutes* (68.8%), *Proteobacteria* (6.82%), and *Bacteroidetes* (8.06%) from the 35 predominant genera. Another study from Heisey et al. (2022) determined how single additions of high-quality organic matter influenced microbial soil communities over multiple cropping cycles. The study showed that a single application of compost led to improved plant biomass response and promoted soil microbial community such as bacteria (*Nostocaceae sp., Steroidobacter sp., Bradyrhizobiaceae sp.*) and fungi (*Lasidioploidia lignicola, and Tetracladium furcatum*). Awasthi et al. (2020) studied the influence of pig manure biochar amendment (PMBA) with different concentration (0%, 2%, 4%, 6% and 10%) during the composting of pig manure and wheat straw. The study presented that 6% PMBA significantly increased bacterial diversity and relative abundance of phyla like *Firmicutes* and *Proteobacteria*. They also noted that the biochar concentration was the main factor of bacterial community richness, primarily the bacterial genera of *Bacillus* and *Clostridia.* Study by Hernández-Lara et al. (2023) showed that the combination of compost and solarisation (CAS) was beneficial to the soil by increasing soil fertility and microbial activity. *Proteobacteria* and *Actinobacteria* were the dominant phylum observed in this study. Ji et al., 2021 said that different organic fertiliser levels could change the diversity and composition of soil microbes in different regions where it has affected saprophytic bacteria (*Botryotrichum, Chaetomium, Conocybe, Lophotrichus* and *Preussia*) and dominant fungi (*Ascomycota* and *Mortierellomycot*a) in maize soil. Shang et al. (2020) expressed that different organic fertilisers applied in the soil of *L. chinensis* grassland have formed different bacterial community structures. High levels of vermicompost and mushroom residues have enhanced the availability of organic matter reservoirs and nutrients as well as increased biodiversity of soil bacterial communities such as *Actinobacteria,* which improved soil fertility and quality. Evidently, these international research studies have actively explored the relationship between organic compost and soil microbial communities. Meanwhile, most of the studies in Malaysia only highlighted the growth performance of crops applied with organic compost and distinguished the differences between organic fertiliser and inorganic fertiliser to crop productivity, with limited studies on soil microbial community. Table 2 shows an overview of the microbial community's involvement in organic compost studies across different countries.

Table 2. Overview of microbial community involvement in organic compost studies across different countries

Country	Methodology	Key findings	Studies involving microbial communities in organic compost	References
China	Biochar was added to the disposal of Chinese medicinal herbal residues (CMHRs) to enhance the quality of compost products specifically on nitrogen and phosphorus transformation.	Biochar incorporation helps in enhancing nutrient conversion process, increase organic matter and humus formation. It also altered the structure of microbial community.	Yes	Yan et al. (2024)

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China	Soil amended with straw-based carbon substrate (SCS) and conventional straw was applied on maize to be compared.	*Rhizobiales, Saccharimonadales,* and *Eurotiales* were detected in SCS amendment during the growth stages of maize. These bacterial and fungal taxa break down organic matter to release nutrients in promoting plant growth and yield.	Yes	Zhang et al. (2024)
Kenya	Determination of the prokaryotic communities in triplicate compost of Lantana- based, Tithonia-based, Grass- based, and mixed (Lantana + Tithonia + Grass)-based at 21, 42, 63, and 84 days of composting.	Prokaryotic community structure for total diversity and abundance were varied with the four compost regimens as well as the composting days. *Actinobacteriota, Bacteroidota, Chloroflexi*, and *Proteobacteria* were the most prevalent phyla during composting.	Yes	Matheri et al. (2023)
Japan	Soil solarization (SS) is the main effect while fertilisers are subeffect which applied to *Brassica rapa*.; SS with organic compost, SS with chemical fertiliser, non-solarized (NS) organic compost, NS with chemical fertiliser.	SS with organic fertiliser enhanced plant shoot biomass. Plant traits heterogeneously related to soil metabolites, minerals, and microbes.	Yes	Ichihashi et al. (2020)
China	Investigation of the bacterial composition, structure, co-occurrence network patterns and topological roles of N transformation in cattle manure-maize straw composting using high- throughput sequencing through the application of cattle manure and maize straw mixture (CM) and CM with 10% biochar addition (CMB).	Bacteria community's evolution similarity was found during cattle manure-maize straw composting and biochar addition. Dominant phyla include *Actinobacteria, Firmicutes, Proteobacteria, Bacteroidetes and Chloroflexi were found in both treatments. CMB contains more important bacteria communities and N transformation compared with CM.*	Yes	Bello et al. (2020)
India	Determining the long-term effect of pulse crops such as pigeonpea *(Cajanus cajan L.)*, chickpea *(Cicer arietinum L.)* and mungbean *(Vigna radiata L.)* in crop rotation (maize- wheat (MW), maize- wheatmungbean (MWMb), maize-wheat-maize chickpea (MWMC, two years rotation), and pigeonpea-wheat (PW) and nutrient management (without fertilisers (CT), integrated nutrient management (INM), and recommended inorganic fertilisers (RDF) on soil microbial functions and enzymes activity.	Long-term use of inorganic fertiliser does not increase enzyme activity. Organic amendments addition is needed. MW crop rotation with INM increased soil organic carbon and soil enzyme activity. PW and MWMb rotations positively affect soil microbial biomass carbon, soil microbial biomass nitrogen, and enzymatic activity after thirteen years.	Yes	Borase et al. (2020)
France	Distinguish the effect of two different organic waste products (OWPs), which are compost of green wastes and sewage sludge (GWS) and farmyard manure (FYM). Each was applied to five different soils to determine the activity, abundance, and diversity of the soil's microbial communities.	FYM increased CO2 emissions 2-fold and delayed N2O emissions compared to GWS. The soil type influenced the effectiveness of OWPs and caused distinct patterns of CO2 and N2O emissions. FYM increased the relative abundance of *Firmicutes* and decreased the Acidobacteria and	Yes	Sadet-Bourgeteau et al. (2019)

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		Planctomycetes groups, while GWS decreased only the *Planctomycetes* group in Couhins (Ch) soil. The population of soil microbes in other soil types were also examined.		
Malaysia	Palm kernel shell and rice husk biochars of different feedstock and pyrolysis conditions were used for amendment and applied on *Zea mays* var. Masmadu.	Biochar-amended soil increased soil physicochemical properties, microbial biomass C, microbial biomass N, and gene abundances. It also influenced soil microbes by elevating microbial habitat potential to a more favourable state and enhancing labile active carbon sources.	Yes	Halmi & Simarani (2021)
Malaysia	Chicken dung, vermicompost, and biochar were applied to eggplant *(Solanum melongena).*	Chicken dung enhanced plant height, number of leaves, leaf area, plant fresh weight and dry weight, and number of flowers among all treatments.	No	Mahamad et al. (2022)
Malaysia	NPK fertiliser and chicken manure with different levels (5 t ha^{-1}, 7 t ha^{-1}, 10 t ha^{-1}) were applied to rice *(Oryza sativa L.)* genotype BRRI dhan75.	Chicken manure at 10 t ha^{-1} was the best in promoting growth and yield contributing characters, grain and straw yields, and NPK nutrient contents in grain and straw.	No	Anisuzzaman et al. (2022)
Malaysia	Determination of the effect of different plant spacings (0.2 m × 0.2 m, 0.3 m × 0.3 m and 0.4 m × 0.4 m) and different fertilisers applications (poultry manure, biochar, and inorganic fertiliser) on moringa leaf biomass and phytonutrient content.	Poultry manure enriched the nutrients in moringa leaf with the highest level of crude protein (25.26%), N (2.83%), Ca (2.19%) and Zn (27.05 mg kg^{-1}) at plant spacing of 0.3 m × 0.3 m.	No	Farahzety et al. (2024)
Malaysia	The pathogen population was evaluated in municipal sludge (MS) compost mixed with landscape waste (LW) for 90 days. Seed compost (SC) was also prepared to provide a habitat for microorganisms.	The pathogen population increased at the early stage of composting and decreased gradually after reaching the peak. R4 (50% MS: 50% SC) positively correlates with organic matter. R2 (40 % LW: 10 % MS: 50 % SC) and R3 (30 % LW: 20 % MS: 50 % SC) removed the pathogen better at the maturity stage.	No, this study only determined the pathogen colonies	Hamzah et al. (2020)
Malaysia	Determining the effects of chicken manure (CM) in addition to vegetable waste (VW) and rice husk (RH) composting.	2.5% CM amendment has the highest amount of stimulation of organic matter degradation. The pH value is closely neutral due to the loss of organic matter.	No	Murshid et al. (2023)

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Malaysia	Determining the effects of different types of fertiliser: inorganic fertiliser, chicken manure, cow manure, empty fruit bunch and cocoa pod husk on the production of cocoa mature tree and its soil fertility.	The effects of organic fertilisers used were closely similar to inorganic fertilisers on crop production and soil chemical properties, especially EFB.	No	Muda et al. (2021)
Malaysia	Evaluating the effects of chemical fertiliser, fermented plant and fruit juices, compost, and biochar on soil properties, morpho-physiological characteristics and yield of black pepper.	- Fermented juices with biochar and compost improved the physical (bulk density and porosity), chemical (pH, EC, CEC, TOC, C/N ratio, exchangeable K, and exchangeable Ca), and biological (soil temperature, soil respiration, and soil microorganism count such as bacteria, actinomycetes, and fungi) properties. - Biochar and compost have a stimulation effect on bacteria, actinomycetes, and fungi.	No, this study only stated that the data obtained from soil respiration was the indicator of soil microbes' presence	Sulok et al. (2021)

CONCLUSION

Many Malaysian practitioners have limited awareness of the extensive benefits of organic compost, especially in relation to its effects on soil microbial communities. consequently, there is a significant dependence on chemical fertilisers. while these fertilisers can yield immediate results, they pose risks to soil health and environmental sustainability over time. this knowledge gap emphasises the necessity for research into the role of organic compost in enhancing microbial activity in Malaysian agriculture, which is vital for improving soil fertility, nutrient cycling, and overall crop productivity. numerous international studies have revealed that using organic compost significantly strengthens sustainable agricultural systems and boosts their ability to withstand various environmental challenges. by exploring and addressing the gap between these global research findings and the current agricultural practices in Malaysia, we can foster scientific progress and pave the way for enhanced food security. in Malaysia, where agriculture is a vital component of food production, encouraging the use of organic compost aligns with the country's objectives to create sustainable food systems. future research should offer factual data to help farmers and policymakers incorporate organic composting techniques into agricultural systems. this change guarantees long-term food availability, environmental preservation, and resilient crip production. because it addresses both local agricultural requirements and global issues for sustainable food security, such research is extremely relevant. these developments will strengthen the country's food production systems while simultaneously reducing environmental deterioration. In the end, we can guarantee the maintenance of soil health, encourage sustainable farming, and ensure food supplies for future generations by coordinating Malaysia's agricultural strategy with accepted international standards.

ACKNOWLEDGEMENT

This paper received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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REFERENCES

A S Mohamad Amir Hamzah, M F Abdul Karim, H L Wong, K A Hambali, M N Mohd Yusoff, N A Amaludin, M C Leong, M A Abas, N H Hassin, L Ismail, & A Amir. (2021). Effect of Organic Amendments on the Growth of Gaharu (Aquilaria malaccensis). *IOP Conference Series: Earth and Environmental Science*, *842*(1), 012078. https://doi.org/10.1088/1755-1315/842/1/012078

Ahmed, H. A., Ishak, C. F., Karam, D. S., & Othman, R. (2021). Efficiency of Rice Husk Biochar with Poultry Litter Co- Composts in Oxisols for Improving Soil Physico-Chemical Properties and Enhancing Maize Performance. *Agronomy*, *11*(12), 2409. https://doi.org/10.3390/agronomy11122409

Ali, S., Ullah, S., Umar, H., Saghir, A., Nasir, S., M. Hamza Jabbar, Zain ul Aabdeen, & Rimsha Zain. (2022). Effects of Heavy Metals on Soil Properties and their Biological Remediation. *Indian Journal of Pure & Applied Biosciences*, *10*(1), 40–46. https://doi.org/10.18782/2582-2845.8856

Anisuzzaman, M., Rafii, M. Y., Ramlee, S. I., Jaafar, N. M., Ikbal, M. F., & Haque, M. A. (2022). The Nutrient Content, Growth, Yield, and Yield Attribute Traits of Rice (Oryza sativa L.) Genotypes as Influenced by Organic Fertilizer in Malaysia. *Sustainability*, *14*(9), 5692. https://doi.org/10.3390/su14095692

Awasthi, M. K., Duan, Y., Liu, T., Awasthi, S. K., & Zhang, Z. (2020). Relevance of biochar to influence the bacterial succession during pig manure composting. *Bioresource Technology*, *304*, 122962. https://doi.org/10.1016/j.biortech.2020.122962

Bello, A., Han, Y., Zhu, H., Deng, L., Yang, W., Meng, Q., Sun, Y., Egbeagu, U. U., Sheng, S., Wu, X., Jiang, X., & Xu, X. (2020). Microbial community composition, co-occurrence network pattern and nitrogen transformation genera response to biochar addition in cattle manure-maize straw composting. *Science of The Total Environment*, *721*, 137759. https://doi.org/10.1016/j.scitotenv.2020.137759

Borase, D. N., Nath, C. P., Hazra, K. K., Senthilkumar, M., Singh, S. S., Praharaj, C. S., Singh, U., & Kumar, N. (2020). Long-term impact of diversified crop rotations and nutrient management practices on soil microbial functions and soil enzymes activity. *Ecological Indicators*, *114*, 106322. https://doi.org/10.1016/j.ecolind.2020.106322

Deqiang, C., Jiawei, Z., Dexing, C., Xin, H., Cuili, Z., Jinwei, L., Siren, L., Zhong-Jian, L., Shuangquan, Z., & Xin, Q. (2023). *Chicken manure application alters microbial community structure and the distribution of antibiotic-resistance genes in rhizosphere soil of Cinnamomum camphora forests*.

Farahzety, A. M., Singh, A., Muhammad Najib, O. G., Wan Rozita, W. E., & Rosniza, K. (2024). Yield and phytonutrient content of moringa leaves as influenced by plantspacings and fertilizer application. *Food Research*, *8*(Supplementary 3), 1–12. https://doi.org/10.26656/fr.2017.8(S3).1

Ghouili, E., Abid, G., Hogue, R., Jeanne, T., D'Astous-Pagé, J., Sassi, K., Hidri, Y., M'Hamed, H. C., Somenahally, A., Xue, Q., Jebara, M., Nefissi Ouertani, R., Riahi, J., De Oliveira, A. C., & Muhovski, Y. (2023). Date Palm Waste Compost Application Increases Soil Microbial Community Diversity in a Cropping Barley (Hordeum vulgare L.) Field. *Biology*, *12*(4), 546. https://doi.org/10.3390/biology12040546

Halmi, M. F. A., & Simarani, K. (2021). Effect of two contrasting biochars on soil microbiota in the humid tropics of Peninsular Malaysia. *Geoderma*, *395*, 115088. https://doi.org/10.1016/j.geoderma.2021.115088

©Authors, 2024

Hamzah, N., Farhana Hashim, N., Syahiza Zainuddin, N., Kassim, J., Abdul Halip, A., & Liza Rahim, N. (2020). Effect of Organic Matter on Pathogen Population During Composting of Municipal Sludge. *IOP Conference Series: Earth and Environmental Science*, *616*(1), 012055. https://doi.org/10.1088/1755-1315/616/1/012055

Heisey, S., Ryals, R., Maaz, T. M., & Nguyen, N. H. (2022). A Single Application of Compost Can Leave Lasting Impacts on Soil Microbial Community Structure and Alter Cross-Domain Interaction Networks. *Frontiers in Soil Science*, *2*. https://doi.org/10.3389/fsoil.2022.749212

Hernández-Lara, A., Ros, M., Cuartero, J., Vivo, J.-M., Lozano-Pastor, P., & Pascual, J. A. (2023). Effects of solarisation combined with compost on soil pathogens and the microbial community in a spinach cropping system. *Agriculture, Ecosystems & Environment*, *346*,

Hissham, N. F. N., Kadir, A. A., Sarani, N. A., Hassan, M. I. H., Fadeli, M. F. A., & Mazlan, S. N. (2024). The Evaluation of Composted Food Waste Effects in Conserving and Enhancing Growth Performance of Azolla Pinnata. *International Journal of Conservation Science*, *15*(1), 685–698. https://doi.org/10.36868/IJCS.2024.01.21

Ho, T. T. K., Tra, V. T., Le, T. H., Nguyen, N.-K.-Q., Tran, C.-S., Nguyen, P.-T., Vo, T.-D.-H., Thai, V.-N., & Bui, X.-T. (2022). Compost to improve sustainable soil cultivation and crop productivity. *Case Studies in Chemical and Environmental Engineering*, *6*, 100211. https://doi.org/10.1016/j.cscee.2022.100211

Ichihashi, Y., Date, Y., Shino, A., Shimizu, T., Shibata, A., Kumaishi, K., Funahashi, F., Wakayama, K., Yamazaki, K., Umezawa, A., Sato, T., Kobayashi, M., Kamimura, M., Kusano, M., Che, F.-S., O`Brien, M., Tanoi, K., Hayashi, M., Nakamura, R., … Nihei, N. (2020). Multi-omics analysis on an agroecosystem reveals the significant role of organic nitrogen to increase agricultural crop yield. *Proceedings of the National Academy of Sciences*, *117*(25), 14552–14560. https://doi.org/10.1073/pnas.1917259117

Ji, L., Si, H., He, J., Fan, L., & Li, L. (2021). The shifts of maize soil microbial community and networks are related to soil properties under different organic fertilizers. *Rhizosphere*, *19*, 100388. https://doi.org/10.1016/j.rhisph.2021.100388

Kamaruddin, N. F. H., Adam, S., & Boll Kassim, N. Q. (2023). The effects of different pineapple wastes on soil chemical properties and growth and yield of Okra (Abelmoschus esculentus L.). *IOP Conference Series. Earth and Environmental Science*, *1182*(1), 012036. https://doi.org/10.1088/1755-1315/1182/1/012036

Kiran, Bharti, R., & Sharma, R. (2022). Effect of heavy metals: An overview. *Materials Today: Proceedings*, *51*, 880–885. https://doi.org/10.1016/j.matpr.2021.06.278

Lazcano, C., Zhu-Barker, X., & Decock, C. (2021). Effects of Organic Fertilizers on the Soil Microorganisms Responsible for N2O Emissions: A Review. *Microorganisms*, *9*(5), 983. https://doi.org/10.3390/microorganisms9050983

Li, K., Xing, X., Wang, S., Liao, R., Hassan, M. U., Aamer, M., Barbanti, L., Wen, T., & Xu, H. (2024). Organic fertilisation enhances network complexity among bacteria, fungi, and protists by improving organic matter and phosphorus in acidic agricultural soils. *European Journal of Soil Biology*.

Liang, Y. Q., Annammala, K. V., Martin, P., Yong, E. L., Mazilamani, L. S., & Najib, M. Z. M. (2020). *Assessment of Physical-Chemical Water Quality Characteristics and Heavy Metals Content of Lower Johor River, Malaysia*. *8*(3).

Liu, C., Tian, J., Chen, L., He, Q., Liu, X., Bian, R., Zheng, J., Cheng, K., Xia, S., Zhang, X., Wu, J., Li, L., Joseph, S., & Pan, G. (2024). Biochar boosted high oleic peanut production with

©Authors, 2024

enhanced root development and biological N fixation by diazotrophs in a sand-loamy Primisol. *Science of The Total Environment*, *932*, 173061. https://doi.org/10.1016/j.scitotenv.2024.173061

Ma'mor, A. S., Wahida, N. H., & Nur Firdaus, A. R. (2023). The Application of Eggshell and Fruit Peels as Soil Amendment on The Growth Performance and Yield of Corn (Zea mays L.). *IOP Conference Series: Earth and Environmental Science*, *1182*(1), 012040. https://doi.org/10.1088/1755-1315/1182/1/012040

Mahamad, N. I. A., Samah, S. N. A. A., & Khidzir, M. N. A. M. (2022). *Effects of different organic fertilizers on growth and yield potential of Solanum melongena (eggplant) in Malaysia*.

Manzoor, A., Naveed, M. S., Ali, R. M. A., Naseer, M. A., UL-Hussan, M., Saqib, M., Hussain, S., & Farooq, M. (2024). Vermicompost: A potential organic fertilizer for sustainable vegetable cultivation. *Scientia Horticulturae*, *336*, 113443. https://doi.org/10.1016/j.scienta.2024.113443

Maru, A., Osumanu, H. A., Jalloh, M. B., Primus, W. C., Musah, A. A., & Ng, J. F. (2023). Co-Composted Chicken Litter Biochar Increases Soil Nutrient Availability and Yield of Oryza sativa L. *Land*, *12*(1), 233. https://doi.org/10.3390/land12010233

Matheri, F., Kambura, A. K., Mwangi, M., Ongeso, N., Karanja, E., Adamtey, N., Mwangi, E. K., Mwangi, E., Tanga, C., Musyoka, M. W., & Runo, S. (2023). Composition, structure, and functional shifts of prokaryotic communities in response to co-composting of various nitrogenous green feedstocks. *BMC Microbiology*, *23*(1), 50. https://doi.org/10.1186/s12866-023-02798-w

Muda, B., Alidin, M. D. @ A. B. H., & Awang, A. (2021). Effect of agricultural waste as organic fertilizer on yield and soil properties of cocoa (Theobroma cacao L.). *Journal of Agricultural and Food Engineering*, *1*(4), 1–4. https://doi.org/10.

Murshid, N., Yaser, A. Z., Rajin, M., Saalah, S., Lamaming, J., & Taliban, M. (2023). Vegetable Waste Composting: A Case Study in Kundasang, Sabah. *Borneo Science | The Journal of Science and Technology*, *43*(1). https://doi.org/10.51200/bsj.v43i1.4405

Parab, C., Yadav, K. D., & Prajapati, V. (2023). Genomics and microbial dynamics in green waste composting: A mini review. *Ecological Genetics and Genomics*, *29*, 100206. https://doi.org/10.1016/j.egg.2023.100206

Ray, P., Lakshmanan, V., Labbé, J. L., & Craven, K. D. (2020). Microbe to Microbiome: A Paradigm Shift in the Application of Microorganisms for Sustainable Agriculture. *Frontiers in Microbiology*, *11*, 622926. https://doi.org/10.3389/fmicb.2020.622926

Sadet-Bourgeteau, S., Houot, S., Karimi, B., Mathieu, O., Mercier, V., Montenach, D., Morvan, T., Sappin-Didier, V., Watteau, F., Nowak, V., Dequiedt, S., & Maron, P.-A. (2019). Microbial communities from different soil types respond differently to organic waste input. *Applied Soil Ecology*, *143*, 70–79. https://doi.org/10.1016/j.apsoil.2019.05.026

Sayara, T., Basheer-Salimia, R., Hawamde, F., & Sánchez, A. (2020). Recycling of Organic Wastes through Composting: Process Performance and Compost Application in Agriculture. *Agronomy*, *10*(11), 1838. https://doi.org/10.3390/agronomy10111838

Shang, L., Wan, L., Zhou, X., Li, S., & Li, X. (2020). Effects of organic fertilizer on soil nutrient status, enzyme activity, and bacterial community diversity in Leymus chinensis steppe in Inner Mongolia, China. *PLOS ONE*, *15*(10), e0240559. https://doi.org/10.1371/journal.pone.0240559

Sindhu, V., Chatterjee, R., Santhoshkumar, G. M., & Sinha, T. (2020). Enrichment of Organic Manures and Their Utilization in Vegetable Crops. *Current Journal of Applied Science and Technology*, 10–24. https://doi.org/10.9734/cjast/2020/v39i3230998

©Authors, 2024

Sulok, K. M. T., Ahmed, O. H., Khew, C. Y., Zehnder, J. A. M., Lai, P. S., Jalloh, M. B., Musah, A. A., Awang, A., & Abdu, A. (2021). Effects of Organic Amendments Produced from Agro-Wastes on Sandy Soil Properties and Black Pepper Morpho-Physiology and Yield. *Agronomy*, *11*(9), Article 9. https://doi.org/10.3390/agronomy11091738

Supian, N. S., Mohd Zin, N. S., Hissham, N. F. N., & Supian, N. S. (2024). The Efficacy of Organic Fertilizer and Leaf Mold to Conserve the Health and Growth of Mango Tree (Mangifera Indica). *International Journal of Conservation Science*, *15*(1), 719–730. https://doi.org/10.36868/IJCS.2024.01.23

Supriatna, J., Setiawati, M. R., Sudirja, R., Suherman, C., & Bonneau, X. (2023). Migration from inorganic to organic fertilization for a more sustainable oil palm agro-industry. *Heliyon*, *9*(12), e22868. https://doi.org/10.1016/j.heliyon.2023.e22868

Tan, J. L., Ang, K. Y., Chow, M. H., Lee, E. T. Y., Lee, K. H., Lee, L. Y., Ooi, S. W., Soh, W. C., & Sithambaram, R. (2020). *A Preliminary Study on Reducing the Dosage of Chemical Fertiliser by using Empty Fruit Bunch as Soil Amendment on the Growth of Choy Sum*. *13*.

Tan, J. L., Wong, D. L., & Ong, M. K. (2021). The Sensory Evaluation of Choy Sum (Brassica chinensis L. var. Parachinensis) Grown with Mineral and Organic Fertiliser in Kampar, Perak, Malaysia. *ASM Science Journal*, *16*, 1–7. https://doi.org/10.32802/asmscj.2021.921

Tangga, C. K., Mohidin, H., & Abdullah, S. (2022). The Effect of Empty Fruit Bunch (EFB) Compost and Trichoderma Biofertilizer on Growth and Yield Performance of Chili (Capsicum annuum L. Var. Kulai). *IOP Conference Series: Earth and Environmental Science*, *1114*(1), 012070. https://doi.org/10.1088/1755-1315/1114/1/012070

Wagg, C., Hautier, Y., Pellkofer, S., Banerjee, S., & Schmid, B. (2021). *Diversity and asynchrony in soil microbial communities stabilizes ecosystem functioning*.

Wu, L., Jiang, Y., Zhao, F., He, X., Liu, H., & Yu, K. (2020). Increased organic fertilizer application and reduced chemical fertilizer application affect the soil properties and bacterial communities of grape rhizosphere soil. *Scientific Reports*, *10*(1), 9568. https://doi.org/10.1038/s41598-020-66648-9

Yan, B., Lan, T., Lv, Y., Xing, C., Liang, Y., Wang, H., Wu, Q., Guo, L., & Guo, W.-Q. (2024). Enhancing simultaneous nitrogen and phosphorus availability through biochar addition during Chinese medicinal herbal residues composting: Synergism of microbes and humus. *Science of The Total Environment*, *930*, 172515. https://doi.org/10.1016/j.scitotenv.2024.172515

Yang, Y., Awasthi, M. K., Bao, H., Bie, J., Lei, S., & Lv, J. (2020). Exploring the microbial mechanisms of organic matter transformation during pig manure composting amended with bean dregs and biochar. *Bioresource Technology*, *313*, 123647. https://doi.org/10.1016/j.biortech.2020.123647

Zainol, R. M., Rosmi, M. N. M., Ibrahim, M. S. N., & Masdor, N. A. (2024). Agricultural chemical input risk management practices in the paddy crop subsector: Evidence from Sungai Panjang, Sabak Bernam district, Malaysia. *Asian Development Policy Review*, *12*(3), 208–225. https://doi.org/10.55493/5008.v12i3.5114

Zhang, J., Ye, L., Chang, J., Wang, E., Wang, C., Zhang, H., Pang, Y., & Tian, C. (2024). Straw Soil Conditioner Modulates Key Soil Microbes and Nutrient Dynamics across Different Maize Developmental Stages. *Microorganisms*, *12*(2), 295. https://doi.org/10.3390/microorganisms12020295

Zhao, N., Wang, X., Ma, J., Li, X., Cao, J., Zhou, J., Wu, L., Zhao, P., & Cao, W. (2024). Co-incorporating green manure and crop straw increases crop productivity and improves soil quality

©Authors, 2024

with low greenhouse-gas emissions in a crop rotation. *The Crop Journal*, *12*(4), 1233–1241. https://doi.org/10.1016/j.cj.2024.07.002

Zhou, Z., Zhang, S., Jiang, N., Xiu, W., Zhao, J., & Yang, D. (2022). *Effects of organic fertilizer incorporation practices on crops yield, soil quality, and soil fauna feeding activity in the wheat-maize rotation system*.

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