Review Article Open Access

Dung Decomposers: Impact on Soil Fertility and Plant Growth

Kaiwen Liang
Agri-Products Application Center, Hainan Institute of Tropical Agricultural Resouces, Sanya, 572025,Hainan, China
Corresponding email: Kaiwen.liang@hitar.org

Molecular Soil Biology, 2024, Vol.15, No.1 doi: 10.5376/msb.2024.15.0005
Received: 05 Jan., 2024
Accepted: 09 Feb., 2024
Published: 23 Feb., 2024

Preferred citation for this article:
Liang K.W., 2024, Dung decomposers: impact on soil fertility and plant growth, Molecular Soil Biology, 15(1): 37-45 (doi: 10.5376/msb.2024.15.0005)

Abstract The findings revealed that dung decomposers significantly enhance soil nutrient content, including nitrogen, phosphorus, potassium, magnesium, and calcium, while reducing soil density, pH, and electrical conductivity. The presence of dung decomposers also led to increased plant growth parameters such as total leaf sugar, vitamin C, polyphenols, total protein, and amino acids. Additionally, dung decomposers improved the net photosynthetic rate, stomatal conductance, and chlorophyll content in plants. The study also highlighted the species-specific effects of dung decomposers on nutrient cycling and soil fertility, emphasizing the importance of maintaining beetle diversity to maximize soil health benefits. The application of dung decomposers as a soil amendment significantly enhances soil fertility and promotes plant growth. This sustainable strategy can improve crop yields and nutrient status, making it a viable option for organic agricultural practices. The study underscores the critical role of dung decomposers in nutrient cycling and soil health, particularly in dryland environments where nutrient losses due to grazing are prevalent.

Keywords Dung decomposers; Soil fertility; Plant growth; Nutrient cycling; Sustainable agriculture; Soil amendments, Organic farming

1 Introduction

Dung decomposition is a critical ecological process that involves the breakdown of animal feces by a variety of organisms, including microbes, invertebrates, and other fauna. This process not only recycles nutrients back into the soil but also supports plant growth and maintains soil health. Invertebrates, such as dung beetles, earthworms, and termites, play a significant role in this decomposition process. They facilitate the breakdown of organic matter through their feeding activities and interactions with microbial communities, which further enhances nutrient cycling and soil structure (Evans et al., 2019; Griffiths et al., 2021; Alves et al., 2022).

Dung serves as a vital nutrient source in many ecosystems, particularly in grasslands and pastures. It provides essential nutrients such as nitrogen, phosphorus, and potassium, which are crucial for plant growth. The decomposition of dung by soil fauna accelerates the translocation of these nutrients into the soil, thereby enhancing soil fertility and promoting plant productivity (Yamada et al., 2007; Evans et al., 2019; Maldonado et al., 2019). Additionally, dung deposition and decomposition influence soil physical properties, such as bulk density and water infiltration capacity, which are important for maintaining soil health and structure (Herrick and Lal, 1995; Hirata et al., 2008). The activity of dung decomposers also contributes to the heterogeneity of nutrient distribution in the soil, which can affect plant community dynamics and ecosystem functioning (Yoshitake et al., 2014).

This study aims to provide a comprehensive overview of the role of dung decomposers in soil fertility and plant growth. It will examine the various organisms involved in dung decomposition, their interactions, and the ecological services they provide. The study will also explore the impact of dung decomposition on soil properties and plant productivity, highlighting the importance of maintaining diverse decomposer communities for sustainable ecosystem management. By synthesizing findings from multiple studies, this study seeks to enhance our understanding of the complex processes underlying dung decomposition and its implications for soil and plant health.

2 Types of Dung Decomposers

2.1 Microbial decomposers (bacteria, fungi)

Microbial decomposers, including bacteria and fungi, are essential for breaking down organic matter in dung. These microorganisms facilitate the mineralization process, converting organic nutrients into inorganic forms that plants can absorb. For instance, specific strains of bacteria in the rhizospheric soil, known as plant growth-promoting rhizobacteria, are used as biofertilizers to enhance soil fertility and suppress pests and pathogens (Pathma et al., 2019). Additionally, the microbial communities in earthworm digestive tracts contribute significantly to nutrient cycling by decomposing organic matter and enhancing soil microbial activity (Medina-Sauza et al., 2019).

2.2 Invertebrate decomposers (earthworms, dung beetles)

Invertebrate decomposers such as earthworms and dung beetles also play a vital role in dung decomposition and nutrient cycling. Earthworms, for example, mix soil layers and incorporate organic matter into the soil, which improves soil structure and fertility. They also influence soil microbial communities, which in turn affect soil processes and plant growth (Medina-Sauza et al., 2019; Ahmed and Al-Mutairi, 2022; Li et al., 2022). Dung beetles, on the other hand, break down dung and incorporate it into the soil, enhancing nutrient availability. Different species of dung beetles vary in their efficiency, with some species like Sulcophanaeus imperator being more effective in incorporating nitrogen and phosphorus into the soil (Jones et al., 2018; Evans et al., 2019; Maldonado et al., 2019).

2.3 Role of different decomposers in nutrient cycling

Both microbial and invertebrate decomposers are integral to nutrient cycling. Microbial decomposers break down complex organic compounds into simpler forms, making nutrients available for plant uptake. For example, earthworm activity enhances denitrification and increases soil nutrient availability, indirectly promoting plant growth (Medina-Sauza et al., 2019; Li et al., 2022). Invertebrate decomposers like dung beetles accelerate the decomposition process, leading to quicker nutrient release and improved soil fertility. The activity of dung beetles has been shown to increase soil nutrients in the topsoil, which is crucial for plant growth (Evans et al., 2019; Maldonado et al., 2019; Ma et al., 2023).

3 Mechanisms of Dung Decomposition

3.1 Breakdown of organic matter

The breakdown of organic matter in dung is a complex process primarily driven by microbial and invertebrate decomposers. Microorganisms, including bacteria and fungi, play a crucial role in the initial stages of decomposition by breaking down complex organic compounds into simpler molecules. This microbial activity is essential for the recycling of nutrients and the formation of soil organic matter (SOM) (Soares and Rousk, 2019; Hicks et al., 2021). Invertebrates, such as earthworms and other soil fauna, further contribute to this process by physically fragmenting the dung and enhancing microbial access to organic substrates (Griffiths et al., 2021). The interaction between these decomposers ensures a continuous and efficient breakdown of organic matter, ultimately supporting soil fertility and plant growth (Griffiths et al., 2021; Sun and Ge, 2021).

3.2 Enzymatic activities involved

Enzymatic activities are central to the decomposition of dung, with various enzymes produced by both microbial and invertebrate decomposers. Microorganisms secrete a range of enzymes, including cellulases, proteases, and lipases, which degrade cellulose, proteins, and lipids, respectively (Hicks et al., 2021; Raczka et al., 2021). These enzymes facilitate the conversion of complex organic compounds into simpler forms that can be assimilated by microbes and plants. Invertebrates also contribute to enzymatic decomposition through their digestive enzymes, which break down organic matter as it passes through their digestive systems (Griffiths et al., 2021). The combined enzymatic activities of microbes and invertebrates accelerate the decomposition process and enhance nutrient availability in the soil (Pimentão et al., 2019; Konschak et al., 2021).

3.3 Interaction between microbial and invertebrate decomposers

The interaction between microbial and invertebrate decomposers is a synergistic relationship that enhances the efficiency of dung decomposition. Invertebrates, such as earthworms and detritivores, physically break down dung into smaller particles, increasing the surface area available for microbial colonization and activity (Griffiths et al., 2021; Sun and Ge, 2021). This physical fragmentation by invertebrates facilitates microbial access to organic substrates, promoting microbial growth and enzymatic activity (Pimentão et al., 2019; Griffiths et al., 2021). Additionally, the presence of invertebrates can influence the composition and diversity of microbial communities, further affecting the decomposition process (Raczka et al., 2021; Mason et al., 2023). This interaction between decomposers not only accelerates the breakdown of organic matter but also contributes to the formation of stable soil organic matter, which is crucial for soil health and plant growth (Fanin, et al., 2021; Griffiths et al., 2021; Raczka et al., 2021) (Figure 1).

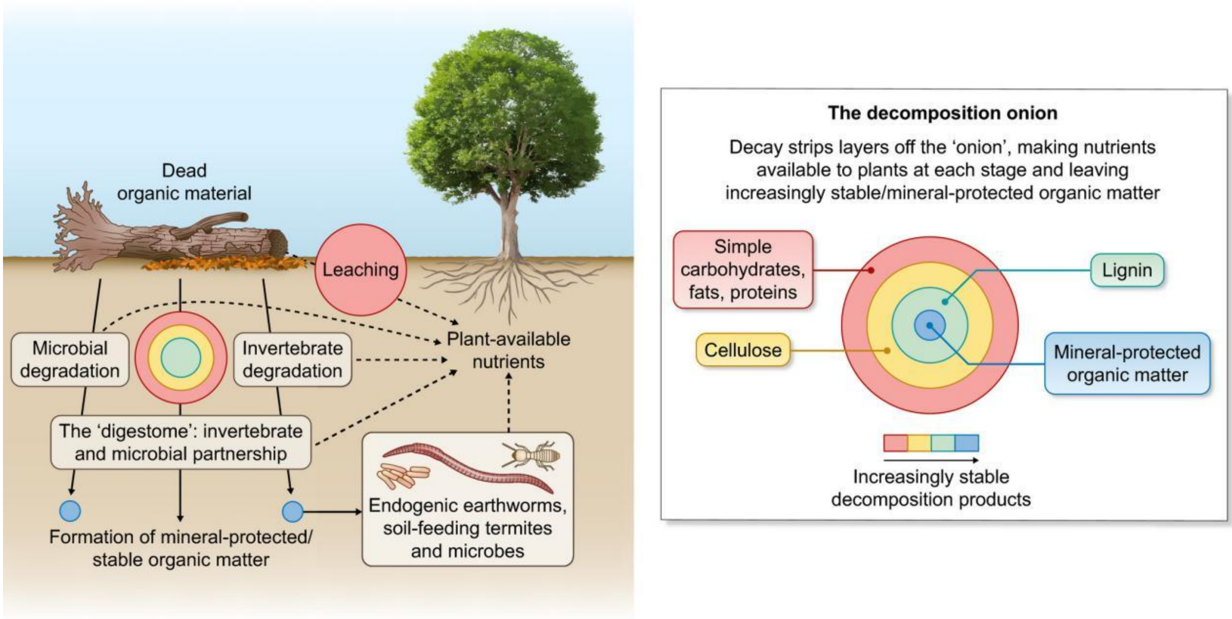

Figure 1 The fate of plant matter through the decomposition process (Adopted from Griffiths et al., 2021)

Image caption: This can be conceptualised as removing different layers of an onion. The initial stages of decomposition involve leaching and multiple organisms (microbial and invertebrate) that can digest simple compounds: carbohydrates, peptides and fats (the red layer of the onion). After this stage multiple organisms can catabolise lignocellulose (the yellow and green parts of the onion). This can be microbes alone, invertebrates alone (using endogenous cellulases, but generally not endogenous lignin-modifying enzymes), or a partnership between endogenous invertebrate cellulases and (mostly) gut symbiont cellulases ('digestomes'). The result of these progressive decomposition processes is the creation of organic matter that becomes smaller in molecular size and is increasingly protected from further breakdown by interaction with mineral surfaces and incorporation into soil aggregates (Lehmann and Kleber (2015) defined here as stable or protected soil organic matter; the blue part of the onion). This protected organic matter is then consumed by a range of organisms, including microbes, soil-feeding termites, and endogeic earthworms. These soil-feeding invertebrates often break down clay-complexed peptides and are thought to be important sources of plant-available nitrogen, key bioavailable parts of the nitrogen cycle (Ji and Brune, 2005) (Adopted from Griffiths et al., 2021)

4 Impact on Soil Fertility

4.1 Nutrient release and availability (nitrogen, phosphorus, etc.)

Dung decomposers, particularly dung beetles, play a crucial role in enhancing soil fertility by facilitating the release and availability of essential nutrients such as nitrogen (N) and phosphorus (P). Studies have shown that dung beetles incorporate significant amounts of nitrogen, ammonium, and phosphorus into the soil, which varies among species. For instance, the dung beetle *Sulcophanaeus imperator* was found to incorporate the highest quantities of organic matter, nitrogen, and phosphate into the soil, thereby improving nutrient cycling and soil fertility (Maldonado et al., 2019). Additionally, the application of dung beetles in soil has been shown to significantly increase the levels of magnesium and potassium, further contributing to soil nutrient status

(Badenhorst et al., 2018). The combined use of cow dung and biochar has also been reported to enhance soil phosphorus availability and improve the growth of plants such as *Populus euphratica* by increasing the abundance of phosphate-solubilizing bacteria (Fan et al., 2023).

4.2 Soil structure and aeration improvement

Dung decomposers significantly improve soil structure and aeration, which are critical for plant growth. Dung beetles, for example, create tunnels under dung pats, which enhance water infiltration rates, reduce soil compaction, and improve soil aeration. This bioturbation activity not only facilitates better root penetration but also enhances the overall soil structure, making it more conducive for plant growth. In reclaimed mined lands, the presence of dung beetles has been shown to reduce soil strength and increase water infiltration rates, leading to improved soil physical properties and higher plant biomass (Badenhorst et al., 2018). These improvements in soil structure and aeration are essential for maintaining healthy soil ecosystems and promoting sustainable agricultural practices.

4.3 Effects on soil microbial communities

The activity of dung decomposers also has profound effects on soil microbial communities. The introduction of dung and dung beetles into the soil has been shown to increase microbial diversity and alter the composition of soil microbial communities. For instance, the application of cow dung and its biochar has been found to enhance the diversity of bacterial communities and increase the abundance of functional genes related to phosphorus conversion (Fan et al., 2023). Similarly, the use of composted dung in combination with arbuscular mycorrhizal fungi (AMF) has been reported to improve the growth and nutrient uptake of mung bean plants by enhancing the colonization of plant roots by beneficial fungi (Wahid et al., 2019). These changes in microbial communities are crucial for maintaining soil health and fertility, as they play a key role in nutrient cycling and organic matter decomposition.

5 Impact on Plant Growth

5.1 Influence of decomposer activity on plant nutrient uptake

Decomposers, particularly dung beetles and vermi-compost, play a significant role in enhancing plant nutrient uptake. Studies have shown that the incorporation of dung beetles into soil can significantly improve the nutrient status, including nitrogen, phosphorus, potassium, magnesium, and calcium, which are essential for plant growth. For instance, the application of dung beetles along with cow dung has been found to increase the nutrient uptake in bok choy, leading to improved growth and physiological processes (Kaleri et al., 2020). Similarly, the use of vermi-compost has been shown to enhance the nutrient uptake in marigold plants, resulting in better vegetative growth and flowering parameters (Shafique et al., 2021) (Figure 2). The combined application of cattle dung and NPK fertilizer also significantly increased the uptake of nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium in fluted pumpkin, demonstrating the synergistic effect of organic and inorganic fertilizers on nutrient uptake (Franko et al., 2019).

5.2 Role in seed germination and early plant development

Decomposers also play a crucial role in seed germination and early plant development. Vermi-compost, for example, has been shown to be highly effective in promoting seed germination and early seedling growth in marigold plants. The optimal concentration of vermi-compost (20%) resulted in the highest germination percentage and early initiation of seed germination (Shafique et al., 2021). Additionally, the activity of dung beetles has been linked to improved seed germination and early plant development by enhancing soil conditions and nutrient availability. In tropical forests, dung beetles contribute to the secondary dispersal of seeds, which can positively affect seed bank structure and dynamics, although the direct impact on seedling performance may vary (Andresen and Urrea-Galeano, 2022).

5.3 Long-term effects on plant health and productivity

The long-term effects of decomposer activity on plant health and productivity are profound. The continuous application of decomposers such as dung beetles and vermi-compost can lead to sustained improvements in soil fertility, which in turn supports long-term plant health and productivity. For instance, the use of cow dung as a soil amendment has been shown to alleviate the ginseng replanting problem by improving soil nutritional status and stimulating beneficial soil microbes, leading to enhanced plant growth and survival rates (Tagele et al., 2023). Furthermore, the combined application of cow dung and green manure has been found to increase the growth and yield of tiger nut by improving soil moisture content, nutrient retention, and microbial activity (Adekiya et al., 2020). These findings suggest that the integration of decomposers into agricultural practices can provide long-term benefits for plant health and productivity by maintaining and enhancing soil fertility.

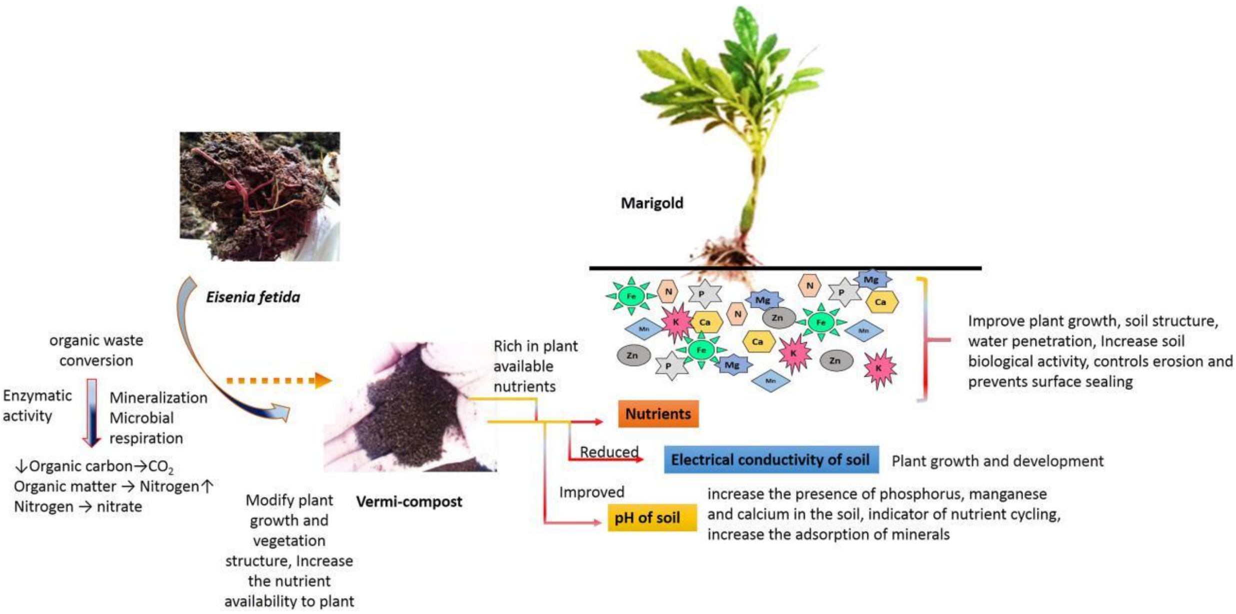

Figure 2 Impact of vermi-compost on the seed germination and growth parameters of marigold (Adopted from Shafique et al., 2021)

6 Environmental and Ecological Considerations

6.1 Effects on carbon sequestration

Dung decomposers, particularly dung beetles and earthworms, play a significant role in carbon sequestration. The incorporation of organic matter into the soil by these organisms enhances soil organic carbon (SOC) storage. For instance, the presence of diverse decomposer species has been shown to increase root biomass significantly, which in turn contributes to higher SOC levels (Eisenhauer et al., 2018). Additionally, organic amendments such as cow dung have been found to improve soil aggregate stability and carbon sequestration in wetland paddy cultivation (Rahman ert al., 2022). Maintaining high levels of plant diversity, which is often supported by the activity of dung decomposers, can further enhance SOC storage and mitigate anthropogenic CO_2 increases (Chen et al., 2018).

6.2 Biodiversity implications

The biodiversity of dung decomposers is crucial for maintaining ecosystem functions. Studies have shown that higher decomposer diversity leads to increased biomass production and nutrient cycling efficiency (Eisenhauer et al., 2018). Dung beetles, for example, vary in their efficiency of nutrient incorporation into the soil, with some species being more effective than others (Maldonado et al., 2019). This variability underscores the importance of conserving a diverse range of decomposer species to maximize their ecological benefits. Furthermore, the presence of dung beetles has been linked to improved soil conditions and plant growth, highlighting their role in sustaining biodiversity and ecosystem health (Kaleri et al., 2020).

6.3 Role in sustainable agriculture and ecosystem services

Dung decomposers contribute significantly to sustainable agriculture by enhancing soil fertility and promoting plant growth. The activity of dung beetles and earthworms accelerates the decomposition of organic matter, leading to improved soil nutrient status and structure (Evans et al., 2019). This process not only supports higher crop yields but also enhances the overall resilience of agricultural systems. For example, the application of cow dung and dung beetles has been shown to improve the growth and physiological processes of crops like bok choy, making it a sustainable strategy for soil and crop management (Kaleri et al., 2020). Additionally, the role of dung decomposers in nutrient cycling is vital for maintaining soil health and mitigating nutrient losses in grazing fields (Maldonado et al., 2019).

7 Challenges and Future Research

7.1 Knowledge gaps in dung decomposition processes

Despite significant advancements in understanding dung decomposition, several knowledge gaps remain. One major gap is the detailed mechanistic understanding of how different decomposers, such as dung beetles and earthworms, interact with microbial communities to influence nutrient cycling and soil health. For instance, while it is known that dung beetles improve soil properties and plant growth by burying dung, the specific microbial processes involved are not fully understood (Badenhorst et al., 2018; Griffiths et al., 2021). Additionally, the role of invertebrates as primary decomposers, rather than just facilitators of microbial decomposition, needs further exploration (Griffiths et al., 2021). Another gap is the variability in decomposition rates and nutrient release depending on the type of organic waste used, such as cow dung, fish sludge, or plant residues, and how these differences impact soil fertility and plant growth (Yuvaraj et al., 2018; Moustafa et al., 2022).

7.2 Potential impact of climate change on decomposer activity

Climate change poses a significant threat to the activity and efficiency of dung decomposers. Changes in temperature and precipitation patterns can alter the habitat suitability for decomposers like dung beetles and earthworms, potentially reducing their populations and activity levels (Badenhorst et al., 2018; Ngone et al., 2018). For example, higher temperatures may increase the metabolic rates of decomposers, leading to faster decomposition but also higher CO_2 emissions, which could exacerbate climate change (Soares and Rousk, 2019). Additionally, extreme weather events, such as droughts and heavy rains, can disrupt the delicate balance of soil moisture and temperature, further impacting decomposer activity and soil health (Ngone et al., 2018; Moustafa et al., 2022). Understanding these impacts is crucial for developing strategies to mitigate the negative effects of climate change on soil fertility and plant growth.

7.3 Future directions for research and application in agriculture

Future research should focus on several key areas to enhance the understanding and application of dung decomposers in agriculture. First, there is a need for more comprehensive studies on the interactions between different decomposers and microbial communities, and how these interactions influence nutrient cycling and soil health (Wang et al., 2020; Griffiths et al., 2021). Second, research should explore the potential of using a combination of decomposers, such as dung beetles and earthworms, to maximize the benefits of dung decomposition (Badenhorst et al., 2018; Yuvaraj et al., 2018). Third, the development of climate-resilient decomposer species through selective breeding or genetic modification could help mitigate the impacts of climate change on decomposer activity (Soares and Rousk, 2019; Cornejo et al., 2021). Finally, integrating decomposer-based strategies into conventional agricultural practices, such as crop rotation and organic fertilization, could improve soil fertility, reduce the need for chemical fertilizers, and enhance sustainable agricultural productivity (Badenhorst et al., 2018; Ngone et al., 2018; Wang et al., 2020).

8 Concluding Remarks

Dung decomposers, particularly dung beetles, play a crucial role in enhancing soil fertility and promoting plant growth. Studies have shown that dung beetle activity significantly improves soil properties such as water infiltration rates, bulk density, and nutrient content, which in turn boosts plant biomass and health. Additionally, the presence of dung beetles has been linked to increased microbial diversity and activity in the soil, further contributing to nutrient cycling and soil health. The application of dung beetles in various soil types, including those simulating reclaimed mined land, has demonstrated their ability to maintain their beneficial activities even under challenging conditions.

The findings underscore the potential of dung decomposers as a sustainable and cost-effective strategy for soil management and agricultural productivity. Incorporating dung beetles into soil management practices can enhance soil structure, nutrient availability, and plant growth, reducing the need for chemical fertilizers and soil rejuvenating tillage practices. This biological approach not only improves soil health but also supports biodiversity, which is essential for resilient agricultural ecosystems. Moreover, the use of dung beetles and other decomposers can mitigate the negative impacts of intensive grazing and other agricultural practices on soil quality.

Dung decomposers are vital for maintaining healthy and productive soils. Their ability to enhance nutrient cycling, improve soil structure, and support plant growth makes them indispensable in sustainable agriculture. The integration of dung decomposers into soil management practices offers a promising avenue for improving soil fertility and crop yields while reducing environmental impacts. Future research should continue to explore the diverse roles of dung decomposers in different ecosystems and develop practical applications for their use in agriculture.

Acknowledgments
The author appreciates the feedback from two anonymous peer reviewers on the manuscript of this study.

Conflict of Interest Disclosure
The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Adekiya A., Olaniran A., Adenusi T., Aremu C., Ejue W., Iranloye Y., Gbadamosi A., and Olayanju A., 2020, Effects of cow dung and wood biochars and green manure on soil fertility and tiger nut (*Cyperus esculentus* L.) performance on a savanna Alfisol, Scientific Reports, 10: 21021. https://doi.org/10.1038/s41598-020-78194-5

Ahmed N., and Al-Mutairi K., 2022, Earthworms effect on microbial population and soil fertility as well as their interaction with agriculture practices, Sustainability, 14(13): 7803. https://doi.org/10.3390/su14137803

Alves F., Aguilera-Olivares D., Rocha M., and Arab A., 2022, Termites are the main dung removals in a degraded landscape in Brazil, Frontiers in Ecology and Evolution, 10: 982602. https://doi.org/10.3389/fevo.2022.982602.

Andresen E., and Urrea-Galeano L., 2022, Effects of dung beetle activity on tropical forest plants, Frontiers in Ecology and Evolution, 10: 979676. https://doi.org/10.3389/fevo.2022.979676

Badenhorst J., Dabrowski J., Scholtz C., and Truter W., 2018, Dung beetle activity improves herbaceous plant growth and soil properties on confinements simulating reclaimed mined land in South Africa, Applied Soil Ecology, 132: 53-59. https://doi.org/10.1016/J.APSOIL.2018.08.011

Chen S., Wang W., Xu W., Wang Y., Wan H., Chen D., Tang Z., Tang X., Zhou G., Xie Z., Zhou D., Shangguan Z., Huang J., He J., Wang Y., Sheng J., Tang L., Li X., Dong M., Wu Y., Wang Q., Wang Z., Wu J., Chapin F., and Bai Y., 2018, Plant diversity enhances productivity and soil carbon storage, Proceedings of the National Academy of Sciences, 115: 4027-4032. https://doi.org/10.1073/pnas.1700298114

Cornejo A., Pérez J., López-Rojo N., García G., Pérez E., Guerra A., Nieto C., and Boyero L., 2021, Litter decomposition can be reduced by pesticide effects on detritivores and decomposers: Implications for tropical stream functioning, Environmental Pollution, 285: 117243. https://doi.org/10.1016/j.envpol.2021.117243

Eisenhauer N., Vogel A., Jensen B., and Scheu S., 2018, Decomposer diversity increases biomass production and shifts aboveground-belowground biomass allocation of common wheat, Scientific Reports,8(1): 17894. https://doi.org/10.1038/s41598-018-36294-3

Evans K., Mamo M., Wingeyer A., Schacht W., Eskridge K., Bradshaw J., and Ginting D., 2019, Soil fauna accelerate dung pat decomposition and nutrient cycling into grassland soil, Rangeland Ecology and Management, 72(4): 667-677. https://doi.org/10.1016/J.RAMA.2019.01.008

Fan Y., Lv G., Chen Y., Chang Y., and Li Z., 2023, Differential effects of cow dung and its biochar on *Populus euphratica* soil phosphorus effectiveness, bacterial community diversity and functional genes for phosphorus conversion, Frontiers in Plant Science, 14: 1242469. https://doi.org/10.3389/fpls.2023.1242469

Fanin N., Lin D., Freschet G., Keiser A., Augusto L., Wardle D., and Veen G., 2021, Home-field advantage of litter decomposition: from the phyllosphere to the soil, The New Phytologist, 231(4): 1353-1358.
https://doi.org/10.1111/nph.17475

Franko O., Paulo J., and AmhakhianS. O., 2019, Influence of combined application of cattle dung and NPK fertilizer on soil physico-chemical properties, growth, nutrient uptake and yield of fluted pumpkin (*Telfairia occidentalis*) in Anyigba, Kogi State, Nigeria, South Asian Research Journal of Agriculture and Fisheries, 2(1): 1-14.
https://doi.org/10.36346/sarjaf.2020.v02i01.001

Griffiths H., Ashton L., Parr C., and Eggleton P., 2021, The impact of invertebrate decomposers on plants and soil, The New Phytologist, 231(6): 2142-2149.
https://doi.org/10.1111/nph.17553

Herrick J., and Lal R., 1995, Soil physical property changes during dung decomposition in a tropical pasture, Soil Science Society of America Journal, 59: 908-912.
https://doi.org/10.2136/SSSAJ1995.03615995005900030040X

Hicks L., Lajtha K., and Rousk J., 2021, Nutrient limitation may induce microbial mining for resources from persistent soil organic matter, Ecology, 102(6): e03328.
https://doi.org/10.1002/ecy.3328

Hirata M., Hasegawa N., Nomura M., Ito H., Nogami K., and Sonoda T., 2008, Deposition and decomposition of cattle dung in forest grazing in southern Kyushu, Japan, Ecological Research, 24: 119-125.
https://doi.org/10.1007/s11284-008-0488-y

Ji R., and Brune A., 2005, Digestion of peptidic residues in humic substances by an alkali-stable and humic-acid-tolerant proteolytic activity in the gut of soil-feeding termites, Soil Biology and Biochemistry 37(9): 1648-1655.

Jones M., Tylianakis J., Reganold J., and Snyder W., 2018, Dung beetle-mediated soil modification: a data set for analyzing the effects of a recent introduction on soil quality, Ecology, 99(7): 1694.
https://doi.org/10.1002/ecy.2374

Kaleri A., Ma J., Jakhar A., Hakeem A., Ahmed A., Napar W., Ahmed S., Han Y., Abro S., Nabi F., Tan C., and Kaleri A., 2020, Effects of dung beetle-amended soil on growth, physiology, and metabolite contents of bok choy and improvement in soil conditions, Journal of Soil Science and Plant Nutrition, 20: 2671-2683.
https://doi.org/10.1007/s42729-020-00333-8

Konschak M., Zubrod J., Baudy P., Fink P., Pietz S., A T., Bakanov N., Schulz R., and Bundschuh M., 2021, Mixture effects of a fungicide and an antibiotic: Assessment and prediction using a decomposer-detritivore system, Aquatic Toxicology, 232: 105762.
https://doi.org/10.1016/j.aquatox.2021.105762

Lehmann J., and Kleber M., 2015, The contentious nature of soil organic matter, Nature, 528: 60-68.

Li Y., Wang J., Wen S., and Shao M., 2022, Effects of different earthworm ecotypes on soil nutrients distribution under straw return management in a maize agroecosystem, Land Degradation and Development, 33: 2327-2339.
https://doi.org/10.1002/ldr.4301

Ma L., Weeraratne N., Gurusinghe S., Aktar J., Haque K., Eberbach P., Gurr G., and Weston L., 2023, Dung beetle activity is soil-type-dependent and modulates pasture growth and associated soil microbiome, Agronomy, 13(2): 325.
https://doi.org/10.3390/agronomy13020325

Maldonado M., Aranibar J., Serrano A., Chacoff N., and Vázquez D., 2019, Dung beetles and nutrient cycling in a dryland environment, CATENA, 179: 66-73.
https://doi.org/10.1016/J.CATENA.2019.03.035

Mason A., Taylor L., and DeBruyn J., 2023, Microbial ecology of vertebrate decomposition in terrestrial ecosystems, FEMS Microbiology Ecology, 99(2): fiad006.
https://doi.org/10.1093/femsec/fiad006

Medina-Sauza R., Álvarez-Jiménez M., Delhal A., Reverchon F., Blouin M., Guerrero-Analco J., Cerdán C., Guevara R., Villain L., and Barois I., 2019, Earthworms building up soil microbiota, a study, Frontiers in Environmental Science, 7: 81.
https://doi.org/10.3389/fenvs.2019.00081

Moustafa Y., Mustafa N., El-Dahshouri M., Ghonim S., Zuhair R., Zhang L., and Hassoub M., 2022, Influence of wastes of taro leaf, sugar beet and saw dust on physiochemical parameters of produced vermicompost, Asian Journal of Soil Science and Plant Nutrition, 8(3): 29-40.
https://doi.org/10.9734/ajsspn/2022/v8i3160

Ngone M., Koottatep T., Fakkaew K., and Polprasert C., 2018, Assessment of nutrient recovery, air emission and farmers' perceptions of indigenous mound burning practice using animal and human wastes in Myanmar, Agriculture, Ecosystems and Environment, 261(1): 54-61.
https://doi.org/10.1016/J.AGEE.2018.02.033

Pathma J., Raman G., and Sakthivel N., 2019, Microbiome of rhizospheric soil and vermicompost and their applications in soil fertility, pest and pathogen management for sustainable agriculture, Soil Fertility Management for Sustainable Development, pp.189-210.
https://doi.org/10.1007/978-981-13-5904-0_9

Pimentão A., Pascoal C., Castro B., and Cássio F., 2019, Fungistatic effect of agrochemical and pharmaceutical fungicides on non-target aquatic decomposers does not translate into decreased fungi- or invertebrate-mediated decomposition, The Science of the Total Environment, 712: 135676.
https://doi.org/10.1016/j.scitotenv.2019.135676

Raczka N., Piñeiro J., Tfaily M., Chu R., Lipton M., Paša-Tolić L., Morrissey E., and Brzostek E., 2021, Interactions between microbial diversity and substrate chemistry determine the fate of carbon in soil, Scientific Reports, 11: 19320.
https://doi.org/10.1038/s41598-021-97942-9

Rahman M., Kamal M., Ranamukhaarachchi S., Alam M., Alam M., Khan M., Islam M., Alam M., Jiban S., Mamun M., Abdullah H., Biswas J., Akhter S., Naher U., Maniruzzaman M., Haque M., and Ahmed F., 2022, Effects of organic amendments on soil aggregate stability, carbon sequestration, and energy use efficiency in wetland paddy cultivation, Sustainability, 14(8): 4475.
https://doi.org/10.3390/su14084475

Shafique I., Andleeb S., Aftab M., Naeem F., Ali S., Yahya S., Ahmed F., Tabasum T., Sultan T., Shahid B., Khan. A., Islam G., and Abbasi W., 2021, Efficiency of cow dung based vermi-compost on seed germination and plant growth parameters of *Tagetes erectus* (Marigold), Heliyon, 7(1): e05895.
https://doi.org/10.1016/j.heliyon.2020.e05895

Soares M., and Rousk J., 2019, Microbial growth and carbon use efficiency in soil: links to fungal-bacterial dominance, SOC-quality and stoichiometry, Soil Biology and Biochemistry, 131: 195-205.
https://doi.org/10.1016/J.SOILBIO.2019.01.010

Sun Y., and Ge Y., 2021, Temporal changes in the function of bacterial assemblages associated with decomposing earthworms, Frontiers in Microbiology, 12: 682224.
https://doi.org/10.3389/fmicb.2021.682224

Tagele S., Kim R., Jeong M., Lim K., Jung D., Lee D., Kim W., and Shin J., 2023, Soil amendment with cow dung modifies the soil nutrition and microbiota to reduce the ginseng replanting problem, Frontiers in Plant Science, 14: 1072216.
https://doi.org/10.3389/fpls.2023.1072216

Wahid F., Sharif M., Fahad S., Adnan M., Khan I., Aksoy E., Ali A., Sultan T., Alam M., Saeed M., Ullah H., Basir A., Noor M., and Khan N., 2019, Arbuscular mycorrhizal fungi improve the growth and phosphorus uptake of mung bean plants fertilized with composted rock phosphate fed dung in alkaline soil environment, Journal of Plant Nutrition, 42: 1760-1769.
https://doi.org/10.1080/01904167.2019.1643371

Wang S., Zhao X., Suvdantsetseg B., and Lian J., 2020, Isolation of efficient cellulose decomposer in sandy cropland and its application in straw turnover in agro-pasture ecotone of northern China, Front. Environ. Sci., 8:528732.
https://doi.org/10.3389/fenvs.2020.528732

Yamada D., Imura O., Shi K., and Shibuya T., 2007, Effect of tunneler dung beetles on cattle dung decomposition, soil nutrients and herbage growth, Grassland Science, 53: 121-129.
https://doi.org/10.1111/J.1744-697X.2007.00082.X

Yoshitake S., Soutome H., and Koizumi H., 2014, Deposition and decomposition of cattle dung and its impact on soil properties and plant growth in a cool-temperate pasture, Ecological Research, 29: 673-684.
https://doi.org/10.1007/s11284-014-1153-2

Yuvaraj A., Thangaraj R., and Maheswaran R., 2018, Decomposition of poultry litter through vermicomposting using earthworm *Drawida sulcata* and its effect on plant growth, International Journal of Environmental Science and Technology, pp.1-14.
https://doi.org/10.1007/s13762-018-2083-2