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(Review Article)

Evaluating the impact of land-use change on Arbuscular Mycorrhizal Fungi (AMF) diversity and function

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Abstract

The ever-increasing change in land utilization has been acknowledged as a primary factor influencing ecological modifications. These alterations have reignited the interest in understanding the enduring consequences on different soil microorganisms, specifically arbuscular mycorrhizal fungi (AMF). This study investigates the effects of land-use changes (LUCs) on AMF diversity, highlighting the impact of forest degradation, intensified farming approaches, and urban growth on the structure of the AMF community and its mediated services. Research has found that deforestation leads to a decrease in AMF diversity, thereby intensifying the susceptibility of particular species to habitat degradation. The transformation of natural habitats into cultivated landscapes due to agricultural spiraling driven by the need for food production also impacts the diversity of AMF. Urbanization, an expeditiously advancing modification of land usage, has been found to have the potential to cause the fragmentation and degradation of habitats, thus impacting ecosystem benefits of AMF, such as nutrient cycling and water filtration. These changes can have far-reaching consequences for plant communities, nutrient cycling, and ecosystem functioning. Future research should prioritize the development of management strategies, investigating AMF-mediated ecosystem services, and comprehending fundamental mechanisms governing AMF responses to land-use change. This knowledge can guide sustainable land management practices emphasizing AMF diversity and function conservation.

Keywords: Arbuscular mycorrhizal fungi; AMF communities; AMF diversity; Deforestation; Urbanization; Agricultural

1. Introduction

The change in land use, exacerbated by human activities, has emerged as a global concern owing to its substantial effects on ecosystems. One critical component of this impact is the modification of communities of arbuscular mycorrhizal fungi (AMF). These fungi establish mutualistic partnerships with the roots of the vast majority of land plants, thereby facilitating the absorption of nutrients from the soil [1,2,3]. They promote plant growth by improving nutrient uptake and optimizing water absorption. Additionally, they play a role in the formation of soil structure and the sequestration of carbon [4,5]. Therefore, AMF play a vital role in sustaining ecosystem stability and functioning. Regrettably, human activities have resulted in extensive land-use changes (LUCs) that disturb AMF communities. Deforestation, for example, obliterates the natural habitats where these fungi thrive [6]. Moreover, urbanization replaces natural landscapes with impervious surfaces that limit fungal colonization [7]. At the same time, agricultural intensification, to a greater extent, relies on chemical fertilizers that reduce reliance on AMF for nutrient acquisition [8]. The decrease in AMF populations as a result of these activities has significant consequences for the ecosystems on a global scale. Reduced nutrient availability, for instance, affects plant growth and productivity, decreasing biodiversity and ecosystem resilience. Equally, altered soil structure negatively impacts water infiltration rates and increases erosion risks [9,10]. To mitigate these concerns, sustainable land management practices should be implemented to preserve natural habitats and promote the recovery of AMF populations.

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1.1. Deforestation

Deforestation, the widespread damage of forests, has become an urgent environmental concern in the past few years. The outcomes of this cutting down of vegetation are extensive and negatively impact diverse aspects of ecosystems. One particular consequence is the depletion of plants, resulting in a decline in the variety and quantity of AMF, which are vital in facilitating the absorption of nutrients and fostering the well-being of plants [11]. These microbes establish symbiotic associations with plant roots, extending their hyphae into the soil to augment nutrient absorption. However, deforestation disturbs this intricate balance by eliminating host plants that AMF depend on for survival [12]. Consequently, AMF populations undergo isolation and a reduction in gene flow. In addition, habitat fragmentation resulting from deforestation amplifies the isolation of AMF populations [13]. The movement of organisms, such as AMF spores, is constrained by fragmented habitats, impeding their dispersal and colonization in new territories. This contributes to a further decrease in their diversity and abundance. Soil disturbance is another consequence of deforestation that negatively affects soil microbes [14]. Logging activities commonly require large machinery that compacts the soil and disrupts its integrity. This disturbance reduces the availability of organic matter and alters soil conditions necessary for AMF survival [15]. Lastly, deforestation leads to the loss of mycorrhizal networks, which are intricate underground connections formed by AMF between different plant species. These networks play a crucial role in promoting nutrient exchange among plants and bolstering the ecosystem's overall health. However, with the adverse effects of deforestation, the capacity to absorb nutrients is compromised, consequently impacting both plant growth and biodiversity.

1.2. Urbanization

Urbanization is a rapid process that has been swiftly transforming the physical environment of the world. As cities continue to expand and populations skyrocket, the previously flourishing natural dwellings in these regions are being wiped out, damaging habitats [16]. This destruction of habitats has far-reaching effects on biodiversity and ecosystem vitality. Soil pollution stands out as one of the notable outcomes of urbanization on habitats [17,18]. The pollutants emitted into the atmosphere through vehicle emissions and industrial activities ultimately settle on the Earth's surface. These pollutants can infiltrate the soil, polluting it and rendering it unsuitable for diverse plant and animal species. This pollution can result in a reduction in the variety and number of both plant and animal species [19]. Moreover, construction operations linked to urbanization add to ground compression. The utilization of substantial machinery in the construction of roads, buildings, and other infrastructure results in the compression of the ground, reducing its permeability. This restricts oxygen availability to the ground, creating difficulty for plants to develop roots and obtain nutrients [20]. As a result, the decrease in plant diversity negatively affects all organisms dependent on them for sustenance and protection.

1.3. Agricultural intensification

Modern agricultural systems have widely embraced intensive farming methods, which include monoculture cultivation, synthetic fertilizer utilization, application of pesticides, and disruption of soil through tillage [21,22,23]. These approaches have positively impacted the increase in crop yields and the overall performance of diverse crops. Nonetheless, research has demonstrated that they can also adversely influence the diversity of AMF [24,25]. This could be attributed to several factors, such as the limited variety of crops grown in monocultures, the reduced dependence on AMFs as an eco-friendly alternative to nutrient absorption because of the dominance of chemical fertilizers, and the destruction of the hyphae and mycorrhizal networks found in AMFs [26,27,28].

1.4. Search strategy

The investigation employed a broad selection of diverse English publications covering the period from 2015 to 2023. The exploration necessitated the splitting up of the research topic into different search terms, specifically "Land-use change" and "AMF diversity and function." After searching, a total of 63 journal articles were discovered, excluding 11 duplicates, resulting in a final count of 52 individual articles. The summaries of all these journals were subject to rigorous scrutiny, and relevant papers were identified for subsequent evaluation. The study set its inclusion and exclusion criteria primarily relying on a 7-year limit. After meeting this requirement, a comprehensive analysis of 48 journal articles was undertaken to ascertain their relevance to the research topic. At this point, 2 of these journals were excluded on the grounds that the study solely prioritized peer-reviewed articles. A thorough assessment of 46 peer-reviewed journals was conducted to determine their suitability for inclusion in this analysis. Two of these journals were labeled irrelevant as they did not contribute to keyword identification. As a result, the research approach led to the identification of 44 publications used in this review (Figure 1).

2. Literature from previous studies

2.1. Effect of deforestation on AMF community composition

Several studies have investigated the impact of deforestation on AMF communities. In the study by Zhang et al., the authors aimed to examine the impact of reforestation on soil microorganism characteristics. Following reforestation, the scientists uncovered a noteworthy surge in soil microorganism biomass, all major microorganism groups, and extracellular enzyme activities compared to bare-land sites [29]. These findings provide valuable insights into the potential benefits of afforestation in improving microbial properties. The increase in soil microbial biomass after afforestation suggests that introducing trees and vegetation can enhance nutrient cycling and organic matter decomposition processes. This is crucial for maintaining soil fertility and overall ecosystem health. The significant increase in all main soil microbial groups indicates a more diverse and balanced microbial community, essential for various ecological functions such as nutrient availability and disease suppression [29]. Furthermore, they observed an increase in the activities of all external proteins following reforestation. These proteins are essential for decomposing complex organic substances into more readily absorbable forms for plants. The enhanced enzyme activity suggests improved nutrient cycling efficiency and availability for plant growth. In general, this study demonstrates a favorable impact of afforestation on soil microbial characteristics. Reforestation enhances soil microbial biomass and stimulates microbial diversity and enzyme activity [29] (Table 1). The results have profound implications for sustainable land management approaches and illustrate the benefits of vegetation restoration on soil health and ecosystem dynamics.

In another study conducted by Delelegn et al., the scientists sought to investigate the impacts of land use changes on the microbial communities in soil, along with the associated physical and chemical factors influencing these shifts. The study's findings unveiled a significant change in bacterial and fungal communities due to variations in land utilization [30]. A crucial finding indicated that the presence of vegetation cover was instrumental in influencing the composition of fungal communities. It was observed that diverse plant cover gave rise to distinct fungal communities in the soil [30]. This indicates that the presence or absence of particular plant species can substantially impact the variety and quantity of fungi. Likewise, it was pointed out that soil characteristics are crucial in influencing bacterial communities. Key factors identified as determinants of bacterial community composition encompassed soil pH, organic matter content, and nutrient availability [30]. These outcomes underscore the importance of soil properties in influencing bacterial populations. Overall, this study presents valuable findings on the relationship between LUCs and soil microbial communities. Understanding these dynamic elements is vital for sustainable land management practices and conservation efforts. Further research should prioritize unraveling the precise mechanisms through which vegetation cover and soil attributes intertwine with microbial communities, ultimately resulting in ecosystem functioning and stability shifts.

In their study, Duarte et al. examined the AMF spore communities and root colonization across REF, LLF, and MTF. To ascertain the discrepancies in AMF communities among these forests, the researchers evaluated spore abundance, diversity indices, and root colonization rates. The study findings showed that spore abundance was at its minimum in LLF and maximum in REF, with no significant variations compared to MTF [31]. This indicates that the abundance of AMF spores is shaped by the particular traits of individual forest types (Table 1). Surprisingly, despite variations in spore abundance, there were no notable differences in spore diversity indices among the three forests. Moreover, the forests had no statistically significant differences in root colonization rates. This suggests that AMF can equally colonize plant roots in all three phytophysiognomies examined [31]. It is essential to highlight that this finding contradicts prior studies indicating potential variations in root colonization rates based on environmental factors. By and large, the study by [31] offers a comprehensive understanding of the distribution patterns of AMF communities across different forest types. Nonetheless, additional investigation is required to comprehend the fundamental elements that contribute to these patterns and assess their consequences for plant-fungal interactions in these ecosystems.

In the investigation by Ontivero et al., the survey examined the occurrence and variety of arbuscular mycorrhizal fungi (AMF) in four distinct land uses, as well as their correlation with soil and vegetation characteristics. The findings of this examination showcased the notable role of vegetation diversity in shaping the AMF population [32]. The researchers collected soil samples from four land use categories: indigenous grassland, reforested area, cultivated field, and abandoned cultivated field. An assessment was conducted on these samples to determine the occurrence of AMF spores, species diversity, and multiple soil and vegetation characteristics, including pH, organic matter content, plant species richness, and aboveground biomass [32]. The results revealed a noteworthy correlation between vegetation abundance and the AMF community. Areas with a greater abundance of diverse plant species showcased an expanded range of AMF species. This suggests that the conservation of various plant communities can enhance the proliferation of AMF in ecosystems [32]. Remarkably, agricultural practices were found to have an adverse impact on the diversity of AMF species while not affecting spore prevalence negatively. This suggests that although farming practices may diminish the diversity of AMF species in a region, they may not necessarily diminish their total population size [32]. In a broader context, this study underscores the significance of vegetation richness in influencing the abundance and diversity of AMF communities. It also offers valuable insights into the potential impact of agricultural activities on these fungal communities. Additional research is required to examine potential approaches for enhancing AMF diversity in agricultural environments while maintaining productive farming methods.

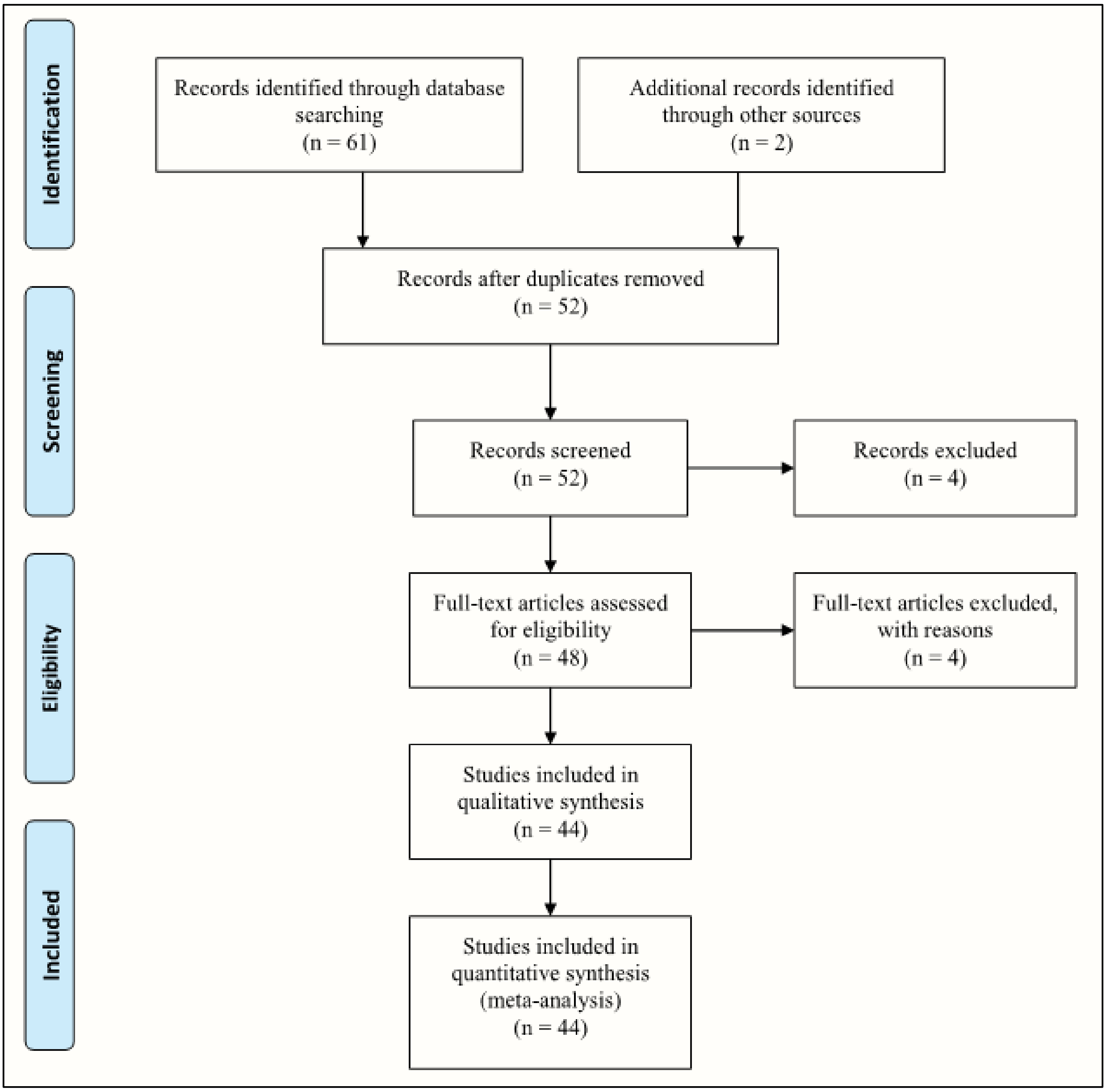

Figure 1 PRISMA diagram showing how papers were selected, excluded and included

2.2. Impact of agricultural intensification on AMF diversity

Intensive agriculture practices, such as using pesticides and fertilizers, can impact AMF diversity and function. Studies have shown that agricultural intensification reduces AMF abundance and alters community structure. A study conducted by Flores-Rentería et al. in the Los Tuxtlas Tropical Rain Forest Landscape in Veracruz, Mexico, aimed to analyze the whole-cell fatty acid profile of the microbial community and physicochemical properties of soils from four different types of land use: crops, pastures, secondary forest, and primary tropical rain forest [33]. The researchers focused on comparing these factors between the dry and rainy seasons. The findings of this study revealed that land use significantly impacts the abundance of microbial communities. It was observed that specific land uses, such as crops and pastures, decreased microbial abundance compared to secondary forests and primary rainforests [33] (Table 1). This showcases the adverse impact of farming techniques on soil microorganisms. Furthermore, the research also highlights the significance of seasonal changes on microorganisms. Microorganism abundance exhibited a decrease during the dry season across all land usage types, in contrast to the wet season. This can be linked to a drop in water availability, prompting changes in microorganism reproduction and performance [33]. In general, this study offers significant findings on the influence of land utilization methods on soil microorganisms in tropical rainforests. It emphasizes the crucial role of protecting natural habitats like secondary forests and primary tropical rainforests in maintaining the well-being of soil ecosystems. However, it is essential to prioritize further investigation into the intricate mechanisms through which land usage techniques impact microorganism communities. Additionally, exploring potential strategies for sustainable land management that can mitigate detrimental effects on soil health should be given precedence.

A study by Guzman and his research peers in 2021 delved into the impact of crop diversity on AMF communities in intensely cultivated farming environments. They sought to understand the complex interplay between various farming methods, soil properties, and the establishment of AMF communities. The study's findings confirmed that introducing diverse crop combinations has a remarkable impact on the diversity of AMF communities, suggesting that integrating multiple crops within agricultural systems can produce positive outcomes for soil microbes and functional ecosystems [34]. Interestingly, the study also discovered that soil properties played a pivotal role in influencing the composition of AMF communities. Various soil characteristics, including pH levels, nutrient availability, and organic matter content, impacted the presence of specific AMF species in a particular field [34]. Additionally, it was noted that the colonization of roots by AMF differed based on the crop host rather than the practices employed in farm management. This suggests that specific crops exhibit diverse capacities to establish symbiotic associations with AMF. Overall, the study by [34] underscores the significance of crop diversity in enhancing AMF communities and advancing sustainable agriculture. By implementing polycultures and integrating soil properties into farming system design, farmers can bolster soil health and improve overall productivity, all while diminishing dependence on synthetic inputs.

In the study conducted by Banerjee et al., the impact of different farming practices on wheat root fungal communities was investigated using PacBio SMRT sequencing. The researchers collected samples from 60 farmlands in Switzerland, comparing conventional, no-till, and organic farming methods. The study's results demonstrated that agricultural intensification, specifically using traditional farming techniques, caused a reduction in AMF network development and the abundance of these essential organisms in the root microbiome [35]. These findings have significant implications for the sustainability of farming and soil health. Notably, the reduction in network complexity observed in conventional farming systems suggests a loss of functional diversity within the root microbiome [35]. Keystone taxa are crucial in maintaining ecosystem stability and resilience by regulating nutrient cycling and disease suppression. Therefore, their decline could negatively affect crop productivity and overall ecosystem health. On the other hand, both no-till and organic farming methods were found to preserve higher levels of network complexity and keystone taxa abundance compared to conventional farming practices. No-till agriculture involves minimal disturbance to the soil structure, while organic farming relies on natural inputs such as compost or manure instead of synthetic chemicals [35]. These findings underscore the significance of sustainable agricultural practices that maintain soil biodiversity and ecosystem functioning. Farmers can optimize crop productivity and mitigate environmental impacts by reducing their dependency on synthetic inputs and preserving natural soil processes.

De Graaff et al. undertook an investigation to analyze the effects of intensified agriculture on soil diversity, with a specific emphasis on the impact of artificial nitrogen fertilization on various components of soil biodiversity. The findings of their study exposed that intensified agriculture can have a substantial impact on soil microbes [36]. An important observation from the study revealed that the implementation of artificial nitrogen fertilization had a detrimental effect on the range of AMF (Table 1). These fungi carry out a critical role in enhancing nutrient uptake by plants. Their decline because of the use of synthetic fertilizers can destabilize ecological balance [36]. Furthermore, a decrease in their population can hinder vital environmental processes, including the breakdown of organic matter and the distribution of nutrients. Surprisingly, the study also discovered that artificial nitrogen fertilization promoted the diversity of other microorganisms with comparable functional attributes. Additionally, bacterial diversity was observed to be positively correlated with lower synthetic nitrogen input rates and the incorporation of organic nitrogen [36]. This suggests that while nitrogen fertilization may negatively affect some components of soil diversity, others may benefit from it due to intensifying this practice. These findings emphasize the value of exploring alternative agricultural nutrient sources to uphold or augment soil biodiversity. In general, the study by [36] offers valuable insights into the impact of agricultural intensification on soil biodiversity. It highlights the importance of implementing sustainable farming techniques that reduce detrimental effects on essential elements of soil biodiversity while encouraging beneficial microbial communities for enhanced ecosystem functionality.

2.3. Impact of urbanization on AMF-mediated ecosystem services

As urban areas continue to expand, the impact of urbanization on AMF-mediated ecosystem services is garnering attention. Urbanization modifies soil properties, decreases habitat availability for AMF, and alters plant community composition. These changes can lead to reduced AMF-mediated benefits, such as nutrient retention and plant stress tolerance, with potential consequences for urban ecosystem functioning and resilience. In the study by Gupta et al., the researchers aimed to investigate the impact of urban usage on AM fungal diversity in Delhi forests. The nine selected sites represented different levels of urban usage, including heavy vehicular traffic pollution, littering, defecation, and recreational activities [37]. The researchers measured AM fungal diversity through alpha diversity and abundance using spore density, biovolume, and mean infection. The study's findings indicated a notable decline in AM fungal diversity and abundance in regions with increased urban utilization [37]. This suggests that human activities, including the pollution caused by vehicles and littering, detrimentally affect the ecological balance of these forests. The decline of AM fungi can have extensive impacts on ecosystem functioning as they are vital for nutrient cycling and plant health. For instance, the decrease in alpha diversity indicates a loss of species richness within these forests. This loss can disrupt the symbiotic relationship between AM fungi and plants, leading to reduced nutrient uptake by plants and decreased overall ecosystem productivity [37]. Furthermore, the decline in spore density, biovolume, and mean infection further support the negative impact of urban usage on AM fungal communities. Overall, the study by [37] highlights the need for adopting effective management approaches to alleviate the effects of urbanization, especially in forest ecosystems. In particular, it underscores the significance of conserving natural habitats as a sustainable approach to maintaining biodiversity and ecosystem functioning.

In another study by Lin et al., the impact of urbanization on plant-arbuscular mycorrhizal (AM) fungal associations in Beijing's Fifth Ring and Jiufeng National Forest Park was thoroughly examined. The findings of this study shed light on the consequences of urban development on these crucial ecological interactions. The researchers discovered that urban areas exhibited higher Shannon, Simpson, and Pielou indices of root AM fungi compared to the national forest park [38]. These indices indicate a greater diversity and evenness of AM fungal species in urban environments. Additionally, a nested mycorrhizal association network was observed in urban areas, suggesting a more complex and interconnected web of interactions between plants and fungi. Contrary to expectations, the study revealed that urbanization led to lower species specialization and fungal dissimilarity [38] (Table 1). This implies that as cities expand, there is a convergence towards a common set of AM fungal species across different plant hosts. This homogenization could have significant implications for ecosystem functioning and resilience. Based on these findings, the study by [38] suggests that urbanization profoundly affects plant-AM fungal associations. It emphasizes the need to conduct additional research to recognize the mechanisms driving these changes and their likely impacts on the well-being of the ecosystem. Furthermore, the study highlights the benefits of integrating ecological factors into urban planning procedures to mitigate the negative consequences of growth on diverse life forms within the ecosystem.

The study conducted by Tatsumi et al. explored the evidence of mutualism breakdown between trees and their fungal root mutualists, specifically ectomycorrhizal (ECM) fungi, with urbanization. The researchers observed a correlation between urbanization and a decrease in ECM fungi colonization on tree roots, as well as a reduction in connectivity within soil microbiome networks in urban forests as opposed to rural forests [39]. However, it is essential to emphasize that despite these changes, the process of urbanization did not lead to a reduction in the relative manifestation of ECM fungi in forested ecosystems. That said, the mutualistic relationships between trees and ECM fungi are crucial for nutrient uptake and overall ecosystem functioning. The breakdown of this mutualism can have cascading effects on forest dynamics, including reduced tree growth and increased vulnerability to stressors such as drought or disease. The decreased colonization of ECM fungi on tree roots in urban forests suggests that urban environments may not provide suitable conditions for these symbiotic associations to thrive [39]. Factors such as altered soil properties, pollution, or disturbance associated with urban development could contribute to this breakdown. Furthermore, the reduced connectivity within soil microbiome networks indicates a disruption in the flow of resources and information among organisms within the ecosystem. This lack of connectivity may hinder nutrient cycling processes and limit the ability of trees to access essential resources. Despite these negative impacts, it is noteworthy that the relative abundance of ECM fungi was not significantly reduced in urban forests compared to rural forests. This implies that while individual trees may experience a decrease in their fungal mutualists, there may still be passable ECM fungi at the community level to sustain overall abundance [39]. In summary, the findings by [39] underscore the importance of integrating ecological interactions when analyzing the impact of urbanization on forest ecosystems. Understanding the influence of human activities on mutualistic relationships can help formulate conservation and management strategies that can minimize the effects of urban development on forest ecosystems.

In the investigation by Rusterholz et al., the impact of urban transformation on the mutual association between AMF and the growth of *Acer pseudoplatanus* tree saplings was examined. The researchers carried out a controlled field trial in forests situated in Basel City and its outskirts in Switzerland. The aim of this study was to establish if urbanization has a negative impact on mycorrhizal symbiosis as well as the overall growth of *A. pseudoplatanus* saplings. The study's findings revealed that urbanization indeed has far-reaching effects on the AM fungal symbiosis (Table 1). In particular, they noticed a substantial decrease in AMF colonization in the saplings growing in developed areas compared to those growing in their natural ecosystems [40]. The decline in AMF symbiosis can have negative effects on the vitality and health of *A. pseudoplatanus* saplings. This is because of the fact that these fungi play a crucial role in nutrient uptake and overall plant growth. The study also established that the urbanization process had a negative impact on the performance of *A. pseudoplatanus* saplings [40]. Saplings growing in urban areas revealed reduced height, biomass, as well as leaf surface area compared to those in non-urbanized forests. Overall, the findings by [40] highlight the adverse effects of urbanization on both AMF symbiosis and the development of *A. pseudoplatanus* saplings. This study highlights the value of factoring in these consequences when planning and executing urban development to safeguard the preservation and longevity of natural ecosystems within urban settings.

3. Potential for future research

3.1. Quantifying how the loss of AMF diversity affects plant community composition and ecosystem functioning

Changes in land use significantly contribute to the gradual decline in species diversity and ecosystem degradation globally. One such concern undoubtedly relates to how changes in land utilization adversely affect the diversity and effectiveness of AMF [15,16]. These advantageous microorganisms are pivotal in disseminating needed nutrients, plant growth, and ecosystem functioning. Therefore, it is vital to understand the unique link between modifications in land utilization, AMF variety, and ecosystem operation to formulate efficient conservation and control strategies. Studies on land-use alteration on AMF variety and function have offered an invaluable understanding of this complex connection. Extensive investigations have revealed that specific land-use approaches, like the intensification of farming methods and urban development, can gradually decrease AMF [41]. The continuous reduction in the diversity of AMF can consequently affect the overall makeup of plant communities and the optimal functioning of ecosystems. To broaden our understanding of this correlation, future studies should concentrate on assessing the effects of reduced AMF diversity on plant community composition and ecosystem function. Through purposeful manipulation of AMF diversity levels across diverse land-use scenarios, researchers can conduct controlled experiments to examine the potential consequences of AMF community modifications on the composition of plant species and their interactions with other organisms.

3.2. Assessing the feasibility of revitalizing AMF diversity and functions through management interventions

The assessment of land-use change (LUC) in AMF diversity and function has illuminated the complex correlation between human activities and subterranean communities. It has been empirically shown that specific land-use techniques, such as farming or urban development, can cause detrimental effects on the diversity and function of AMF [17,18]. This informative awareness provides opportunities for further exploration to delve deeper into the current understanding of this correlation. One potential area for future research involves assessing the potential for re-establishing AMF diversity and functions through management interventions. Restoration ecology strives to alleviate the adverse effects of human activities on ecosystems by implementing a range of strategies. By examining the impact of management interventions like reforestation or sustainable agricultural practices on AMF diversity and function, it is possible to formulate effective restoration strategies.

3.3. Examining the contribution of AMF-mediated ecosystem services to soil carbon storage and nutrient cycling across different land-use change scenarios

LUC is a fundamental driver of global biodiversity decline and ecosystem deterioration. Recently, there has been a growing interest in understanding how land-use alteration affects AMF diversity and operation, as these fungi play a crucial role in nutrient circulation and plant productivity [23,24].

Delving deeper into this assessment can uncover possibilities for prospective research to enhance our understanding of the intricate connection between LUC and AMF. One potential area for future exploration involves assessing the impact of AMF-facilitated ecosystem advantages, such as soil carbon preservation and nutrient circulation, in different LUC scenarios. Changes in land use, such as deforestation or the conversion of native habitats into agricultural and urban areas, can significantly impact AMF communities and their activities [42]. Assessing the influence of these modifications on AMF-mediated advantages to ecosystems can yield valuable understandings of the consequences of modifying land utilization on broader ecosystem processes. For instance, investigating how different land-use practices influence soil carbon storage through AMF associations can help develop sustainable land management strategies promoting carbon sequestration.

Table 1 Summary of results from previous studies on the impact of land-use change on AMF diversity and function

Type of change in land use	**Findings from previous studies**	**Reference**
1. Deforestation	Reforestation stimulates AMF diversity and enzyme activity	[29]
	Diverse plant cover gives rise to distinct fungal communities in the soil	[30]
	Abundance of AMF spores is shaped by the particular traits of individual forest types	[31]
	Conservation of various plant communities enhance the proliferation of AMF	[32]
2. Agricultural intensification	Land uses, such as crops and pastures, decreased microbial abundance	[33]
	Integrating multiple crops produces positive outcomes for soil microbes	[34]
	Traditional farming techniques reduce AMF network development	[35]
	Artificial nitrogen fertilization has a detrimental effect on the range of AMF	[36]
3. Urbanization	AM fungal diversity and abundance reduces in urban regions	[37]
	Urbanization leads to lower species specialization and fungal dissimilarity	[38]
	Urbanization decreases ECM fungi colonization on tree roots	[39]
	Urbanization has negative effects on the AM fungal symbiosis	[40]

Similarly, studying the effects of LUC on nutrient cycling mediated by AMF can inform agricultural practices that optimize nutrient use efficiency while minimizing environmental impacts.

3.4. Identifying the fundamental mechanisms that govern AMF responses to land-use change, encompassing alterations in soil physicochemical properties and plant community composition

Studies have demonstrated that persistent changes in land use can influence the formation of AMF in soil, causing changes in their diversity and functionality. Despite this, the intricate mechanisms that trigger these reactions still need to be adequately explored [43]. One potential avenue for future research is the study of the specific factors that prompt AMF responses to LUCs. For instance, closely examining the potential variability in soil physiochemical properties can provide a deeper understanding of the link between these changes and AMF functionality. LUCs can lead to fluctuations in soil acidity, nutrient accessibility, and organic matter composition. These changes can directly influence the ability of AMF communities to survive, reproduce, and establish. Apart from soil properties, changes in plant community composition can be another potential factor affecting AMF responses to LUC. According to [44], each plant species shows its distinct relationships with specific AMF species. As such, the modifications in plant community composition caused by LUC may indirectly influence the diversity and function of AMF. Understanding these underlying mechanisms can offer valuable insights into the impact of LUC on AMF communities and their ecological roles. This understanding can then be applied to formulate efficient plans for preserving the diversity of AMF in human-altered ecosystems.

4. Conclusion

Understanding the biological impact of changes in land use on AMF populations is vital for effective land management and protecting diverse microbial species. By examining the effects of forest depletion, intensified farming, and urban growth on AMF diversity, this review extensively highlights the critical role of conservation initiatives that support sustainable land practices. Subsequent research should offer a deeper understanding of the interplay between LUCs and AMF communities. This will enable the formation of well-informed choices for ecosystem preservation and restoration.

References

[1] Bahadur, A.; Batool, A.; Nasir, F.; Jiang, S.; Mingsen, Q.; Zhang, Q.; Pan, J.; Liu, Y.; Feng, H. Mechanistic Insights into Arbuscular Mycorrhizal Fungi-Mediated Drought Stress Tolerance in Plants. *International Journal of Molecular Sciences* **2019**, *20* (17), 4199. https://doi.org/10.3390/ijms20174199.

[2] Zarik, L.; Meddich, A.; Hijri, M.; Hafidi, M.; Ouhammou, A.; Ouahmane, L.; Duponnois, R.; Boumezzough, A. Use of Arbuscular Mycorrhizal Fungi to Improve the Drought Tolerance of Cupressus Atlantica G. *Comptes Rendus Biologies* **2016**, *339* (5), 185–196. https://doi.org/10.1016/j.crvi.2016.04.009.

[3] Emmanuel, O. C.; Babalola, O. O. Productivity and Quality of Horticultural Crops through Co-Inoculation of Arbuscular Mycorrhizal Fungi and Plant Growth Promoting Bacteria. *Microbiological Research* **2020**, *239*, 126569. https://doi.org/10.1016/j.micres.2020.126569.

[4] Al-Maliki, S.; Ebreesum, H. Changes in Soil Carbon Mineralization, Soil Microbes, Roots Density and Soil Structure Following the Application of the Arbuscular Mycorrhizal Fungi and Green Algae in the Arid Saline Soil. *Rhizosphere* **2020**, *14*, 100203. https://doi.org/10.1016/j.rhisph.2020.100203.

[5] Bhattacharyya, S. S.; Ros, G. H.; Furtak, K.; Iqbal, H. M. N.; Parra-Saldívar, R. Soil Carbon Sequestration – an Interplay between Soil Microbial Community and Soil Organic Matter Dynamics. *Science of the Total Environment* **2022**, *815*, 152928. https://doi.org/10.1016/j.scitotenv.2022.152928.

[6] Hanna, W.; Abd, W.; Afnan Ahmadi Zahuri; Mohamad Faizal Ibrahim; Show, P.-L.; Zul Ilham; Adi Ainurzaman Jamaludin; Patah, A.; Usuldin, A.; Rowan, N. J. Role of Ascomycete and Basidiomycete Fungi in Meeting Established and Emerging Sustainability Opportunities: A Review. *Bioengineered* **2022**, *13* (7-12), 14903–14935. https://doi.org/10.1080/21655979.2023.2184785.

[7] Bedla, D.; Halecki, W. The Value of River Valleys for Restoring Landscape Features and the Continuity of Urban Ecosystem Functions – a Review. *Ecological Indicators* **2021**, *129*, 107871. https://doi.org/10.1016/j.ecolind.2021.107871.

[8] Brito, I.; Carvalho, M.; Goss, M. J. Managing the Functional Diversity of Arbuscular Mycorrhizal Fungi for the Sustainable Intensification of Crop Production. *PLANTS, PEOPLE, PLANET* **2021**, *3* (5), 491–505. https://doi.org/10.1002/ppp3.10212.

[9] Penuelas, J.; Janssens, I. A.; Ciais, P.; Obersteiner, M.; Sardans, J. Anthropogenic Global Shifts in Biospheric N and P Concentrations and Ratios and Their Impacts on Biodiversity, Ecosystem Productivity, Food Security, and Human Health. *Global Change Biology* **2020**, *26* (4), 1962–1985. https://doi.org/10.1111/gcb.14981.

[10] Talukder, B.; Ganguli, N.; Matthew, R.; van Loon, G. W.; Hipel, K. W.; Orbinski, J. Climate Change-Triggered Land Degradation and Planetary Health: A Review. *Land Degradation & Development* **2021**. https://doi.org/10.1002/ldr.4056.

[11] Upadhyay, S. K.; Rajput, V. D.; Kumari, A.; Espinosa-Sáiz, D.; Menéndez, E.; Minkina, T.; Dwivedi, P.; Saglara Mandzhieva. Plant Growth-Promoting Rhizobacteria: A Potential Bio-Asset for Restoration of Degraded Soil and Crop Productivity with Sustainable Emerging Techniques. *Environmental Geochemistry and Health* **2022**. https://doi.org/10.1007/s10653-022-01433-3.

[12] Afridi, M. S.; Fakhar, A.; Kumar, A.; Ali, S.; Medeiros, F. H. V.; Muneer, M. A.; Ali, H.; Saleem, M. Harnessing Microbial Multitrophic Interactions for Rhizosphere Microbiome Engineering. *Microbiological Research* **2022**, *265*, 127199. https://doi.org/10.1016/j.micres.2022.127199.

[13] Aavik, T.; Träger, S.; Zobel, M.; Honnay, O.; Van Geel, M.; Bueno, C. G.; Koorem, K. The Joint Effect of Host Plant Genetic Diversity and Arbuscular Mycorrhizal Fungal Communities on Restoration Success. *Functional Ecology* **2021**. https://doi.org/10.1111/1365-2435.13914.

[14] Szoboszlay, M.; Dohrmann, A. B.; Poeplau, C.; Don, A.; Tebbe, C. C. Impact of Land-Use Change and Soil Organic Carbon Quality on Microbial Diversity in Soils across Europe. *FEMS Microbiology Ecology* **2017**, *93* (12). https://doi.org/10.1093/femsec/fix146.

[15] Nazari, M.; Eteghadipour, M.; Zarebanadkouki, M.; Ghorbani, M.; Dippold, M. A.; Bilyera, N.; Zamanian, K. Impacts of Logging-Associated Compaction on Forest Soils: A Meta-Analysis. *Frontiers in Forests and Global Change* **2021**, *4*. https://doi.org/10.3389/ffgc.2021.780074.

[16] Kruize, H.; van der Vliet, N.; Staatsen, B.; Bell, R.; Chiabai, A.; Muiños, G.; Higgins, S.; Quiroga, S.; Martinez-Juarez, P.; Aberg Yngwe, M.; Tsichlas, F.; Karnaki, P.; Lima, M. L.; García de Jalón, S.; Khan, M.; Morris, G.; Stegeman, I.

Urban Green Space: Creating a Triple Win for Environmental Sustainability, Health, and Health Equity through Behavior Change. *International Journal of Environmental Research and Public Health* **2019**, *16* (22). https://doi.org/10.3390/ijerph16224403.

[17] Valdiviezo, G.; Carlos Alberto Castañeda-Olivera; Rita Jaqueline Cabello-Torres; Fernando, F.; Munive, V.; Alfaro, A. Scientometric Study of Treatment Technologies of Soil Pollution: Present and Future Challenges. **2023**, *182*, 104695–104695. https://doi.org/10.1016/j.apsoil.2022.104695.

[18] Zaghloul, A.; Saber, M.; Gadow, S.; Awad, F. Biological Indicators for Pollution Detection in Terrestrial and Aquatic Ecosystems. *Bulletin of the National Research Centre* **2020**, *44* (1). https://doi.org/10.1186/s42269-020-00385-x.

[19] Magura, T.; Lövei, G. L. Consequences of Urban Living: Urbanization and Ground Beetles. *Current Landscape Ecology Reports* **2020**. https://doi.org/10.1007/s40823-020-00060-x.

[20] Palmeira, E. M.; Silva, L.; Eder Soares Santos. Sustainable Solutions with Geosynthetics and Alternative Construction Materials-a Review. **2021**, *13* (22), 12756–12756. https://doi.org/10.3390/su132212756.

[21] Muhie, S. H. Novel Approaches and Practices to Sustainable Agriculture. *Journal of Agriculture and Food Research* **2022**, *10*, 100446. https://doi.org/10.1016/j.jafr.2022.100446.

[22] Shrestha, J.; Subedi, S.; Timsina, K. P.; Subedi, S.; Pandey, M.; Shrestha, A.; Shrestha, S.; Hossain, M. A. Sustainable Intensification in Agriculture: An Approach for Making Agriculture Greener and Productive. *Journal of Nepal Agricultural Research Council* **2021**, *7*, 133–150. https://doi.org/10.3126/jnarc.v7i1.36937.

[23] Francaviglia, R.; Almagro, M.; Vicente-Vicente, J. L. Conservation Agriculture and Soil Organic Carbon: Principles, Processes, Practices and Policy Options. *Soil Systems* **2023**, *7* (1), 17. https://doi.org/10.3390/soilsystems7010017.

[24] Kuila, D.; Ghosh, S. Aspects, Problems and Utilization of Arbuscular Mycorrhizal (AM) Application as Bio-Fertilizer in Sustainable Agriculture. *Current Research in Microbial Sciences* **2022**, *3*, 100107. https://doi.org/10.1016/j.crmicr.2022.100107.

[25] Nirmal Philip George; Joseph George Ray. The Inevitability of Arbuscular Mycorrhiza for Sustainability in Organic Agriculture-a Critical Review. *Frontiers in sustainable food systems* **2023**, *7*. https://doi.org/10.3389/fsufs.2023.1124688.

[26] Hage-Ahmed, K.; Rosner, K.; Steinkellner, S. Arbuscular Mycorrhizal Fungi and Their Response to Pesticides. *Pest Management Science* **2018**, *75* (3), 583–590. https://doi.org/10.1002/ps.5220.

[27] Meena, R. S.; Kumar, S.; Datta, R.; Lal, R.; Vijayakumar, V.; Brtnicky, M.; Sharma, M. P.; Yadav, G. S.; Jhariya, M. K.; Jangir, C. K.; Pathan, S. I.; Dokulilova, T.; Pecina, V.; Marfo, T. D. Impact of Agrochemicals on Soil Microbiota and Management: A Review. *Land* **2020**, *9* (2), 34. https://doi.org/10.3390/land9020034.

[28] Thirkell, T. J.; Charters, M. D.; Elliott, A. J.; Sait, S. M.; Field, K. J. Are Mycorrhizal Fungi Our Sustainable Saviors? Considerations for Achieving Food Security. *Journal of Ecology* **2017**, *105* (4), 921–929. https://doi.org/10.1111/1365-2745.12788.

[29] Zhang, H.; Xiong, X.; Wu, J.; Zhao, J.; Zhao, M.; Chu, G.; Hui, D.; Zhou, G.; Deng, Q.; Zhang, D. Changes in Soil Microbial Biomass, Community Composition, and Enzyme Activities after Half-Century Forest Restoration in Degraded Tropical Lands. *Forests* **2019**, *10* (12), 1124. https://doi.org/10.3390/f10121124.

[30] Delelegn, Y. T.; Purahong, W.; Sandén, H.; Yitaferu, B.; Godbold, D. L.; Wubet, T. Transition of Ethiopian Highland Forests to Agriculture-Dominated Landscapes Shifts the Soil Microbial Community Composition. *BMC Ecology* **2018**, *18* (1). https://doi.org/10.1186/s12898-018-0214-8.

[31] Duarte, L. M.; Bertini, S. C. B.; Stürmer, S. L.; Lambais, M. R.; Azevedo, L. C. B. Arbuscular Mycorrhizal Fungal Communities in Soils under Three Phytophysiognomies of the Brazilian Atlantic Forest. *Acta Botanica Brasilica* **2019**, *33* (1), 50–60. https://doi.org/10.1590/0102-33062018abb0236.

[32] Roberto Emanuel Ontivero; Lucía Risio; Iriarte, H. J.; Lugo, M. A. Effect of Land-Use Change on Arbuscular Mycorrhizal Fungi Diversity in an Argentinean Endemic Native Forest. **2022**. https://doi.org/10.3390/iecd2022-12430.

[33] Flores-Rentería, D.; Sánchez-Gallén, I.; Morales-Rojas, D.; Larsen, J.; Francisco Javier Álvarez-Sánchez. Changes in the Abundance and Composition of a Microbial Community Associated with Land Use Change in a Mexican

Tropical Rain Forest. *Journal of Soil Science and Plant Nutrition* **2020**, *20* (3), 1144–1155. https://doi.org/10.1007/s42729-020-00200-6.

[34] Guzman, A.; Montes, M.; Hutchins, L.; DeLaCerda, G.; Yang, P.; Kakouridis, A.; Dahlquist-Willard, R. M.; Firestone, M. K.; Bowles, T.; Kremen, C. Crop Diversity Enriches Arbuscular Mycorrhizal Fungal Communities in an Intensive Agricultural Landscape. *New Phytologist* **2021**, *231* (1), 447–459. https://doi.org/10.1111/nph.17306.

[35] Banerjee, S.; Walder, F.; Büchi, L.; Meyer, M.; Held, A. Y.; Gattinger, A.; Keller, T.; Charles, R.; van der Heijden, M. G. A. Agricultural Intensification Reduces Microbial Network Complexity and the Abundance of Keystone Taxa in Roots. *The ISME Journal* **2019**, *13* (7), 1722–1736. https://doi.org/10.1038/s41396-019-0383-2.

[36] de Graaff, M.-A.; Hornslein, N.; Throop, H. L.; Kardol, P.; van Diepen, L. T. A. Effects of Agricultural Intensification on Soil Biodiversity and Implications for Ecosystem Functioning: A Meta-Analysis. *Advances in Agronomy* **2019**, *155*, 1–44. https://doi.org/10.1016/bs.agron.2019.01.001.

[37] Gupta, M.; Gupta, A.; Kumar, P. Urbanization and Biodiversity of Arbuscular Mycorrhizal Fungi- the Case Study of Delhi, India. *Revista de Biología Tropical* **2018**, *66* (4). https://doi.org/10.15517/rbt.v66i4.33216.

[38] Lin, L.; Chen, Y.; Xu, G.; Zhang, Y.; Zhang, S.; Ma, K. Impacts of Urbanization Undermine Nestedness of the Plant–Arbuscular Mycorrhizal Fungal Network. *Frontiers in Microbiology* **2021**, *12*. https://doi.org/10.3389/fmicb.2021.626671.

[39] Tatsumi, C.; Atherton, K. F.; Garvey, S. M.; Conrad-Rooney, E.; Morreale, L.; Hutyra, L. R.; Templer, P. H.; Bhatnagar, J. Urbanization and Edge Effects Interact to Drive Mutualism Breakdown and the Rise of Unstable Pathogenic Communities in Forest Soil. *Proceedings of the National Academy of Sciences of the United States of America* **2023**, *120* (36). https://doi.org/10.1073/pnas.2307519120.

[40] Rusterholz, H.-P.; Studer, M.; Zwahlen, V.; Baur, B. Plant-Mycorrhiza Association in Urban Forests: Effects of the Degree of Urbanization and Forest Size on the Performance of Sycamore (Acer Pseudoplatanus) Saplings. *Urban Forestry & Urban Greening* **2020**, *56*, 126872. https://doi.org/10.1016/j.ufug.2020.126872.

[41] Kumawat, K. C.; Razdan, N.; Saharan, K. Rhizospheric Microbiome: Bio-Based Emerging Strategies for Sustainable Agriculture Development and Future Perspectives. *Microbiological Research* **2022**, *254*, 126901. https://doi.org/10.1016/j.micres.2021.126901.

[42] Danielson, R. E.; Jorge. Impacts of Land-Use Change on Soil Microbial Communities and Their Function in the Amazon Rainforest. *Advances in Agronomy* **2022**, 179–258. https://doi.org/10.1016/bs.agron.2022.04.001.

[43] Díaz-Vallejo, E. J.; Seeley, M.; Smith, A. P.; Marín-Spiotta, E. A Meta-Analysis of Tropical Land-Use Change Effects on the Soil Microbiome: Emerging Patterns and Knowledge Gaps. *Biotropica* **2021**, *53* (3), 738–752. https://doi.org/10.1111/btp.12931.

[44] Aslani, F.; Juraimi, A. S.; Ahmad-Hamdani, M. S.; Alam, M. A.; Hasan, M. M.; Hashemi, F. S. G.; Bahram, M. The Role of Arbuscular Mycorrhizal Fungi in Plant Invasion Trajectory. *Plant and Soil* **2019**, *441* (1-2), 1–14. https://doi.org/10.1007/s11104-019-04127-5.