THE IMPACT OF GLOBAL WARMING ON DECOMPOSITION OF ORGANIC MATTER IN GRASSLAND ECOSYSTEMS – SHORT REVIEW

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Abstract

Grasslands, as dominant terrestrial ecosystems, play key roles in maintaining biodiversity, carbon sequestration and soil fertility. However, their vulnerability is increasing due to natural disasters and human-induced disturbances, which are amplified by climate change. The aim of this research is to analyze the process of decomposition in grassland ecosystems, focusing on how climate change and other disturbances influence this essential process. Understanding how the rate and efficiency of organic matter decomposition in these natural environments can be affected by climate variability, including changes in temperature and precipitation patterns. Organic matter decomposition in grasslands plays an important role in the global carbon cycle, storing soil carbon and controlling atmospheric CO_2 concentrations. Therefore, understanding and controlling the decomposition process in grassland ecosystems is essential for the conservation and sustainable management of these natural environments.

Keywords: grasslands ecosystems, climate change, plant species, microorganisms, decomposition, organic matter.

INTRODUCTION

Grasslands are essential terrestrial ecosystems (SCHOLTZ et al. 2022), being the most dominant form of land cover and providing a rich array of renewable natural resources. They perform various vital ecological functions such as soil stabilization, water conservation and maintenance of biodiversity (HOPKINS & HOLZ, 2006; BENGTSSON et al. 2019; LAL, 2014). They are also essential for agriculture, economy and tourism, contributing to the income of many communities. At the same time, the natural landscapes of grasslands and the cultural elements of the communities that use them are landscape resources of great cultural and ecological importance (WANG et al. 2022).

Grasslands are fragile ecosystems are often vulnerable to natural disasters (FANG et al. 2022), such as fire (JOSEPH et al. 2024; CURY-LINDALH, 2019), drought and insect attacks. Even small changes in surface area can have significant consequences for the dynamic processes in these ecosystems. Monitoring human activities and natural disasters is therefore crucial for grassland management and post-disaster reconstruction, as well as for the sustainable development of these natural resources. (WANG et al. 2022; LEAD et al. 2005).

Grassland are dominated by herbaceous plants (DIXON et al. 2014; GAUJOUR et al. 2012) and are often found in areas with unfavorable climatic conditions for growing trees. Some grasslands are regularly managed by humans and are called semi-natural grasslands (BENGTSSON et al. 2019). Dead organic matter, such as leaves, needles, twigs and roots of plants, form plant litter, which is present both above and below ground. In terrestrial environments, the layer of plant organic matter plays a vital role in controlling biogeochemical cycles. By maintaining soil fertility and nutrient availability, it influences plant growth processes, diversity, composition, structure, and productivity (HASSAN et al. 2021).

Grasslands play a major role in the global carbon cycle, covering about 40% (LEI et al., 2020) of the Earth's land surface, excluding the areas permanently covered by ice. These large ecosystems contribute significantly to carbon sequestration and soil carbon flux dynamics (WANG & FANG, 2009). Grassland ecosystems are one of the most important carbon (C) reservoirs on Earth and sequestrate about 20% of total global soil carbon (ZHAO et al. 2022).

Grasslands are more susceptible to disturbance than other ecosystems (LI & GUO, 2014), and climate change, through increased frequency and intensity of droughts, has a considerable impact on their functioning and structure. In the current context of climate change, it is essential to analyze the response of grasslands to drought (CRAINE et al. 2013; WELLSTEIN et al. 2017), as extreme weather events are becoming more frequent. In recent decades, droughts have become longer, more frequent, and more intense, especially in semi-arid and arid regions (LEI et al. 2020).

The grassland ecosystems (Fig.1.) are crucial for sustaining the nutrient cycle (FRISSEL, 2012), within the Earth's terrestrial ecosystems. Nevertheless, over fifty percent of the world's grassland regions have experienced considerable degradation (LIU et al. 2019; BARDGETT et al 2021), primarily as a result of extensive human activity and the effects of global climate change. These disturbances not only change soil physico-chemical characteristics such as salinity, moisture, and nutrient availability, but also negatively affect the productivity, stability and resilience of grassland ecosystems over time (LI et al. 2023).

The aim of this study is to highlight the implications of climate change on the microbial community involved in the decomposition of organic matter in grassland ecosystems.

MATERIAL AND METHOD

Information and data were collected using the Web of Science platform. Specific keywords, combination between: grasslands ecosystems, climate change, plant species, microorganisms, decomposition, and organic matter were used to obtain this data, all directly related to the decomposition process of organic matter. This search method allowed access to a wide range of relevant studies and articles on the subject.

MANAGEMENT STRATEGIES AND MICROBIAL INFLUENCE ON SOM DECOMPOSITION

The primary strategy of management to prevent land degradation (PANDIT et al. 2018), and to restore ecological integrity to disturbed ecosystems is to conserve agricultural land by allowing spontaneous succession to happen. This approach is associated with the enhancement of ecosystem services provided by the vegetation that naturally grows on these lands. Changes in microbial community composition are essential for this transition and can be assessed by monitoring the activity of soil microorganisms (DALE et al. 2005). These activities are mainly related to the vital roles of these microorganisms in the cycling and release of nutrients, including carbon, nitrogen and phosphorus, and how they respond to changes in the environment (LI et al. 2020).

Soil carbon pools are influenced by inputs of organic matter, such as plant litter and root exudates (LEI et al. 2023; PANCHAL et al. 2022), and losses of organic matter due to decomposition, erosion and leaching. The decomposition of plant litter is central to the global carbon cycle, releasing a significant amount of carbon into the atmosphere (GOUGOULIAS et al. 2014), about ten times more than the annual burning of fossil fuels. This litter contains resistant polymeric compounds such as lignin and cellulose, which are broken down by extracellular enzymes into smaller components. In contrast, root exudates are considered largely labile and are rapidly taken up by microorganisms due to their high energy content (ULLAH et al. 2023; MA et al. 2022).

Soil organic matter (SOM) decomposition is mainly mediated by microbial processes that depend on extracellular enzymes to break down organic polymers into oligomers and monomers (DE BEECK et al. 2021; WALLENSTEIN & BURNS, 2011). The "selective conservation" of SOM by microbial processes has proposed that the pool of labile C, including proteins, aminosaccharides and carbohydrates of plant and microbial origin, is depleted over time. What remains is a suite of recalcitrant organic compounds, including lignin, tannin and condensed aromatic C, which require more energy to be broken down by microorganisms (GLEIXNERl et al. 2001; FIELD, 2001). The theory of 'selective conservation' suggests that the microbial community regulates the decomposition of C, thereby determining OM transformations in the soil (ZHAO et al. 2022).

The capacity to use different carbon sources is closely connected to the production of extracellular enzymes (RATHNAN et al. 2013). Most studies use either individual fungal substrates and species or combinations, and often measure only a few specific enzymes. However, litter decomposition is a complex process involving a variety of different enzymes (HATTENSCHWILER et al. 2005).

The chemistry of the litter, including its quality, has a significant influence on the functional ability to decompose (WARDLE et al. 2002). A key aspect of litter chemistry is the amount of water-soluble carbon and the identity and availability of certain carbon sources. These elements can affect the relative abundance of different individual species, thus influencing the composition of the fungal community. Decomposition of litter is also affected by variables such as plant species, type of plant tissue (e.g. leaves or branches), and the diversity and number of litter types present, along with the nutrient status of the litter and soil (LEIFHEIT et al. 2024).

DECOMPOSITION DYNAMICS: CLIMATE EFFECTS ON SOIL MICROORGANISMS

Changes in climate can influence decomposition processes through short-term variations in soil moisture or temperature, which have a direct impact on biological activities in the soil, including the composition and activity of microbial and soil communities (GREGORICH et al. 2017). Climate change may indirectly alter decomposition through litter chemistry changes at the level of individual plants and changes in plant species composition (WALTER et al. 2013).

A changing global climate is expected to bring modifications in growing season precipitation patterns (WELTZIN et al. 2003), possibly reducing total precipitation amounts. These changes will directly influence ecological processes (BARDGETT et al. 2008), including those regulating carbon cycling and storage, through their impact on the spatio-temporal patterns of plants and solar processes influenced by soil moisture. Finally, a change in the amount of carbon exchanged between the atmosphere and ecosystems will be observed. However, a precise understanding of how these processes will respond to climate change is still lacking. It is well known that drought will have significant effects on microbial communities in terms of biodegradation (BOGATI & WALCZAK, 2022). In general, reduced rainfall and lower substrate moisture make decomposition more difficult (SANAULLAH et al. 2012).

Climate change can affect soil organic matter (SOM) decomposition by altering the balance of plant supply and microbial degradation In general, higher temperatures can stimulate microbial activity (DALAL et al. 2011), which can dagrade SOM rapidly. There is an increased enzyme activity stimulated by high temperature Studies have shown that there is generally a significant positive correlation between average annual temperature and SOM degradation rate, resulting from increased enzyme activity stimulated by high temperature (BLAGODATSKAYA et al. 2016; CHEN et al. 2020; CONANT et al. 2011).

Precipitation also plays a significant role in modifying soil organic matter (SOM). In general, an increase in rainfall can reduce drought stress, improve soil nutrient use and promote plant and microorganism growth. At the same time, an increase in soil moisture can enhance enzyme activity, which accelerates SOM decomposition (CHEN et al. 2020).

Soil structure has a major control on microbial decomposition processes in terrestrial ecosystems. Organic matter is physically protected in the soil, allowing a significant amount of readily decomposable compounds to accumulate in close proximity to microbial populations (VAN VEEN & KUIKMAN, 1990).

Biotic and abiotic factors influence the structure and activity of the microbial community, including soil biota, climate, soil chemistry and the quality of organic matter (KUMAR & KARTHIKA, 2020). Diversity at the local scale can influence composition at the regional scale, while organic matter quality can influence microbial dynamics (PAUL, 2016), at the local scale. The relative importance of environmental factors and organic matter quality in the decomposition process is still under discussion. The transfer of organic material between sites may alter the effects of these factors, depending on the adaptation of local communities to faster decomposition of certain types of organic material. However, if the type of organic material influences decomposition independently of the site, microbes may be considered redundant in their function of decomposing organic material (McGUIRE & TRESEDER, 2010). To better understand the factors influencing microbial decomposition, it is necessary to analyse the interactions at local and regional scales over time, as well as the diversity and origin of the organic material. Biotic and abiotic factors change as the decomposition process progresses, affecting the associated microbial community and extracellular enzyme activity. The differential response of microorganisms to chemical changes in the organic material is essential to classify them according to their specific role in the decomposition process (BURESOVA et al. 2019).

It is well recognised that the process of breakdown of litter is influenced by several factors, including climate, quality of litter and soil microorganisms (ZHANG et al. 2008). For example, higher quality waste tends to decompose faster. At the regional level, waste quality has been considered as the main factor controlling decomposition, while at the global level, climate may play a predominant role. Recent models suggest that climate and waste quality together contribute about 60-70% to the decay rates of litter. However, the impact of soil fauna on waste decomposition remains unclear. It is possible that soil fauna play a crucial role in waste decomposition (KUMAR & SINGH, 2016), because, in addition to direct effects such as fragmentation and waste consumption, soil fauna can influence the structure and activity of microbial communities and indirectly affect the waste decomposition process (SONG et al. 2020).

The decomposition of organic matter is essential in the cycling of nutrients in terrestrial ecosystems (HORWATH, 2007; FINDLAY, 2021). Different types of organic matter added to the soil change the content of nutrients such as carbon, nitrogen, phosphorus, etc., resulting in changes in the activity of extracellular enzymes in the soil. These enzymes, which are mainly produced by microorganisms, are crucial for the breakdown of soil carbon and nutrient mineralisation (LI et al. 2023).

MICROBIAL DECOMPOSER DYNAMICS IN GRASSLAND ECOSYSTEMS

The decomposition of organic matter and nutrient mineralisation in soil is governed mainly by the activity of microorganisms, in particular bacteria and fungi (ESMAEILZADEH & AHANGAR, 2014). These microorganisms have a major impact on the terrestrial carbon equilibrium and hence on the response to climate change. Although both bacteria and fungi in soil are affected by warming-induced climate change and shifts in precipitation patterns (HU et al. 2023), they may react differently to these factors. For example, fungi appear to be more resilient to warming-induced water stress and decreased precipitation compared to bacteria. This is partly due to the distinct morphology and cell structure of fungi, which gives them the ability to access nutrients and water from the soil over longer distances, with their thicker cell walls and extensive hyphal networks (QIU et al. 2023).

Soil microorganisms are fundamental to the balance and health of terrestrial ecosystems, playing a vital role in nutrient cycling and maintaining carbon stability in both the soil and the atmosphere. Bacteria and fungi are two main categories of microorganisms that make their essential contribution by breaking down organic materials and mineralising nutrients, processes that are vital for their availability to plants. They also have a significant impact on how terrestrial ecosystems respond to climate change (QIU et al. 2023).

Soil microorganisms play a vital role in grassland ecosystems, influencing the dynamics of organic matter decomposition and nutrient availability to plants (RIGGS & HOBBIE, 2016). They are also crucial in regulating carbon exchange and nutrient cycling in all types of terrestrial ecosystems. Changes in land use, land cover, plant management and productivity can affect the biomass, structure and functional processes of soil microorganisms by altering the amount and types of organic matter present. Bacterial species are sensitive to environmental changes due to their high growth and short life cycle. Fluctuations in soil microbial biomass are related to modifications in microbial community composition, with specific attention to changes in the ratio of bacteria to fungi (JIN et al. 2010).

Fungi and bacteria are considered to be the main agents responsible for the breakdown of soil organic matter and generally account for more than 90% of soil microbial biomass (CONDRON et al. 2010). However, their relative contribution to the decomposition process remains unclear and may be influenced by a number of factors, including the quality of carbon in plant material. Fungi usually use more recalcitrant carbon sources, while bacteria can respond quickly to increasing resource levels and colonise more labile organic materials. Fungi are equipped with well-developed extraradical mycelium and aggressive enzyme systems for hydrolytic and lignolytic activities. On the other hand, a more labile vegetal substrate can lead to a shift in microbial dominance from fungi to bacteria. However, relationships between carbon substrate quality and the microbial community are complex, and fungi and bacteria may adopt mixed strategies of substrate utilisation (ULLAH et al. 2023).

Fungi have long been recognised as the main agents in the decomposition of complex substrates, but recently increased attention has been paid to the role of bacteria in this process. Bacterial groups such as Actinobacteria, Proteobacteria, Firmicutes and Bacteroidetes are known for their ability to secrete extracellular enzymes and to be active in the degradation of organic materials (De BOER et al. 2005). For example, Actinobacteria can synthesise lignolytic enzymes and secondary metabolites, exhibiting strategies similar to those of fungi, such as filament formation. This suggests that bacteria may be involved in the decomposition process to a greater extent than previously thought. However, research exploring the interactions and interdependencies between fungi and bacteria during the decomposition process is still in its early stages. Investigating the patterns of coexistence between these two microbial groups under the influence of different abiotic factors could provide a better understanding of the mechanisms involved in the decomposition of organic materials in terrestrial ecosystems (BANI et al. 2018; FUKAMI et al. 2010; GLASSMAN et al. 2018)

The crucial role of soil bacteria in interacting with plants and in the decomposition of organic matter and plant litter underlines their importance in the cycling of soil elements, with a particular focus on the carbon cycle and its impact on global warming. Global greenhouse gas fluxes can be significantly affected by even small changes in the activity of these microbial organisms. Understanding how microbial communities change over the course of ecological succession is essential for designing and managing restoration of degraded areas (ZENG et al. 2017).

Degradation of grassland is a serious problem (ZHOU et al. 2005), leading to loss of biodiversity and damage to essential ecosystem functions. Soil microorganisms such as bacteria and fungi play a crucial role in maintaining the health and functionality of grasslands (MEETEI et al. 2022). However, more research is needed to understand how the diversity, structure and network characteristics of interactions of these microorganisms respond to the degradation of grasslands.

Studies by Wu et al. showed that in the soil microbiome, the dominant bacterial groups were represented by Actinobacteria, Proteobacteria, Chloroflexi and Acidobacteria, while the predominant fungal filaments were Ascomycota, Basidiomycota and Zygomycota. As the degree of grassland degradation increased, the relative abundance of some bacterial taxa, such as Actinobacteria, Gemmatimonadetes, Firmicutes and Deinococcus-Thermus, increased, while those affiliated with Acidobacteria and Nitrospirae showed a decreasing trend. As for fungi, the relative abundance of most phyla decreased as the degree of grassland degradation increased (WU et al. 2021).

The degradation of grassland can have significant consequences for the soil ecosystem and its microorganisms (LORANGER-MERCIRIS et al. 2006). A crucial aspect is the influence on soil physico-chemical properties as well as on vegetation characteristics. These properties include salinity, moisture and nutrient availability, all of which play an important role in the health and functioning of soil microorganisms. For example, degradation can alter soil salinity levels, which has been linked to changes in the diversity and structure of microbial communities (ZAMAN et al. 2018). Studies indicate a decrease in the biomass, activity and diversity of microorganisms with increasing soil salinity. This phenomenon affects bacterial and fungal communities differently, with a tendency for the proportion of bacteria to increase in saline soils. In addition, soil nutrient availability and content can be negatively affected by degradation, inhibiting microbial activity and reducing their abundance. These changes can lead to a decrease in the richness and diversity of microorganisms in degraded soils (THOMPSON & KAO-KNIFFIN, 2019).

A fascinating issue is the identity of a significant interplay between improved precipitation and decomposition, which shows that the effect of precipitation on decay would possibly fluctuate depending on the composition of the available organic matter. It is also demonstrated the important role of soil water content in regulating litter decomposition in different grassland types. The complexity of interactions between climatic conditions and litter composition in controlling nutrient cycling in grassland ecosystems are a critical study for the establishment of coherent actions (SU et al. 2022).

CONCLUSIONS

Grasslands have a crucial role in maintaining soil stability, water retention, biodiversity, and other ecological processes. They are also an important source of resources for the tourist, agricultural, and economic sectors.

Natural catastrophes and human activity-induced degradation of these grasslands are a major threat to the resilience and stability of ecosystems.

It is esential to monitor and manage grasslands after a disaster in order to recover ecosystems and use resources sustainably.

In grassland ecosystems, soil microorganisms, such as bacteria and fungi, have a significant impact on the breakdown of organic matter, the availability of nutrients, and the cycling of carbon.

The increase of droughts and other extreme weather events is a major characteristic of climate change and a major threat to grassland ecosystems. Variations in temperature and precipitation patterns have a direct impact on the breakdown of organic matter and microbial activity, which in turn impacts the cycling of nutrients and the overall health of ecosystems.

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