MJAVL
Manas Journal of Agriculture Veterinary and Life Sciences
ISSN/e-ISSN 1694-7932
Volume 14 (Issue 1) (2024) Pages 101-115

Review Article

Under Long-Term Agricultural Systems, the Role of Mycorrhizae in Climate Change and Food Security

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ABSTRACT

Over the past 100 years, the rapid growth in population from 2 billion to 8 billion has significantly impacted the environment and climate change. In addition, food consumption has skyrocketed, and there are widespread worries about global food security. Due to inadequate soil and plant management techniques, including high soil tillage, chemical fertilizers, inappropriate irrigation, and genetically engineered crops, this spike has made it more difficult to guarantee food security for everyone on the planet. These actions have resulted in societal unrest, climatic change, and land degradation. With organic carbon mineralization, more CO2 is released into the atmosphere because of atmospheric heating and climate change. Long-term greenhouse gasses released into the atmosphere cause global climate change. Increasing climate changes and the inefficiency of soil productivity result in the natural effects of the rhizosphere on plant growth and food security. One of the most effective mechanisms of the rhizosphere is mycorrhizal fungi, which are injured microorganisms. Frequently disregarded mycorrhizal fungi present a potential solution. While sequestering carbon from the atmosphere, they can increase agricultural yields, plant health, and soil fertility. For sustainable agriculture and environmental preservation, it is essential to understand and take advantage of the potential of mycorrhizal fungi. A crucial area for study and practical application is the function of mycorrhizal fungi in reducing these difficulties and enhancing food security. Considering rising environmental challenges, understanding their contributions and researching their relationships may help create a more stable and secure global food system..

ARTICLE INFO

Recieved: 29.03.2024

Accepted: 27.05.2024

Keywords: *Mycorrhizae, Climate change, food security, ecosystem management*

Cite this article as: Ortas, I. (2024). Under Long-Term Agricultural Systems, the Role of Mycorrhizae in Climate Change and Food Security. Manas Journal of Agriculture Veterinary and Life Sciences, 14(1), 101-115. https://doi.org/10.53518/mjavl.1433838

INTRODUCTION

The present Situation of Our Food Security Problem

In the last 90 years, the world population has increased from 2 billion to 8 billion (Figure 1). These 6 billion had a significant influence on the environment and climate change. For the food security of 8 billion people, poor soil and plant management, such as heavy soil tillage, chemical fertilizers/persists, unsuitable irrigation, and genetically modified plants and seeds, causes soil degradation, climate change, and unsafe social life.

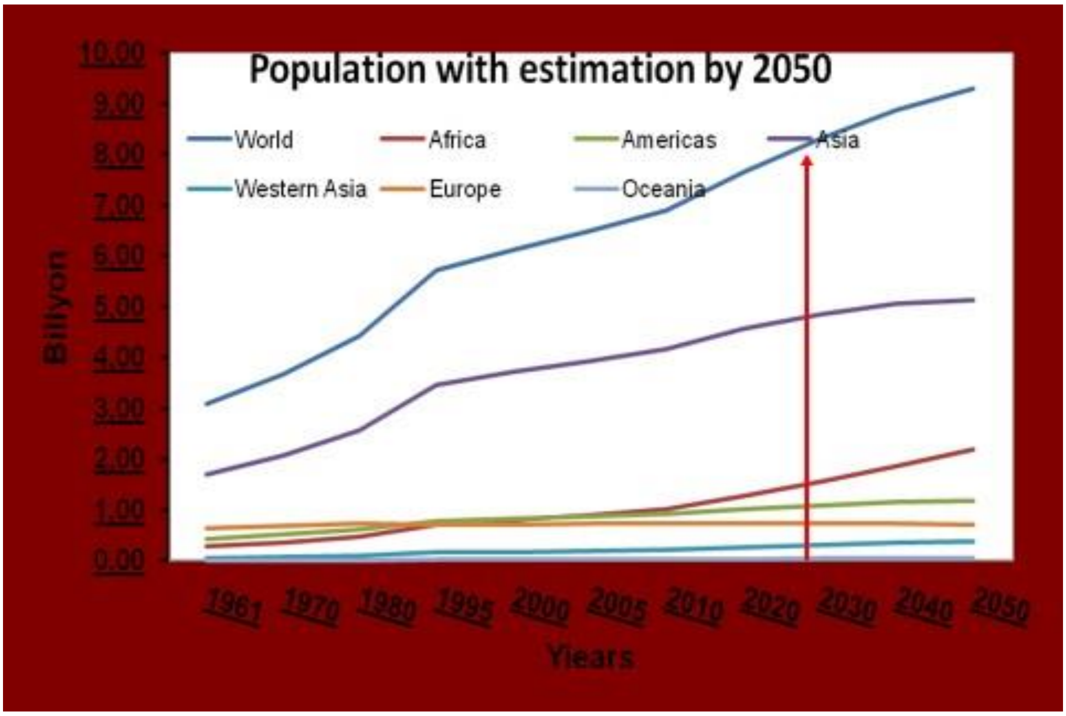

Figure 1. *World population growth (FAOSTAT, 2023)*

In the short history of humanity, and especially after the industrial revolution in the last 100 years, nature has been heavily interfered with by human activities. The excessive production– consumption relationship for the various needs of billions of people has reduced the biological budget capacity of nature and changed the balance of greenhouse gasses in the atmosphere. The climate crisis has begun to threaten our lives, especially the terrestrial ecosystem, just as we had in the past.

Global population growth and mismanagement of soil and plant resources have resulted in soil degradation, climate change, and a threat to social well-being. The industrial revolution has further aggravated the situation by disrupting the balance of greenhouse gasses in the atmosphere and reducing the capacity of nature's biological budget.

What have we created for food security?

Heavy fertilizers have been widely employed in plant production in traditional agricultural systems since the turn of the century. Nevertheless, many traditional field-cropping methods have come under fire for being unsustainable because they worsen the ecosystem.

Critics criticize the current global management and agriculture production system. The production system has also come under fire in several ways. One is that the chemicals used have a direct impact on human health as they travel up the food chain from soil to people. The other is the decrease in chemical fertilizer sources. What causes climate change and how?

What connection does it have to farming? primarily population expansion, urbanization, and rising food prices. If asked, "Who governs nature's life today?" Who is the world's strongest? Developed nations or powerful leaders? No! The Covid-19 virus, one of the microscopic bacteria that we all know are invisible, first affected our lives three years ago. Approximately 7-8 million people died, and for a protracted period, we were in despair.

Do microbes play a role in nature and have any other effects on how we live? If so, what animals?

Naturally, they have been for a few million years. They existed, but we were unaware of them. To guarantee food security, reduce climate change, and encourage biodiversity preservation, it is essential to understand the role of mycorrhizal fungi in carbon sequestration, soil fertility, and plant health. By using their potential, native management techniques can produce more resilient agricultural systems and a better environment.
Looking back, we can see that these intangible beings contain highly diligent life forms that have aided the sustainability of our planet's natural environment and our way of life (Redecker, Szaro, Bowman, and Bruns, 2001).

How much do we know about the relationship between climate change and microorganisms?
The atmospheric CO_2 content has already increased from 280 to 414 mg L^1 since the Industrial Revolution. The increase in yearly means a 2.08 ppm yr^{-1} average growth rate over the previous ten years. Climate change significantly impacts agriculture, altering crop production systems by altering temperature, rainfall patterns, and fertilizer availability. Mycorrhizal fungi are essential for sustainable agriculture because they improve plant growth, nutrient uptake, and water use efficiency.
At present, the biggest aim, again climate change is to maintain atmospheric CO_2 and transfer it into the soil (Figure 2). Without plants, mycorrhizae are not possible

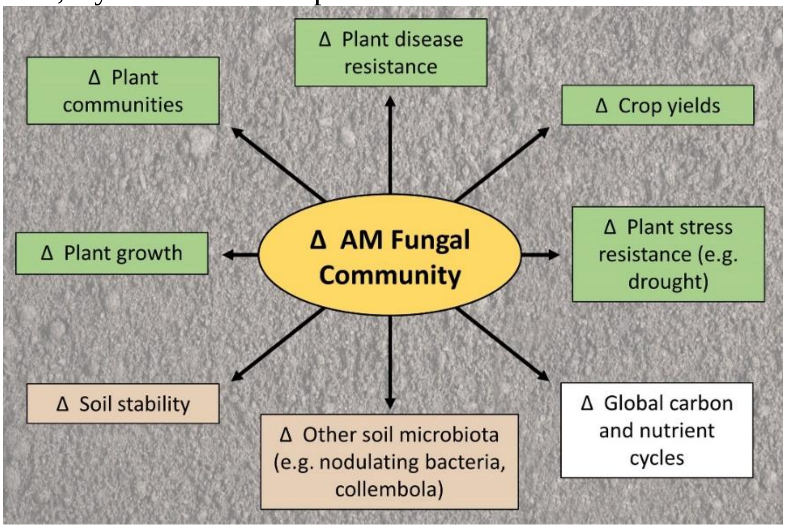

Figure 2. *Potential consequences of changes in AM fungal communities due to global change (Cotton, 2018).*

Perhaps we have paid little attention to the role and function of mycorrhiza in nature and human life. The relationship between human nutrition and soil and atmosphere through plants seems to have been neglected.
How have we neglected the relationship between mycorrhiza and human life?
As indicated by Field, Daniell, Johnson, and Helgason (2020), only the edible mushroom industry is worth 42 billion dollars annually. Orchid mycorrhiza also has more benefits for food and health.
Finally, the potential consequences of changes in AM fungal communities due to global change are clear. Mycorrhizae act between soil plants and the atmosphere in several ways to survive and contribute to sustainable food security.
Thus far, our knowledge about mycorrhizae does not reflect the contribution of mycorrhizae to ecosystem services. Wrage, Chapuis-Lardy, and Isselstein (2010) reported that global climate change influences soil P availability. In addition, it is widely known that plants' mycorrhizal hyphae acquire 75% of the P. Additionally; mycorrhiza inoculation is reported to increase the root surface by 140 times. The majority of mycorrhizal research has been conducted in forestry, agriculture, and plant science. Perhaps we have paid little attention to the role of mycorrhiza in nature and human life. The relationship between human nutrition and soil and atmosphere through plants seems to have been neglected.

These complex symbiotic relationships between fungi, plants, and the rest of life are sustained by a complex underground food exchange web that is invisible to the naked eye and forms the basis of virtually all land-based life.
Effectively using mycorrhizal fungi in field settings is difficult. To maximize mycorrhizal spore quality and effectiveness for sustainable plant growth and development, these issues must be addressed.

Ortas / Manas Journal of Agriculture Veterinary and Life Sciences 14 (1) (2024) 101-115

The world's first and oldest symbiosis (Figure 3) is mycorrhizal fungi, which hold great promise for resolving our current environmental and food security problems. It is impossible to undervalue their contribution to ecosystem resilience, nitrogen cycling, and carbon sequestration. We can strive toward a more sustainable future for agriculture and the planet as a whole by prioritizing the preservation and use of mycorrhizal fungi. It seems that we know a lot about mycorrhizae, but not about their role in climate change. It seems that there is still much that we do not know. To me, we do know the role of mycorrhizae on plant nutrient uptake and healthy plant growth. However, we do not exactly know the function and link of mycorrhizae between soil and their mutually beneficial effects on carbon capture. Because plants and/or mycorrhizae know the soil phosphorus and other nutrient concentrations, they make mycorrhiza efficient. How do they know? We are still not aware of these mechanisms. Mutual chemical and biological usefulness is important for ecosystem sustainability. In addition, mycorrhizal fungi support the health of native ecosystems, the resilience of forests, and ecosystem functioning. They make it easier for plants to transport organic carbon-based molecules to their fungal symbionts, enhancing mutualistic relationships and fostering biodiversity.

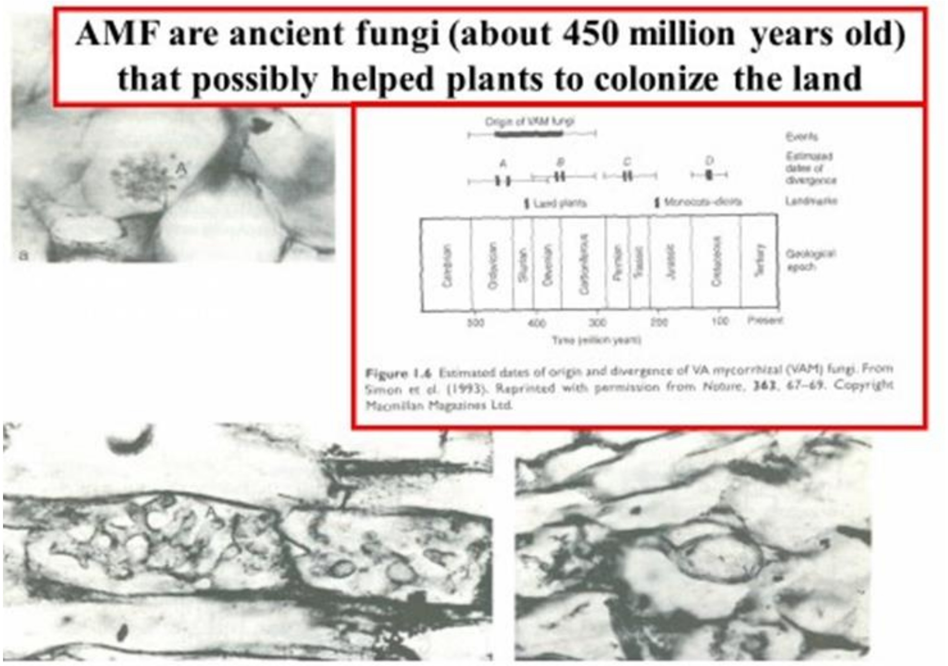

Figure 3. *The oldest mycorrhizal fossil (Simon, Bousquet, Lévesque, and Lalonde, 1993)*

Publication on Mycorrhizae and Climate Change

The question is, because microorganisms exist in our lives and undertake dreadful tasks. What then is the problem we are experiencing now? What is the solution?

How broad and deep do we know about climate change or the climate crisis?
How much basic knowledge do we have about the effects of mycorrhiza on plants and ecosystems?
How much do we know about the effects of mycorrhizal and climate changes on soil– plant and ecosystem functioning?
It appears that we know a lot about the role of mycorrhizae. However, what we still do not know is more than our knowledge. Recently, the number of papers published on the mycorrhizae area is increasing. Since 1990, 35572 papers were published with mycorrhizae on WOS (Figure 4). Most of the work was done on mycorrhizae's role in agriculture, and most of the work was done on phosphorus uptake and bioavailability (WOS 2023).

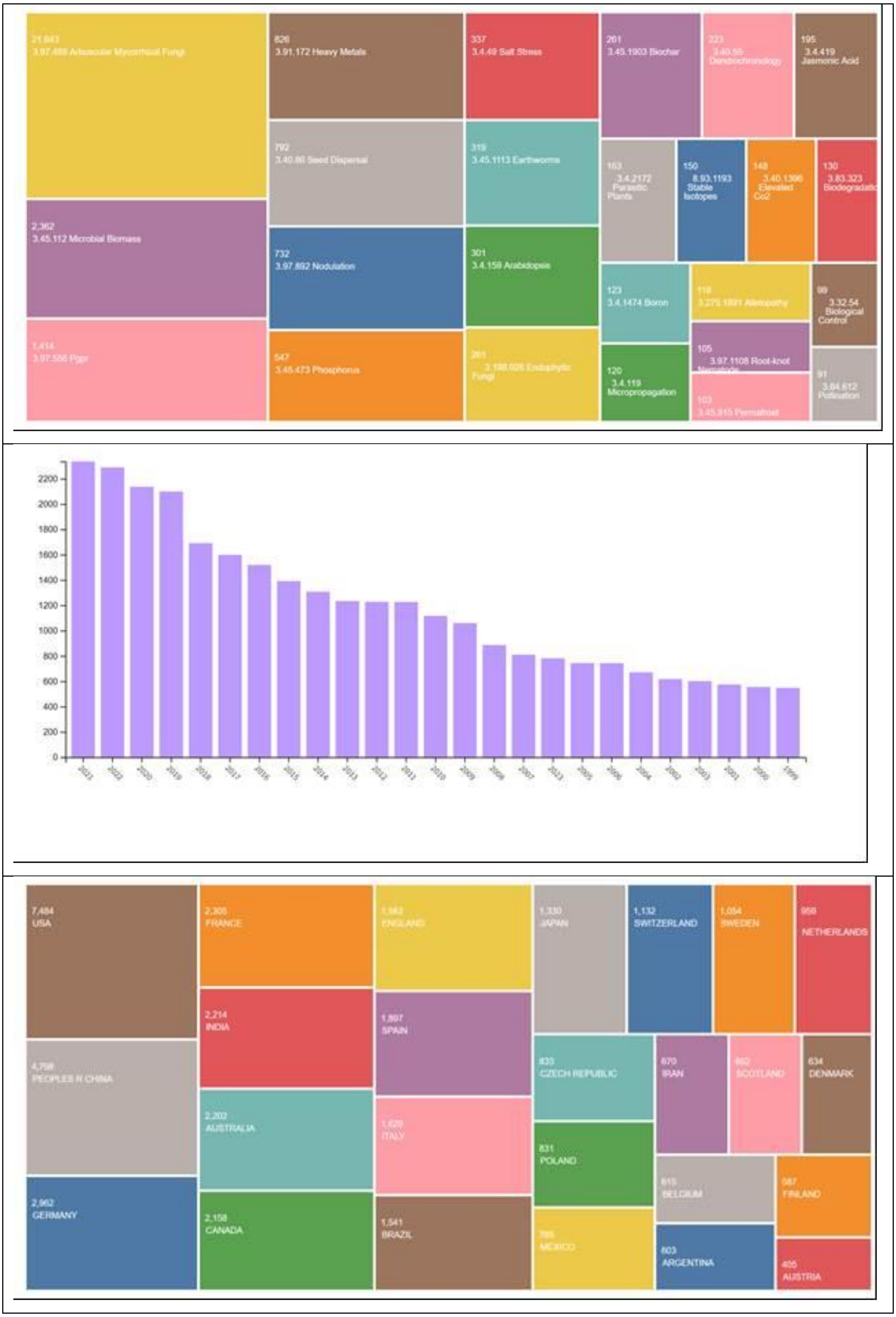

Figure 4. *Research papers on climate change and mycorrhizae works (data were gathered from WOS)*

240 papers on water resources have been published and fewer on global warming. Additionally, publications on mycorrhiza and climate change were published in 1845. Only 148 citations were done on elevated CO_2. Mycorrhizae are mostly searched in developed countries. Not in Africa and poor countries.

In the last 90 years, the world's population has exponentially increased from 2 billion to 8 billion, putting unprecedented pressure on Earth's natural resources, especially for food security. In addition, global plant temperatures are set to rise >1.5°C by the end of the 21st Century (IPCC, 2014). The temperature increase is expected to affect soil macro- and microorganisms. The effects of CO_2 and/or temperature on plant growth and fungal functioning could have influenced both the capacity of plants to allocate carbon to AM fungi, which increased/inhibited the nutritional or other benefits plants obtain from the symbiosis (Duarte and Maherali, 2023).

Recently, increasing research and publications have been conducted on CO_2 fixation through photosynthesis from the atmosphere to the roots and soil. Many studies have shown that elevated atmospheric CO_2 levels positively influence the abundance of mycorrhizae (Compant, van der Heijden, and Sessitsch, 2010). Mycorrhizae play a key role in CO_2 fixation in the atmosphere. It is not sufficient to fix CO_2 through photosynthesis in plant tissue. It is also important to store carbon long-term in plant tissue and allocate it to the plant roots. It is also necessary to keep more organic carbon in special positions in the soil, such as macro- and microstructures. Plant roots play a critical terminal role in leaking carbohydrates to the rhizosphere, where many microorganisms collaborate, challenge, and compete with each other (Figure 5). Some beneficial microorganisms enter the root systems of their hosts as part of an entophytic lifestyle. Thus, organisms have a significant contribution not only to host plants but also to soil development. Mycorrhizae and plant roots collaborate to create strong macro- and microstructures to keep C in side aggregates. Since 1975, several researchers have investigated the effect of carbon fixation and allocation on roots. So far, it is known that 22% of the carbohydrate leaked into the rhizosphere.

A crucial part of carbon sequestration is played by mycorrhizal fungi, which have been sustaining life on Earth for millions of years. They do this by absorbing carbon dioxide from the air and transferring it to the soil via a sophisticated underground network. This procedure reduces CO_2 emissions and fights climate change. In a study published recently in Current Biology, they estimated that mycorrhizal fungi in nature release 13.12 gig tons of carbon dioxide equivalents ("CO2e") into soil ecosystems each year by capturing carbon from the atmosphere and transferring it to the soil. This equates to approximately 36% of annual global fossil fuel emissions. This shows that mycorrhizal fungi play a vital role in combating climate change.

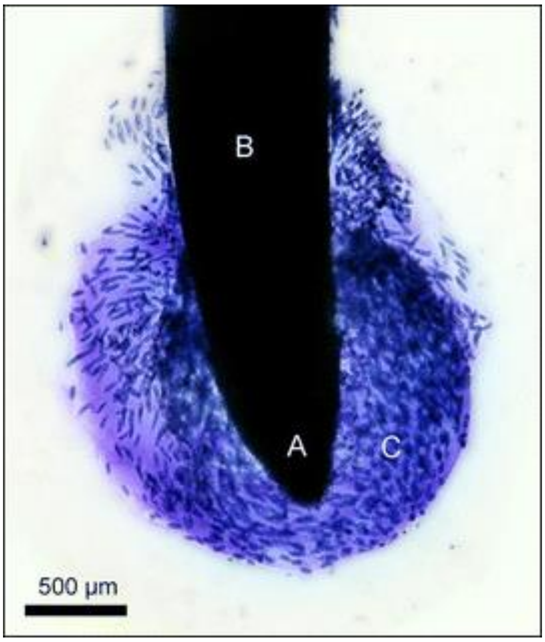

Figure 5. *Light microscopy image showing mucilage (blue halo surrounding the root) and border cell production in a Zea mays L. root tip (Jones, Nguyen, and Finlay, 2009).*

Organisms produce most of the mucilage as well. In addition, there are positive correlations between root exudate organic acids and total microbes, fungi, Azotobacter, PSB, and PSF (Sumarsih, Nugroho, and Widyastuti, 2017).

The invention and use of sciences and technologies, including insecticides, nitrogen- and phosphorus-rich fertilizers, and improvements in plant breeding and genetic technologies, led to a huge increase in agricultural production following the "green revelation". However, in the last 20 years, many key crop yields have plateaued (Thirkell, Charters, Elliott, Sait, and Field, 2017). It is estimated that by 2050, the need to increase agricultural productivity by at least 70% can be met using sustainable agricultural management. Because of environmental pollution problems, the role of soil biodiversity, particularly arbuscular mycorrhizal (AM) fungi, will become more important. More importantly, because of severe extreme climate events, future agricultural productivity needs to become more resistant and resilient, and agriculture production and management needs to become climate-smart (Lipper et al., 2014).

With the population increase and increasing the intention of climate change on plant growth and soil quality is a serious measurement for food security (Ortas, 2022). Due to mismanagement of agriculture, forestry, and other land uses, global atmospheric gas emissions increased by nearly 80%, and projections suggest continual increases from 1940 to the present. This sustainable future is under pressure from climate change.

Crop production is sensitive to climate change. Climate change may affect crop production systems in several ways, including direct and indirect effects such as changes in rainfall leading to drought or flooding, warmer, or cooler temperatures leading to changes in the length of the growing season of plant species. In addition, climate change may significantly affect the nutritional properties of many crops such as maize, wheat, soybeans, and rice. According to Elbehri (2015), under high conditions of elevated CO2 levels, the concentrations of minerals in wheat, rice, and soybeans are lower by up to 8%. Approximately 13% of anthropogenic greenhouse gas emissions are attributed to agricultural practices (Metz, Davidson, Bosch, Dave, and Meyer, 2007). Since crop and food production are sensitive to climate change, urgent mitigation is required. The effect of climate change on agriculture is related to adverse growing conditions such as drought and temperature increases. On the other hand, crop production can reduce the negative effects of CO2 pressure on climate change. Improving crop and soil management practices can increase carbon storage in plants and later in the soil.

Since increasing CO_2 concentrations in the atmosphere have a direct effect on soil warming or drought stress, they also have indirect effects on plant-associated fungi (Augé, 2001). Poorter and Navas (2003) reported that elevated CO_2 levels enhanced the aboveground biomass of C3 plants on average by 45%, whereas C4 plants showed an increase in their biomass production by only 12%. In previous studies, it has been shown that with ambient CO_2 (350 mL L-1) rhizosphere organisms are grown, and as a result, C allocation increases to the root area, external hyphae (Rillig and Allen, 1999), and internal hyphae of AMF. In addition, there is a contrasting result showing no response to CO_2 effects on rhizosphere growth. Compant et al. (2010) indicated that distinct mycorrhizal strains, plant genotypes, or specific associations respond differently to altered environmental conditions. In our experience under field conditions, mycorrhizal responses are diverse.

Root colonization is facilitated by rising temperatures and CO_2 levels, which are often increased. AMF could consequently promote plant growth and nutrient uptake (Figure 6).

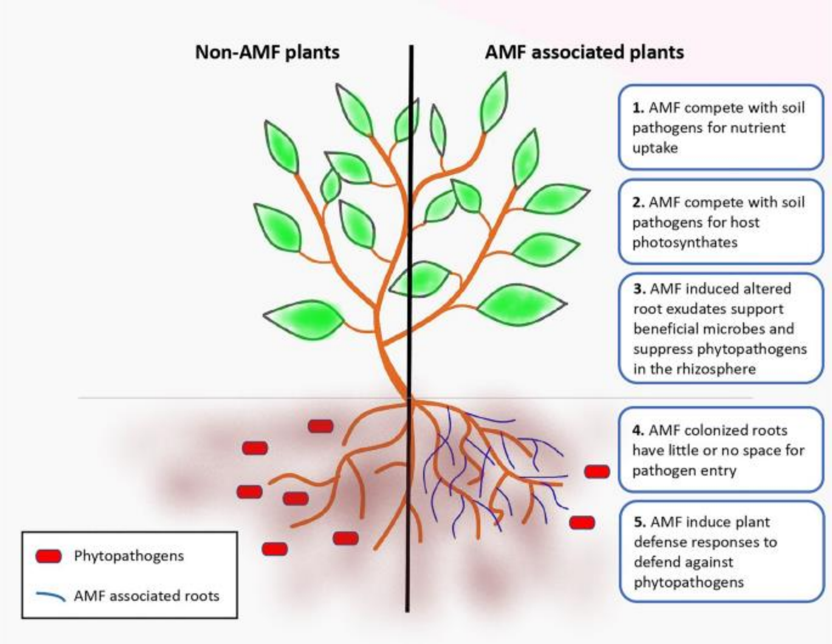

Figure 6. *Effect of mycorrhizae on plant growth under phytopathogen disease (Augé, 2001)*

Most plant species (approximately 90% of plants) are growth-promoting microorganisms that colonize the rhizosphere, which is influenced by root exudates and microorganisms (Smith and Read, 2010). Some beneficial microorganisms enter the root systems of their hosts and enhance their beneficial effects.

AM fungi are considered a crucial biotechnological tool in crop production (Sitoe and Dames, 2022). Soil microorganisms, such as mycorrhizal fungi and Rhizobium bacteria, have an important influence on soil fertility and plant growth/health. Mycorrhizal fungi such as endophytes and PGPB have been applied as biocontrol agents, bio fertilizers, and/or phytostimulators in agriculture (Lugtenberg and Kamilova, 2009).

Soil and crop management, soil types, and crop species play a significant role in mycorrhizae diversity and effectiveness. AM diversity significantly contributes to mineral nutrient uptake (Ortas and Ustuner, 2014) and water use efficiency (Brussaard, De Ruiter, and Brown, 2007). AM fungi specifically compete for nutrients and water uptake , thereby reducing nutrients for other microbes such as decomposers (Sosa-Hernández, Leifheit, Ingraffia, and Rillig, 2019). Mycorrhizae and other beneficial soil organisms have resilience against abiotic disturbances and stress factors. In agroecosystems, the relationships between management, plant and soil biodiversity, soil structure, and nutrient and water use efficiencies were investigated by Brussaard et al. (2007).

Mycorrhizae inoculated with most plants transfer organic carbon-based compounds (e.g., sugars and lipids) to their fungal symbionts. As a symbiosis, the relationship between mycorrhizal fungi and plant roots is usually considered to be a mutualistic interaction. Mycorrhizal fungi are essential in the formation and functioning of sustainable global ecosystems (Field et al., 2020). It has great potential for the future of plants, animals, and the planet in terms of food security and climate change (Figure 7).

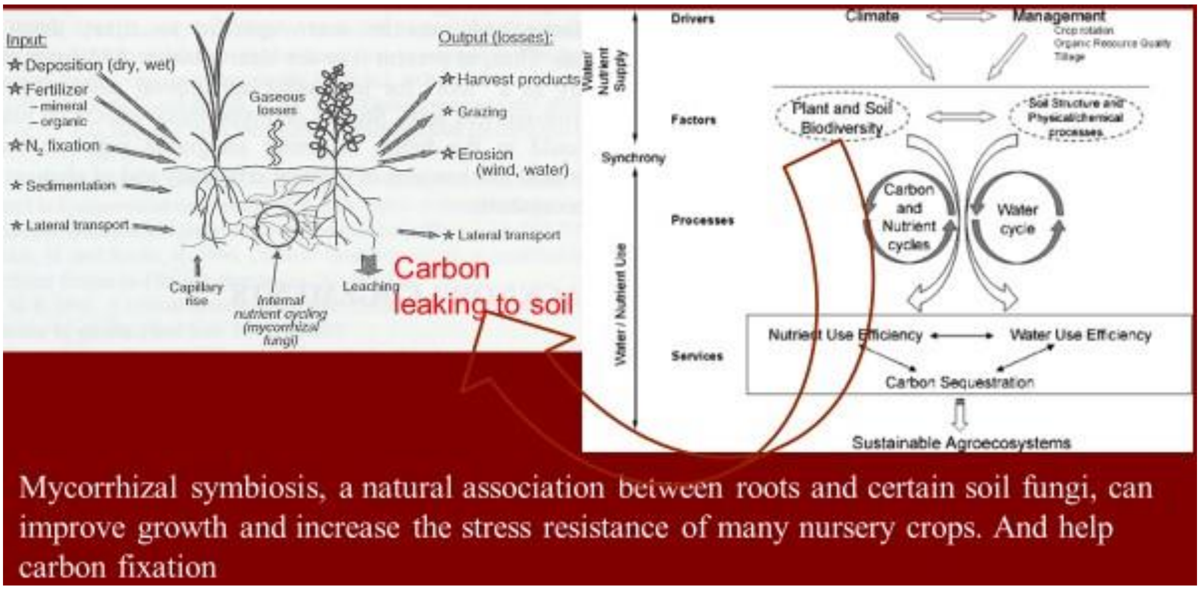

Figure 7. *Underground nutrient and carbon exchange mechanisms (Ortas, 2022)*

Arbuscular Mycorrhizae Role in Plant Restoration in Native Ecosystems

Due to increasing climate changes, it is expected that important changes will occur in the natural vegetation. For example, some plant species may migrate to other areas where they will find new habitats, and some of them may disappear. Due to this situation, it is expected that the Mediterranean areas, especially in Central Anatolia and Southern Anatolia, will expand under drought and soil degradation, and pasture and natural vegetation areas will decrease. As a result, the reduction of the natural mycorrhizal flora in the rhizosphere zone of the plants in question may delay the development and adaptation of new plants. There is high plant biodiversity in southern Turkey due to the floristic mixing of the warm temperate Mediterranean climate.

Mycorrhiza have several positive effects on soil and plant development.

Carbon (C) and nitrogen sequestration and mineral nutrient cycling are the many significant ecosystem services provided by plant and mycorrhizal symbiosis. In terms of global climate change and the carbon cycle, mycorrhizal fungi play a critical role in carbon sequestration in soils. All plant species, especially the three plants, are major carbon sinks, and they play a vital role in mitigating the CO_2 gasses caused by climate change.

While the increased amount of CO_2 in the atmosphere increases the abundance and activity of mycorrhizal fungi, it increases the abundance of fungi in the case of increasing high temperature, but their activity in soil nutrient transfer to plants decreases. At that time, SOC can be out of the rhizosphere part of roots, which is essential for the mitigation of atmospheric CO_2. In drought and warmer conditions, mycorrhizal fungi can reduce plant stress and increase plant productivity. In European grassland communities, it has been reported that AM fungi stimulate soil respiration of pasture soil, leading to elevated CO_2 levels and temperature, with most carbon sequestered in belowground parts (Bahn et al., 2008).

Mycorrhizae contribute to soil nutrient cycling by enhancing plant mineral nitrogen uptake; increased nitrogen in the plant is more likely to demand more carbon fixation, leading to enhanced microbial development via increased root exudation(Ortas, 2019a). Since AM is competitive with other microorganisms for nutrients and water, in the absence of AM in the rhizosphere, higher rhizodeposition would stimulate microorganisms to stimulate SOM decomposition. According to (Bago, Pfeffer, and Shachar-Hill, 2000), AM fungi receive up to 20% of a plant's assimilates for their metabolism. After the extra radical mycelium forms the root, exudates can be released and make an important contribution to SOM. It has been reported by (Clemmensen et al., 2013) that in boreal forests, in subsoil, when root densities are high in deep horizons, up to 70% of soil C can be root-derived. Sosa-Hernández et al. (2019) indicated that AM mycelium can be a crucial pathway of C to the SOM pool (Figure 8) when mycelial exudes organic compounds to soil parts more distant from the root system. The hyphae of mycorrhizal fungi play an important role in maintaining soil structure, holding soil particles together, increasing soil aggregation, and thus increasing soil pore size (Mardhiah, Caruso, Gurnell, and Rillig, 2016). Thus, keeping more carbon and water in aggregates is critical for soil fertility and plant growth. In addition, they indicated that soil loss can be explained by the combined effect of roots and AMF extra radical hyphae, and the unique effect of AMF hyphal length significantly reduced soil loss. As can be seen in the figure. AMF has an important influence on soil and plant parameters, which increase plant growth.

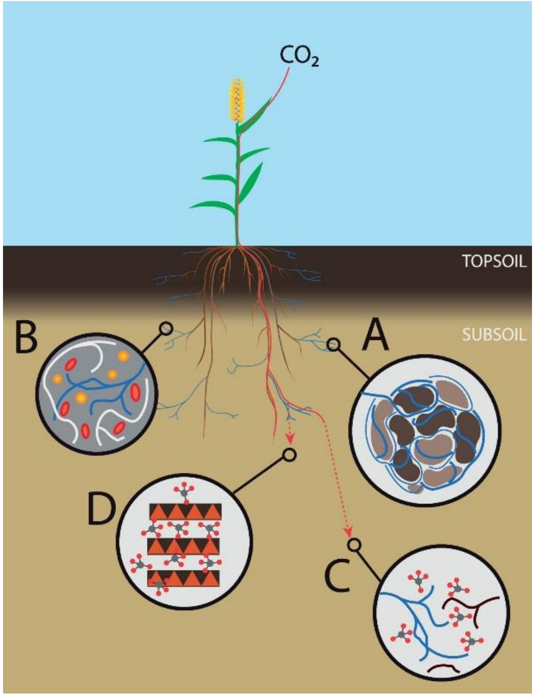

Figure 8. *Role of mycorrhizae hypha on soil development (Sosa-Hernández et al., 2019)*

Mycorrhizae's power of exploitation and management to facilitate a variety of sustainability programs in agriculture such as conservation and restoration, considerations that are particularly relevant during this time of global climate change and widespread depletion of natural resources. The role of soil biota, particularly arbuscular mycorrhizal (AM) fungi, in carbon sequestration and sustainable agriculture is of paramount importance. Orr, Rillig, and Jackson (2021) indicated that the anthropogenic stressors that are impacting biodiversity and ecosystem functioning worldwide can be physical, chemical, and biological.

Recent AM fungal research results showed that plant and fungi species may play a key facilitative role in belowground micro- and meso-organism community dynamics similar to those of a bioengineer. Mycorrhizosphere dynamics are more interesting. Wrage et al. (2010) indicated that increasing temperatures tend to increase the P mineralization of litter. Temperature increases by 5°C have been found to double the colonization of roots by mycorrhiza. In addition, it has been reported that nitrogen mineralization was enhanced by an average of 48% by temperature increases between 0.3°C and 6.0°C (Wrage et al., 2010). Larger N uptake may stimulate phosphatase exudation and plant P uptake. In the presence of AM fungi, phosphorus losses by 50% under both rainfall scenarios and nitrogen losses by 40% under high rainfall intensity were reduced (Martinez-Garcia, De Deyn, Pugnaire, Kothamasi, and van der Heijden, 2017). This means that the AM fungi reduced the nutrient leaching risk when rainfall intensity increased, which is essential for future climate change on nutrient management in soil. Also, this finding is important under climate change caused by increased rainfall AM fungi can enhance ecosystem resilience and reduce the negative impact of increased precipitation on nutrient losses.

Mycorrhizae symbionts act as a barrier to the absorption of heavy metals by plants and reduce root-to-shoot mineral translocation. The results of Amir, Lagrange, Hassaine, and Cavaloc (2013) indicate the potential of selected native AMF isolates from native areas for ecological restoration of such degraded ecosystems. The growth of many plants is tightly correlated with AM root colonization. Possibly for optimum growth and nutrient uptake, the plant is planning to have root exudate and demand mycorrhizal colonization (Figure 9).

Native microbial communities and mycorrhizal inoculation have a significant contribution to native plant succession against invasive species. The results of Wilson, Hickman, and Williamson (2012) indicate that the restoration of native AM fungal communities may be a fundamental consideration for the successful establishment of native grasses in invaded sites.

Soil and Crop Management with Mycorrhizae Development, Crop Production, and P Uptake

In general, heavy tillage breaks down the soil structure, and as a result, this extra radical hyphal network is disrupted, which can reduce the inoculation potential of the mycorrhizae spores (T. P. McGonigle, Miller, and Young, 1999). Also, because of the breakdown of the hyphal network, the absorptive abilities of the mycorrhizae hyphae can be reduced (T. P. McGonigle and Miller, 1999). Jansa et al. (2003) have shown that under long-term field conditions, soil tillage changes microbial activity and nutrient content of the soil. T.P. McGonigle, Evans, and Miller (1990) also reported that heavy tillage reduced root colonization of maize plants and reduced the P and Zn contents of shoot parts.

It is quite clear that mycorrhizae are an essential component of ecosystem biodiversity and sustainability. Mycorrhizae play a significant role in plant nutrition, water uptake and protection, and ecosystem services. The applications of mycorrhizal fungi in sustainable agriculture and forestry systems can make an additional contribution from nature to soil life. It is also important to manage soil organism, especially mycorrhizal fungi, which is a powerful tool to fix more CO_2 from the atmosphere to soil through plant leaves and roots. AM enhances the (SOC) pool, the development of the soil structure, and the transfer of atmospheric CO_2 to the soil through photosynthesis is a crucial strategy for mitigation of climate change effects. In general, there is a large difference between plant species in terms of mycorrhizal species inoculation and CO_2 fixation, which is dependent on the C3, C4, and photosynthesis systems.

The effect of mycorrhizal inoculation and indigenous mycorrhizae effectiveness is much greater on soil fertility, the effectiveness of spores, and the number of spores. There is a need to work more. A suitable soil-crop management system will help mitigate climate change and ensure safe food security.

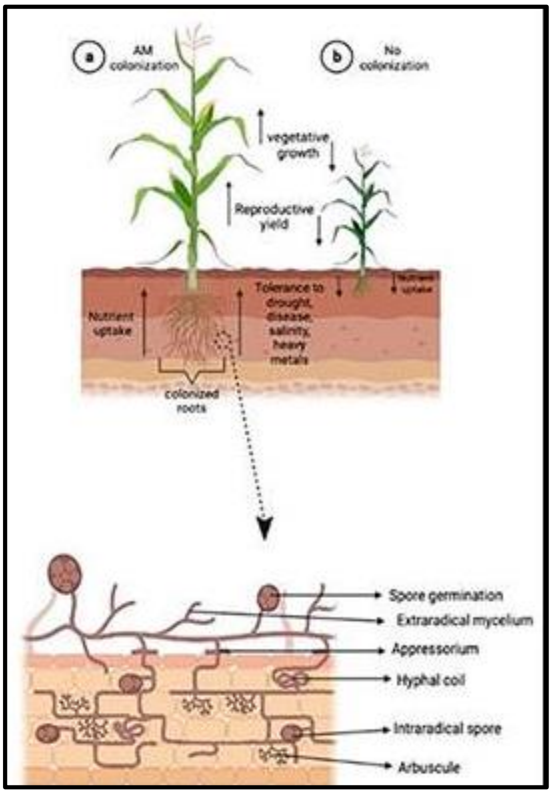

Figure 9. *Effect of AM fungi on stress factors and crop growth (Sitoe and Dames, 2022)*

Role of mycorrhizae fungi to tolerance to drought, temperature and salinity

Plant growth and soil quality are affected by environmental strass factors such as drought and salinity. Increasing temperatures caused by climate change increase drought and salinity issues in many regions. In many parts of world especially under the semi-arid climate conditions, because of miss managements of soil and plant, more and more arable land are getting under salt conditions (Ortas, Rafique, and Çekiç, 2021). A significant portion of plant species develop a tolerance to salinity and drought thanks in large part to AM fungi. The host plants' capacity to flourish in the face of stressors like drought is aided by AM fungus' capacity to utilize soil resources. Soluble salt accumulation in the rhizosphere can lead to decreased water potential (Li, George, Marschner, and Zhang, 1997) and, consequently, less water available for plant use. The biggest threat to food security arises when these salts are absorbed by plants growing in these conditions, as this can affect their physiological functions.

Mycorrhizal contributions to sustainability

Arbuscular mycorrhizal (AM) fungi were found in many native plant roots that grow in coastal southern Turkey. Most native species were grown under natural conditions of poor and salty soil conditions that depend on AM fungi. The symbiotic relationship between AM fungi species and native halophytic plants is important in the marginal soil ecosystem (Jayachandran and Fisher, 2008). In addition, it is useful for the restoration of native plants for healthy animal and human food quality. From viruses and fungi to big mammals, animal life is controlled by epicontinental conditions. Because most plant species are directly and/or indirectly affected by mycorrhizal inoculation, it is important to look at mycorrhizae in different ways.

Atmospheric CO_2 concentration increases (Cotton, 2018) and changing temperatures have been shown to affect the rate and quantities of carbon and mineral nutrients exchanged between mycorrhizae and plant species (Gavito, Schweiger, and Jakobsen, 2003). With climate change in our region, land degradation associated with unsustainable farming practices the crop yield does not increase, in those cases, it decreases. In the last 20 years, many plants' yields have plateaued despite increasing fertilizer and other inputs (Grassini, Eskridge, and Cassman, 2013).

Under climate change conditions, the stability of carbon largely depends on the interactions and balances between plants, mainly trees, and mycorrhizal fungi. CO_2 enrichment, temperature rise, increased N deposition, soil degradation, and biological diversity losses are the main drivers of climate change and have a significant impact on mycorrhizal functionality. Under climate change, mycorrhizae play an important role in the resilience and recovery of forest ecosystems. The physiological function of mycorrhiza-like symbioses is dependent on several abiotic and biotic factors (Field and Pressel, 2018).

Godfray et al. (2010) reported that there is significant potential to exploit the power of soil fungi in the production of food. If mycorrhiza spores are successfully applied, mycorrhizae could help reduce agricultural fertilizer inputs while maintaining and increasing crop yields. Under the most natural conditions, mycorrhizae inoculation has a competitive advantage over non-mycorrhizal plants (Chen, Arato, Borghi, Nouri, and Reinhardt, 2018).

How Much Carbon Transfers from Plant to Fungus?

Plant-to-fungus C transfer is a very important fundamental aspect of mycorrhizal partnerships, particularly in AM symbioses where the fungi, being obligate biotrophs, are entirely reliant on their host plants for organic C (Smith and Read, 2010). It has been reported that plants may direct up to 50% of their photosynthesis to their mycobionts in mycorrhizal partnerships (Soudzilovskaia et al., 2015). estimated that mycorrhiza symbioses alone annually contribute significantly to global carbon emissions of 5 billion tons. Previously (Douds, Johnson, and Koch, 1988) estimated that plants have transferred 4%–20% more photoassimilate to mycorrhizal root systems. Also recently, it has been indicated that AMF might also have an unappreciated role in plant host N nutrition. Since carbon and nitrogen control each other with a C: N ratio, it is important to focus on the subjects.

Under field conditions, the contribution of mycorrhiza to the mitigation of CO_2 emissions is important in several ways. The results show that under field conditions, mycorrhizae-inoculated seedlings such as pepper, melon, cucumber, and marrow produce up to 35 % yield increases in several horticultural plants (Ortas, 2019b). This means that mycorrhizal colonization fixed more atmospheric CO_2 than non-colonized ones. The biggest problem with using mycorrhizae under field conditions is the quality and effectiveness of mycorrhizae spores. Indigenous mycorrhizal management is important.

CONCLUSION

Due to factors including a fast-expanding population, poor management of soil and plant resources, and the negative effects of climate change, the existing level of food security is under increasing threat. Furthermore, the exponential increase in the world's population has increased the need for food production, putting unprecedented strain on the earth's natural resources. The environment and natural ecosystems have been considerably transformed and disrupted by human activities during the past century, particularly those connected to industrialization and agriculture.

Unsustainable agricultural methods, such as intensive soil tillage, improper irrigation, overuse of chemical fertilizers and pesticides, and reliance on genetically modified organisms and seeds, are major contributors to these problems. Soil deterioration and climate change are the results of these practices.

In this setting, the importance of mycorrhizal fungi in addressing food security and reducing climate change appears to be a crucial and frequently disregarded factor. Mycorrhizal fungi may promote soil fertility, boost plant health, boost agricultural yields, improve soil quality, and even store carbon from the environment. To achieve food security and environmental sustainability in a changing world, the potential of mycorrhizal fungi in agriculture and ecosystem management can be recognized and fully used.

However, there is still much that we do not fully comprehend regarding the intricate connections that exist between mycorrhizal fungi, plants, and the environment, particularly considering climate change. To create sustainable farming methods and guarantee food security despite environmental threats, research understanding these relationships is essential. A more resilient and secure global food system will only be possible with additional study and practical applications of this understanding.

CONFLICT OF INTEREST

The authors declare no conflict of interest in this study.

AUTHORS CONTRIBUTION

The author fully contributed to the manuscript.

ACKNOWLEDGEMENT

This paper was presented in International Symposium on Microorganisms and The Biosphere Microbios-2023. June 15-16, 2023 / Bishkek – Kyrgyzstan.

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