Latest Studies and Developments in Agriculture and Environment

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PREFACE

The accountability of the agricultural industry towards all life forms in the cosmos is progressively mounting. The primary challenge facing this sector is the surging global population. The secondary challenge is to furnish sustenance to this populace whilst concurrently curtailing environmental impacts, and safeguarding and conserving natural endowments for future generations.

Numerous non-governmental organisations, public institutions, and scientists worldwide objectively monitor the interrelation between agriculture and the environment and provide recommendations for enhancing policy adherence to elevate environmental sustainability in the agricultural sector. Many developed countries have recently boosted funding for agriculture and agriculture-based industries, marking a surge in this sector's momentum. In numerous countries that prioritize agriculture and the environment, farmers are dedicated to preserving natural resources by enhancing land management strategies, producing value-added agricultural goods, minimizing their use of insecticides, conserving energy and water, and reducing inputs per unit of land.

Are these activities and practices sufficient?

Can policymakers and implementers work alongside an adequate number of stakeholders ?

Are more efforts and collaborations needed?

Such questions and problems are among the main problems in many countries around the world.

Further, in order to address the dual challenges of ensuring global food security for a growing population and enhancing environmental performance, it is imperative to improve the efficiency of agriculture in terms of both resource usage and environmental impact. This can be achieved through the implementation of effective land management practices, minimizing pollution, mitigating damage to biodiversity, and strengthening policies that combat environmental degradation. In order to support this process, it is necessary to prevent all forms of environmentally harmful production and decrease input subsidies. Agriculture and environmental importance can be enhanced through increased consideration of scientific and technical studies.

In summary, in a process where issues such as soil, agriculture, food security, forests, nature conservation areas, biodiversity, water, climate change, energy policies, mining, spatial planning and environmental impact assessment are carefully monitored, all stakeholders have important duties.
Because there is no other world…..

Sincerely Yours,
October, 2023

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CHAPTER 1

THE EFFECT OF SOIL ORGANIC CARBON FRACTIONS ON CLIMATE CHANGE

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1. Introduction

Soil organic matter (SOM), and soil organic carbon (SOC) plays a significant role in all organisms' life in the world (Brevik, Slaughter et al. 2020). The soil organic carbon (SOC) influences soil physical (Ito and Wagai 2017, Razzaghi, Vignozzi et al. 2017, Toosi, Kravchenko et al. 2017), chemical (Beare, McNeill et al. 2014, Curtin, Beare et al. 2015), and biological properties (Tang, Luo et al. 2021, Serafim, Mendes et al. 2023). Bossio, Cook-Patton et al. (2020) refers to the potential of SOC to contribute to natural climate solutions (25%). According to the mentioned study, increasing the levels of SOC in agricultural soils through practices such as reduced tillage, cover cropping, and crop rotation can contribute to mitigating climate change by sequestering carbon from the atmosphere into the soil.

It is important to note that the actual potential of SOC to contribute to climate solutions may vary depending on a range of factors, such as soil type (Mao, Qiu et al. 2020, Yang, Jansen et al. 2020), climate, and management practices (Ćirić, Belić et al. 2016). Plants contribute to the soil by depositing photosynthetic products, including litter and root exudates, which in turn release carbon dioxide (CO2) into the atmosphere through the activities of microorganisms (Jia, Cao et al. 2019). The process of soil carbon sequestration assumes a vital role in mitigating the positive feedback loop between terrestrial carbon dynamics and climate change (Chen, Wang et al. 2018). Furthermore, it is essential to quantitatively assess the potential benefits of carbon sequestration associated with specific soil management practices. Such quantification can provide valuable insights to inform the formulation of policies and incentives that promote the widespread adoption of sustainable soil management practices. Overall, understanding the interactions between SOC sequestration and climate change is critical for developing sustainable soil management practices that can contribute to climate mitigation and adaptation (Bossio, Cook-Patton et al. 2020).

Labile carbon fractions are highly reactive and are easily mineralized by soil microorganisms (Bongiorno, Bünemann et al. 2019), which can release nutrients and energy that can support plant growth and other soil processes (Wang, Feng et al.). Changes in labile carbon fractions can affect soil structure, nutrient cycling, water holding capacity, and other important soil properties (Kopecký, Peterka et al. 2021). Therefore, understanding the dynamics of labile carbon fractions in soil is important for developing sustainable soil management practices that can improve soil health, soil quality and ecosystem services (Wang, Wang et al. 2014, Awale, Emeson et al. 2017, Fine, van Es et al. 2017, Bongiorno, Bünemann et al. 2019, Sainju, Liptzin et al. 2022). While the role of soil organic carbon (SOC) in maintaining soil fertility has been widely studied (Geraei, Hojati et al. 2016, Awale, Emeson et al. 2017), the impact of SOC fractions on climate change has not received as much attention. Labile carbon fractions are highly reactive and can be rapidly mineralized by soil microorganisms, which can release carbon dioxide and other greenhouse gases into the atmosphere. Therefore, changes in labile carbon fractions can influence soil carbon sequestration potential and the net exchange of carbon dioxide between the soil and atmosphere. Moreover, climate regimes exert a crucial influence on the structure of microbial communities (Celik, 2019).

Furthermore, the composition of microbial communities was primarily shaped by labile fractions (Ramírez, Fuentes-Alburquenque et al. 2020). Therefore, labile carbon fractions of soil can also play an important role in climate change mitigation and adaptation. Several studies have shown that management practices such as conservation tillage, cover cropping, and crop rotation can increase SOC levels and promote the formation of more stable SOC fractions, which can help to mitigate climate change. More research is needed to better understand the complex interactions between SOC fractions, soil management practices, and climate change. This chapter can provide an overview of the significance of SOC and SOC fractions in mitigating climate change based on previous and recent studies.

This chapter initially focuses on the identification of soil organic carbon (SOC) and its various fractions. Subsequently, we provide a detailed analysis of their relationships with climate change.

1.1. Soil Organic Carbon (SOC)

As mentioned above the SOC affects many physical, chemical, and biological properties of soil, including water holding capacity, nutrient availability, pH, soil structure, and biological activity. (Duval, Galantini et al. 2018, Xu, Li et al. 2021) and these properties also affect SOC stabilization (O'Brien, Jastrow et al. 2015, Hengl, Mendes de Jesus et al. 2017, McNally, Beare et al. 2017, Totsche, Amelung et al. 2018). Furthermore, the parent material, which represents the underlying geological material from which soils originate, assumes a crucial role in governing soil texture, mineral composition, fertility, as well as the stabilization and retention of soil organic carbon (SOC) (Herold, Schöning et al. 2014, Barre, Durand et al. 2017, Pichler, Gömöryová et al. 2021, Zhang, Li et al. 2022). Furthermore, there is a relationship between soil depth and soil organic carbon (SOC) content in the soil. Generally, as soil depth increases, the amount of SOC stored in the soil also increases. This is because deeper soil layers are typically more protected from disturbances, such as tillage and erosion, and have had more time to accumulate organic matter. In addition, deeper soil layers tend to have more stable environmental conditions, such as less fluctuation in temperature and moisture, which can promote the accumulation and stabilization of SOC (Fanin, Maxwell et al. 2021). According to Li, Wu et al. (2021) the topsoil layers are typically more biologically active, and the decomposition of organic matter in these layers is more sensitive to changes in moisture availability. Elevation and topografy is another important factor that influence SOC content (Wiesmeier, Urbanski et al. 2019, Che, Gong et al. 2021, Guo, Fu et al. 2021). The microbial residues associated with SOC tend to decrease at higher altitudes (Yang, Lyu et al. 2020). For example, a study conducted in the Tibetan Plateau found that the amount of microbial residues associated with SOC decreased with increasing altitude. Similarly, a study conducted in the Himalayas found that microbial biomass and activity decreased with altitude. The decrease in microbial residues associated with SOC at higher altitudes may be due to a variety of factors. One possible explanation is that lower temperatures at higher altitudes can reduce microbial activity and the rate of organic matter decomposition, leading to a lower accumulation of microbial residues in the soil. Additionally, changes in precipitation patterns and vegetation at higher altitudes can also affect soil microbial communities and their activities, potentially leading to changes in the amount and composition of microbial residues associated with SOC. Therefore environmental changes, can affect OC pool in the soil (Pendall, Rustad et al. 2008).

Moreover, temperature as a climate factor plays a crucial role in determining the rate of decomposition of SOM and the storage of SOC in the soil. Increased soil temperature and moisture levels have been observed to stimulate the decomposition of soil organic carbon (SOC). However, it is important to note that the extent of this decomposition process is significantly influenced by the availability of labile carbon supply and the metabolic activity of soil microorganisms. Furthermore, these dynamics are particularly pronounced along the gradient of vegetation restoration. Conversely, cooler temperatures can slow down the rate of decomposition, leading to higher SOC storage (Viscarra Rossel, Webster et al. 2014, Gray, Bishop et al. 2015, Tan, Han et al. 2020, Li, Wu et al. 2021, Fang, Zhu et al. 2022). At global and regional scales, climate is often the primary factor that explains the largest proportion of variation in soil organic carbon (SOC) decomposition rates. For example, in temperate regions with cool and moist climates, SOC is typically stored in the form of peat, which is very stable and decomposes slowly. However, in warmer and drier regions, SOC is stored in the form of more labile organic matter, which decomposes more quickly (Carvalhais, Forkel et al. 2014).

According to Vasques, Grunwald et al. (2010), Mayes, Marin-Spiotta et al. (2014) microbial activity is a key driver of the decomposition and mineralization of SOC and is highly sensitive to changes in soil moisture. When soil moisture is limited, microbial activity and the rate of decomposition of organic matter can be reduced, leading to an accumulation of SOC in the soil. Conversely, when soil moisture is high, microbial activity and the rate of decomposition can increase, leading to a loss of SOC from the soil. Soil management practices and land use such as tillage, crop rotation (Tiemann, Grandy et al. 2015; Çelik and Akça, 2017), cover cropping (Bolinder, Crotty et al. 2020, Razzaghi 2021), and the application of organic amendments can all have a significant impact on the amount of soil organic carbon (SOC) that is stored in soil. However, it's important to note that the specific impact of soil management practices on SOC storage can vary depending on factors such as climate, soil type, and the specific management practices used (Viscarra Rossel, Webster et al. 2014, Demir and Mirici 2020). Additionally, SOC stocks can be influenced by other factors such as land use change, wildfire, and erosion (Hamza and Anderson 2005). Organic amendment such as green manure refers to crops that are grown specifically to be incorporated into the soil as a source of organic matter (Ansari, Choudhury et al. 2022). These crops can be annual or perennial are typically grown for their ability to fix atmospheric nitrogen and provide other nutrients to the soil. Furtheremore, Xu, Wu et al. (2023) indicated that the simultaneous application of chemical fertilizer and Chinese milk vetch promoted the bonding of recalcitrant carbon with iron/aluminum oxides. This synergistic effect substantially enhanced the stabilization of organic carbon within the organo-mineral complexes of paddy soil. Overall, the use of green manure crops as a strategy for increasing SOC storage can be an effective and sustainable approach to improving soil health and mitigating climate change. However, the effectiveness of this strategy can vary depending on factors such as crop selection, timing of incorporation, and soil conditions, and requires careful management to ensure optimal results (Almagro, Ruiz-Navarro et al. 2021, Wan, Ma et al. 2021). Consquently, Manure input may enhance SOC stabilization is through the formation of Ca-OC. Calcium is an important element in soil, as it can form strong bonds with organic matter, helping to protect it from decomposition. When manure is applied to soil, it can increase the availability of calcium, which in turn can lead to the formation of Ca-OC. This Ca-OC is relatively stable and can persist in soil for long periods of time, contributing to the overall pool of stabilized SOC in the Fluvic Cambisol(Wan, Ma et al. 2021). Moreover, az mentioned above the vegetation cover types like forest and grassland can affect th SOC content depended to differences in plant litter chemistry and root biomass production (Liu, Du et al. 2016, Razzaghi, Oskouei et al. 2016, Razzaghi, Vignozzi et al. 2017, Poeplau 2021, Sanderman, Baldock et al. 2021, Razzaghi, Islam et al. 2022). Han, Tang et al. (2020) reported that SOC content reduced when the forest was converted to agricultural land. The similar result were found when the grassland changed to agricultural land (Wei, Shao et al. 2014). The increase in CO2 emissions from the soil is also a significant consequence of grassland degradation. This occurs because as soil organic matter breaks down, it releases carbon dioxide into the atmosphere. Overall, grassland degradation can have serious implications for soil health and carbon cycling, with potential effects on ecosystem functioning and global climate change (Dong, Zhang et al. 2020).

1.2. Soil Organic Carbon (SOC) Fractions

The soil organic carbon (SOC) pool, which consists of both labile and recalcitrant carbon, is relatively insensitive to short-term variations in carbon dynamics. This is because the bulk SOC pool represents a large, stable reservoir of carbon that turns over very slowly over decades to centuries. In terms of chemical composition, soil labile organic carbon is predominantly constituted of polysaccharides that are sourced from plant litter and root exudates, such as hemicellulose, cellulose, and starch residues, as well as microbial biomass, which includes microbial cell walls (Rovira and Vallejo 2007).

However, the labile portion of the SOC pool, which consists of more readily decomposable organic compounds such as microbial biomass (MB), root exudates, and fresh plant litter, can be more sensitive to short-term changes in carbon dynamics (Zhao, Li et al. 2016, Razzaghi, Islam et al. 2022). These labile carbon pools have shorter turnover times, typically on the order of months to years, and are therefore more responsive to changes in management practices such as tillage (Bongiorno, Bünemann et al. 2019), crop rotation (Wang, Feng et al.), and organic amendments (Wu, Zhang et al. 2023). Changes in the labile SOC pool can be used as an indicator of early SOC changes and can provide valuable information for SOC management (Razzaghi, Islam et al. 2022). By increasing the input of labile carbon through practices such as cover cropping (Razzaghi 2021), reduced tillage (Jastrow, Amonette et al. 2007), and the addition of organic amendments (Gross and Glaser 2021), it may be possible to enhance soil health and productivity, while also sequestering carbon in the soil. Fustheremore, Hu, Huang et al.

(2022) suggested that a substantial input of green manure, coupled with the application of phosphorus (P) fertilizer, proves advantageous in facilitating the transport of organic carbon fractions deeper into the soil profile. This process promotes the accumulation of organic carbon and serves as a significant agronomic management strategy for enhancing soil acidity in tropical regions. In addition, determining the soil organic carbon (SOC) fraction is an essential component of biogeochemical models that simulate carbon cycling in terrestrial ecosystems. This is because the SOC fraction represents the pool of carbon that is stored in soil over a long period of time and is therefore an important indicator of ecosystem carbon sequestration potential and soil fertility (Sanderman, Baldock et al. 2021).

One example of a labile carbon fraction is dissolved organic carbon (DOC), which refers to the amount of carbon that is present in organic compounds that are dissolved in water (Leinemann, Preusser et al. 2018). Hot water extractable carbon (HWEC) is another example of labile organic carbon which can be extracted from soil using hot water. HWEC is a common method used to assess the amount of labile carbon in soil, as it is an inexpensive and relatively easy procedure that can be conducted in most laboratories (Ghani, Dexter et al. 2003). During the HWEC extraction process, soil samples are mixed with hot water and then filtered to remove any solid particles. The resulting extract amino acids, and other labile carbon compounds that can be rapidly decomposed by microorganisms. HWEC measurements are useful for a variety of research purposes, including soil quality assessments, studies of carbon cycling and sequestration, and investigations of the impacts of land use and management practices on soil carbon. HWEC is also often used in conjunction with other soil carbon measurements, such as total carbon and particulate organic carbon, to provide a more complete picture of soil carbon dynamics (Yousefi, Hajabbasi et al. 2008). Particulate organic carbon (POC) refers to the small particles of organic matter that are found within soil aggregates. These particles are important for soil health, as they provide a source of nutrients for soil microbes and help to stabilize soil aggregates, which can improve soil structure and water-holding capacity. POC primarily indicates the consistent pattern, namely, the inclination towards the alteration of carbon constituents that are resistant to decomposition. It is widely regarded as the primary indicator for characterizing the transformation and stabilization of labile organic carbon in soil (Xu, Lou et al. 2011, Tang, Xiao et al. 2020). In addition, the permanganate oxidizable carbon (POXC or AC) is considered the most sensitive fraction of soil labile organic carbon, and it can be rapidly influenced by management practices in the soil (Weil, Islam et al. 2003, Tatzber, Schlatter et al. 2015). Moreover, microbial biomass carbon (MBC) that explained above in detail is other type of SOC fraction.

When plant material and microorganisms are decomposed in soil, they release a variety of organic compounds that can be used as a food source by other microorganisms. This process is known as mineralization, and it leads to the formation of labile carbon compounds that are readily available for microbial decomposition (Huang, Crowther et al. 2021, Wu, Ren et al. 2023). Furthermore, determining the soil organic carbon (SOC) fraction is an essential component of biogeochemical models that simulate carbon cycling in terrestrial ecosystems. This is because the SOC fraction represents the pool of carbon that is stored in soil over a long period of time and is therefore an important indicator of ecosystem carbon sequestration potential and soil fertility (Sanderman, Baldock et al. 2021). The labile C provides a source of energy and nutrients for microorganisms, which in turn can promote the formation of more stable SOM (Cotrufo, Wallenstein et al. 2013). AC play a significant role in increasing the SOC content and as mentioned above by AC measurement we can estimate C sequestration rate, SOC content, and also soil quality (Islam and Weil 2000, Culman, Snapp et al. 2012, Hurisso, Culman et al. 2016, Kallenbach, Frey et al. 2016, Bongiorno, Bünemann et al. 2019, Singh, Nouri et al. 2020). According to Wander (2004) analyzing POXC and AC, in addition to total C, can provide a more comprehensive understanding of how management changes influence nutrient content and the possible accretion or deficiency of OC in the soil. A recent study reported that the highest C content was found in the POC fraction in the topsoils (Shah, Xu et al. 2021). Moreover, HWC portion and also POC fraction reported as the active portions of the global C cycle (Ghani, Dexter et al. 2003, Lavallee, Soong et al. 2020). In addition, soil microbial biomass carbon (MBC) and dissolved organic carbon (DOC) are significant carbon sources that are readily accessible to soil microorganisms and actively contribute to the soil carbon cycle (Chan, Heenan et al. 2002).

In light of all these studies, alterations in management practices can exert a significant influence on the physicochemical characteristics of soil by impacting the abundance and quality of soil organic carbon

(SOC) fractions. Therefore, a comprehensive understanding of SOC fractions is essential for improving soil health and fertility and achieving sustainable land management practices and mitigating climate change (Blair, Lefroy et al. 1995).

1.3. Soil Organic Carbon (SOC) and Climate Change

Soil organic carbon (SOC) plays a crucial role in the global carbon cycle and can have a significant impact on climate change (Paustian, Lehmann et al. 2016). Hence, the assessment of the efficiency in converting organic carbon inputs into soil organic carbon (SOC) becomes imperative in the context of climate change mitigation strategies that focus on organic carbon sequestration (Poeplau, Don et al. 2021). Luo, Feng et al. (2017) also indicated unveiled the comparative significance of climate, soil properties, carbon inputs, and carbon pools, along with their intricate interrelationships, in governing the dynamics of soil organic carbon. Even minor fluctuations in soil organic carbon (SOC) can exert a significant influence on atmospheric CO_2 concentrations. Consequently, there is a considerable scientific interest in comprehending soil carbon stocks and their potential interactions with and effects on climate change (Davidson and Janssens 2006). SOC is the carbon stored in the soil in the form of organic matter, which is derived from plant and animal residues, root exudates, and microbial biomass. Long-term climate conditions can indirectly influence the amount and turnover time of carbon in passive soil carbon pools by affecting factors such as soil maturity and mineralogy. Understanding these relationships is important for predicting how soils may respond to future climate change (Trumbore 1997). To anticipate the alteration of soil organic carbon (SOC) in response to climate change, numerous models have also been developed (Parton, Scurlock et al. 1995, Falloon and Smith 2002, Ludwig, Hu et al. 2010).

SOC can influence climate change in several ways. Firstly, SOC serves as a significant carbon sink, as it stores a vast amount of carbon in the soil (Tong, Brandt et al. 2020). In fact, soils are estimated to store two to three times more carbon than the atmosphere. The amount of carbon stored in soils is influenced by various factors, including climate, soil type, vegetation, and land use (Odebiri, Mutanga et al. 2023, Wang and Huang 2023). Changes in these factors, such as deforestation (Razzaghi, Islam et al. 2022), land-use change, and soil degradation (Razzaghi, Kapur et al. 2021) can lead to the loss of SOC and the release of carbon into the atmosphere, contributing to climate change. Actually, carbon sequestration is the most important factor in mitigating climate change (Lal 2004, Lehmann and Kleber 2015, Liang, Amelung et al. 2019, Bell, Barriocanal et al. 2020, White 2022). The benefits of conservation agriculture in soil carbon sequestration can vary depending on the regional climate conditions. Conservation agriculture can sequester more carbon in arid regions compared to humid and colder regions due to several factors (Sun, Canadell et al. 2020). However, conservation agriculture practices, such as reduced tillage, cover cropping, and crop rotation, can help mitigate these losses and promote carbon sequestration in the soil. For example, reduced tillage can help reduce soil disturbance and minimize the exposure of organic matter to oxidation, which can lead to increased soil carbon storage(Jakab, Madarász et al. 2023). Additionally, cover crops can increase the amount of plant biomass and root exudates, contributing to soil organic carbon accumulation (Ali, Hussain et al. 2023).

By drawing on the meaning of C sequestration, Karlen and Cambardella (2020) reported that Mollisols are a type of soil that are characterized by a thick, dark topsoil rich in organic matter, making them highly suitable for agriculture. When covered with grass, Mollisols can sequester carbon in the form of plant biomass and soil organic matter.

Secondly, SOC can influence climate change through its impact on soil health and ecosystem services (Datta, Nayak et al. 2022). SOC is essential for maintaining soil fertility and nutrient cycling (Gerke 2022), and it can improve soil structure, water-holding capacity, and resilience to drought and other environmental stresses (Amanullah, Yar et al. 2022). Healthy soils can also sequester carbon more effectively, providing a significant potential for mitigating climate change(Khan, Jhariya et al. 2021).

Finally, the management of SOC can have a significant impact on climate change. Agricultural practices, such as conservation tillage, cover cropping, and crop rotation, can increase SOC levels, improving soil health and fertility and sequestering carbon in the soil (Lehmann, Hansel et al. 2020). In contrast, land-use changes, such as deforestation (Han, Tang et al. 2020) and conversion of grasslands to croplands (Wei, Shao et al. 2014), can lead to the loss of SOC and the release of carbon into the atmosphere. According to Lal (2004) the management of SOC can have a significant impact on reducing atmospheric CO_2 levels and increasing the SOC content. Sustainable agriculture practices that promote SOC sequestration can help mitigate the effects of climate change and improve soil health and productivity (Kumara, Pal et al. 2023). Furtheremore, when farmland is abandoned, natural vegetation can take over, leading to the restoration of ecosystem processes and the accumulation of organic matter in the soil (Bell, Barriocanal et al. 2020). As mentioned above, the accumulation of organic matter in the soil can lead to increased soil carbon sequestration, which can help mitigate climate change.

By drawing on the concept of soil management there are several soil management and land-use changes that can increase soil carbon sequestration. Here are some examples:

1. Conservation tillage: This is a farming practice that involves reducing the amount of disturbance to the soil during tillage. This can include techniques such as no-till or reduced tillage, which leave the crop residue on the soil surface rather than plowing it under. Conservation tillage helps to retain more organic matter in the soil and reduces soil erosion, which can lead to increased carbon sequestration (Du, Angers et al. 2017, Bai, Huang et al. 2019).

2. Cover cropping: This involves planting a cover crop, such as a legume or grass, between periods of cash crop production. Cover crops help to reduce soil erosion, increase soil fertility, and add organic matter to the soil, which can increase carbon sequestration (Razzaghi 2021, Wulanningtyas, Gong et al. 2021).

3. Agroforestry: This involves integrating trees into agricultural landscapes, either as windbreaks or as intercropped species. Trees help to improve soil health, reduce soil erosion, and increase the amount of organic matter in the soil, which can lead to increased carbon sequestration (Clivot, Petitjean et al. 2020, Gusli, Sumeni et al. 2020).

4. Grazing management: This involves managing livestock grazing to prevent overgrazing and promote the growth of grasses and other vegetation. Proper grazing management can help to increase soil organic matter and carbon sequestration (Jiang, Hu et al. 2020, Kim, Ale et al. 2023). Furtheremore, the outcomes of Dang, Guo et al. (2023) study which showed in Figure 1, carried significant implications for the formulation of future grassland management policies pertaining to soil nutrient balances, restoration of degraded grasslands, control of shrub expansion, and mitigation of climate change.

5. Soil amendments: This involves adding organic amendments, such as compost or manure, to the soil. Organic amendments help to increase the amount of organic matter in the soil, which can increase carbon sequestration (Elkhlifi, Iftikhar et al. 2023, Li, Wei et al. 2023).

6. Wetland restoration: This involves restoring wetland habitats, such as peatlands or marshes, which can store large amounts of carbon in their soils. Restoring wetlands can help to increase carbon sequestration and provide other environmental benefits,

such as improved water quality and habitat for wildlife(Xu, Liu et al. 2019, Thura, Serrano et al. 2023).

These are just a few examples of the soil management and land-use changes that can increase soil carbon sequestration. It's important to note that the effectiveness of these strategies can vary depending on factors such as soil type, climate, and land use history, so a combination of practices may be needed to achieve the greatest benefits.

In conclusion, SOC plays a critical role in the global carbon cycle and can have a significant impact on climate change. The management of SOC is essential for achieving sustainable land use practices, improving soil health and fertility, and mitigating the impacts of climate change.

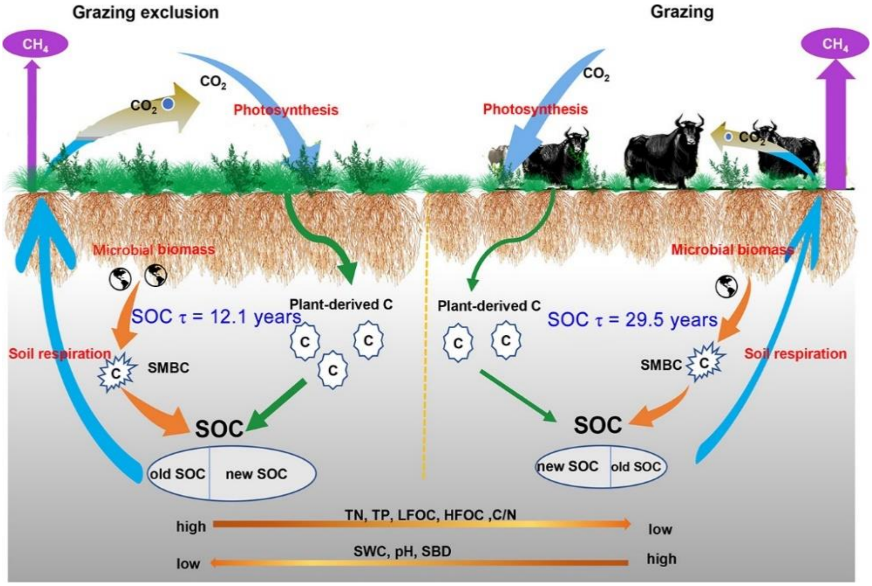

Figure 1. The relation between grazing managment and SOC and climate change over time (Source=(Dang, Guo et al. 2023))

1.4. SOC Fractions and Climate Change

SOC is composed of different fractions, which have different properties and play different roles in soil health and climate change mitigation (Gray, Karunaratne et al. 2019, Pang, Cui et al. 2019, Ramesh, Bolan et al. 2019). In addition, the findings suggested that soil labile carbon exhibited a comparatively higher susceptibility to alterations in the environment in comparison to soil organic carbon (Wang, Zhou et al. 2005). The response of SOC fractions to global changes such as climate change and land use change is a relatively newer area of research, and there is still much to learn about how these factors affect SOC dynamics at the fraction level and how these fractions affect climate change. However, there is growing interest in this topic, and there have been a number of recent studies investigating the response of SOC fractions to climate change, land use change, and other global changes.

As mentioned above labile SOC fractions are typically considered to be the most sensitive indicators of changes in soil organic matter Dynamics (Haynes 2005, Verma, Datta et al. 2013). POXC is sensitive to climate changes and impotant for a rapid estimation of SOC (Morrow, Huggins et al. 2016, Ramírez, Calderón et al. 2020). Microbes play a critical role in soil organic matter decomposition, which releases CO_2 and other greenhouse gases to the atmosphere. As such, changes in the abundance and activity of soil microbes can have a direct effect on soil C dynamics. In summary, shifts in microbial community composition and activity can have a significant impact on soil C pool Dynamics (SOC Fractions), and understanding these dynamics is essential for predicting the long-term effects of land-use and climate change on ecosystem C cycling (Ramírez, Fuentes-Alburquenque et al. 2020). Rocci, Lavallee et al. (2021) indicated that understanding the responses of SOC fractions to global changes is an important avenue of research that can help to inform efforts to mitigate the climate crisis and promote sustainable land management practices. They also reported that POC can decrease with atmospheric warming and increase with increase in atmospheric carbon dioxide (CO_2) concentrations (Fig. 2). Therefore, different fractions of soil organic carbon (SOC) can exhibit contrasting reflections to global changes such as climate change, land use change, and nutrient management (De Feudis, Cardelli et al. 2019, Chen, Xiao et al. 2020). Increase of MAOC and POC with increase of temprature was reported by He, Chen et al. (2012) and Cheng, Luo et al. (2011), respectively. In converse, Fang, Smith et al. (2005) have demonstrated that the temperature sensitivity of soil organic matter (SOM) decomposition remains unaltered, implying that the temperature sensitivity of recalcitrant organic matter pools does not significantly differ from that of labile pools. Consequently, both SOM categories are anticipated to exhibit comparable responses to global warming. Deng, Han et al. (2023) indicated that climate warming has the potential to influence the soil carbon reservoir by modifying constituents of soil labile carbon, which remain unaffected by fertilization practices. According to the prevailing viewpoint, the decomposition of labile carbon in the soil is highly responsive to fluctuations in temperature, whereas the more resistant components exhibit limited sensitivity to such variations(Thornley and Cannell 2001, Fang, Smith et al. 2005).

In this vein, Hu, Wang et al. (2017) indicated that, the temperature sensitivity of soil dissolved organic carbon (DOC) was found to be greater under warming conditions (5.1% °C−1) compared to cooling (3.0% °C−1). However, soil labile organic carbon (LOC) showed a symmetrical response, which can be attributed to its dependence on soil moisture regulation.

Jastrow, Miller et al. (2000) and Hofmockel, Zak et al. (2011) indicated increase of MAOC and POC with increase of CO_2 concentrations, respectively. Furtheremore, Padhy, Bhattacharyya et al. (2020) reported that in lowland rice ecology, the regulation of both actual and perceived soil carbon priming and climate change feedback is dependent on the dynamics of labile carbon pools. In addition, according to Chen, Chang et al. (2020), the principal driver of greenhouse gas (GHG) emissions from wetlands is the input of global nitrogen, which primarily influences the release of dissolved organic carbon (DOC). They also indicated that under global nitrogen input, GHG emissions from wetlands are predominantly attributed to microbial biomass carbon (MBC), which serves as a direct driver of carbon flux from the ecosystem.

Padhy, Bhattacharyya et al. (2020) also reported that to account for greenhouse gas (GHG) carbon (C) budgeting and climate change mitigation in the mangrove (Sundarban, India) ecosystem, it is essential to consider not only soil labile C pools but also seasonal variations in GHG emissions and tidal effects. The existence of labile carbon (C) pools not only stimulates the growth and metabolism of methanogens, but also augments the activity of the denitrifying bacterial population, which leads to heightened emissions of methane (CH4) and nitrous oxide

(N_2O) from the soil (Paul 2014). To further explore the relationship between greenhouse gas emissions and labile carbon and nitrogen, the researchers employed variation-partitioning analysis and structural equation modeling. The findings from these analyses unveiled that, in wetland ecosystems subjected to global nitrogen input, dissolved organic carbon (DOC) emerges as the predominant driver of greenhouse gas emissions. Additionally, among the various labile carbon and nitrogen components, microbial biomass carbon (MBC) exerts a more direct influence on greenhouse gas emissions (Chen, Chang et al. 2020).

Overall, investigating the responses of different SOC fractions to global changes is an important area of research that can help to inform efforts to mitigate climate change and promote sustainable land management practices.

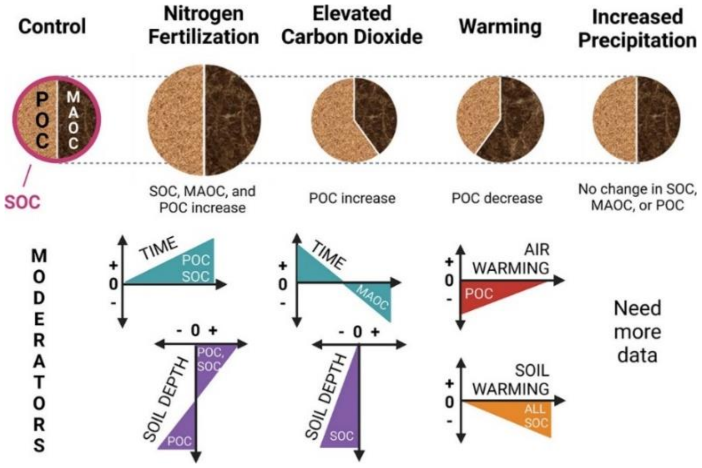

Figure 2: The relation of the particulate organic carbon (POC), mineral-associated organic carbon (MAOC) with climatic conditoins and N fertilization (Source=(Rocci, Lavallee et al. 2021)).

2. Conclusion

In summary, the labile organic carbon fractions in soil, also known as soil organic carbon fractions (SOC fraction), play a significant role in relation to climate change. These fractions are highly sensitive to environmental changes and management practices, and their abundance and quality directly influence greenhouse gas emissions and carbon sequestration.

Labile organic carbon refers to the portion of SOC that is readily available for microbial decomposition and can be rapidly exchanged with the atmosphere. When labile organic carbon is decomposed by soil microbes, it releases carbon dioxide (CO2) into the atmosphere, contributing to greenhouse gas emissions and climate change.

On the other hand, increasing the levels of labile organic carbon in soil through sustainable soil management practices can help mitigate climate change. By increasing carbon sequestration, labile organic carbon acts as a sink, effectively removing CO_2 from the atmosphere and storing it in the soil. This process helps offset the excess CO_2 in the atmosphere and reduces the greenhouse effect.

In conclusion, the relationship between labile organic carbon fractions in soil and climate change is significant. Managing and increasing labile organic carbon levels through sustainable soil management practices can have a positive impact on mitigating climate change by reducing greenhouse gas emissions and promoting carbon sequestration.

3. Implication/Recommendation/Suggestion

In light of all these studies, SOC and its various fractions play a crucial role in mitigating climate change and fostering sustainable agriculture. Ensuring the preservation and enhancement of SOC levels in soils is vital for attaining these objectives, necessitating the adoption of sustainable soil management practices. Implementing practices that enhance labile organic carbon, such as reducing soil disturbance, adopting organic farming methods, incorporating cover crops, and managing organic amendments effectively, can contribute to increasing carbon sequestration and reducing greenhouse gas emissions. These practices not only promote climate change mitigation but also improve soil fertility, water retention, and overall ecosystem health.

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CHAPTER 2

MICROBIAL BIOFORTIFICATION: A MUCH-NEEDED STRATEGY TO COMBAT PREVAILING MICRONUTRIENT MALNUTRITION

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Introduction

The expanding population poses a danger to food security throughout the world, calling for action to develop practical and affordable solutions. The global shortage of essential micronutrients like Fe and Zn affects over 2 billion people. Soil micronutrient deficiencies have also been documented in numerous regions, restricting plant nutrition and, by extension, human nutrition (Tigchelaar et al., 2022). Due to their importance, deficiencies in certain micronutrients can have serious physiological consequences. Due to inadequate and low-quality fodder production, there is also a significant demand and supply mismatch in the cattle industry. Therefore, from the standpoint of both human and animal health, nutritional security is a major issue. Food that has been fortified with vitamins and minerals is what's meant by "nutritional security." Staple crops make up the bulk of people's diets in poor nations (Stevens et al., 2022). As a result, there is now an urgent requirement to cultivate super-nourishing food for the purpose of achieving food security. Medical supplementation, dietary variety, and food fortification are just some of the options. Biofortification, which permits specific nutrients to be put into the edible section of a particular crop for their ingestion by people and animals, has been presented as a viable approach to reduce hunger (Ritchie and Roser, 2017).

Increasing crop yield and ensuring food safety using microbial-based biofertilizers plays a crucial part in ensuring agriculture's long-term viability. Microbial life in soil consists of bacteria, actinomycetes, and cyanobacteria, and mycorrhiza offers a sustainable method for boosting nutrient absorption and plant development (Tulchinsky, 2010). These "invisible soil engineers" are essential for maintaining soil health and building a hub for many biogeochemical cycles (Beal et al., 2023). The colonization of plant roots by microorganisms, including plant growth promoting rhizobacteria (PGPR), has been found to aid in the adaptation of plants to various environmental and biotic stressors. Plant growth-promoting microorganisms perform various functions, including atmospheric nitrogen fixation, solubilization of soil-fixed nutrients, and phytohormone production, to facilitate nutrient availability for plants (Sati et al., 2023). These bacteria are essential for the mineralization of organic matter and the transformation of inorganic nutrients, both of which are necessary for plant growth. Bacteria can affect a plant's health in several ways, including by secreting antibiotics that protect it from disease-causing pathogens and by chelating, solubilizing, oxidizing, or reducing nutrients. In addition to increasing crop productivity, the goal of today's agricultural practices is to supply people with food that is both abundant and healthy. Crop-based meals are extremely important to the human population's fundamental diet, and eating foods low in vital micronutrients can lead to major health problems (Nagrale et al., 2023).

Malnutrition among the global population is threatened by a lack of micronutrients like zinc, iron, selenium, manganese, and vitamins, which is described as "hidden hunger" in both people and plants. To provide the best answer for growing food crops with increased levels of essential micronutrients, biofortification strategies need to be put into practice. In contrast to "standard fortification," which refers to the addition of synthetic nutrients to meals, "biofortification" refers to the natural process through which nutrients are concentrated inside plant cells.

Increasing the bioavailability of essential nutrients in crops is the focus of the biofortification process.

Micronutrient Associated Malnutrition

Humans can be micronutrient deficient if they consume a diet consisting of staple foods that are low in bioavailability of key micronutrients, as is the case in many underdeveloped nations. Where this is most true is in poor and middle-income countries, are already struggling to make ends meet, when vitamin deficiencies are common, widespread disease becomes more likely (Dupont et al., 2018). This is because people in these countries are less likely to have access to more expensive nutrient-rich foods and other nutrient supplements. More than half of all infant death and the leading risk factor for maternal mortality are both linked to a lack of micronutrients.

Several essential biological processes rely on the micronutrients zinc (Zn), iron (Fe), and selenium (Se), all of which must be consumed on a regular basis in the diet (Robinson et al., 2010). Negative effects on human health manifest in a variety of disorders due to a lack of one or more micronutrients (Fig. 1).

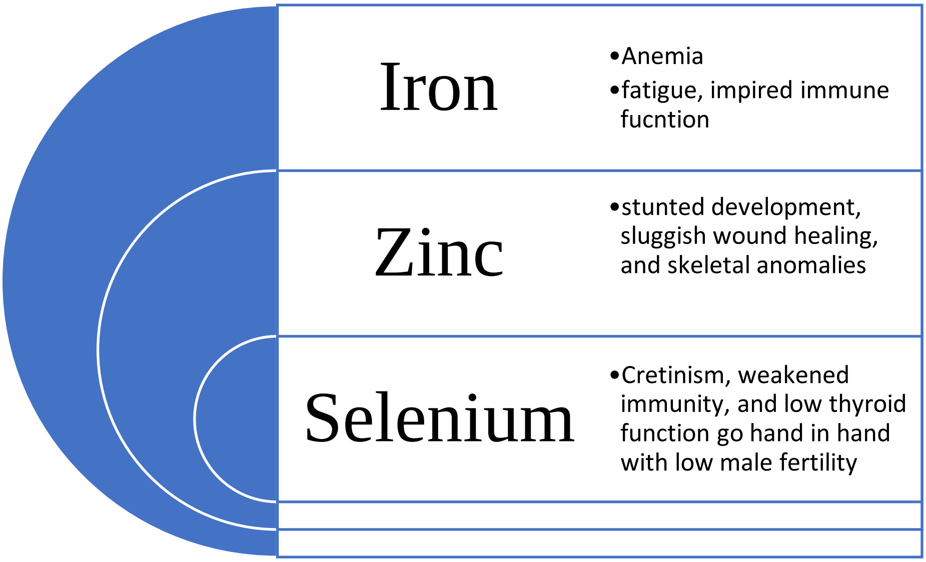

Figure 1: Illustration of human health problems caused by a lack of micronutrients (iron, zinc and selenium)

Zinc is classified as a micronutrient that serves a pivotal structural function in diverse proteins, rendering it indispensable for all living organisms. The insufficiency of zinc is a prevalent micronutrient inadequacy that has been associated with various health complications in humans. These include but are not limited to, hindered growth, delayed wound healing, skeletal anomalies, diarrhea, and an elevated likelihood of abortion (Salgueiro et al., 2000). Chlorosis in plants caused by a lack of iron reduces crop productivity, which in turn impacts the health of humans who rely on plant foods for their nutrition. Nutritional anemia is caused by a lack of iron, which is also linked to reduced immunological functioning and slowed brain growth in children (Hatfield et al., 2014). The mineral selenium is yet another example of an essential micronutrient with a significant function in numerous biochemical processes. Epilepsy, cancer, infections, and a weakened immune system due to a lack of selenium (Se) are only some of the disorders that may be connected to the mineral's absence (Murray-Kolb, 2013). Vitamin (B6, B12, C, E, and folic acid) and mineral (zinc, iron) deficiencies are linked to cancer and other impairments and are thought to harm DNA in a manner like that of radiation and other chemicals. Research into methods that enhance plant nutrient digestion is necessary to avoid issues related to micronutrients malnutrition (Awuchi et al., 2020).

Global Impact of Malnutrition

Vitamins and minerals are crucial to health at any age, but they are especially important in the first few years of a person's life. Malnutrition occurs when the body does not receive an adequate supply of essential nutrients such vitamins, minerals, and protein. The three main manifestations of malnutrition are short stature (wasting), short stature (stunting), and short stature (underweight). All of them stem from subpar dietary standards and can contribute to the development of chronic diseases. Micronutrient deficiency affects about 2 billion individuals worldwide (Von Grebmer et al., 2022). As per the report by the World Health Organization and Food and Agriculture Organization of the United Nations, approximately 149 million children who are below the age of five are experiencing stunted growth, 47 million are suffering from wasting, and 462 million are underweight. Research conducted by the Food and Agriculture Organization and its collaborators in 2020 has revealed that malnourishment is a contributing factor in approximately 50% of all deaths of children under the age of five in developing nations.

Malnutrition poses a hindrance to the potential of human life, particularly in low- and middle-income countries (LMICs), due to its impact on physical and cognitive growth, immune function, and general well-being. The prevalence of micronutrient deficiencies is extensive, with particular concern for vulnerable populations such as children, women of reproductive age, and lactating mothers. This intricate health matter has its origins in the food system and can be resolved by enhancing the availability of a diverse range of food items, encompassing animal and dairy products. Enhanced food production can lead to the attainment of both food and nutrition security. There has been a lack of consideration for this matter in recent agricultural research and development endeavors aimed at promoting development. Through the Green Revolution, agriculture was able to gain momentum in creating large yields, but at the expense of crop-based necessary nourishment. Food crops with higher nutritional value should be prioritized in alternative agriculture to reduce malnutrition in underdeveloped regions (Patel, 2013).

Persistent undernourishment is a major barrier to human development, affecting the country's potential for future economic growth due to its effects on health, education, and productivity. Increasing yields and decreasing negative repercussions affecting yields in certain settings are just two of the long-term strategies being pursued to combat this tragic scenario of malnutrition. It is still difficult to reduce the prevalence of malnutrition worldwide. A stunning impact of malnutrition in emerging nations is over 11% in Asia and Africa in terms of gross domestic product (GDP) (Smith and Haddad, 2000; Demment et al., 2003).

The task of alleviating the prevalence of micronutrient deficiencies in developing nations can be achieved in a sustainable and cost-efficient manner by augmenting the nutrient content of staple crops' edible components through crossbreeding, biotechnology, or agronomy by administering soil and leaf fertilizers (Garg et al., 2018; Celik et al., 2020). The CGIAR HarvestPlus Programme has been a leading entity in the field of nutrition research for development since 2003, as noted by Stevens et al. (2022). The main objective of this programmed is to address prevalent inadequacies in iron (Fe), zinc (Zn), and vitamin A. Anemia, weariness, weakness, and cognitive impairment are all results of a lack of iron. Children with zinc deficiencies are more likely to experience growth retardation, increased infection risk, and cellular damage. Poor pregnancy outcomes, reduced eyesight, and night blindness are all associated with vitamin A insufficiency. Except for a few short-term bilateral collaborations, nutrition is rarely prioritized in national or international research and investments into key crop development programmes. Therefore, it is still a difficult task to reduce the prevalence of malnutrition, especially in rural settings. After the COVID-19 pandemic, malnutrition rates are likely to skyrocket. In the Global South, the rates of malnutrition are appallingly high. In LMICs, the price tag for combating malnutrition continues to rise. Over the past two decades, preschoolers in LMICs have received an estimated 10 billion vitamin A capsules (Tam et al., 2020). Sustainable Development Goal 2 (SDG 2) calls for an end to all forms of hunger by 2030 (Montagnini and Metzel, 2017), highlighting the significance of food security and improved nutrition. Investments in crop breeding and modernization by the CGIAR are currently undergoing a period of transition, highlighting the importance of focusing on nutrition features to reach SDG2.

Human Mineral Deficiency and Its Societal and Economic Consequences

The prevalence of mineral deficiencies has been observed to impact a substantial number of individuals, resulting in the manifestation of diseases and adverse health outcomes at the individual level. Furthermore, this phenomenon contributes significantly to the overall disease burden experienced by the societies in which these individuals reside. Apart from the ethical and humanitarian obligation to assist individuals afflicted by hunger, malnutrition, and poor health, there exists a purely financial justification for managing malnutrition. Mineral malnutrition has been observed to result in significant economic costs as it impedes not only individual productivity but also overall economic progress. This line of thinking is predicated on the idea that hunger perpetuates poverty, rather than vice versa, or that hunger and poverty feed off of each other to perpetuate the cycle of poverty (Figures 2).

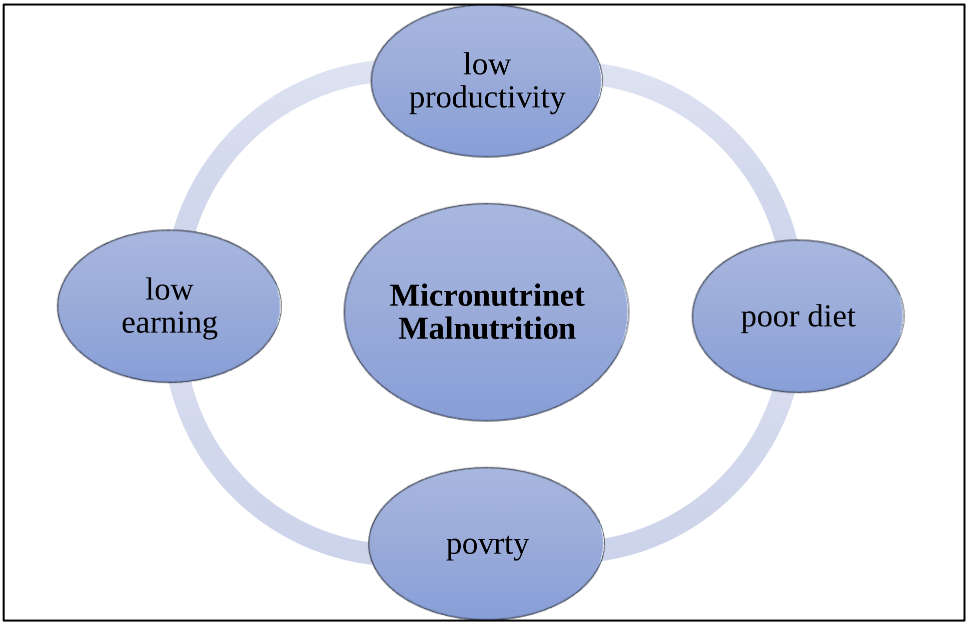

Figure 2: The vicious cycle of hunger and poverty

Strategies for Fortification

Several methods of fortification are being investigated in the fight against hunger. Direct and indirect interventions are the two primary focuses of the current study. Nutrition-specific direct intervention targets eating habits, such as using dietary supplements and creating a varied diet. The frequency of specific deficiencies, the availability of food sources, the local infrastructure, and governmental laws all play a role in determining whether direct or indirect intervention (which combines biofortification and is nutrition-sensitive) is ideal for a given location (Bose *et al*., 2019). Many rural poor suffer from micronutrient deficiencies, and there are few effective methods of intervention. Therefore, biofortification, also known as indirect fortification, looks to be the best solution currently available. The bioavailability of nutrients in food has been improved through food fortification, supplementation, and food diversity (Vinoth and Ravindhran, 2017). By expanding the availability and consumption of nutrient-rich food, dietary diversity helps to make nutrients accessible to plants. Fortification can also take the form of supplying nutrients in the form of tablets, pills, and medicines. Food fortification is defined as the process by which dietary food products have their inhibitory impact reduced and bioavailable iron added (Shubham et al., 2020). Biofortification is the most effective method currently known for increasing the number of bioavailable micronutrients in each food (Kumar et al., 2023). To address these threats to food security, several methods including breeding, genetics, fortification, agronomic approaches, soil acidification via acids, microbial inoculation, and micronutrient fertilization are implemented.

Plant-Breeder and Breeding Techniques

Breeding and genetic approaches are combined in plant breeding to create the desired crop varieties. The most notable advances in this area have been the result of combining breeding with biotechnology (Senguttuvel et al., 2023). Better for humans and crops alike, these breeding methods alter the plant's nutrient balance, making them more desirable. Breeding practices during the green revolution era prioritized increasing crop output over improving their nutritional value (Borlaug, 2002). Soil nutrient extraction and the resulting micronutrient deficiency are the inevitable results. Plants high in micronutrient content can be developed using conventional breeding methods, alongside cultivars with improved agronomic performance, product quality, and nutritional value (Das et al., 2010). Because features related with improvement and absorption of iron and zinc are also connected with boosting yield, these breeding strategies take on further significance when applied to raise iron and zinc levels. Multiple investigations have demonstrated the viability of inserting desirable alterations into genes to acquire desirable features, hence increasing yield and improving nutritional quality (Ashworth et al., 2009). Bio-fortification plays a significant role in the development of about 2500 different types (Buturi et al., 2021). Micronutrient-rich genotypes have been the target of breeding and genetics research for some time. Genes involved in creating iron-encircled rice grains influence iron homeostasis. The "Golden rice" developed by Ye et al. (2000) is enriched with vitamin A and iron. It has been hypothesized that the iron content of crops varies by genotype, as suggested by modern plant breeding, conventional breeding, and biotechnology (White and Broadley, 2005).

Micronutrient deficiency is reduced in humans and food plants are enriched in micronutrients by breeding strategies in impoverished nations (Graham et al., 2001). Due to their greater price, non-staple foods like fish, animal products, and other fortified foods with micronutrients are out of reach for many people living in underdeveloped nations like Pakistan. People in poor nations rely heavily on refined grains, which are micronutrient-poor due to the calcareous soil in which they are grown (Pahlavan-Rad and Pessarakli, 2009). In the long run, eating such foods could cause major health problems for people. To address vitamin deficiencies in staple foods, researchers are looking into fortifying grains with micronutrients through breeding tactics (Pahlavan-Rad and Pessarakli, 2009). The breeding approach prioritizes the selection of grain-feeding breeds (Welch & Graham, 2005). Plant breeders work to improve crop quality by increasing yields of high-nutrient, high-yielding "genetically variable verities" that can withstand environmental challenges (Cakmak, 2008). Breeders employ breeding techniques to create an animal with desirable characteristics. Methods like this include conventional breeding, molecular breeding, and mutant breeding (Unnevehr et al., 2007). These methods are widely employed in developed nations, but in countries like Pakistan, they are only used on a small scale for breeding.

Lack of genome, genotypic interaction, and environmental restrictions reduce the efficacy of these breeding strategies (Zhao and Bai, 2012). Due to iron content differences, classic breeding methods for biofortifying rice have failed (Masuda et al., 2013). The iron and zinc levels in various rice varieties from Asia, the Caribbean, and Latin America were analyzed. According to the findings, the highest nutritional concentration in rice grains was around 8 mg kg^{-1} ((He et al., 2013).

Transgenic Approach

Bio-fortified crops are successfully developed through transgenic approaches. Garg et al. (2018) found that transgenic varieties absorb micronutrients at a higher rate than traditional cultivars. Specific crop transporter proteins are targeted in transgenic agriculture for manipulating iron and zinc concentrations in individual plant tissues (Pfeiffer et al., 2007). Transporter proteins play a role in the uptake and accumulation of iron and zinc in the vacuole and also have the potential to increase the enzymes used in the synthesis of substances, needed for nutrient binding close to the roots. Uauy et al. (2006) found that increasing the expression of the NAC-transcription factor (NAM-B1) increased the micronutrient content of the fruiting bodies by remobilizing mineral nutrients from the leaves. Table 1 shows that numerous crops have been genetically genetically engineered to include macronutrient and micronutrient features that may help consumers get their money back (Newell, 2008).

Table 1: The uptake of macro- and micronutrients by genetically modified crops (Newell, 2008)

Characteristics	**Crops with specific features**
Carbohydrate	
Starch	Rice (amylase) Wheat (amylase)
Fructans	Maize (fructan) Potato (fructan)
Protein and amino acids	
Protein	The amino acid and protein content of potatoes. Protein content and amino acid composition of rice. The amino acid composition of soybeans. Protein-rich sweet potato
Protein building blocks	Maize (Lys↑, Trp↑) Potato (Met ↑) Soybean (Lys, Trp, Met) Sorghum (Lys)
Functional metabolites and micronutrients	Canola (vitamin E↑) Mustard (+β-carotene) Potato (β-carotene and lutein↑) Wheat (vitamin A precursor) Tomato (folic acid, phytoene, and lycopene)

Agronomic Biofortification

Biofortification, which makes use of agronomic techniques to boost the nutritional value of crops for a limited time, requires the physical application of nutrients, and the ingestion of said crops enhances the nutritional well-being of individuals. Micronutrients can also be added to the soil and the plant's leaves as a form of biofortification. On occasion, the soil's mineral reserves will be depleted, rendering them unavailable to the plant. Mineral fertilizers, which are inorganic chemicals that include micronutrients, are given to the soil to improve the uptake of these minerals by the plant. Topical applications of low concentrations of macro- and micronutrients are safe for plants (de Lima Lessa et al., 2019).

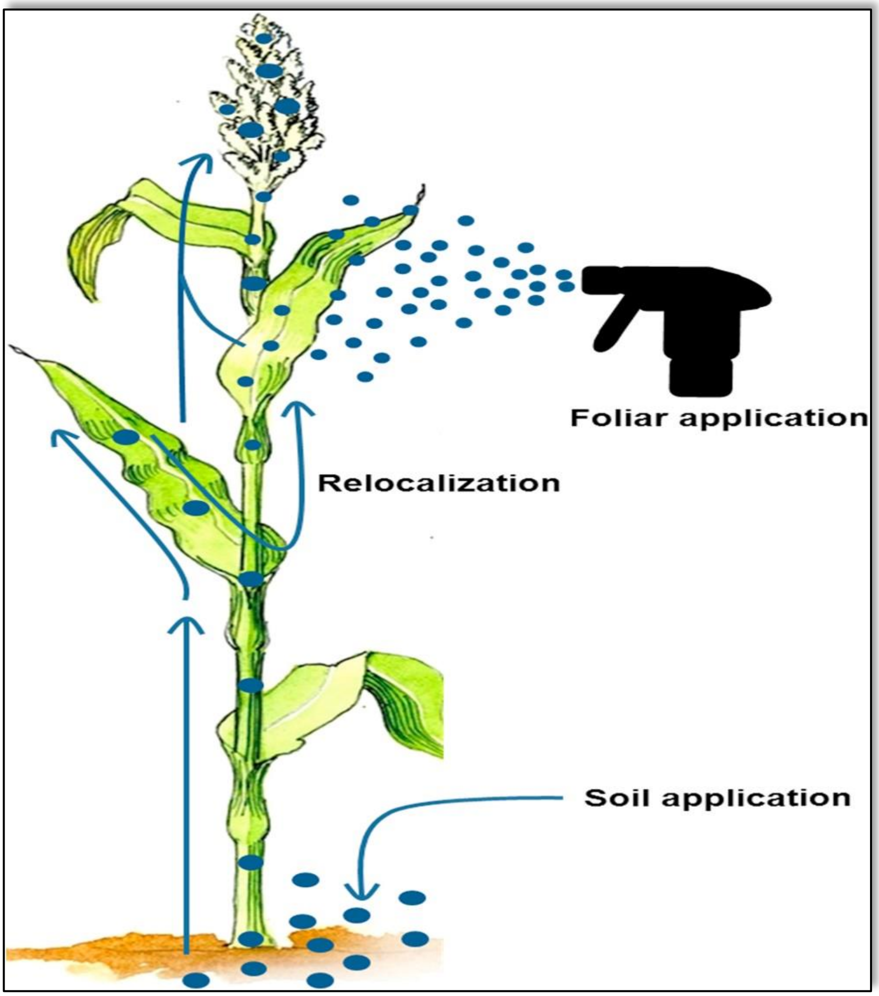

Figure 2. The practice of utilizing mineral fertilizers that contain micronutrients on either the soil or the leaves of plants, commonly referred to as foliar application, with the aim of enhancing the micronutrient levels in the consumable parts of food crops is recognized as agronomic biofortification.

Soil and foliar applications are useful when a rapid response from the crop is needed, when nitrogen loss must be minimized, when inert plant nutrients like iron and zinc must be supplied, and when other fertilizers are already being applied, hence reducing the cost per application. While investigating the application of micronutrients in soil and foliar treatments, scientists uncovered various limitations. For starters, the soil's health and mineral availability can be jeopardized if fertilizers aren't administered consistently or continually (Cakmak and Kutman, 2018). The soil's composition and, by extension, any deficiencies in soil micronutrients, are also determined by location. Because of these differences, not all fertilizers will work in all areas. Finally, plant amendments can be less effective due to external influences like weather, which reduces mineral bioavailability and increases costs (Prasad et al., 2014).

Microbial Biofortification: A Novel Approach

Along with transgenic cultivars, biofortification of crops using PGPMs has the potential to increase micronutrient concentrations in the food crop system, as well as boost yield and boost soil fertility. Plant growth promoting microorganisms have demonstrated the ability to enhance both soil fertility and crop yield, as well as to increase the micronutrient content of food crops through biofortification (Rana et al., 2012; Khan et al., 2019). PGPR play a vital role as biofertilizer, biopesticide and more importantly stress controller (Table 2). Microorganisms that promote plant development do so in several ways, including N2 fixation, insoluble phosphorus solubilization, phytohormone production, ethylene reduction, antibiotic and antifungal metabolite synthesis, and induction of systemic resistance. Soil fertility is increased by PGPM, and plants respond by providing nutrients and growth regulators and increasing resistance to ethylene-mediated stress through increased production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase and pesticide toxicity tolerance (Tripathi et al., 2022). The allure of PGPM as a viable alternative to the use of chemical fertilizers, insecticides, and other additives in farming is growing as time goes on. The utilization of PGPMs for biofortification of crops is a promising supplementary strategy that, when integrated with breeding techniques, has the potential to enhance the micronutrient levels in wheat crops, while also improving soil fertility and yield (Singh et al., 2017).

Table 2: PGPR with multifunctional characters

Biopesticide	Microorganisms that aid plant development by preventing the spread of disease to healthy plants.	Chemicals like antibiotics and HCN are manufactured. Enzyme hydrolysis production Systemic resistance can be both acquired and induced.	Riaz et al., 2021
Biofertilizer	Application of a substance containing living microorganisms to a seed, the surface of a plant, or the soil causes the microorganisms to colonize the rhizosphere, which in turn increases the host plant's access to water and nutrients.	Fixation of nitrogen by organisms Phosphorus utilization that is not water-soluble	Muthusamy et al., 2023
Phytostimulator	Phytohormone-producing microorganisms include indole acetic acid, gibberellic acid, cytokinin's, and ethylene.	Phytohormone Synthesis	Tariq et al., 2017

Mechanism of PGPR

Rhizobacterial microorganisms have been found to augment the growth and development of plants via both direct and indirect mechanisms. PGPR enhance crop plant growth and development by increasing nutrient use efficiency, releasing plant hormones, and mitigating the effect of hazardous microorganisms (Glick, 2012). Some of the mechanisms are explained below;

i) Atmospheric N_2-Fixation

Nitrogen, which constitutes 78% of the Earth's atmosphere, is one of the most important plant nutrients. The issue with atmospheric nitrogen is that plants cannot use it directly; it must be converted into a form that is plant-available, such as nitrate (NO3-) or ammonium (NH4+). The agricultural community relies significantly on nitrogen fertilizers to meet crop needs. The planet's nonrenewable energy sources have a strong relationship with nitrogen production. Not only do industrial nitrogen fertilizers reduce the use of fossil fuels, but nitrate can be lost from soil as excess nitrogen through denitrification, leading to eutrophication (Bhattacharyya and Jha, 2012).

Biological nitrogen fixation is an efficient method for converting atmospheric nitrogen to plant-available ammonia through the enzyme nitrogenase. The microorganisms responsible for nitrogen fixation are classified as symbiotic nitrogen bacteria and non-symbiotic nitrogen bacteria (Sessitsch et al., 2002). Leguminous crops use symbiotic Rhizobium spp. to fix atmospheric nitrogen (Mia et al., 2010). *Azospirillum* spp. were found to fix atmospheric nitrogen in nonleguminous crops. According to Lugtenberg and Kamilova (2009), the significance of non-symbiotic nitrogen-fixing bacteria on a global scale appears to be minimal.

Phosphorus-Solubilization

One of the most important macronutrients for a plant's health and development is phosphorus (P). In developing nations, the issue with phosphatic fertilizers is their continually increasing price. The high cost of fertilizers is primarily attributable to competition from other culinary industries in terms of quality (Bashan et al., 2013). In calcareous Pakistani soils, the problem with phosphorus availability is that it readily becomes fixed and often precipitates in the soil; this is the primary cause of limited phosphorus availability to crop plants. Under both alkaline and acidic conditions, plants absorb phosphorus in the form of orthophosphate. Farmers blindly use fertilizers that readily precipitate or fix into insoluble forms, including Fe-P and Al-P (iron and aluminium phosphates), and may have a deleterious impact on the environment, resulting in eutrophication (Vessey, 2003; Haroon et al., 2023). The soil pH is the most influential factor in phosphorus availability.

The issue can be remedied by employing phosphate solubilizing bacteria (PSB) to solubilize the plant's inaccessible phosphorous into an accessible form. PSB solubilize the inorganic form of phosphorous by releasing organic acids (citric acid) whose functional groups can form complexes with phosphate-bound cations, or indirectly by releasing protons to alter the pH of the rhizosphere (Bashan et al., 2013). Through mineralization, plants can assimilate phosphorus (Rodrguez et al., 2006).

Iron Chelation Through Siderophore Production

Eukaryotes and prokaryotes need iron. It's in hemoglobin, the electron transport chain, and several enzymes. In an aerobic environment, iron is present as $Fe^{3+,}$ which is insoluble at neutral pH, rather than $Fe^{2+,}$ which plants may absorb. Numerous fungi, bacteria, and plants have an uncommon adaption that allows them to manufacture siderophores, low-molecular-weight molecules (10 KD) with a high affinity for Fe^{3+} ions, to sequester iron. Siderophores, released by PGPM, transfer iron molecules to plants. Siderophore may provide iron to plant roots. Thus, microbial siderophore increases iron absorption and competes with plant diseases to biofortify plants and grains with iron (Khan et al., 2018). Many researchers have reported siderophore production in a wide range of bacterial and fungal species, including *Bacillus, Pseudomonas, Azotobacter, Arthrobacter, Burkholderia, Enterobacter, Rhodospirrilum, Serratia, Azospirillum*, *Rhizobium*, and *Aspergillus* (Leong and Neilands 1982; Borah et al., 2023). Different microorganisms secrete different siderophores, such as hydroxamate, catacholate, and carboxalate. Siderophores are also produced by many bacilli (Beneduzi et al., 2012). Siderophore-producing PGPM is better than chemical fertilizers for iron-boosting plants and cereals.

Zinc (Zn) Solubilizer

Zinc is a vital mineral for proper development and metabolic function. In both prokaryotes and eukaryotes, zinc ions participate in a wide range of physiological processes, including as a cofactor in several enzymes, in defense, and in cell division and growth. Soluble zinc is low in soil because zinc ions are extremely reactive and interact strongly with other soil components. Oxides, phosphates, and carbonates are the most common occurrences. Microorganisms associated with plants use a variety of strategies to increase zinc solubility in the soil, including chelation (Hussain et al., 2015; Whiting et al., 2001), lowering soil pH (Jha and Subramanian, 2014), and enhancing root development and absorptive surface area. The process through which microorganisms chelate zinc and make it available to plant roots is well established. Chelating chemicals are produced by microbes and, when bound to zinc, form a complex. In addition, they cause zinc biofortification in plants because they release chelated zinc at the root surface and increase zinc availability. One possible method bacterium use to chelate Zn is the creation of metallophones, as detailed by Whiting et al. (2001). The availability of zinc is diminished by soil acidity. A lower pH is associated with Pseudomonas and Bacillus spp. solubilizing zinc complex molecules (ZnS, ZnO, and ZnCO3) into zinc ions in a broth culture (Saravanan et al., 2004). To make more zinc available in the soil and plant tissues, several bacteria use their own unique methods of solubilization. As a result of their extraordinary ability to solubilize Zn from complex compounds (Whiting et al. 2001; Kumar et al., 2019), many bacterial and fungal species, including *Pseudomonas, Microbacterium*, *Enterobacter, Bacillus,* and *Arbuscular mycorrhizae*, aid in improving the quality of food and the nutritional status of plants and grains.

Plant-Based Stress Reducing Agents and Stimulants

Phytohormones are a class of substances that stimulate root growth and other aspects of plant development. The generation of phytohormones is a crucial part of plants' defense mechanisms and growth. In order of importance, the most crucial phytohormones are cytokinin’s, auxins, gibberellins (Gas), ethylene (ET), abscisic acid (ABA), and salicylic acid (SA) (Sati et al., 2023). Hormones that produce PGPR play a pivotal role in communication with plants. The Phyto-stimulating effect is the result of microbial regulation (Nagrale et al., 2023). Plants can take in more soil nutrients because of the indole acetic acid (IAA) system's role in encouraging root branching (Slimani et al., 2023).

PGPR as Biofertilizer

Chemical fertilizers are widely used nowadays to boost plant growth and production as well as to restore depleted soil nutrient levels. But the use of chemical fertilizers is accompanied by several issues, including high cost, the lack of availability of substantial portions of nutrients, their toxic and non-degradable character, which increases environmental pollution and renders land unfit for farming, and so on (Harahap et al., 2023). Therefore, biofertilizer application can be employed to increase crop yield and biofortification of nutrients in grains as an alternative method. In place of synthetic substances, biologically derived biofertilizers like microorganisms (including bacteria and fungi) are used. Biofertilizers are biological in nature and have a low persistence, making their use an eco-friendly strategy. Biofertilizers are used so that nitrogen, iron, zinc, calcium, and phosphorus are retained in the soil and are not lost as runoff. Because of their capacity to convert complicated forms of nutrients into a solu ble form (Khan et al., 2022), biofertilizers serve as a source of all nutrients. Orthophosphate (Pi) is the form of phosphorus used by plants. Mycorrhizal related plants were found to be

3.1-4.7 times more efficient at phosphorus uptake compared to nonmycorrhizal plants by Jones et al. (1998). Biofertilizers are created commercially by bacterizing seeds with beneficial bacteria like *Azotobacter, Azospirillum, Rhizobium, Pseudomonas,* and *Bacillus*. Biofertilizers are made from a combination of phosphorating, which is produced by *Bacillus megaterium*, and *azotobacterin*, which is produced by *Azotobacter chrococcum* (Sharma et al., 2022). Even if these bacteria don't form a symbiotic relationship with the plant, they still improve its nutrient status by increasing its ability to absorb minerals and water through its lateral root hairs and by secreting substances that promote plant growth, such as vitamins, auxins, gibberellic acid, and cytokinin's. The annual N fixation rate for rhizobial biofertilizers is between 50 and 150 kg. Biofertilizers have long been known to greatly improve plant growth, nutritional status, and resistance to disease attack (Mishra et al., 2022).

Conclusion

To address the issue of micronutrient insufficiency, it is critical and essential that crops with enhanced concentrations of these nutrients be developed. Interacting with plants, plant growth-promoting microorganisms (PGPMs) promote plant growth by increasing a plant's ability to absorb micronutrients from the soil. To increase the amount of zinc and iron in the various edible parts of crop plants and to provide an alternative technique to fortify micronutrients and generate micronutrients rich foods, zinc solubilization and siderophore secreting microorganisms are used. Inoculants made from these microorganisms can be used instead of more expensive biofortification methods like agronomic and genetic engineering. Biofortification strategies may one day be used to combat the issue of hidden hunger through the creation of microorganisms with various positive properties. A more effective way to achieve environmental sustainability may be to use plant growth-promoting microorganisms for biofortification as part of a green technology approach.

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CHAPTER 3

THE EFFECTS OF GLOBAL WARMING ON SOIL AND SOIL PROPERTIES

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1. Introduction

Global warming is one of the world's most important problems. Global warming can be defined as the increase in the temperature of the Earth’s surface by absorbing the sun rays of these molecules due to the increase in the concentrations of greenhouse gases (CO_2, CH_4, N_2O, etc.) in the atmosphere (Korkmaz, 2007). In particular, human activities such as excessive use of fossil fuels, rapid population growth, and raising standard of living are events that increase the effects of global warming (Akın, 2006). Global warming can directly affect human life by causing abnormal climatic events, disruptions in food supply, and some parts of the world becoming uninhabitable. Global warming, which is one of the most important problems threatening the world, has begun to be felt differently in different regions. (Karaman & Gökalp, 2010).

A large part of people's food and clothing needs are supplied by agricultural production. Agriculture has great importance in the supply of food, which is one of the basic needs of human beings, and agricultural activities are the sector most affected by global warming. (Tıraşcı & Erdoğan, 2021).

Soil is directly related to global warming both because it is one of the basic items of agricultural production and because it contains a high amount of carbon. Most of the carbon in terrestrial ecosystems is in soils. (García-Palacios & Chen, 2022). The carbon stock in soils is about two times that in the atmosphere and about three times that in vegetation. Small losses from soil may have significant future effects on atmospheric carbon dioxide concentrations (Smith et al., 2008). Considering that an increase in the concentration of CO_2 in the atmosphere will increase global warming, the soil-global warming relation is clearly understood. In addition, it is thought that the effect of global warming on soil properties will also affect agricultural production.

In addition to the role of soil in global warming, global warming also has direct and indirect effects on soil properties. For this reason, this issue is very important and needs to be taken into account. In this study, studies on the effect of global warming on soil and soil properties were examined. The role of soil in global warming, the relation between global warming and soil, and how global warming will affect soil properties are discussed.

2. Material and Method

In this study, studies on the global warming-soil relation and the effect of global warming on soil properties were examined. It is thought that it will provide an approach to the global warming-soil relation and the effect of global warming on soil properties in the future.

3. Research Results and Discussion

Due to the interaction of soil and atmosphere, soil can both contribute to and reduce the effects of climate change. All soil processes will be significantly affected to the extent that global climate change occurs. (Rosenzweig & Hillel, 2000).

In this study, the effect of global warming on different soil properties has been examined under separate headings. In this context, the effect of soil on global warming and the relation between global warming and soil are also examined.

3.1. Global warming and soil carbon

The most important soil parameter in terms of global warming is soil carbon. Because it is a general idea that global warming occurs due to the increase in greenhouse gases in the atmosphere if the carbon in the soil mixes with the atmosphere.

Soil is a potential source of carbon. García-Palacios and Chen (2022) reported that soils are the largest carbon pool in the terrestrial ecosystem. Substantially more carbon is stored in the world's soil than in the atmosphere. (Davidson & Janssens, 2006). Soil organic carbon contains three times as much carbon as the world's atmosphere (Hicks Pries et al., 2017). According to Davidson et al. (2000), soils store two or three times more carbon than is present in the atmosphere as CO_2.

The retention of carbon in soils that have a large carbon stock is very important in terms of slowing down or stopping the rate of global warming. García-Palacios and Chen (2022) reported that the conservation and increase of soil carbon plays an important role in the fight against climate change. Carbon sequestration in the soil is very important in limiting global warming to 2 °C (Lal, 2013). Small losses from soil can have significant effects on future atmospheric carbon dioxide concentrations, so the response of soils to global warming is critical when evaluating climate-carbon cycle feedback (Smith et al., 2008). Georgiou et al. (2022) reported that soil is the largest territorial store of organic carbon and centrically to climate change reduction and carbon-climate feedback. Bossio et al. (2020) reported that soil carbon is important for preventing carbon emissions and eliminating atmospheric carbon dioxide.

Carbon emission from soil increases global warming, and carbon emission from soil may increase with the increase of global warming. Analysis by Kirschbaum (1995) has shown that soil organic carbon content may decrease significantly with global warming. Plaza et al., (2019) reported that 5-15% of the soil carbon stored in northern permafrost ecosystems could be released as a greenhouse gas under the current path of global warming by 2100. Increased temperatures cause more carbon dioxide emissions from the soil to the atmosphere, while increased carbon dioxide emissions can lead to higher carbon dioxide levels and accelerated global warming (Jones et al., 2005). A change in total soil organic carbon by 10% would be equivalent to all anthropogenic CO_2 emitted in 30 years (Kirschbaum, 2000).

There are some uncertainties about the relationship between global warming and carbon emissions from the soil. Davidson and Janssens (2006) reported that there is disagreement about the effects of climate change on global soil carbon stocks. They noted that despite a lot of research, there is still no consensus on the temperature sensitivity of soil carbon decomposition. As reported by Hicks Pries et al. (2017), soil organic carbon is a major cause of uncertainty in climate change feedback and climate projections. Knorr et al., (2005) reported that the sensitivity of soil carbon to warming is a significant uncertainty in carbon dioxide concentration and climate projections. Varney et al., (2020) reported that carbon cycle feedbacks represent the greatest uncertainty in climate change forecasts, and also that the response of soil carbon to climate change adds the greatest uncertainty to this.

Anthropogenic activities can affect the amount of carbon in the soil. Lal (2013) reported that with the adoption of proven technologies, significant amounts of carbon can be sequestered in cropland, grassland, woodland, and arid lands. García-Palacios et al. (2021) stated that anthropogenic warming is expected to expedite global soil organic carbon losses through microbial decomposition, but there is no consensus on the magnitude of the loss.

Anthropogenic activities can cause carbon sequestration in the soil as well as carbon release. According to Zhang et al. (2022), anthropogenic activity can lead to the loss or storage of soil organic carbon, thereby exacerbating or mitigating climate change. The main factors of gains or losses in soil organic carbon involve land management, land use change, and climate change (Beillouin et al., 2022). These factors are largely anthropogenic activities.

As a result, it is known that soils are a major source of carbon. It is thought that the release of carbon from the soil to the atmosphere will cause an increase in greenhouse gases in the atmosphere. It is also known that soil has a potential for the reuptake of greenhouse gases in the atmosphere. However, there are still some uncertainties related to the impact of global warming on soil carbon stocks, and carbon cycle, and the sensitivity of soil carbon to warming. Soil carbon represents a significant uncertainty in climate change scenarios.

3.2. Global warming and soil respiration

The relationship between global warming and soil respiration has been reported in many studies. Raich et al. (2002) reported that monthly soil CO_2 emission changes in the Northern Hemisphere are closely related to temperature. However, there are uncertainties about how much the temperature will increase soil respiration or how much the sensitivity of soil respiration to temperature will decrease.

Soil respiration is the primary path that CO_2 fixed by plants on land returns to the atmosphere (Schlesinger and Andrews, 2000). Global warming is likely to stimulate CO_2 emissions from soils (Raich et al., 2002). In a study conducted on increasing soil temperature (15, 21, and 27 °C), soils were incubated at 3 different temperatures. As a result, on average 26%, 14%, and 12% more CO_2 was released from warmed soils than non-warmed soils at each incubation temperature. (Hou et al., 2016).

Soils contain enormous amounts of carbon, so even a very small loss or gain can have a large impact on net CO_2 emissions into the atmosphere (Kirschbaum, 2004). Although it is thought that the increase in soil temperature due to global warming will increase soil respiration, the decreases that may occur in the temperature sensitivity of soil respiration will also reduce soil respiration. Luo (2001) stated that the temperature sensitivity of soil respiration decreases under warming -or acclimatizes-, and acclimatization is greater at higher temperatures. Peng et al. (2009) reported that the result of their study implied that the temperature sensitivity of soil respiration would decrease under continued global warming. Carey et al.

(2016) noted a universal decrease in the temperature sensitivity of soil respiration at soil temperatures above 25 °C. They also emphasized that colder climates are significantly more sensitive to increased ambient temperatures than warmer regions (Carey et al., 2016). As seen in these studies, the sensitivity of soil respiration has decreased and acclimation to the temperature has occurred against the increasing soil temperature.

Some factors affect soil respiration other than soil temperature. Guan et al. (2019) reported that soil respiration rates were positively correlated with precipitation, soil temperature, and volumetric soil water content throughout the seasonal cycle. In addition, anthropogenic factors can be effective in soil respiration. Schlesinger and Andrews (2000) reported that conventional tillage and increased temperature increase CO_2 flux from the soil without increasing soil organic matter stock.

As with the effect of global warming on other soil properties, many uncertainties remain about soil respiration. Peng et al. (2002) emphasized that due to the complexity of global change affecting soil respiration in natural ecosystems, there is a lot of uncertainty about how long-term increasing CO_2 concentrations will affect the ecosystem. Chen et al. (2022) reported that soil respiration significantly affects the global carbon cycle. They also emphasized that the response of soil respiration to climate warming in grasslands shows significant heterogeneity for reasons that are poorly understood.

3.3. Global warming and soil erosion

Soil erosion means the removal of the upper layers of the soil by a factor such as water and wind. Soil erosion is the most common form of soil degradation (Lal, 2003). Soil erosion, accelerated by wind and water, is the removal of soil organic carbon along with finer silt and clay particles. (Lal, 2020). The current soil erosion potential in the world is estimated to be 0.38 mm yr^{-1} (Yang et al., 2003).

It is known that there is a current erosion problem in the world. It is also of great importance how soil erosion, which is very important for our future, will be affected by global warming and climate change. Kumar et al. (2023) reported that soil erosion will accelerate climate change because it reduces soil fertility and causes carbon loss in the soil. In addition, they stated that climate change is expected to increase soil erosion.

Changes in the precipitation regime are expected as a result of global warming. Precipitation changes will have significant effects on soil erosion rates (Nearing et al., 2004). The risks of soil degradation may increase further due to predicted climate change (Lal, 2017). Yang et al. (2003) reported that global warming can greatly increase the potential for soil erosion, and the regions with increasing trends in precipitation and population may face very important problems related to soil erosion in the future.

One of the most important issues in the relationship between global warming-soil erosion is the transport of soil carbon. Soil erosion has a significant impact on the global carbon cycle (Lal, 2003). Soil organic carbon is removed by wind and water erosion (Lal, 2019). The increase in soil carbon displacement due to water erosion and climate change means an intense vulnerability to soil loss and further perturbation of the carbon cycle (Ito, 2007).

The effect of erosion on soil organic carbon is also important for global carbon budget calculations. Data on the global carbon budget are incomplete and unclear when the impact of erosion on soil organic carbon and the associated gas emissions are not taken into account. (Lal, 2019; Lal, 2020)

In some studies, it has been stated that some measures can be taken to reduce soil erosion, which is thought to increase with global warming. Kumar et al. (2023) reported that soil erosion can be reduced in an environmentally friendly way by adopting various adaptation and mitigation strategies. According to Borrelli et al. (2020), current conservation agriculture practices are estimated to reduce global potential soil erosion rates by ∼5%. Ito (2007) reported in his simulation that both predicted precipitation and land use changes affect the erosion regime in many regions and as a result, the total amount of carbon displacement of the soil increases by 32-57%. In a study by Dou et al. (2022), for Central Asia, it was stated that higher vegetation helps to decrease wind and water erosion.

Although there are some studies on the relationship between global warming and soil erosion, it is thought that more studies are needed on this subject. Currently, the factors causing soil erosion under climate warming remain rather uncertain. (Ma et al., 2021).

3.4. Global warming and soil moisture

Soil moisture is an important variable for regulating the carbon, water, and energy cycles of terrestrial ecosystems. (Xu et al., 2013). In this title, the effect of global warming on soil moisture has been examined. The effect of global warming on soil moisture is mostly related to the precipitation regime and temperature. After all, soil moisture and water retention capacity may also be affected by global warming due to soil degradation. Feddema and Freire (2001) reported that soil degradation will cause reduced water retention capacity, and reduced water retention capacity will cause a high flow rate of water, and less recharge to groundwater during rainy periods. In addition, it has been emphasized that the water lost due to the flow will increase the time and intensity of the dry periods.

It is thought that global warming will seriously affect soil moisture and drought. Berg et al. (2017) predicted that global warming will increase land drought. Gu et al. (2019) reported widespread soil moisture reduction in Eurasia during the warm seasons over the past 63 years. They stated that this problem should cause international concern. According to Makra et al. (2005), in eastern Hungary, significant fluctuations in soil moisture content were detected in the region during the 20th century. In addition, they reported that the soil has become drier in recent years. Xu et al. (2013), as a result of their meta-analysis, found that trend of soil drying in most ecosystems as a result of increasing temperature. As a result of the simulation study conducted by Wetherald and Manabe (2002), they emphasized that while the soil moisture tends to decrease in the summer months in the middle and high latitudes in the Northern Hemisphere, it increases in the winter months. In addition, in many semi-arid regions in subtropical and mid-latitudes, they reported that soil moisture was reduced for most of the year. Elkouk et al. (2021) reported that soil moisture droughts may pose serious threats to the food security of North African and Sahel societies. Cheng and Huang (2016), in their analysis of soil moisture trends between 1948 and 2010, reported that soil moisture tends to dry out significantly in East Asia and the Sahel. As a result of this study, they stated that precipitation has the dominant effect on the variation of soil moisture, but temperature is the main reason for the long-term trend of soil moisture. Dai (2011) reported that global drought has increased substantially since the 1970s. Dai (2013) reported that the global drought changes observed until 2010 are consistent with model predictions suggesting that severe and widespread droughts will occur in many places in the next 30-90 years due to decreased precipitation and increased evaporation. In the study conducted by Akbolat and Coşkan (2020), the soils were irrigated to 60% saturation and kept at temperatures of 40, 36, and 32 °C. At the end of twenty-two days, 81% of the water supplied to the soil in the 40 °C application, 73.6% in the 36 °C application, and 66.6% in the 32 °C application decreased. The decrease in control application was 47.5%.

(Li et al., 2022b) emphasized the importance of moisture loss from the plant through transpiration, as well as moisture loss directly from the soil under global warming.

There are different views on the relationship between global warming and soil moisture. Robock et al. (2000), based on data from the Global Soil Moisture Data Bank, stated that summer soil moisture increased while temperatures have risen with the longest records in the top 1 m for stations, in contrast to the predictions of summer drying up with increasing temperatures. They reported that the increasing trend in precipitation more than compensated for the increased evaporation.

Trenberth et al. (2014) reported that increased warming from global warming may not cause drought, but is likely to be faster and more intense when drought occurs. Vogel et al. (2017) noted that soil moisture-temperature feedbacks contribute significantly to the increased warming of the hottest days compared to the global average temperature.

Elkouk et al. (2021) emphasized important uncertainties arising from climate forcing and impact patterns. Trenberth et al. (2014) reported that several recently published studies produced conflicting results on how drought changes under climate change. They stated that these results are thought to be due to the data sets used to determine the formulation and evapotranspiration component of the Palmer Drought Severity Index (PDSI).

It has been emphasized in many studies that soil moisture will be affected by global warming. However, some uncertainties remain in this regard.

3.5. Global warming and soil temperature

Air temperature and soil temperature are directly related to each other. Petersen (2022) reported that with the increase in air temperature in a warming climate, the soil temperature will also increase. Harte et al. (1995), in their study where they provided heat increase to the soil with infrared radiators, observed that the greatest temperature increase was in the daytime and the drier, more sparsely vegetated region of each plot.

The increase in soil temperature due to global warming will affect the organisms living in the soil. Robinson et al. (2018) reported that the α-diversity of plants and invertebrates decreases with increasing soil temperature due to decreased plant species abundance and increased dominance of certain invertebrate species in warmer habitats. In a study examining the response of spruce roots to soil temperature, trees in warmer soils formed longer and less branched absorbent roots with higher particular root area and length, and lower root tissue density (Parts et al., 2019). Saxe et al. (2001) reported that the selection of the best species for the new conditions in forests against global warming will be of vital importance.

As seen in the studies examined, the increase in soil temperature will affect the life of organisms in the soil. It is thought that plants may respond differently to an increase in soil temperature.

3.6. Global warming and soil organic matter

Organic matter in the soil is very effective on soil fertility. Agricultural soils should contain at least 5% organic matter in terms of productivity. Organic matter is also like a reservoir of carbon in the soil. Organic matter in soil is one of the largest carbon reservoirs on a global scale (von Lützow and Kögel-Knabner, 2009). Soil organic matter contains more than three times the carbon of the atmosphere or terrestrial vegetation on a global scale (Schmidt et al., 2011).

The importance of soil organic matter in global warming is mostly related to its decomposition. The microbial breakdown of soil organic matter affects the amount of carbon dioxide released into the atmosphere and the carbon sequestration potential of terrestrial ecosystems (Craine et al., 2010). The microbiological decomposition of organic matter in the soil makes an important contribution to soil respiration, which is the main source of CO_2 (Yuste et al., 2011). There is a concern that if organic matter decomposes at a high rate depending on the temperature, carbon emissions to the atmosphere will increase. The extent to which global warming will affect the decomposition of soil organic matter is an important issue. Feng and Simpson (2011) stated that the organic matter in the soil is one of the most complex structures in the world. They also emphasized that it is tough to predict the response of soil organic matter to global climate change.

It is thought that increased temperature as a result of global warming is not the only factor controlling soil organic matter decomposition. Schmidt et al. (2011) emphasized that recent advances do not only determine the stability of soil organic matter, but also environmental and biological controls are important. Hou et al. (2016), as a result of their study, concluded that the increased soil organic matter decomposition due to the stimulation of microorganisms by warming is long-lasting. A study conducted by Xiang and Freeman (2009) in North Wales determined that the temperature sensitivity of soil organic carbon decomposition in Northern peatland areas is regulated not only by temperature but also by soil water content, dry-rewet event, and phenologies. Li et al. (2022a) emphasized that soil organic carbon decomposition changes with soil aggregate size and is affected by increased nitrogen and phosphorus inputs due to anthropogenic activities.

The stability of soil organic matter against decomposition is very important. The temperature dependence of stable soil organic matter is the primary question determining carbon stocks and stock changes under global warming. (von Lützow, and Kögel-Knabner, 2009). Craine et al. (2010) suggest that biogeochemically persistent organic matter will respond the most sensitively to expected warming although physico-chemical preservation of soil organic matter and substrate availability will also affect the temperature sensitivity of decomposition. The response of the decomposition of soil organic carbon to global warming is a very important source of uncertainty in climate forecasts (Wang et al., 2019).

While we want the organic matter level in the soil to be at a certain rate, what should be done so that global warming does not cause organic matter decomposition? According to Cerri et al. (2007), the decrease of organic matter in the soil means an increase in gas emissions to the atmosphere and global warming. Therefore, measures should be taken to protect and increase soil organic matter. Navarro-Pedreño et al. (2021) emphasized that the increase of biologically stabilized soil organic matter adapted to local environmental conditions should be supported.

As a result, soil organic matter is of great importance in terms of global warming because it contains a large amount of carbon. There is a concern that a large amount of carbon will be released into the atmosphere as a result of the decomposition of organic matter in the soil. However, it is seen that temperature is not the only factor in the decomposition of soil organic matter. The resistance of soil organic matter against decomposition is also important. It is thought that the organic matter contained in the soil should be protected.

3.7. Global warming and soil organisms

As a result of global warming, some changes in the atmosphere, climate, and soil will occur. These changes will affect the organisms living in the soil. Mukherjee (2022) reported that greenhouse gas emissions and carbon sequestration are factors controlling soil ecology. Peng et al. (2022) determined that the density of soil fauna is affected by changing precipitation regimes. According to Yin et al. (2022) reported that the warm season can greatly promote the role of both fauna and microbes in litter decomposition.

There are multifaceted relationships between global warming and soil organisms. Some of these are; the effect of global warming on soil organisms, different reactions of soil organisms against global warming, the use of some organisms against global warming, and the addition of carbon to the soil through organisms.

The sensitivity of organisms in the soil to global warming will be different. Yuste et al. (2011) found that fungal diversity is less sensitive to seasonal changes in humidity, temperature, and plant activity than bacterial diversity. Tian et al. (2022) reported that the thermal adaptation of microbial communities and fungal species has been proven, but studies on the thermal adaptation of bacterial species are still lacking.

There are studies that some organisms can be used to reduce the effects of global warming. Goyal and Shukla (2018) conducted a study to determine the effect of metal-oxidizing bacteria on reducing global warming. As a result of the model analysis they applied, it was determined that the increase in the average atmospheric temperature with the help of metal-oxidizing bacteria would be 0.22°C less in the next 100 years than if metal-oxidizing bacteria were not used. Shahid et al. (2022) reported that the soil carbon cycle is largely dependent on the activity of CO_2-fixing bacteria. Gupta et al. (2014) stated that microbes have an important potential in the struggle against global warming.

It has also been reported in some studies that increasing CO_2 gas in the atmosphere will stimulate plant growth. Pritchard (2011) reported that increased atmospheric CO_2 will stimulate organic C flow into the soil, increase root production and exudation, but decrease litter quality. Although it is reported that the increasing CO_2 ratio will stimulate plant growth, it is thought that drought, another effect of global warming, will negatively affect the soil fauna and flora. According to Kudureti et al. (2023) reported that drought will lead to low soil porosity and water retention capacity, reducing the soil fauna population and changing their community composition. They also stated that drought can reduce the coverage of flora and change the microclimate of the soil surface, which will indirectly reduce fauna abundance.

There are some studies on the adaptation of soil organisms to global warming. Tian et al. (2022) found that continuous warming leads to a decrease in respiratory temperature sensitivity (Q10) in bacterial species with an increase in the minimum temperature required for growth. They also stated that the thermal adaptation of microorganisms in the soil will weaken the positive feedback between climate warming and soil respiration.

There are many unknowns about the relationship of soil organisms with global warming. Pritchard (2011) stated that more studies are needed to develop a more holistic understanding of the effects of climate change on below-ground processes.

It is observed that the soil fauna and flora are affected by global warming. Although it is thought that the increase in atmospheric CO_2 will positively affect the soil flora, it is thought that events such as temperature and drought, which are the other effects of global warming, may negatively affect the soil flora. In addition to this, the sensitivity of the living things that constitute the soil fauna to global warming has been different. This situation may result in some species becoming more dominant in the soil fauna in the future. The ability of soil organisms to adapt to global warming is important in this subject.

However, it is also known that some organisms can be used to prevent global warming. As a result, the exact effect of global warming on soil organisms is not known for certain.

4. Conclusion

Soil features that are thought to be affected by global warming can be listed as follows; Soil carbon content, soil respiration, soil erosion, soil moisture, soil temperature, soil organic matter, and soil organisms.

As it is known, one of the main causes of global warming is the increase in the rate of CO_2 in the atmosphere. The fact that the soil contains a very large part of the global carbon reserve increases its role in global warming. It is widely believed that carbon emission from the soil to the atmosphere will increase the effect of global warming, whereas the return of CO_2 from the atmosphere to the soil will reduce the effect of global warming. Soil respiration, that is, the release of gases from the soil into the atmosphere, has a major role in this regard. Soil respiration is not controlled by temperature alone. It is known that there are many factors affecting soil respiration. In addition, a decrease in the sensitivity of soil respiration is expected against the temperature increase. For this reason, uncertainties continue about the relationship between global warming and soil respiration.

Soil degradation and precipitation changes that will occur with global warming will cause soil erosion to increase. It is very important to take precautions to prevent soil erosion.

Soil moisture is a parameter that is influenced by both temperature and precipitation. In addition to the expectation of a general drought, it is expected that the rainwater will be removed from the soil by surface runoff as a result of heavy rains. Since global warming is expected to cause changes in precipitation regimes as well as temperature increases, there are great uncertainties regarding the relationship between soil moisture and global warming.

An increase in atmospheric temperature will cause an increase in soil temperature. The increase in soil temperature will be more effective on soil fauna and flora and will affect the life of soil organisms.

Soil organic matter is an important carbon stock. It is worried that the decomposition of soil organic matter as a result of global warming will increase carbon emissions from the soil to the atmosphere. However, the decomposition of organic matter is not only controlled by temperature. The stability of organic matter against decomposition is also important. It is necessary to take precautions to increase the rate of organic matter in the soil.

One of the soil properties that global warming will affect is soil organisms. It is known that the temperature increase caused by global warming will directly affect soil organisms. However, soil organisms are expected to respond differently to temperature increases. As a result, the current situation of the fauna and flora in the soil may change. Interestingly, some organisms are used to reduce the impact of global warming.

Although many studies have been conducted on the relationship between global warming and soil properties, it is observed that uncertainties regarding this issue continue. Soil properties are generally controlled by many factors. In addition, the sensitivity of soil properties to the temperature increase caused by global warming may also change. For this reason, it remains unclear to what extent global warming will affect soil properties.

It is known that global warming will affect soil properties. However, the severity of this effect is uncertain. It is of great importance to take agricultural measures to reduce the severity of global warming and protect the soil.
As a result of traditional tillage carried out for years, approximately 50% of the initial carbon of the soils has been lost. Minimal soil tillage and no-tillage techniques reduce oxidation of organic carbon, resulting in net C gain of the soil. (Koçyiğit, 2008). Some of the measures to reduce greenhouse gas emissions in irrigated or rainfed conditions are as follows: reduced tillage,

expanding of direct sowing methods, reduction of surface or flood irrigation applications and expansion of drip or subsurface pressure irrigation systems instead, supporting the use of renewable energy in irrigation, effective application of plant stubble and residue management, expanding of cover plant applications, increasing nitrogen use efficiency, supporting the use of animal manure and other biofuels, evaluation of agricultural lands by the use class, expansion the consolidation of agricultural lands, improvement and protection of forest and rangeland, supporting biological control applications and supporting precision agriculture practices (Vurarak and Bilgili, 2015).

The increase in forest areas and the transformation of degraded forests into productive forests are the main reasons for the increase in the amount of biomass and carbon in the forest ecosystem. (Sivrikaya and Bozali, 2012). For this reason, we should protect forests and attach importance to afforestation activities.

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CHAPTER 4

USE OF ORGANIC AMENDMENTS FOR SUSTAINABLE CROP PRODUCTION IN MARGINAL LANDS

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1. Introductions

Agricultural land systems, such as crops, grasslands, and permanent crops, make up 40%-50% of the Earth's surface and are crucial for food supply (Calabi-Floody et al., 2018). The world's population is expected to reach 9.5 billion by 2050, which will increase food and feedstock fodder demand (Nations, 2013). The future of food production and the health of human populations are both threatened by various environmental and edaphic factors. The consequences of climate change are a major issue for farmers, environmentalists, and the public because of the fluctuations in temperature and the unpredictability of changes in rainfall patterns and intensity (Glæsner et al., 2014). The growing population demands more food, which leads to intensive cultivation using more fertilizer and pesticides. These factors, together with deforestation, overgrazing, and river pollution have accelerated land degradation (Kopittke et al., 2019). Moreover, frequent droughts, floods, and other extreme weather events caused by global warming and climate change are worsening land degradation (Hasnat et al., 2018). Land degradation is widely recognized as a significant issue affecting both developed and developing nations, and it is closely linked to the process of desertification (Prăvălie et al., 2021). However, it is projected that an additional 147 million hectares of cultivated land will be required by the year 2050 to meet the growing demands of the population. Therefore, the practice of cultivating marginal lands is considered a crucial approach to ensuring global food security in a sustainable manner (Lambin & Meyfroidt, 2011).

Marginal lands are characterized by limited agricultural output and lower economic returns than ideal lands. Marginal areas include areas with poor soil fertility and quality, erratic rainfall, extreme temperatures, poor drainage, salt-affected, water-logged, and contaminated soil with various pollutants or other problematic soil that reduce crop production (Mellor et al., 2021; Jamal et al., 2022). There are several primary factors contributing to the expansion of marginal lands, including poor soil quality, freshwater scarcity, industrialization, transfer of soil particles, and inadequate land slope (Jamal et al., 2022). This means that marginal land cannot produce enough food unless major management efforts are undertaken to increase its quality. Genetic modification, increased fertilizer, and chemical application are frequently used to improve crop growth and yield (Qaim, 2020; Gao et al., 2020). However, these crop management techniques often lead to poor soil health due to low organic matter, micronutrient deficiency, biodiversity loss, and chemical persistence, resulting in soil degradation and reduced agricultural productivity (Celik and Akça, 2017; Mukherjee et al., 2019; Costantini & Mocali, 2022). Thus, long-term soil fertility maintenance may need alternatives to costly agricultural chemical inputs. Some of these problems can be alleviated by the use of organic amendments such as animal manure, municipal waste, composts and vermicompost, and biochar which are natural, beneficial, and eco-friendly (Lazcano et al., 2009). Organic amendments to problematic soils have been a common strategy in agriculture since ancient times. These amendments improve soil properties, improve soil quality, and provide beneficial effects on plants, ultimately increasing crop protection and sustainability. This chapter reviews marginal lands (soil under drought, salinity, and metals stress), highlights the source and types of organic amendments in marginal lands, and makes recommendations for sustainable food production from marginal lands through organic amendments.

2. Sources and Types of Organic Amendments Applied to Marginal Lands.

Most agricultural soils undergo degradative processes like soil erosion, nutrient runoff losses, and organic matter depletion while conserving them with organic amendments is a vital technique to increase soil fertility and stabilize degraded sites. Organic matter can be incorporated into marginal soils to improve the productivity of the soil by several means, encompassing (i) agricultural byproducts such as animal manure, crop leftovers, and green manure crops, and (ii) off-farm waste materials like composted garbage and sewage sludge. Additionally, the introduction of organic amendments promotes the activity of microorganisms, which results in the production of organic acids and other metabolites that break down nutrients and enhance the availability of essential nutrients. Most used organic amendments are listed below and their beneficial effects on soil characteristics and crop yield are elaborated in figure 1.

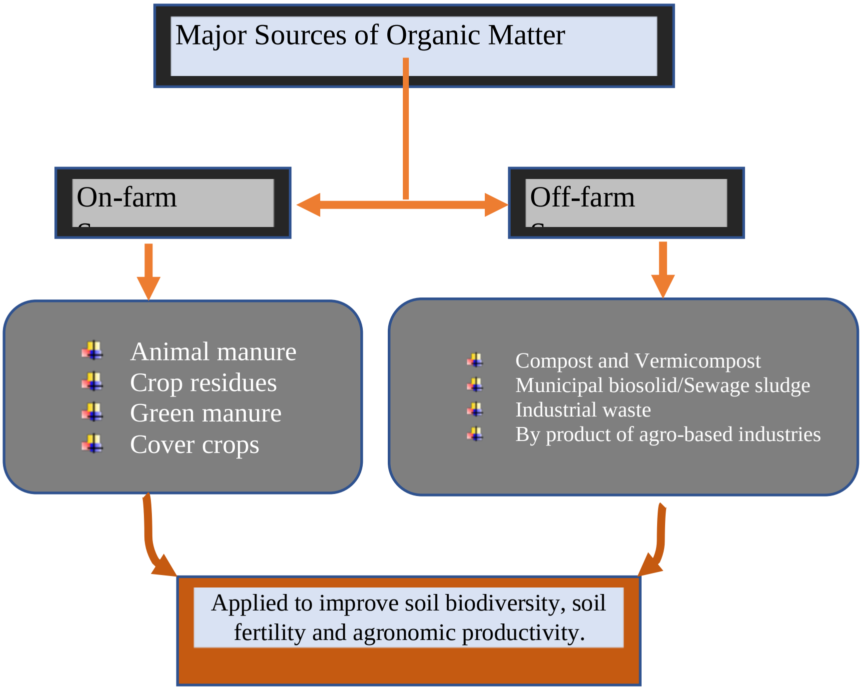

Figure 1. Major sources of organic amendments

2.1. Animal Manure

Animal manure is a solid, semisolid, and liquid byproduct of animals that provide meat, milk, eggs, and other food for humans. Manure mixes contain animal feces, urine, waste feed, wash fluids, bedding materials such as sawdust, straw, rice hulls, etc., and any chemical or physical additions employed during manure management and storage (Goss et al., 2013; Rashmi *et al*., 2022). It has a strong organic material and a high level of microbial activity, such as actinomycetes, pseudomonads, and fungi (Elsayed et al., 2023). Manure is also considered to be a highly valuable and essential resource in terms of providing macro and micronutrients for the growth and development of crops and grasslands (Araji et al., 2001). Additionally, animal manure adds several benefits to soil productivity. It improves soil structure by supplying organic matter (Xia et al., 2017). Organic matter binds soil particles, making them more stable and erosion-resistant. Improves soil water-holding capacity, making it simpler for crops to get water during dry seasons (Colazo and Buschiazzo, 2010; Williams et al., 2016; Bhadha et al., 2017). However, manure composition varies due to factors like animal species, age, diet, feed digestibility, environmental conditions, and handling methods. Factors like feed concentrates, enzymes, nitrogen content, and rainfall can affect manure composition, affecting its use and disposal (Sims & Maguire, 2005). Moreover, Manure undergoes changes from urine and feces excretion to storage, with the enzyme "urease" causing rapid mineralization. The essential products are NH_4^+, HCO_3^-, and OH^-, Urease activity has a cumulative impact of elevating the pH levels of manure, consequently leading to the release of ammonia (NH_3) and bicarbonate ions (HCO_3^-) into the atmosphere (Goss et al., 2013). Although, animal manure is a major source of organic amendment in crop production. But it's crucial to remember that improper manure usage can cause environmental harm. Manure contaminates can enter and pollute the atmosphere, land as well as water bodies, with harmful gases, minerals, germs, and parasites (Chadwick et al., 2011; Zhongqi et al., 2016) To eliminate these issues, the implementation of manure management practices has the potential to mitigate the environmental consequences associated with urease activity.

2.2. Municipal Biosolids

Municipal biosolids, commonly referred to as sewage sludge, are residual solid matter that remains after wastewater treatment in a wastewater treatment plant. The composition of matter includes a diverse range of organic matter, essential nutrients, and trace elements (Scotti et al., 2015; Brown et al., 2020). Biosolids have the potential for beneficial use in a variety of applications, including landfills, energy production, and agriculture. In agriculture uses; municipal biosolids are used to meet crop essential nutrient needs, it provides a complete nutrient package that is essential for crop growth and development (Brown et al., 2020). Recently, techniques have been developed to precipitate nitrogen and phosphorus from wastewater, yielding compounds that are comparable to those utilized in conventional fertilizer production (Le Corre et al., 2009). The total nitrogen content of biosolids ranges from 1 to 7%. However, initially, nitrogen is present in organic form, and mineralization occurs at different rates depending on the treatment process, soil type, crop, and climatic conditions (Barbarick *et al*., 2010; Rigby *et al*., 2016). Moreover, Biosolids contain phosphorus (Penn & Sims, 2002; O'connor et al., 2004), nevertheless, potassium concentration in biosolids is low due to high solubility, causing it to partition to effluent (Warman and Termeer, 2005). According to several studies, the addition of biosolids to soils results in higher grain concentrations of micronutrients like zinc (McGrath et al., 2012; Barbarick et al., 2017). Biosolids contain all necessary plant nutrients and carbon, providing fertility for crops, enhancing soil health, reducing erosion, and increasing water infiltration, promoting ecosystem resilience and sustainability in changing climates (Brown et al., 2020). Biosolids as organic amendments can be applied to marginal agricultural soils; however, this must be done in accordance with regulatory standards that establish limitations for the presence of heavy metals, weeds, and human and plant infections.

2.3. Green Manure and Crop Residue

Green manuring is a technique that uses plant material to increase the soil's biological, chemical, and physical properties (Tejada et al., 2008; Garcia-Franco et al., 2015). Green manure is a form of cover crop that is grown specifically for the purpose of being tilled into the soil before or soon after flowering (Scotti et al., 2015; Reed-Jones et al., 2016). When green manure plants are completely buried, they return nitrogen, organic matter, and biological activity to the soil (Talgre et al., 2017). Several green manure crops such as soybeans, cowpeas, and clover are preferred because they are capable of fixing nitrogen from the environment with bacteria at the root level (Scotti et al., 2015; Baiyeri and Olajide, 2023). These crops release between 70 and 120 N (lbs acre^{-1}) into the soil depending on the crop species (Chatterjee & Clay, 2016), as a direct result, succeeding crops have access to this nitrogen, reducing the need for synthetic fertilizers (Naher et al., 2020). Whereas, non-legumes such as forage sorghum, millet, annual ryegrass, and buckwheat generate biomass while also suppressing weed growth (Sharma et al., 2018). Green manure and cover crops are advantageous because of their ability to enrich the soil with nutrients, organic matter, microorganisms, and water retention (Baiyeri & Olajide, 2023). Green manure crops, particularly leguminous are useful for marginal fields, it enhances soil quality and boosts agricultural productivity.

The annual global production of agricultural residues is estimated to be 3.7Pg dry matter, with roots, straw, shaft, and other crop parts (Bentsen et al., 2014). Large-scale crop residue burning in open fields results in ash input, which improves soil fertility. Residue burning accounts for 27% of global biomass burned annually (Crutzen et al., 2016), it generates large amounts of particulate material, greenhouse gases, volatile organic carbon, NH_3, and other pollutants (Sun et al., 2016; Crutzen et al., 2016), causing atmospheric pollution and significant impacts on atmospheric chemistry, global climate, and human health (Udeigwe et al., 2015). The increasing worldwide population poses new challenges for food security and environmental sustainability, using harvesting residues as raw materials for composting and production of organic fertilizer, can boost food output and environmental quality while also supporting a circular economy.

2.4. Compost and Vermicompost

Composting and vermicomposting are binary common methods for recycling organic waste into useful products; the resulting product (composts & vermicomposts) can be added to improve soil quality, used as a nutrient source to increase crop yield, or used as a component of soilless growth medium (González et al., 2010; Fornes et al., 2012; Kılbacak et al., 2021). Composting is a common practice for stabilizing organic materials into nutrient-rich soil amendment through natural decomposition, promoting sustainable waste management (Ayilara et al., 2020; Wojnowska-Baryła et al., 2020). It is an aerobic process in which naturally occurring thermophilic and mesophilic microorganisms break down organic materials into a stable and sterile byproduct called compost (Gonawala & Jardosh, 2018). Composts are sanitized from unwanted seeds and harmful microbes during the thermophilic phase (45–70 °C). later, in the maturation phase, the remaining more recalcitrant organic molecules are slowly decomposed, a process like soil humification, removing residual phytotoxicity. Moreover, watering and aerating support aerobiosis in composting (Fornes et al., 2012). It is a common treatment for stabilizing nitrogen in wastes and reducing the volume of organic waste (Vigneswaran et al., 2016). Soil quality, erosion rates, agricultural productivity, and environmental protection are all enhanced by composting. As such, it is essential for residue management and can contribute to a more sustainable future.

Vermicomposting is a fast and cheap natural composting process of recycling organic waste into useful soil amendments involving earthworms and microbes (González et al., 2010). The earthworm digestive system has a significant impact in determining the composition of microbial communities, leading to a smaller but more active population in the egested material. This addition modifies the activity and functional diversity of microbial populations in vermicomposting systems (Gómez-Brandón & Domínguez, 2014). Mostly, four species of epigeic earthworms have been widely utilized in vermicomposting facilities, although they all have these traits. *Eudrilus eugeniae, Perionyx excavatus, Eisenia andrei,* and *Eisenia fetida* (Dominguez & Edwards, 2011). This process improves soil health, productivity, and biodiversity, while also enhancing hormone concentration and promoting soil decontamination. Vermicompost application also maintains soil fertility, makes it suitable for crop production, and reduces reliance on chemical fertilizers (Gómez-Brandón & Domínguez, 2014; Mondal et al., 2017; Kalika-Singh et al., 2022). Compost and vermicompost are organic fertilizers that enhance crop productivity, soil health, and environmental protection.

Other organic amendments include biochar (Kavitha et al., 2018), forest-derived materials, and urban as well as industrial waste (Gatta et al., 2015; Arias et al., 2021), these amendments provide nutrient content and are commonly used in crop fields. Additionally, microbial inoculants and biofertilizers are also used to improve biological nitrogen fixation, nutrient uptake, and water use efficiency and to affect crop yield.

3. Organic Amendments to Increase the Productivity of Marginal Lands.

The excessive use of chemical fertilizers has led to a number of environmental issues (Rashtbari et al., 2020). One of the main issues with the excessive use of synthetic fertilizers is that it causes pH changes in the soil, soil acidifications, and reduced levels of humic acid (Suthar 2009). Around the world, millions of tons of organic material are produced in the form of animal manure and crop waste (Rehman et al., 2020). As a result, biomass is abundant throughout the world. A considerable portion of the biomass is not used for energy generation, but is instead left to degrade spontaneously, creating methane, or is burnt publicly, causing smoke, CO_2 emissions, smoke, and other particles that contaminate our environment.

In order to preserve the tilth, fertility, and productivity of agricultural soils, shield them from wind and water erosion, and stop nutrient losses through runoff and leaching, regular inputs of organic materials like animal manures and crop residues are crucial. These substances reduce the impact of salt and heavy toxic metals while improving soil physical qualities including enhanced water-holding capacity, soil aggregation, aeration, and permeability (Cui et al., 2020).

Furthermore, organic resources may be employed efficiently for land reclamation. For example, mining of topsoil, sand, and graver deposits in metropolitan areas has left huge tracts of exposed, extremely erodible subsoils that, due to their poor chemical and physical qualities, are not favorable to plant development. Such places detract from an urban environment's aesthetic appeal and are substantial contributors to environmental degradation via surface runoff, eutrophication (nutrient enrichment) of lakes and streams, and sedimentation from soil erosion. As a result, excellent procedures for restoring the productivity and value of these lands in the most cost-effective and time-efficient manner are required (Hafez et al., 2020).

A wide range of organic wastes and residues can be employed as soil conditioners and plant nutrition sources on agricultural soils with little or no negative impact on public health or the environment. Organic amendments may help restore the productivity of marginal, degraded, and infertile soils, as well as how changes in cultural practices might alter crop quality. The drought, salinity, toxicity of heavy metals, and severe temperature is all favorably impacted by these organic sources.

3.1. Drought

The need for water has multiplied due to population development and the expansion of the agricultural, energy, and industrial sectors, and water shortage has been a problem virtually every year in many regions of the world. The paucity of water has also been made worse by additional reasons including climate change and water supply pollution. As a result, crop development and output are constrained by drought stress from germination through maturity (Cui et al., 2020). The application of animal manure increases the amount of organic matter in the soil and enhances a variety of soil characteristics, such as soil tilth, soil fertility, soil oxygen content, and soil water-holding capacity. The management method is sometimes referred to as "organic farming" when organic substances, such as compost and vermicompost, animal manures, green manures, and municipal waste, are employed as the main sources of plant nutrients. Vermitechnology is the use of surface and subsurface earthworm species in composting and soil management (Ansari & Ismail 2012). In addition to creating aggregates and enhancing the physical conditions for plant development and nutrient uptake, earthworms have a significant impact on soil structure. (Ansari & Sukhraj, 2010). When an organic matter like animal manure, municipal waste, green manure, biochar, compost, and vermicompost is used, it improves the soil's physical and chemical health, increases fertilizer usage efficiency, and mitigates the impact of drought. (Rehman et al., 2020).

The activity of antioxidant enzymes such as catalase, superoxide dismutase, and peroxidase was considerably impacted by drought stress and vermicompost treatment in both cultivars of wheat. The use of vermicompost boosted antioxidant enzyme activity in both drought- and well-watered environments. (Ahmad et al., 2022). Previous research has extensively covered the beneficial effects of using vermicompost together with other organic fertilizers on morpho-physiological and yield parameters under drought stress. (Aboelsoud & Ahmed, 2020; Hafez et al., 2020). The use of vermicompost fertilizer and humic acid has been shown to stimulate the activity of scavenging enzymes, such as the antioxidant enzymes catalase, superoxide dismutase, and peroxidase, in order to detoxify ROS. (Kiran, 2019). Additionally, the positive benefits of compost or vermicompost on plant development under water shortage conditions may be attributable to improved root aeration, an increase in the quantity of water that is easily accessible, and the induction of N, P, and K exchange, which results in greater plant growth. (Manivannan et al., 2009)

3.2. Salinity

One of the main causes of land degradation, declines in agricultural output, and obstruction to social advancement and way of life is salt buildup in the soil. High salt buildup has a detrimental impact on the physical and chemical environment of the soil and leads to poor soil microbial activity (Basak et al., 2023). High concentrations of NaCl in soil cause morphological, physiological, biochemical, and metabolic adaptations in plants; the strength of these adaptations is determined by environmental factors such as light intensity, soil conditions, and the severity of the stress. (Kamran et al., 2019). Salinity increases the osmotic pressure in the root-mycorrhiza complex of the plant, which lowers the amount of water that is accessible to the plant. Water stress has an impact on global agriculture productivity and plant development. (Adhikari et al., 2020). Stress from salinity lowers leaf biomass, stem length, and root length. (Pradi-Vendruscolo & Seleguini, 2020); Changes in the photosynthetic pathway are also brought about by salt stress. (Adnan et al., 2020). Salt stress causes gene expression alterations in greenhouse plants. Reactive oxygen species (ROS) are produced in salt-stressed plants; a high production of these ROS can damage molecules. ROS can act as signaling molecules for osmotic tolerance. Chlorophyll is destroyed as a result of the increasing concentration of ROS, which also damages enzymes and cell walls. Plants activate detoxification processes by controlling antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT), and L-ascorbate peroxidase (APX) to sustain cellular homeostasis in response to this oxidative stress. (Rehman et al., 2019). Previous research has demonstrated that salt stress boosted the antioxidant activity in soybeans and wheat (Shafiq et al., 2020).

Different techniques, such as soil leaching with water, chemical remediation, and phytoremediation utilizing salt-resistant cultivars, might be used to control the remediation of increasing soil salinity (Qadir et al., 2007). Globally, the addition of OM has proven to be an effective method of combating soil salinization. (Tejada et al., 2006). Low organic content saline soils offer weaker structural stability. Previous studies have validated the use of organic resources as soil additions, such as compost and food industry waste (Tejada et al., 2006). It has been demonstrated that horticultural crops like tomatoes, peppers, and sweet corn grow more quickly when vermicompost is put in the soil (Lazcano et al., 2009). By lowering the negative impacts of toxic components and producing an anti-stress effect, these investigations have demonstrated that vermicompost effectively modifies the detrimental effects of salty soil on plant morphological and physiological characteristics (Zhang et al., 2010)

Furthermore, soil salinity may have an impact not only on plants but also on soil microbes that are responsible for nitrogen cycling. Soil salinity is known to cause significant stress to ecosystem living components by increasing osmotic pressure on cells and decreasing water availability (Mitran et al., 2017). The integration of organic matter into the soil is one approach for reducing detrimental salinity impacts (Wichern et al., 2020), because they improve the soil's physical, chemical, and biological qualities (Iqbal et al., 2016; Chahal et al., 2017; Leogrande & Vitti, 2019). The beneficial biological benefits are probably brought about by the increased organic matter's availability of carbon (C), which enables microbial cells to adapt to osmotic stress by creating osmolytes that counteract it (Wichern et al., 2020). Additionally, agricultural waste is digested by soil microbes and hence contributes significantly to soil nutrient availability, especially when external input is limited. However, compost, particularly vermicompost, is a completely decomposed material, and the addition of vermicompost increases nutrient availability, which helps to reduce the effect of salt. The presence of soil microorganisms and appropriate circumstances for their activity, such as temperature and enough oxygen for plants, play a big role in the breakdown of crop wastes and organic matter (Wichern et al., 2020).

3.3. Heavy Metal Toxicity

Heavy metal contamination of soil is one of the world's most serious environmental issues. Human activities, such as the burning of fossil fuels, the use of fertilizers, including sewage sludge and pesticides, road transport, and numerous industrial operations, are major contributors. (Stefanowicz et al., 2020). Large concentrations of heavy metals have been found in the soil as a result of human activities such as the mining and smelting industries, agricultural irrigation, and the use of pesticides and pollutants, which have contributed to the acceleration of urbanization and industrialization. (Wei & Yang, 2010). Typically, heavy metals are not biodegradable and are extremely challenging to remove from soil (Rizwan *et al.*, 2016) It may be passed on to crops via the soil-plant-food cycle, causing dangers to human health. (Seleiman *et al.*, 2020). Heavy metals such as Cd, Zn, and Pb have a negative impact on plant development and, as a result, on human health. Due to its high toxicity and mobility in agricultural soil, Cd has garnered the most attention among them. (Rizwan et al., 2016). As a result, remediation of Cd-contaminated soils is critical.

The presence of heavy metals in the soil in quantities harmful to microorganisms. Microorganisms are one of the most promising. (Guo et al., 2017) First off, they have a high surface-to-volume ratio, which puts them in close contact with the environment and enables them to react fast to changes in the environment. (Zhang et al., 2010). Second, they play an important role in key ecological activities such as organic matter decomposition, element cycling, soil structure creation, and plant nourishment. (Zhang et al., 2010). Therefore, any qualitative or quantitative alterations in the soil's microbial population brought on by heavy metal contamination may result in alterations in how the ecosystem functions. (Stefanowicz et al., 2020).

Heavy metal buildup in food plants caused by polluted soils is reduced using organic amendments. Large-scale addition of organic composts improves soil's physical qualities by acting as a soil conditioner in addition to supplying nutrients. Utilized to reduce the availability of heavy metals in polluted soils, organic composts are low in metals (Park et al., 2011). Vermicompost and wasted mushroom compost are also used in the bioremediation of heavy metal-contaminated soils. Vermiremediation is a method of bioremediation. A practical science called vermiremediation is used to remove heavy metals from soil different varieties of *Lumbricus rubellus* were employed to separate soil polluted by leachate and containing different heavy metals (Cheng-Kim et al., 2016). The concentrations of heavy metals in the earthworm's internal body were substantially and adversely linked with the concentrations of heavy metals in the vermicompost. The higher the bioaccumulation factor, the more metal accumulates in earthworm tissue, affecting the food chain. Metal buildup in worm tissue not only remediates metals from urban garbage but also enhances vermicompost quality by lowering metal concentration. The capacity of earthworms to reduce heavy metal toxicity and improve the nutritional content of organic wastes may be beneficial in sustainable land *restoration* strategies. Heavy metals can bond with tissue ligands, resulting in bioaccumulation (Cheng-Kim et al., 2016). A positive link between metal concentrations in earthworms and soils was found, which may be related to the fact that various metals have varying bioaccumulation factors. Earthworms can live and thrive in metal-contaminated environments, and they may store heavy metals in the cells of their yellow tissue. Populations of earthworms might evolve a defense against or tolerance to the effects of metal-induced stress. Earthworms can either modify their genetic makeup or undergo reversible physiological changes to gain this tolerance. The life cycle characteristics of earthworms, such as growth, reproduction, and survival, are adversely impacted by heavy metal contamination. Due to the creation of a metal-phosphate complex in the soils, the treatment of high phosphorus considerably reduced lead, zinc, and cadmium bioavailability to the earthworm (Shahmansouri et al., 2005). Vermicompost decreased the ecological risk to invertebrates that live in soil and are exposed to soils that are polluted with heavy metals. When heavy metal toxicity is present in the materials and is bio-converted, earthworms serve as an indication, signaling a possible environmental concern (Singh et al., 2018).

Despite an increase in their overall composition, vermicompost reduces heavy metals most likely through creating organic complexes. Vermicompost, which is often regarded as an excellent alternative for lowering the availability of heavy metals to plants, is both readily accessible and inexpensive (Alam et al., 2020).

Organic Amendments

Improve soil quality

- Increase soil organic matter content
- Improve soil structure by binding soil particles
- Increase water holding capacity by absorbing and holding more water in rhizosphere.
- Improve nutrients availability (CEC)
- Reduce soil erosion and nutrient losses
- Increase soil microbial activity

Increase crop productivity

- Improve nutrients availability (N, P, S, Ca etc)
- Greater root exploration and nutrient acquisition
- Enhance antioxidant activity and stress tolerance
- Reduce salt accumulation and alleviate salinity stress
- Enhance photosynthetic pigments
- Increase plant immune system
- Improve crop yield and productivity

Organic amendments improve soil health, making marginal areas more productive and sustainable.

Figure 2. Potential benefits of organic amendments on soil quality and crop productivity under marginal lands

4. Conclusion

Marginal lands are distinguished by poor soil health, unsuitable for crop cultivation, and low economic returns. However, to ensure food security and to reduce land use competition for the burgeoning population, growing crops on marginal land has emerged as an alternative option. Currently, the detrimental effects of intensive agricultural practices, excessive exploitation of natural resources, and changing climate patterns also contribute to the expansion of marginal lands. Many conservation efforts have been undertaken to reduce marginal land and boost agricultural productivity in these areas. Organic amendments are a viable alternative to the present intensive farming system, amendments have been a common strategy in agriculture since ancient times. Additionally, there is enough evidence that organic amendments come from various sources, such as animal manure, municipal biosolid, green manure, crop residue, compost, and vermicompost, etc. are important in tackling the various challenges of dryness, salinity, and heavy metal toxicity. These amendments, directly and indirectly, affect soil physicochemical and biological properties. Compared to animal manure, green manure, and municipal waste, compost, and vermicompost is better. Compost and vermicompost are formed from decomposing of organic matter. They contain various essential nutrients, beneficial microorganisms, enzymes, and hormones that can help plants to tolerate various abiotic stresses (drought, salinity, and heavy metals toxicity). Moreover, compost and vermicompost improve soil structure, increase water retention, suppress weeds and diseases, attract beneficial insects, and reduce greenhouse gas emissions making marginal lands more productive and sustainable.

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CHAPTER 5

ENHANCING PHYTOREMEDIATION EFFECT WITH SUSTAINABLE BIOSTIMULANTS

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1. Introduction

1.1. Pollution and Environmental Pressures

Environmental pollution and increased energy use are interrelated, according to recent research. One of the main problems that humanity will soon face is environmental degradation. Species extinction, ecological damage, and the depletion and pollution of natural resources are signs of environmental degradation. Soil, water, and air pollution are concerns linked to environmental pollution (Nasrollahi et al., 2020). These concerns raise the issue of developing effective preventive and remedial measures. (Destek et al., 2019; Ozcan et al., 2020). Globally, heavy metals are recognized as one of the most important pollutants. Heavy metals are continuously released into the environment due to human activities such as the burning of fossil fuels, mining and smelting of metal ores, the growth of cities and industries, the generation of enormous volumes of municipal garbage, and agricultural activities (Song et al., 2017; Panfili et al., 2017; Nazir et al., 2022). Depending on their chemical and physical properties, heavy metals may not be dangerous to living organisms until they are present in very amounts. In addition to slowing down photosynthesis, accelerating senescence, and causing oxidative stress in plants, it can also displace other metals from pigments and limit growth (Bartucca et al., 2017; Li et al., 2017).

The accumulation of pesticides in soil and water poses a threat to human and animal health. Although pesticides are used in agriculture for control purposes, they are selective in their targets (Mostafalou and Abdollahi, 2017). Some pesticides can affect non-target organisms, causing morphological, physiological, and biological changes. For example, pesticides have been shown to inhibit plant growth and biomass production, interfere with the absorption and utilization of minerals, reduce chlorophyll concentrations, and cause cell death (Bartucca and Del Buono, 2020).

Stricter legislation is needed to limit environmentally damaging emissions. Another step in reducing pollution is the transition to renewable energy sources (Del Buono et al., 2020). To understand how pollution affects ecosystems in the soil, water, and air and to choose the appropriate course of action, it is essential to model a variety of sources of pollution (Nazir et al., 2019). In addition to reducing emissions, restoring contaminated sites also requires special attention (Srinivas et al., 2020). Currently, numerous strategies can be used to clean up or recover the contaminated environment, and these often include in situ remediation procedures (Lima et al., 2017). But these techniques can be expensive, more energy-intensive, require specialized equipment, or cause secondary pollutants. As a result, contamination cleaning may not be perfect (Dhanwal et al., 2017; Gunarathne et al., 2019). This review highlights the effectiveness of the beneficial relationship between plants and biostimulants in environmental pollution and the role of some biostimulants in phytoremediation. Furthermore, plant growth, yield, and resistance to biotic and abiotic stress factors of biostimulants are discussed to support the phytoremediation process.

1.2. *Phytoremediation*

Recent years have seen an increase in the search for innovative and affordable bio-based remediation methods due to ecological hazard concerns (Sarma, 2011). Thus, the practice of "bioremediation," which involves using microorganisms to purge contaminated environments, has grown in acceptance (Aafi et al., 2012). Some bacteria, fungi, and algae can exhibit significant potential to remove or neutralize various pollutants (Dangi et al., 2019). Some enzymes present in bacteria direct the cleanup process in bioremediation (Kumar and Bharadvaja, 2019). Phytoremediation is another environmentally friendly method that can be used to restore damaged environments. This state-of-the-art, biologically-based technique takes advantage of the capacity of plants to remove various types of toxins from air, soil and water or convert them into less harmful molecules or derivatives (Pannacci et al., 2020). Phytoremediation is popular because it is effective and environmentally friendly (Bartucca et al., 2016). According to studies, various plant species can actually reduce, eliminate or stabilize large amounts of toxins in contaminated sites. Phytoremediation practices reduce the harmful impact of toxic substances that can seriously interfere with vital functions (Buono et al., 2016). These species often express substantial quantities of enzymes and antioxidants that aid in detoxification. A variety of contaminants are removed or converted into less toxic derivatives using different phytoremediation strategies (Del Buono, 2020). The primary phytoremediation methods are, however, briefly listed below.

Phytoextraction is a method that relies on a plant's ability to take pollutants from polluted areas and move them to its above-ground tissues via its roots. This skill is typically appropriate for cleaning up heavy metal-polluted locations. Plants known as "hyperaccumulators" are particularly valued in phytoremediation. Due to their ability to remove and store substantial amounts of toxic substances in their tissues, these species are frequently used in phytoextraction (Baştabak et al., 2021).

The idea behind phytostabilization is to provide plants the capacity to absorb or precipitate contaminants to pull them out of the rhizosphere (Ekta and Modi, 2018; Del Buono, 2020). This method greatly reduces the availability of the hazardous substance, limiting its ability to contaminate water or enter the food chain (Dhanwal et al., 2017).

Phytodegradation is a strategy that exploits the potential of xenobiotics to be detoxified or metabolized by plants through the action of multiple enzymes. Because of the capacity of some plants to inactivate and separate/demobilize organic pollutants such as herbicides, phytodegradation is typically used to remove them from polluted environments (Baştabak et al., 2021).

The process known as phytovolatilization relies on the tendency of some species to absorb pollutants from the growing medium through their roots and convert them into volatile forms. Subsequently, stomata may release xenobiotics into the atmosphere (Farraji et al., 2020). This method is commonly employed to remove certain metals, metalloids, or volatile chemical compounds from polluted areas (Dhanwal et al., 2017).

The use of biofiltration of aquatic and terrestrial plants to remove pollutants from the aqueous environment is the focus of this technique. Instead, the plant can precipitate the desired chemical, reducing its bioavailability and mobility (Baştabak et al., 2021). Heavy metals, dyes, and organics can be successfully removed by this technique (Dhanwal et al., 2017; El-Aassar et al., 2018).

This method, known as phytostimulation, focuses on bacterial and fungal organisms living in the rhizosphere that break down pollutants. Substances found in plant roots, such as sugars and amino acids, are used as a food source for these organisms and to increase their biological activity and metabolism (Dhanwal et al., 2017). Phytostimulation is often used to remediate soils contaminated with organic matter such as pesticides, polycyclic aromatic hydrocarbons, or biphenyls (Farraji et al., 2020). Used to reduce the damage caused by different pollutants, phytoremediation has several benefits such as being efficient, environmentally friendly, can be used in situ, requires little energy and does not need a lot of equipment. However, they have the disadvantages of being dependent on environmental conditions and slower than traditional methods (Bartucca et al., 2022). Phytoremediation in environmental pollution is given in Figure 1.

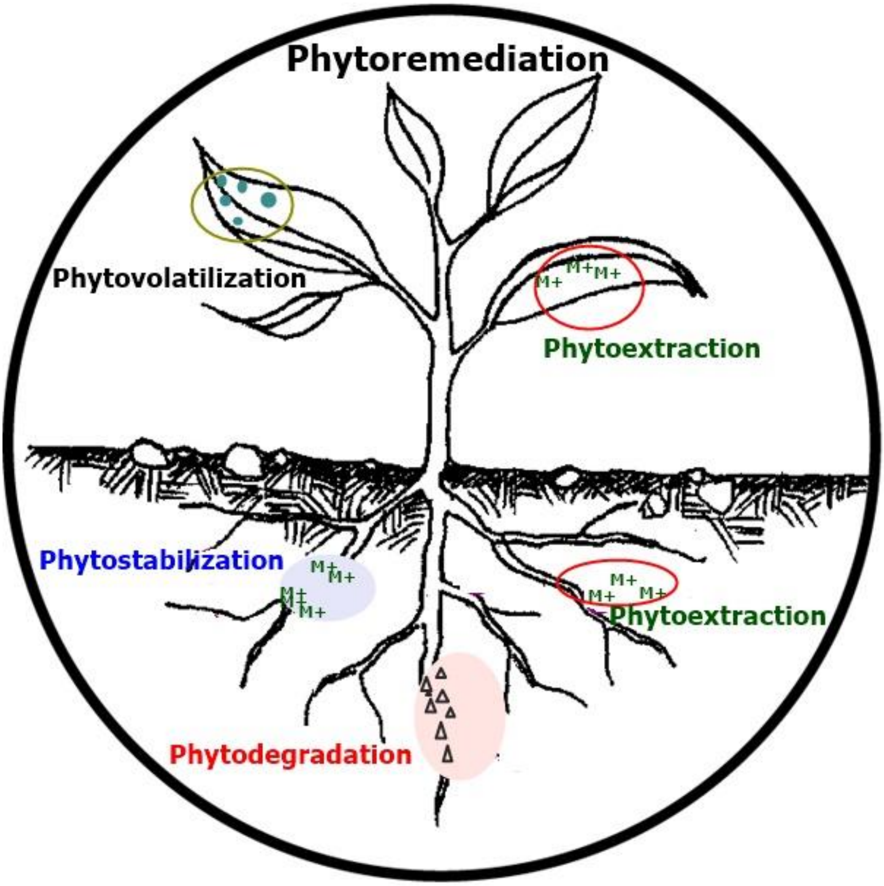

Figure 1. Phytoremediation in environmental pollution

1.3. *Biostimulants*

Biostimulants are substances used in agricultural applications to increase the availability and uptake of nutrients by plants, increase crop yields and improve the ability of plants to cope with stress conditions. These compounds can be derived from microorganisms, humic substances, or plant waste and have the potential to enhance phytoremediation. As they are natural substances, they pose no threat to the environment (Bartucca et al., 2022; Sandhu et al., 2022). Plant biostimulants, also called biological fertilizers, biostimulants, plant antibiotics, and metabolism enhancers, are compounds currently used in agriculture to improve the quality and productivity of plants. Their use on crops enables the activation of physiological and molecular processes that may enhance production and product quality (Rouphael and Colla, 2018; Del Buono, 2021; Sible et al., 2021).

Fertilization products are used to improve any or all of the properties of plant rhizospheres, regardless of their nutrient content. Biostimulants include 1) plant nutrient uptake, 2) the ability to tolerate or resist biotic and abiotic stressors, and 3) enhanced nutrient availability in the soil. Biostimulants do not fall into the category of fertilizers or plant protection products, as their primary purpose is not to deliver nutrients or protect plants from pathogens and pests (Sible et al., 2021; Bartucca et al., 2022). They help plants utilize minerals more effectively and overcome abiotic stress factors. They also absorb them, increasing the availability of nutrients for plant roots (Calvo et al., 2014). Biostimulants may also make it possible to use less of the chemical fertilizers typically used in agriculture due to their effectiveness in enhancing plant nutrient uptake. This activity can therefore promote environmentally friendly sustainability in agriculture at the level of potential reduction of highly consumed synthetic compounds (Puglia et al., 2021). Despite their origins in horticulture, biostimulants are increasingly employed on a variety of crops to encourage beneficial outcomes (Sible et al., 2021). It is feasible to observe the stimulating effects of biostimulants on plants by starting with fundamental elements that have tremendously various compositions and sources (Rouphael and Colla, 2018).

Therefore, biostimulants grouped into protein and amino acids, inorganic salts, humic substances, organic substances, seaweed and plant extracts, and animal/herbal helper microorganisms (Bacillus, mycorrhiza, Trichoderma and algae) (Du Jardin, 2015; La Torre et al., 2016). The synergistic interaction between many components determines how well biostimulants enhance plant growth, productivity, yield, and quality (Koleška et al., 2017). The role of plant biostimulants on pollutants in phytoremediation is given in Figure 2.

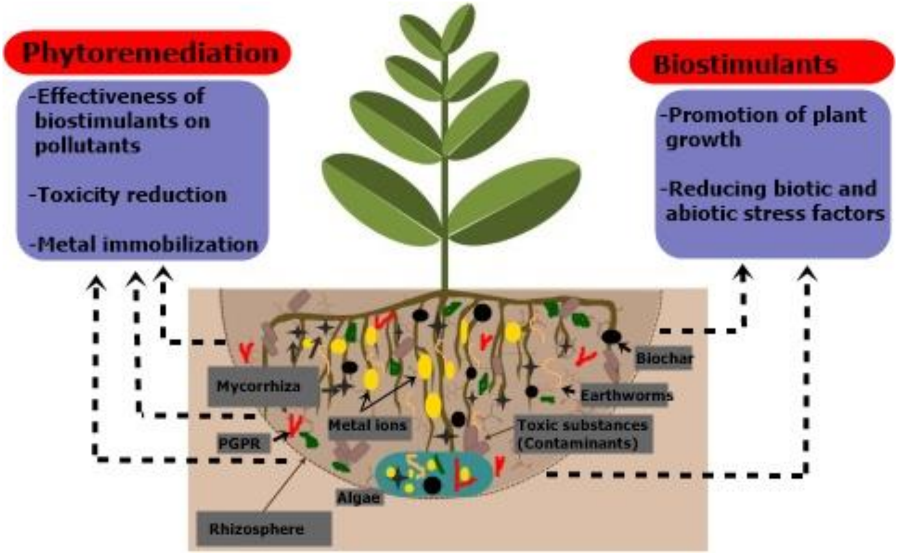

Figure 2. The role of plant biostimulants on pollutants in phytoremediation

1.4. Toxic Compounds: How Biostimulants Can Help

Biostimulants can grow the plant's tolerance to diverse stress factors. Application of biostimulants to the plant, seed, or soil can increase its tolerance to abiotic stressors such as drought and salinity (Du Jardin, 2015; Yakhin et al., 2017; Del Buono, 2021). Chlorophyll and pigment production, plant transpiration, leaf water content, or the activity of antimicrobial enzymes that regulate water loss and barrier disruption are a few physiological and biochemical processes in plants that are affected by salt and drought stress. According to recent research, biostimulants may be able to mitigate these effects (Goñi et al., 2018; Del Buono et al., 2021). Furthermore, because biostimulated crops are more effective at collecting and utilizing nutrients, biostimulants may enable a reduction in the usage of artificial fertilizers (Du Jardin, 2015).

Biostimulants have also been tested on plants planted in contaminated areas, helping these species to rid the plants of toxic substances. Some of this study has been done in areas where pesticides and heavy metals (HMs) from the most important global pollutants pollute soil or water (Bartucca et al., 2022). Recent research suggested that biostimulants could lessen the toxicity of heavy metals to plants. According to Calvo et al. (2014)'s research, products including protein and also fulvic and humic acids may be responsible for this advantageous effect. Furthermore, biostimulants with protein and amino acid active components can increase plant resistance to heavy metals. Since proline can chelate metal ions inside of plant cells, act as an antioxidant, and be crucial to osmoregulatory processes, it is one of the amino acids that plants have more of, which helps protect them more effectively. Furthermore, humic substance-based plant stimulants can increase the content of antimicrobial agents essential for the health of plants and stimulate the activity of certain enzymes that protect cells. In particular, it is responsible for promoting the synthesis of alkaloids and phenols and the rise in the concentration of non-enzymatic antioxidants. Humic substances interact with heavy metals, complexing them with carboxyl and aromatic hydroxyl molecules, which can reduce their movement in the soil and their absorption by plant roots (Canellas et al., 2015).

1.4.1. Arbuscular Mycorrhizal Fungi (AMF)

Fungal bioremediation is the safest and most sustainable way to decontaminate contaminated environments. Thanks to the enzymes secreted by fungi, it is easy to for getting different toxins and resistant contaminants. Fungi play important roles in bioremediation due to their large numbers, robust morphology, and diverse metabolic capabilities (Tomer et al., 2021). Phytoremediation, one of the effective biotechnological methods for the removal of environmental pollutants, is a low-cost sustainable solution. It uses microorganisms and the right nutrients to convert organic and inorganic pollutants into non-toxic forms (Adeleye et al., 2018; Nkereuwem et al., 2022). Adeley et al. (2019) stated that bioremediation technology can utilize biostimulation or enhancement technology to break down, detoxify pollutants harmful to human health. Plant-microorganism association is the most ideal way to address environmental pollution in a sustainable, economical, and environmentally friendly way (Slama et al., 2021). Mycorrhizal fungi that populate the surface area of root-soil contact and rhizosphere microbial activity have been suggested to enhance the biodegradation of resistant organic pollutants (Sharma et al., 2008; Gao et al., 2011). Numerous studies have shown that some microorganisms work together with mycorrhizal fungi in the phytoremediation process (Alarcon et al., 2008; Liu and Dalpe, 2009; Teng et al., 2010). In some studies, degradation of Polycyclic Aromatic Hydrocarbon (PAH) such as chrysene, phenanthrene, anthracene, pyrene, and benzopyrene by AMF application has been successfully detected. The reduction of PAHs in soil has been associated with mycorrhiza microorganisms in soil (Liu et al., 2004; Gao et al., 2011).

Arbuscular mycorrhizal fungi (AMF), which have a symbiotic relationship with most land plants worldwide, are one of the effective phytoremediation methods (Khodaverdiloo and Homaee, 2008). Numerous factors like root colonization and soil spore density can be used to explain the role of AMF in reducing the impact of environmental pollutants (Güneş et al., 2021; Herath et al., 2021). AMF can retain or accumulate contaminants such as heavy metals and petroleum in the host plant's roots. In other words, it supports the phytostabilization of soil (Joner et al., 2000; Citterio et al., 2005; Audet and Charest, 2006). Parrish et al. (2005) reported a more rapid reduction of petroleum hydrocarbon toxicity in plant-mycorrhiza-associated soils. According to Nkereuwem et al. (2022), mycorrhizal application can reduce the toxicity of crude oil-contaminated soil and improve soil fertility in the root zone environment. Spore density increases at the first point where AMF and pollutants interact. Therefore, the decrease in heavy metal concentration is supported by immobilization reactions in the rhizosphere and the tolerance of AMF microorganisms based on the phospholipid fatty acid profile (Holtan-Hartwig et al., 2002; Almås et al., 2004). According to some studies, AMF acts as a filtering barrier to prevent pollutant damage, and pollutants adhering to AMF hyphae do not spread to plant shoots (Gaur and Adholeya, 2004; Herath et al., 2021). Microorganisms use organic materials from environmental contamination for wholesome growth and development. They even facilitate plants' access to multiple macro and micronutrients like nitrogen and phosphorus (Tomer et al., 2021; Güneş et al., 2021).

AMF hyphae can secrete glomalin, a glycoprotein. Glomalin is one of the sustainable methods that can improve soil quality and structure and contributes to increased soil fertility (Herath et al., 2021). Glomalin, a component of the soil organic matter fraction, makes up a significant portion of the total protein content of soil and helps bind soil particles to increase aggregate stability (Preger et al., 2007). Moreover, according to some molecular data, this protein is also an important component of spores and hyphal cell walls as a homolog of several heat shock proteins associated with environmental stresses (Gadkar and Rillig, 2006; Malekzadeh, 2022). Therefore, the role of glomalin in phytostabilization processes in contaminated soils has become a crucial factor to be acceptable (Cornejo et al., 2017). In phytoremediation research, strigolactones are one of a limited class of phytohormones. Strigolactones, which reduce oxidative stress, have several functional roles in controlling the growth and development of both plant shoots and roots. In addition to promoting capillary root elongation, AMF has also been found to activate hyphae branching (Lovejoy and Smemo, 2021). So far, about 20 different strigolactones have been isolated and identified from plant root secretions. Synthetic strigolactone analogs have been produced to increase their use in industry (Yoneyama et al., 2009; Ruyter-Spira et al., 2011; Vassilev et al., 2015).

Soil management techniques reduce the percentage of colonization by disrupting the mycelium network of mycorrhizae. However, AMF produces more mycelium to avoid stress conditions in the environment.

Therefore, some AMF host plants (maize, alfalfa, cloves, onions, tomatoes) can be applied to soil for fertilization (Herath et al., 2021). Cotton plants are suitable for phytostabilization in contaminated (heavy metal) soils, according to research by Rabie (2005). This is because AMF mycelia have been found to inhibit metal accumulation in cortical cells or metal transport from roots to shoots. The use of such sustainable mycorrhizal plants for soil pollutants is to reduce soil contamination, provide detoxification through sorption on phosphate granules and improve plant growth parameters (Solís-Ramos et al., 2021). Mycorrhiza is one of the methods used for phytoremediation of many pollutants, including aliphatic hydrocarbons, other petroleum hydrocarbon mixtures, pesticides and chlorinated organic compounds (Joner and Leyval, 2003). The use of mycorrhizae in biotechnological methods is an effective, efficient, and long-needed research topic. AMFs are obligate biotrophs due to their life cycle. However, there are approximately 1000 possible organic pollutants and roughly 170 AMF species (Gao et al., 2010). However, much less research based on the relationship between AMFs and organic pollutants remains to be done.

1.4.2. Trichoderma

Trichoderma is one of the biostimulants that can improve plant growth by altering the microbiome of the rhizosphere, increasing soil nutrient solubility, and enhancing plant nutrient uptake (Harman, 2000; Harman et al., 2004). Furthermore, according to the research of Wei Lin and Zhang (2006), *Trichoderma harzianum* can produce growth-promoting substances that resemble plant hormones, such as gibberellic acid and indole acetic acid. *Trichoderma* members have been reported to play several roles in soil bioengineering, including inducing systemic resistance in plants, improving rhizospheric competence to compete with soil-based competitors, producing siderophores, secreting numerous additional cellulosic enzymes, and having the potential to neutralize toxic organic compounds of primary origin and secondary metabolite structure (Gomes et al. 2020). According to reports, fungi can adapt to the unfavorable and unfavorable conditions of soil contamination with a high degree of plasticity and a large wide amplitude (Frac et al. 2018; Nazir et al., 2022).

Biostimulant compounds and plant-beneficial microorganisms containing Trichoderma have recently been investigated in assisted phytoremediation (Fiorentino et al., 2013; Visconti et al., 2020). *Trichoderma* has symbiotic interactions with many plant species. In addition to promoting plant growth, they are tolerant to toxic substances and provide plant resistance and protection against these pollutants (Visconti et al., 2023). *Trichoderma*-based products have been particularly successful among fungal species due to their biostimulating activity, ability to control phytopathogenic fungi, and ability to improve tolerance to abiotic stresses (López-Bucio et al., 2015). A liquid solution is prepared to produce sufficient numbers of viable inoculum for field applications. These solutions are considered harmless to humans, animals, and agricultural plants. The biostimulant abilities of Trichoderma are based on the communication between the fungus and the root with auxins and volatiles. Genomic studies show that Trichoderma activates several enzymes, gene synthesis proteins, and transcription factors in plants (Bartucca et al., 2022). *Trichoderma* spp.

is an effective method to increase biomass and promote nitrogen uptake. Microbial biostimulants such as biochar, mycorrhiza, and *Trichoderma* work in harmony to promote the establishment of a fescue grass mixture on soils with poor qualities (Leung et al., 2013).

1.4.3. Plant Growth Promoting Rhizobacteria (PGPR)

Since the past few decades, several Plant growth-promoting rhizobacteria (PGPR) have been investigated and linked to phytoremediation of metalliferous soils. These PGPR exhibit both heavy metal detoxifying traits and plant growth-promoting activities (Ahemad, 2015). Plant growth-promoting rhizobacteria (PGPR) are a promising biostimulant from soil microorganisms that protect plant nutrient and water use diffusion and uptake, reducing pollutant damage (Armada et al., 2014). Stimulants using plant growth-promoting rhizobacteria (PGPR) can reduce heavy metal uptake by plant roots by chelating, binding, and precipitating heavy metals. Low levels of heavy metals in the tissues above ground of biologically stimulated plants also reflect the advantages of PGPRs (Hamid et al., 2021). PGPR produces siderophores that remove iron from the soil and reduce the growth of harmful soil microorganisms (Kloepper et al., 1980). PGPR's plant growth-promoting properties and pollutant detoxification can enhance the biological remediation capacity of plants by promoting plant growth even at hazardous levels of different metals. PGPR aims to overcome levels of harmful pollutants that significantly reduce plant growth. Together with plants, PGPR reduces contaminant toxicity by promoting phytostabilization or phytoextraction. The phytoremediation capacity of plants may be contributed by many plant growth-promoting properties of PGPR, including organic acid synthesis, siderophore secretion, IAA and ACC deaminase activity (Ahemad, 2015). The most significant auxin that controls many morphological and physiological processes in plants is indole-3-acetic acid (IAA) (Glick 2012). In addition to reducing salt stress, IAA contributes to root growth, plant-pathogen interactions, and the induction of systemic susceptibility to different diseases. It also encourages the development of lateral roots in plants and improves water and mineral absorption (Egamberdieva, 2009). Under metal stress, bacterial IAA alters the metabolism of plant cells physiologically, facilitating host plant adaptability in metal-contaminated environments (Glick 2010).

1.4.4. Atrazine-Degrading Bacteria

Atrazine's lengthy half-life, moderate persistence, and high solubility make it a very concerning pesticide to find in soil and water (Yue et al., 2016; Henn et al., 2020). Atrazine use is reported to pose a significant ecological risk to fish, birds, mammals, and aquatic plants (Abd Rani et al., 2022). Atrazine applied to plants exposes cell organelles to harsh conditions (such as loss of chlorophyll and other pigments) and causes their death (Sherwani et al., 2015). In addition to its negative impact on human reproduction, atrazine has also been reported to cause cancer and neurological diseases (Gu, 2016; Pogrmic-Majkic et al., 2018). In recent years, researchers have focused on approaches through innovative technologies to reduce the impact and toxicity of atrazine in aquatic environments (de Albuquerque et al., 2020). A review of atrazine treatment technology, including the advantages and disadvantages of combined biological, physicochemical, and microbial technology, was completed in 2019 (He et al., 2019).

Microorganism utilization has been acknowledged as a strategy between bioremediation methods for soils contaminated with heavy metals, herbicides, chlorophenols, and aromatic hydrocarbons (Azubuike et al., 2016). Biotechnology is the conversion of pollutants into non-toxic substances by organisms such as fungi, bacteria, and plants (Chandra et al., 2019; Zhang et al., 2020a). In some cases, the separation of toxins or pollutants has been the focus, as the accumulation of intermediates can be more harmful than primary molecules (Gu, 2016). Some bacteria have been found to play an important role in degradation through enzymatic mechanisms (atrazine chlorohydrolase, hydroxy atrazine hydrolase, N-isopropyl acrylamide, amide hydrolase, cyanuric acid, allophane, and triazine) and atrazine reducing genes. This degradation mechanism has been used as an alternative to bioremediation. The degradation mechanism of atrazine is best recognized in the ADP strain encoding genes in the Pseudomonas sp. pADP1 plasmid (Abd Rani et al., 2022).

1.4.5. Impact of Biochar and Earthworms on Pollutant Removal

To improve the economy and raise living conditions, more sources of bio-waste are produced in everyday life (Zhou et al., 2021). A biomass treatment technique that is effective in producing organic waste is biochar. In order to make biochar, raw materials such as animal manure, agricultural and forestry waste, industrial bio-waste, and marine and aquatic organisms are used. Pyrolysis of biomass can be solid, liquid, or gaseous. Biochar is a substance obtained by high-temperature pyrolysis of biomass (solid) in an oxygen-free environment (Yang et al., 2020).

Biochar, obtained from various sources, is a substance with high carbon content formed by pyrolyzing organic raw materials with little oxygen (Wang and Wang, 2019). The primary objective of using biochar is to improve soil fertility and promote plant growth (Lipiec et al., 2016). Its large pores and very large surface area make it an optimal physical support for soil microorganisms (Atkinson et al., 2010). In fact, recent research has suggested that biochar used in soil contamination areas increases its stability against environmental stress factors (Elzobair et al., 2016; Zhu et al., 2017).

Emissions of greenhouse gases (CO_2, CH4, and N_2O) and pollutants (H_2S, SO_2, and NH_3) that lower crop output and value are common characteristics of treatment methods used to dispose of these agricultural wastes. Composting or incineration, however, can reduce these drawbacks (Dunnigan et al., 2018; Yang et al., 2021). However, the e technique of producing biochar through the pyrolysis of agricultural wastes offers many advantages and potential, including significant quantities and resources as well as a wide variety of application sectors (Yang et al., 2018; Gunes et al., 2023). The prepared biochar can be used in areas such as wastewater treatment, soil improvement, carbon sequestration and carbon emission. By retaining nutrients in the soil, biochar promotes agricultural sustainability and yield when it is applied to agricultural fields (Hu et al., 2021). When organic wastes are used in agricultural production, they return the nutrients they contain to the soil and provide a circular economy (Kwoczynski and Čmelík, 2020). In addition to these advantages, earthworms can be employed as promoters in mobilizing the biosphere. According to Jones et al. (1994), they actively contribute to altering the physical, chemical, and biological characteristics of soil. The subsurface soil contains 60 to 90% earthworms. They can be found in soil at a density of 5 to 150 earthworms per square meter (Xiao et al., 2022). There are more than 4000 earthworm species reported to exist, and they differ in appearance, size, and ecological activity. According to how they feed and live, earthworms are categorized as epigeic, aneic, or endogeic (Sizmur and Richardson, 2020; Huang et al., 2021). Earthworm feeding and burrowing activities promote the growth of microorganisms (Huang et al., 2018; Lipiec et al., 2016). This increases the efficiency of soil organic matter decomposition and nutrient cycling system (Brown et al., 2004; Sanchez-Hernandez, 2018). Exotic earthworms are less sensitive than other earthworm species. They have a higher impact on soil contaminants and soil properties (Marichal et al., 2012; Ardestani and van Gestel, 2019). Besides being reliable indicators of soil contamination, earthworms help to restore contaminated soil (Sizmur et al., 2020; Xiao et al., 2022). Biotechnological research involving microorganisms is called "micro-remediation." Earthworms have recently been employed to eliminate soil contaminants. "Vermi-remediation" (Sinha et al., 2009) is another name for the practice of utilizing earthworms to remove pollutants from soil. There are two methods for vermi-remidation. These are, respectively, ex-situ vermicomposting with active biochars and in-situ bioactivation (vermiremediation), which consists of direct application of the earthworm to the soil. Both strategies rely on the ability of earthworms to enhance microbial activity (Sanchez-Hernandez, 2018). Vermi-remidation, unlike composting, uses pest worm species such as Eisenia fetida and E. andrei. Vermicomposting can be characterized as a two-stage decomposition process that takes place simultaneously (Domínguez et al, 2011). These are the muscular processes of the earthworm as well as the processes associated with its intestines. In the tissues of earthworms, contaminants from the soil bioaccumulate (Nozaki et al., 2009; Sinha et al., 2009; Sanchez-Hernandez et al., 2019). Research on the enzymatic nature of vermic-remidation shows that a wide range of digestive enzymes, including glucosidase, urease and phosphatases, are involved in earthworm muscles (Castillo et al., 2013; Ghosh et al., 2018).

Conclusions

Natural resource degradation is an important issue that cannot be put off any longer. Undoubtedly, one of the main factors leading to ecosystem degradation and depletion of natural resources is the continuous discharge of hazardous compounds and their consequent accumulation in the natural environment. Therefore, there is a need for a technologically and environmentally friendly, effective, and sustainable model for the disposal of chemical and radiation pollutants. This model is phytoremediation, a method of removing/reducing pollutants that heavily pollute our soil, water, and air. Due to the current use in sustainable agriculture of biostimulants that can enhance the phytoremediation effect and make it more effective, we proposed their use in this review. They can increase the effectiveness of cleanup of contaminated sites (heavy metals, salts, etc.) and reduce the adverse effects of hazardous compounds on plants.

Biostimulants from various sources provide the opportunity to experiment with biostimulants with different modes of action. In this study, studies testing the effect of biological stimulants derived from Arbuscular Mycorrhizal Fungi (AMF), Trichoderma, Plant growth-promoting rhizobacteria (PGPR), Atrazine-degrading bacteria, Biochar, and earthworms on pollutant removal in phytoremediation were reviewed and discussed. These investigations show how biostimulants can lessen the harmful effect of pollutants under stress conditions and help the plant to overcome the stress. Most of the studied samples show that the phytoremediation procedure is successful when the appropriate amount of biostimulants is employed.

The numerous benefits of using biological stimulants in phytoremediation procedures have been described above. The application of biostimulants to the plant or plant growth medium facilitates the phytoremediation system, which is a common agricultural practice. Since biostimulants are natural, their use has no negative impact on the environment.

Phytoremediation is one of the most promising techniques for the eco-rehabilitation of contaminated sites to their natural state, but further investigation is required to advance our knowledge of the role of biostimulants in phytoremediation.

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CHAPTER 6

DETECTION OF PESTICIDES RESIDUE IN THE FRUITS AND VEGETABLES BY USING OF PORTABLE SERS SENSORS

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1.1. INTRODUCTION

Organic agriculture is a production system that maintains the balance in nature, contributes and maintains soil fertility, ensures the continuity of living creatures in nature by controlling diseases and pests, and ensures optimum use of natural resources and energy. In organic and conventional agriculture, "pesticide" substances are used to prevent, control or reduce the damage of harmful organisms.

According to the European Commission Pesticide approval database, there are 490 pesticides currently approved in the EU, and only 28 of these are approved for use in organic farming. Provisions regarding the control/inspection of organic agricultural products are stated within the scope of the "Regulation on the Principles and Implementation of Organic Agriculture".

This Regulation; Production or supply of inputs to be used in the production of all kinds of plant, animal and aquatic products in accordance with the organic farming method, collection of products from forests and natural areas in accordance with organic farming principles, processing, packaging, labeling, storage, transportation, marketing, control and certification of these products. It covers technical and administrative issues regarding auditing and criminal provisions.

In order to determine whether organic farming activities are carried out in accordance with this Regulation, authorized organizations, enterprises and entrepreneurs, controllers and certifiers are determined by inspections carried out by the Ministry or organizations authorized to audit by the Ministry. Analyzing pesticide residues is very important in implementing organic farming norms. Nowadays, detection of pesticide residues is usually performed in the laboratory using large-scale equipment such as liquid chromatography mass spectrometry (LC-MS/MS). These detection methods often require complex pretreatments and professional operators, which are time-consuming and expensive. Surface Enhanced Raman Scattering (SERS) technology makes trace detection of pesticide residues feasible, but currently the SERS devices on the market are all large-scale and rapid detection of pesticide residues has not yet been achieved.

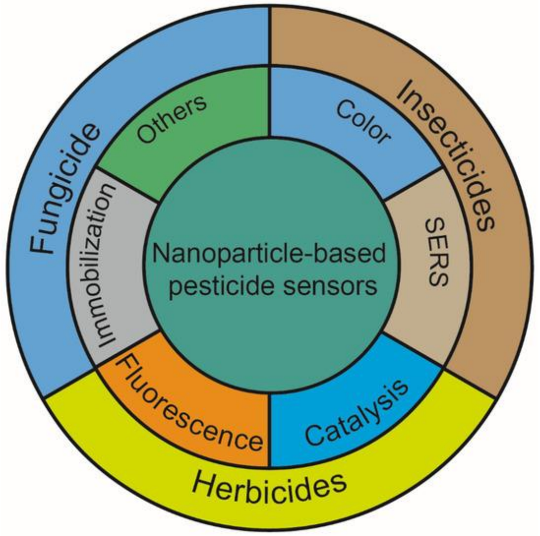

Figure 1: The functions of nanoparticles and their application in soil pesticide detection (Zhang et al., 2023)

1.2. SERS

SERS method is used to enhance Raman scattering. The scattered light with the same wavelength as the incident light (Rayleigh scattered light) is the same light scattered by the produced molecules. In this method, both Rayleigh scattered light and a small amount of scattered light of different wavelengths are emitted from Raman scattered light. The difference in frequency between the incident light and Raman scattered light (Raman shift) arises from the natural frequencies of the molecules. Raman scattering light spectroscopy provides information about the type and structure of the molecule (type of chemical bond, level of crystallinity, distortion of the crystal lattice, etc.). (Han et al., 2017).

Raman spectroscopy is a spectroscopic technique used for the identification of biochemical substances or biomolecules. Raman spectroscopy relies on inelastic scattering, also known as Raman scattering, when a laser interacts with molecules. Changes or shifts in the energy of laser photons can provide information about interacting molecules. This technique has recently been used to detect chemical or biomolecular substances, i.e. narcotic drugs, trace substances and emerging diseases (Wang et ai., 2014).

Recently, there were few processes to develop substrates that helped amplify Raman signals and efficiencies. Surface-enhanced Raman scattering (SERS) substrates have been a subject of interest among scientists. Theoretically, SERS substrates can be developed from gold, silver, copper or other noble metals and are anticipated to be widely used in the detection of biomolecules and chemical molecules. In the SERS method, the effect of nanostructured metal particles changes the intensity of Raman scattering. Ray; Some metals such as silver, gold and copper excite the electrons in the conduction band, creating enrichment in the molecules absorbed on these metals.

1.3. SENSOR EVALUATION

As a result of the examinations carried out with Raman spectroscopy, each substance's own vibration spectrum is obtained. The resulting vibration spectrum allows identification and interpretation of the analyte. When samples are examined with Raman spectroscopy, two disadvantages are encountered: fluorescence emission due to the laser source and weak Raman signals. To overcome fluorescence emission, a laser light source of long wavelengths of 785, 830 or 1064 nm is required, which falls into the visible-near-infrared region of the electromagnetic spectrum (Fan and Brolo, 2009).

Similar devices have been examined and the optical design for efficient detection of pesticide residues has been improved by increasing the laser wavelength (980 nm), reducing excitation efficiency and fluorescence, increasing heat absorption, etc. Important innovative ideas have been put forward. In addition, a customized device design for the analysis of pesticide residues, whose vibration spectrum is allowed for use in organic agriculture, is not yet available in the relevant market.

1.4. FOOD RESIDUATE CONTROL

In our country, 41 Food Control Laboratories and 97 private Food Control Laboratories affiliated with the Ministry of Agriculture and Forestry continue their activities. Food control devices used in laboratories require expert operators and the device must be imported from abroad at high costs. In order to increase the efficiency of use of these devices, the final product of this business idea will be designed as a portable, low-cost analyzer that can be used in laboratories (by the controller and/or certifier) and does not require an expert operator. In the first prototype production of the device, kinematic lens plate, dichroic mirror, achromatic lens, etc. to be used in the Raman spectroscopy device. Although the components are imported, when mass production begins, negotiations will be held to produce the components of the device in our country (Aselsan Precision Optical Production Center, Tübitak Optical Systems Research and Application Laboratory). This study will be carried out by Ostim Technical University and Agri Ciel Institute company (He et al., 2008).

1.5. SERS FOR DETECTION OF PESTICIDES IN FOOD SAMPLES

Detection of pesticides in real food samples is different compared to standard solutions. Different food groups are classified as follows: grains, oilseeds, vegetables, fruits, nuts, sugars, beverages, edible mushrooms, flavorings, medicinal plants, foods of animal origin. Pesticides can be observed in food in the form of conversion products, metabolites, reaction products and impurities. Detection of pesticides using SERS is done based on food groups and their characteristics (Zheng et al., 2023).

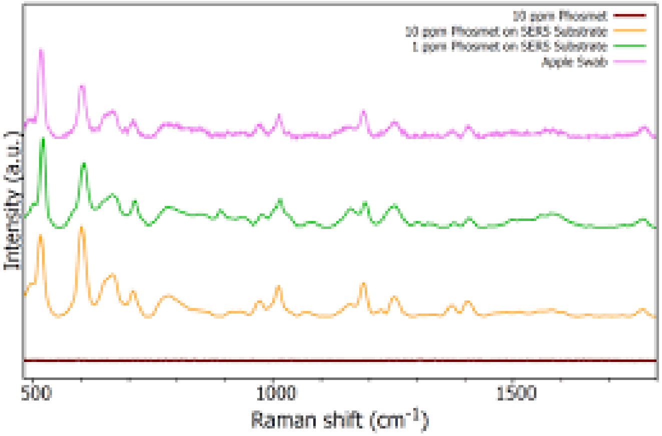

Figure 2: Pesticide Residue Detection | SERS Applications

1.6. FUTURE TRENDS AND PERSPECTIVES

SERS has great potential for the detection of pesticide residues in food as a rapid assessment technique. Super sensitive diagnosis, simpler protocols and cost reduction are the advantages of SERS technique.

1.7. CONCLUSION

Raman spectroscopy is an analytical method that can be used to analyze the quality and authenticity of agricultural food products. While important information can be obtained with this technique, such as specific matrices based on model compounds regarding lipids, carbohydrates and proteins, trace components have low sensitivity in identifying microorganisms that cause food spoilage and contamination (Ruoff et al., 2006a).

Although infrared and Raman spectroscopies are both vibrational, unlike the absorption of light in infrared spectroscopy, Raman spectroscopy uses the energy between a molecule and a photon. is based on exchange.

When the Raman effect occurs, the energy of the molecule interacting with a photon from the radiation source increases to a virtual level. The increase in energy is equal to the photon energy. As the excited molecule returns to its ground state, it emits at wavelengths different from the wavelength of the exciting radiation (Gayo and Hale, 2007). This emission is at shorter and longer wavelengths than the excitation radiation. Advances in instrumentation make Raman spectroscopy the tool of choice for a growing number of applications in the food industry (McCreery, 2001).

Some studies confirm that Raman spectroscopy has become a preferred tool by mentioning the effectiveness of different Raman spectroscopy methods in certain fields (such as agriculture and food sector). Raman and infrared spectroscopy are complementary techniques for food and food analysis. The surface-enhanced Raman spectroscopy (SERS) technique combines Raman spectroscopy and nanotechnology using metallic nanosubstitutes to increase the sensitivity and capacity of conventional Raman spectroscopy. The food industry is becoming more complex day by day in parallel with developing technology and rapidly changing consumer expectations, and this increases the tendency for food adulteration. Food adulteration may be accidental or intentional; However, food verification analysis is always needed (Kuswandi etal., 2015).

Detection of unintentional adulteration is relatively simple, but detection of intentional adulteration is quite complicated because the foreign material and the original material often have the same chemical and physical properties. Apart from food adulteration, food contamination is of great concern to the food industry and regulatory bodies as it adversely affects the health of the consumer. The impact of chemical contamination on consumer health generally occurs after long-term exposure to low levels. Determining food quality and authenticity requires comprehensive monitoring of food with effective analytical methods. Recently, various food quality assurance associations have been setting standards and recommending various analytical methods for measuring and identifying adulteration in food products (Rocha et al., 2011).

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CHAPTER 7

PHYTOREMEDIATION OF ARSENIC CONTAMINATED SOIL BY USING RICE PLANT

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1.Introduction

Today, soil pollution is one of the important global problems (Anonim, 2013). Recently, the use of microorganisms and plants to eliminate heavy metals in soil and water and their involvement in environmental protection practices have created awareness on this issue (Söğüt et al., 2011). One of the heavy metals studied in this regard is arsenic. Arsenic is one of the most abundant elements in the earth's crust. Although it is used as a raw material in many industries as well as agriculture and pharmacy, it is a very dangerous metal for human health (Blaylock ve Huang 2000). As groundwater comes into contact with the surface, it may contain high amounts of arsenic as a result of dissolving some compounds and minerals such as arsenic in the rocks and minerals it comes into contact with.

As a serious problem in many countries, instructions arsenic has been the cause of the extinction of more than 100 million people to this day (FDA, 2013a). Among the countries with abundant arsenic in drinking water in the world are countries such as the USA, China, India and New Zealand (Sing and Ghosh, 2012).. In many countries around the world, arsenic pollution of drinking water and the health problems it causes are accepted as 0.01 mg/L by the World Health Organization in order to prevent its effects. In 2008, this value was accepted as 0.01 mg/L with the Regulation on Water Intended for Human Consumption. Many methods such as ion exchange, coagulation/filtration, adsorption processes, membrane processes, and softening with lime are used to remove arsenic from wastewater (Anonymous,2013). Among these ratios, adsorbent diversity, ease of processing and economy make adsorption processes more prominent than other distributions (Glass, 1999). Because many absorbents (such as aluminum oxide, lignite, peat, silica gel, activated alumina, activated carbon, alumina silicates, zeolites) can be used in this method (Erdoğan, 2005).

Although physical and chemical treatment methods used for soil protection and control have some advantages such as ease of application and shortness of application development, they are not preferred due to the high treatment costs and the difficulty in removing other treatment forms that arise from decomposition treatment methods (Türkoğlu 2006). Another method used to remove heavy metals is the phytoremediation method (Terzi and Yılmaz, 2011). Some plants have mechanisms that can detoxify heavy metals; Metal can maintain its vitality under stress. Heavy metals are removed from the soil by utilizing these ratios of plants. Phytoremediation method, which is used as an alternative to chemical treatment and is defined as the removal of organics and metals from the soil in situ with short-term plants, is a newly emerged, preferred method because it is economical and ecological, does not require special equipment and allows reuse in the applied area. is becoming (EPA,1995). Long-term treatment processes produced by microorganisms to break down hazardous substances and harmless or less harmful substances are known as microbial remediation.

Rural adaptation is met from the producible resources of the solution. The use of arsenic-affected systems for the management of arsenic-contaminated production management causes excessive transfer of arsenic to crops in these regions. Many studies have found arsenic directly in food, a secondary and significant arsenic intake after consumption of contaminated water. Among the foods, rice is the plant most sensitive to arsenic. Many regions affected by arsenic rely on rice as their primary agriculture. The possibility of recent exposure to arsenic through the food chain is not limited to polluted areas but can reach unpolluted areas due to the open market. This spread explains the very wide range of effects observed. The sooner this problem produces sustainable solutions, the sooner the health, socio-economic and socio-economic dangers will be eliminated. (Singh, 2004).

2. Arsenic

Arsenic is a natural element that is not actually a metal but has some properties of a metal. It is generally found in trace amounts in all rocks, soil, water and air and is a natural component of the Earth's crust (Jiang and Singh, 1994). However, concentrations may be higher in some areas due to natural conditions or human activities.

Arsenic is a metalloid commonly found in the earth's crust at an average concentration of 2 mg/kg. –3, 0, +3 and +5 of arsenic. Four valence states may exist: Under reducing conditions, arsenite (As(III)) is the dominant form; arsenate (As(V)) is usually the stable form in oxygenated environments. Arsenic salts have wide solubility depending on pH and ionic environment, while elemental arsenic is insoluble in water (Jiang and Sing , 1994)..

2.1.Environmental Transport and Distribution

Arsenic is released into the atmosphere by burning vegetation, volcanic events, and high-temperature processes from facilities such as coal-fired thermal power plants. Natural low-temperature biomethylation and arsine reduction also cause the release of arsenic into the atmosphere. Arsenic is released into the atmosphere primarily as Arsenic trioxide (As2O3) and is mainly found adsorbed on particulate matter. These adsorbed particles are dispersed by wind and return to the earth's surface through wet or dry deposition (Jiang and Singh, 1994).

Arsines released from microbial sources in soil or sediments undergo oxidation in the air, turn into non-volatile arsenic forms and precipitate back into the soil.

2.2. Levels of Arsenic that Humans Exposed to

Human exposure to arsenic in the environment outside of their occupation occurs primarily through the consumption of food and water. Generally, the largest contribution to the total daily arsenic intake is from food intake (Jiang and Singh, 1994; FDA, 2013c). The high amount of arsenic in drinking water also constitutes an important source of exposure to inorganic arsenic.

In this case, arsenic in drinking water often constitutes the primary source of daily arsenic intake. Soils near mining sites and contaminated with mine tailings are also a potential source of arsenic exposure. The total daily intake of arsenic from food and beverage generally ranges from 20 to 300 μg/day. It is estimated that approximately 25% of the arsenic found in foods is inorganic, depending largely on the type of food consumed. Shows (FDA, 2013b).. Inorganic arsenic levels are low in fish and shellfish (< 1%), while food items such as grains, dairy products, meat and poultry contain higher levels of inorganic arsenic (Tünay , 1996; Singh, 2004).

2.3. Health Problems

Soluble inorganic arsenic salts are acutely toxic. If taken into the body in high doses, it causes gastrointestinal symptoms, impairment of cardiovascular and nervous system functions, and ultimately death. Apart from this, different health problems (bone marrow depression, hemolysis, hepatomegaly, melanosis, polyneuropathy and encephalopathy) may also be observed in people (FDA, 2013c).

3.Phytoremediation

Phytoremediation is the cleaning of polluted environments using plants (Raskin et,al., 1997). Plants help clean many pollutants (metals, pesticides, explosives and oils) in the environment. In fact, cleaning pollutants with plants gives better results in environments where the amount of pollutants is low. Because high concentrations can inhibit or limit plant growth and the clearance process can take a very long time. Plants also help prevent pollutants carried by various factors (wind, rain and groundwater flow) from moving from their area to surrounding areas or deeper underground.

When some plants take up water and nutrients from contaminated soil or groundwater through their roots, they can remove or break down harmful chemicals from the soil EPA, 2000).

Plants try to clean pollutants at depths that their roots can reach by using the following natural processes (Figure 1):

- Plants accumulate pollutants in their environment in their roots, stems or leaves,
- By converting them into less harmful chemicals within itself or mostly in the root area,
- By allowing these to evaporate into the atmosphere,
- By ensuring that pollutants are taken up by microorganisms living in the soil and that these pollutants are broken down into less harmful chemicals

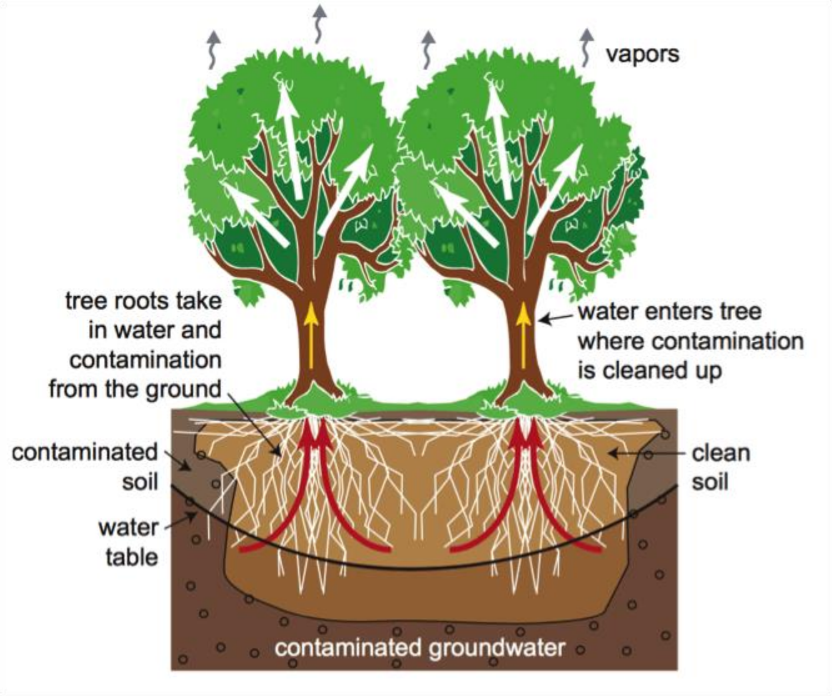


Figure 1. The working principle of phytoremediation

Some plants used in phytoremediation have better properties in removing pollutants from the environment. These plants can tolerate the types and concentrations of pollutants in the environment better than others (Baker and Brooks, 1989; Brooks, 1998).. Plants grown for phytoremediation must develop and grow well in their environment. The depth of pollution is one of the important factors in selecting plants to be used in phytoremediation (Aybar et al., 2015). While small plants such as ferns are used in places where the pollution is superficial and shallow, trees such as poplar and willow whose roots grow deeper should be preferred in deeper pollution conditions. Plants with deep roots are used to clean deeper soil and contaminated groundwater (Long et al. , 2002).

Environmental pollution and pollutants in the environment pose a global problem for wildlife and human health. Phytoremediation is a technology developed in recent years that offers a low-cost solution by using relevant microorganisms in the soil together with plants to reduce the concentration or toxic effects of pollutants in the environment (Benavides et al., 2005; Clemens, 2006)..

Phytoremediation technologies include phytostabilization (retention of pollutants in the soil) (Berti et al., 2000; Bert et al., 2005), phytodegradation (conversion of organic pollutants into less harmful substances), phytovolatilization (conversion of pollutants into gases within plants and their release into the atmosphere through the evaporation-transpiration process) and phytoextraction (harvestable biomass where pollutants accumulate in the upper parts of plants) (Lasat, 2000; Arshad, et al., 2008), (Table 1 and Figure 2).

Table 1. Comparison between phytoremediation technologies (Hamutoğlu 2012)

Mechanism	Description	Cleanup goal
Phytosequestration	The ability of plants sequester certain contaminants in the rhizosphere through exudation of photochemicals ond onthe root through transport proteins and cellular processes	Containment
Rhizodegration	Exuded phytochemicals can enhance microbial biodegration of contaminants in the rhizosphere	Remediation by destruction
Phytohydraulies	The ability of plants to capture and evaporate water off the plant and take up and transpire water throughthe plant	Containment by controlling hydrology
Phytoextraction	The ability of plants to take up contaminants into plant with the transpiration stream	Remediation by removalof plants
Phytodegradation	The ability of plants to take up and break down contaminants in the transpiration stream through internal anzymatic activity and photosynthetic oxidation/reduction	Remediation by destruction
Phytovolatilization	The ability of plants to take up, translocate and subsequently transpire volatile caontaminants in the transpiration stream	Remediation by removal through plants

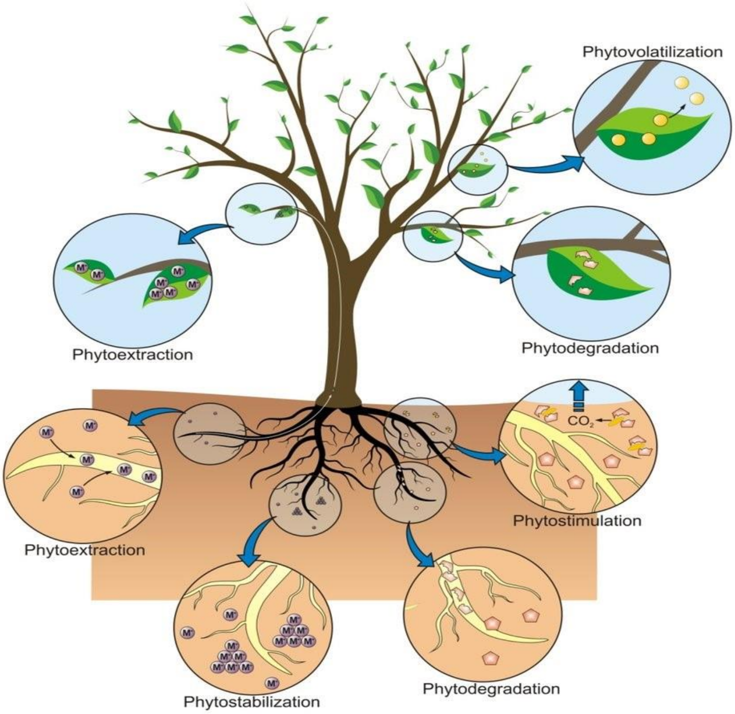


Figure 2. Phytoremediation types (Favas et al., 2014)

4.Bioremediation

Bioremediation is a method in which macro and microorganisms such as plants, earthworms, fungi and bacteria are used together to remove pollutants (agricultural chemicals (pesticides, fertilizers) leaking into the soil and groundwater) and to eliminate pollution in polluted soil and water in an environmentally friendly way (Niess, 1999; Anonymous 2015).

With this method, some toxic metals such as selenium and arsenic compounds and metal oxides can be removed from water (Ellis and Salt, 2003).

Bioremediation is an environmentally friendly technology that enables the use of natural biological activity to render harmless pollutants in the environment.

4.1.Bioremediation Organisms

Microorganisms that carry out biological degradation in many different environments are defined as active members of the microbial association. These microorganisms are: Acinethobacter, Actinobacter, Acaligenes, Arthrobacter, Bacillins, Berijerinckia, Flavobacterium, Methylosinus, Mycrobacterium, Mycococcus, Nitrosomonas, Nocardia, Penicillium, Phanerochaete, Pseudomonas, Rhizoctomiet Includes.

Microorganisms cannot mineralize many hazardous polluting compounds alone. Mineralization can occur in a sequential degradation pattern by a group of microorganisms. This degradation takes place thanks to the synergy of microorganisms and their joint metabolic actions (Niess, 1999).

5. Material and Method

5.1. Material

5.1.1. Chemical and Biologic Materials Used in the Experiments

Table 2. Chemical and biological materials used in the experiments

1	Soil
2	Sodium arsenate(Na2HAsO4.7H2O)
3	Rice (Osmancık)
4	Isolated arsenic bacterial strain(Halomonas sp.) from Lake Van
5	Physiological Salina (Distilled water including 0,85% NaCl)
6	Luria Bertani(LB) Agar

Soil

The soil were taken from Menemen Research and Application Farm, and have been analysed. The characteristics of this soil are given in Table 3.

Table 3. Some Physical and Chemical Properties of the Experiment Soil.

pH			7.68	Light alkaline
Total soluble salt		%	0.050	No salinity problem
Lime $CaCO_3$)		%	7.10	Calcic
Sand (%)		%	73.28	
Silt (%)		%	18.00	
Clay (%)		%	8.72	
Texture			Sandy loam	
Waterholding capacity		%	212	
Organic matter		%	1.28	Poor
Total N		%	0.067	Medium
Available	P	ppm	7.52	Sufficient
	K	ppm	172	Poor
	Ca	ppm	3650	Sufficient
	Mg	ppm	169	Sufficient
	Na	ppm	38	No problem
	Fe	ppm	8.12	Sufficient
	Cu	ppm	0.78	Sufficient
	Zn	ppm	1.84	Sufficient
	Mn	ppm	24.12	Sufficient
	As	ppm	0.058	Poor

Rice (Osmancık)

It is a paddy variety developed by Thrace Agricultural Research Institute from the ROCCA X EUROPA hybrid and registered in 1997. Plant height is 95-100 cm. The leaves are erect and dark green. It has a solid handle and is resistant to bending. Paddy grains are yellow in color and long. The weight of 1000 grains of paddy is 33-34 g. It is a variety with high yield potential that matures in 130-135 days. It can adapt to different ecologies. Rice yield is 60-65%. Its grain is long, glassy and matte in appearance. Rice thousand grain weight is 24-25 gr.

5.1.2. Instruments Used in the Experiments

Table 4. Instruments used in the Experiment

	Electronic Apparatus used	Trademark
1	Autoclave	Hırayama Hıclave HVE-50
2	Precision sacales	Denver Instrument(d=0,0001 g)
3	Incubator (drying oven)	NÜVE EN 055 PID
4	Magnetic stirrer	CHILTERN MS1S
5	ICP-OES	CEM Mars

5.2. Method

The research was carried out as a pot experiment in the greenhouse of Ege University Faculty of Agriculture, Department of Soil Science and Plant Nutrition.

5.2.1.Preparation of Sodium Arsenate Solution

Required sodium arsenate concentrate for each pot is determined as 2 ppm for to provide the pollution intended in the experiment soil. Calculations have been made for 15 pots each of having 2,75 kg soil. Amount of arsenic that has to be solved to obtain a level of 2ppm contamination is calculated as follows.

2 ppm=2 mg/kg

If 2 mg arsenic is required in 1 kg soil

Then there has to be 5.5 mg arsenic in 2.75 kg soil (for 1 pot)

In 312 g $Na2HAsO4.7H2O$ 75 g As

<u>In X g $Na2HAsO4.7H2O$ 82,5 mg A</u>

X = 0.35 g Na2HAsO4.7H2O (Sodium Arsenate) is required.

2 ppm sodium arsenate solutions of 100 mL solutions have been prepared to be given to 15 pots .

5.2.2. Investigation of Effect of Arsenic on Germination

Rice plant is chosen among phytoremediatiom method applications to be used in the experiments. Proper environmental conditions are searched for the development of this plant and planting has been done considering the effect of arsenic to the germination. It has been determined by an preliminary experiment whether arsenic should be given to the soil before germination or after germination.

Figure3. Seeds left for germination

Figure 4. Addition of arsenic

Figure 5. Germination after 3 days.

Seeds left in perlite for germination are covered with glass to prevent the water loss and to obtain optimum temperature. Soil and fertilization were not needed at this stage. Rice planting is made in perlite material on a layer composed of 4 parts as seen in Figure 3. This system is composed of 2 parallel groups of 2 sections. In sections 3 and 4, 100 ml sodium arsenate (Na2HAsO4.7H2O) and 200 ml water is added to each. In sections 1 and 2, only 300 ml water is added to each (Figure 4). As a result it has been seen that arsenic has delayed germination (Figure 5).

Addition of arsenic to the main experiment pots are done after the germination of the plant is observed taking into account the results of this preliminary experiment.

5.2.3. Preparation of Bacterial Strain

Bacterial Strain used in the experiments is obtained from Ege University Faculty of Science, Department of Biology, Basic and Industrial Microbiology Instructor. Halomonas sp. bacterial strain isolated from Lake Van was cultured at Luria Bertani(LB) Agar media. Combination ratio of LB media in 1 liter water is as follows:

Table 5. LB media combination ratio

Material	Amount(g/L)
Tryptone	10
Yeast Extract	5
Sodium Chloride(NaCl)	5
Agar	15

Samples are taken from gliserol stocks and line planting is made in LB agar petris. It is incubated for one night at 30 °C and bacterial suspensions of which bacterial density corresponds to 1 McFarland(3,0 x 108 numbers/mL) in 10 mL FTS are prepared by using magnetic stirrer and they are prepared in separate tubes for each pot(4 pots in total) in which bacteria will be inoculated.

5.2.4. Preparation of Rice and Planting

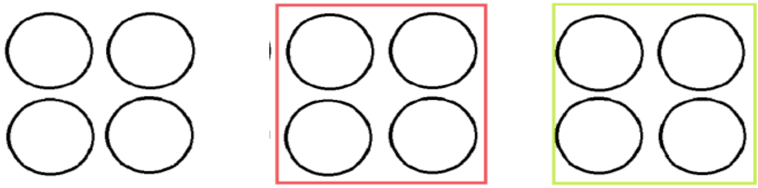
12 pots of 2.75 kg each are filled in with soil and seed beds are prepared. Rice that was soaked for 2-3 days is prepared for planting. 120 proper rice seeds are chosen from among the swollen rice seeds, 10 seeds for each pot. Seed beds are

prepared in the pots filled in with soil and rice is planted in the pots in equal intervals

Figure 6. Soaked rice seeds

Figure 7. Chosing rice seeds

Figure 8. Preparation of the pots for planting



Experiment Group-1
Rice Plant (Control Group)

Experiment Group-2
Rice plant and arsenic

Experiment Group-3
Rice plant, arsenic and bacterial strain

Figure 9. Research topics

Experiment stage consists of three different groups. Each group has four parallels in itself and twelve experiment pots are used in total. First group is the control group and in this group there is rice plant planted in the soil without additional arsenic. This group is formed to be compared to the others.In the second group rice plant is planted in the soil which was polluted with 100 mL sodium arsenate These potsa re watered with 100mL distilled water.Every other day considering the rice farming. Arsenic amount in the plant, which is constituted by ICP-OES method, is proportioned with the control group and arsenic uptake is determined. Data that will be acquired from this experiment group will represent decontamination of arsenic by phytomediation method from arsenic contaminated soil.

In the third experiment group there are four pots in which 100 mL sodium arsenate is added to each and rice plant is planted. Additionally, arsenic resistant Halomonas sp. bacterial strain which was isolated from Lake Van is inoculated to arsenic contaminated soil. Stage of preparation of the bacteria is detailed in method part. Bacterial suspensions prepared in 10 mL solutions are added to the pots and it has been tried to determine the remediation by microbial way of arsenic in arsenic contaminated soil. This group is compared to the second group and contribution of rice plant and bacteria to the process in decontamination of arsenic from arsenic contaminated soil used in rice farming has been determined.
All the pots are watered every other day with 100 mL distilled water and rice is raised. Pots are located in room conditions (25°C) in a position to get sun light.

5.2.5. Bacteria and Sodium Arsenate İnoculation into Pots

After the observation of germination of rice in the pots bacterial strain prepared in the tubes are added to four pots of experiment group 3.

Figure 9.Observation of germination

Figure 10. Addition of bacterial strain and sodium arsenate to experiment groups

5.2.6. Observation of Growing Process of the Plants

Figure 11. 30 Days-old rice plant in 1st, 2ndand 3rd experiment groups

Figure 12. 40 Days-old rice plant in 1st, 2ndand 3rd experiment groups

Figure 12. 50 Days-old rice plant in 1st, 2ndand 3rd experiment groups

5.2.7. Harvest

Figure 13. Rice plant before harvest (60 days-old)

After a 2 months development period rice plants have reached a size from which results can be obtained. Two parallels have been chosen from each experiment group, roots and leaves are kept separate and they are harvested. The reason why the other parallels are not used is that in the further stages of the project product obtainment is expected. Only the roots are washed and all the groups are packed separately. Without the need for drying, the samples are treated in the form of grass for the purpose of examining by wet firing technique.

6. Results and Discussion

The studys purpose is to decontaminate arsenic in soil by using rice plant which is consumed widely by people and to minimize the harmful effects to human health. Arsenic quantity in plant's roots and leaves are analyzed using ICP-OES technology. According to analysis results, there is an serious increase in arsenic uptake when bacteria strains are added to the soil experiment -1.

The sodium arsenate solution of 2 ppm concentration which is added to the experiment group 2 is observed to be uptaken by plant. As taking the difference of arsenic uptake quantity between experiment -2 and experiment -1 phytoremediation ratio is found. Root and leave values are examined separately and are shown on the Figure14. Roots ands leaves of the rice plant have uptaken 33,25% and 14% of arsenic in soil 2 (ppm) respectively. According to the rice plant's total arsenic uptake 0,945 ppm concentration of arsenic is accumulated by phytoremediation method

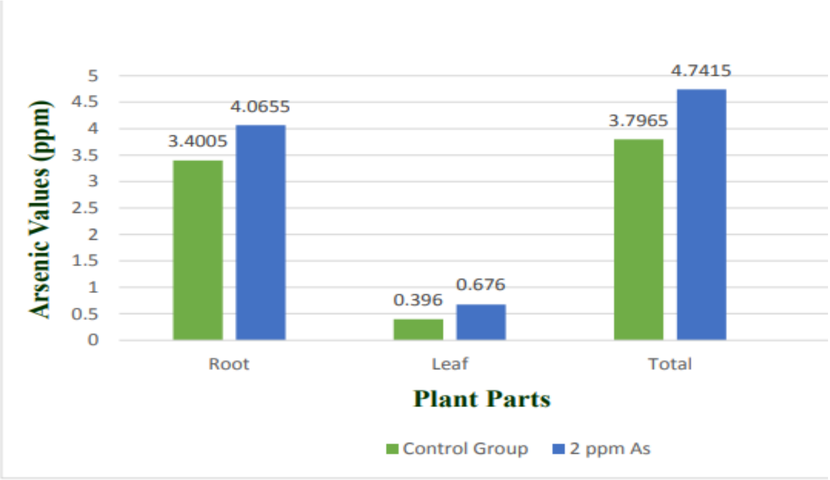


Figure 14. Phytoremediation values of rice plant

2) In the third experiment group, in addition to second experiment group Halomonas sp. Bacterial strain is inoculated. Since this bacterial strain reducts Arsenate (AsO_4^{-3}) to arsenite of which solubility is higher than arsenate, arsenic uptake by plant gets easier. As taking the difference between experiment -2 and experiment -3 the contribution of bacterial strain to phytoremediation is found. As shown in the Figure15, bacteria strain has transformed the 40,65% of 2 ppm concentration of arsenic and increased the plant's arsenic uptake capacity. By this microbial method bacteria strain has provided rice plant to uptake 0,813 ppm concentration of arsenic in addition to the experiment

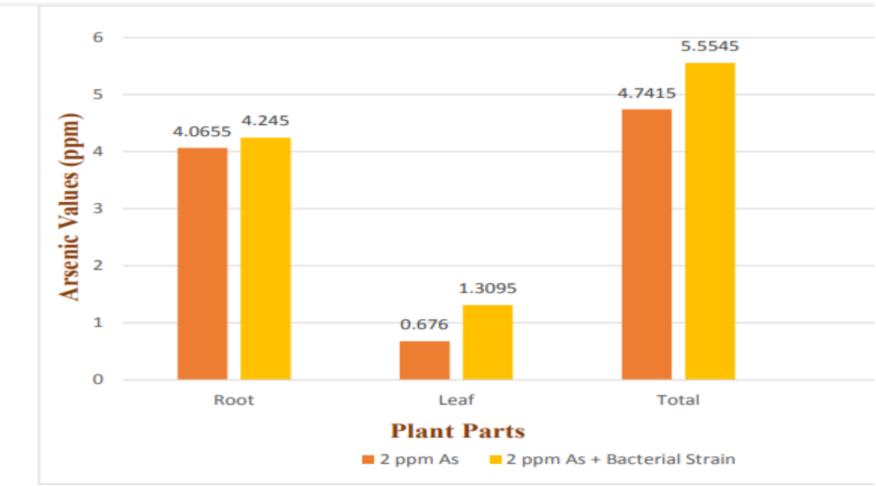


Figure 15. Contribution of bacterial strain to bioremediation method

3)By making a comparison between experiment -1 and experiment-3, as a result of cooperation of rice plant and bacteria strain the 1,7576 ppm of arsenic concentration is uptaken by the plant. As shown in the Figure 16; in total, %87,88 of arsenic contamination in soil is bioremediated

uptaken by the plant. As shown in the *Graph-3;* in total, %87,88 of arsenic c
soil is

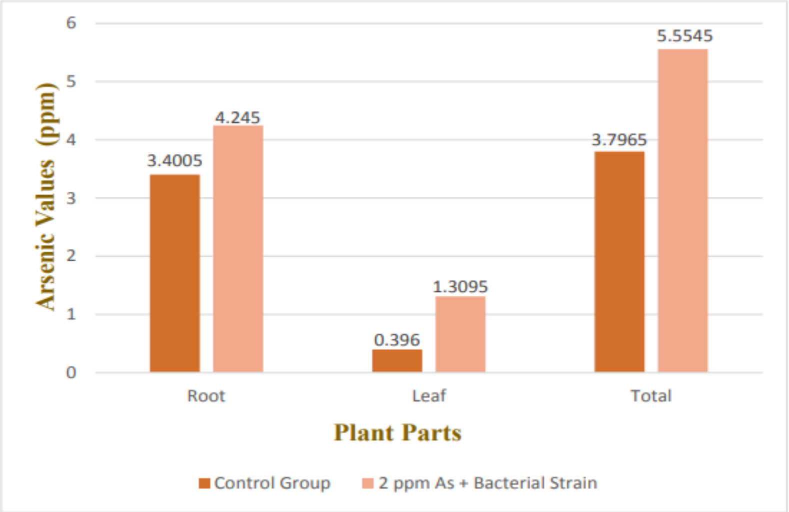


Figure 16. Arsenic values extracted by bioremediation

4)There is parallel raises both in arsenic value in roots and leaves. But after a while the raise in arsenic value in roots start to decrease, conversely the raise in arsenic value in leaves start to increase. It is observed that after a while the arsenic uptaking capacity of root declines, therefore it transmits the excess arsenic to the leaves by causing an increase in the leaves’s arsenic uptaking capacity.

When the analysis of variance of data is calculated, the significant changes in arsenic uptaking value has been ascertained in the leaves though no significant changes observed in roots. Changes in the arsenic uptake in leaves and roots are shown in Figure 17.

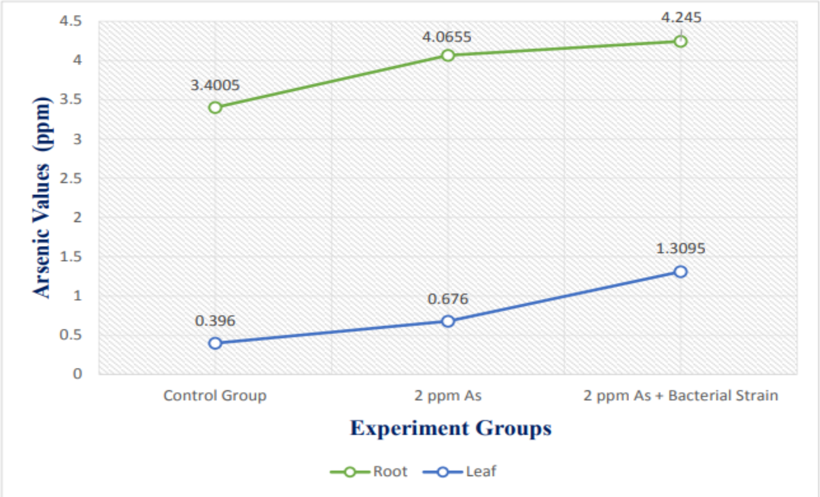


Figure 17. Arsenic values of roots and leaves

High level of arsenic uptake shows that soil can be remediated by rice plant, by the method of phytoremediation. Along with this, the doubling of arsenic uptake demonstrates that the presence of the microorganisms affect the pyhtoremediation in a positive way. As a conclusion, the interoperation of rice plant and Halomonas sp. bacterial strain have decontaminated the soil from arsenic without requiring expensive technologies.

Rice is of particular concern because it is a major part of the diet in many parts of the world. It is also a major component of many of the cereals eaten by infants and young children. (Nearly all rice products have been found to contain at least some arsenic, although the levels can vary widely.) Rice plants which is grown in soil with arsenic, will extract arsenic and emerging data indicate that rice consumption may lead to potentially harmful arsenic exposure. After all, the countries exporting rice to all over the world like India, USA, China, New Zeland, Bangladesh -where arsenic is detected in the water- consitutes a threat for rice cultivation. Since rice plant has an arsenic accumulating system, the arsenic stored in the plant structure and by the event of use of rice in food industry it is possible for arsenic to pass on to human body. As a result of the arsenic analysis conducted by the US Food and Drug Administration (FDA) on approximately 1,300 rice samples, they determined that although portion sizes vary depending on the type of rice, the average amount of inorganic arsenic for various rice and rice products varies between 0.1-7.2 micrograms per serving. The low level of arsenic determined in the analyzes of the FDA indicates that it will not cause any negative effects in terms of health yet. Rice is an important food source for humans. Therefore, all consumers, including pregnant women, babies and children, are strongly encouraged to eat a good and balanced diet, minimizing the negative consequences that may arise from excessive consumption of any food.

The rice-based food products shouldn’t be put on the market without being subjected to arsenic analysis. It is assumed that in the years ahead the arsenic contamination depended on human activity will grasually increase. For that matter the food organizations should establish mechanisms which detect arsenic in food. Thereby effects of the possible arsenic exposure (disease, death,intoxication) can be minimalized (U.S. Department of Health and Human Services, 2014).

7. SUGGESTIONS

As the data obtained from the research are evaluated it is observed that microorganisms contribute to the phytoremediation of the plant.

In order to progress in this project, it is planned to wait for the rice plant to give seed which in analysis will both show the arsenic uptake by seed and the transmisson of arsenic ratio by different parts of the plant. By detecting the extracted arsenic in seed, the studies will focus on the subject how rice carry risk for human health.

In the lights of the results, as regarding the percentage of bioremediation of the soil from arsenic it can be calculated to find how many times should bioremediation process be applied for maximum arsenic treatment.

Different parameters should be added on experiment system (pH, temperature, amount of bacterial strain, kind of heavy metals) and the plant activity should be investigated under different conditions.

Instead of rice plant, other plants used in food industry which have ability to phytoremediate can be chosen and the plants should be studied whether they have an effect upon human health.

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CHAPTER 8

PLANT PROTECTION AND PLANT PROTECTION ORGANIZATION IN TÜRKİYE

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INTRODUCTION

Agriculture is a strategic sector that will never be neglected both for our country and for the world (Avan, 2021). There are many diseases, pests and weed types that limit the yield in agriculture (Avan, 2021a). Among the most important factors limiting the quantity and quality of agricultural products, biotic factors take the first place. (Avan, 2022). It constitutes the most important factor in determining the quality and quantity of agricultural production in the fight against pests, which are among these biotic factors.

Agriculture or agriculture is an applied science that deals with the production of plant and animal products, increasing quality and efficiency, storing, processing and marketing them for human use. In other words, it is expressed as all of the maintenance, feeding, cultivation, preservation, storage and mechanization activities of all kinds of plant and animal products that have economic value and are grown as human food, and all of the fishing activities carried out in the waters or in private areas. (Karagölge et al., 1995).

It is estimated that the world population, which was 8 billion at the beginning of 2000, will reach 10 billion by the end of this century. It is seen that agriculture is becoming more and more important every day in order to adequately feed such a world population and to supply raw materials to industry. The most important factor of agricultural production is vegetative production and it is carried out in an agricultural area of approximately 1.5 billion hectares in the world. In this area, around 7 billion tons of 500 plant species are produced every year. It is under the threat of 19,500 - 20,000 harmful organisms, of which approximately 4500 - 5,000 are active and 15,000 - 20,000 are potentially harmful to plants in the world, and approximately 35% of the products produced in the world are lost every year (Anonymous, 2015).

In order for the scarce resources in the world to be used for the benefit of humanity in a sustainable way, it is very important that we understand the ecologies of human-modified systems and the organisms living in those ecologies (Losey, 2006). Agroecosystems include agricultural activities and the living and non-living components that interact with these activities. Insects such as pests, weeds and natural enemies in agricultural areas play an important role in the economic and ecological success of agro-ecosystems (Klein et al., 2007). The beneficial insects found in these areas increase the productivity and sustainability of agroecosystems by increasing the yield of agricultural products and reducing the dependence on pesticides. Because with the frequent use of synthetic pesticides in plant production, the damage to both human health and the environment has increased significantly (Avan, 2021b). For this reason, people have recently focused on alternative methods of control due to the harmful effects of chemicals used in the fight against plant diseases on human health and the environment (Atay et al., 2020; Atay and Soylu, 2022).

In our country, there are about 150 plant species that have economic importance and are cultivated, and there are about 600 harmful organisms such as fungi, bacteria, viruses, weeds, nematodes and general pests that cause economic damage to these plants. As a result of the development of agricultural control methods in recent years, the losses of around 75% in plant production have been reduced by 50-60% (Alkan, 1968). Different methods of control have been developed to prevent these losses or to keep them at a minimum level. These; Cultural Control, Quarantine (Legal) Measures, Mechanical or Physical Control, Biological Control, Biotechnical Control, Chemical Control and Integrated Management (Anonymous, 2015)

In this study, the development stages of agricultural control after the establishment of the Turkish Republic were investigated. The parallelism between these developments in agricultural control and the development of the country's agriculture was emphasized.

Pesticides

The use of pesticides dates back to ancient times. B.C. The first insecticides were used in 1500 BC. It was determined that non-selective herbicides were used in 1200. The insecticide and fungicide properties of sulfur are in BC. It was discovered in 1000. Chinese M.S (Rao et al., 2007). It has been reported that they used arsenic sulfites against insects in their gardens in 900 BC and that Arsenic was the first insecticide used against locusts. M.S. of tobacco extracts in 1690, it was used as a contact insecticide, and its fumes were used in M.S. It was used as a fumigant in 1773 (Ritter, 2009). The first pesticide known in Mesopotamia was elemental sulfur powder, which was used in ancient Sumer about 4500 years ago. In the 15th century, toxic chemicals such as arsenic, mercury and lead were used to kill pests in agricultural products (Miller et al., 2002).

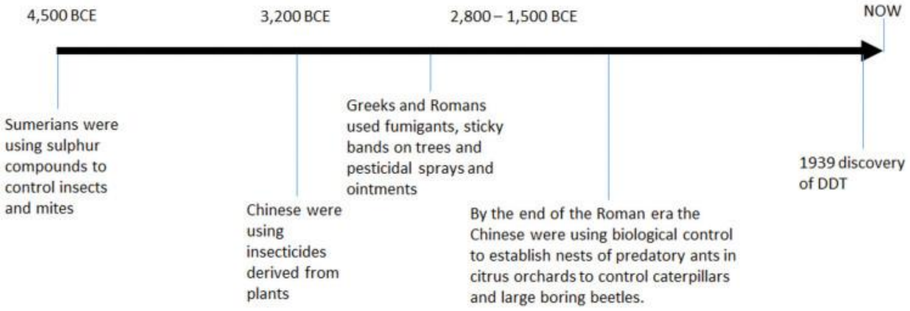

Figure 1. Displaying a timeline, drawn to scale, showing the history of the use of pesticides (https://www.groundstraining.com/pesticides-a-brief-history-and-analysis/)

Although it is known that sulfur is used against some plant diseases, the actual plant protection studies started with Pasteur's discovery of microorganisms belonging to some plant and animal diseases in the 19th century. Following this, pesticides were started to be used in the field of plant protection with the research of pesticide that can affect these organisms. When DDT was discovered in 1939 and herbicides with 2,4-D hormone compositions that kill weeds were discovered in 1941, there was a chemical revolution in plant protection (Goldman, 2007).

Substances and methods such as chemicals, some organic components, disinfectants used to eliminate the harmful effects of bacteria, viruses and pests are called "Pesticide". Although the name is foreign to us, Pesticides that we encounter a lot in our lives; In addition to providing benefits such as growing vegetables and fruits in nature without harm and purification of our living spaces from harmful microorganisms, it can pose a great threat to human health due to incorrect use (Ritter, 2009). Although there are many pesticides that have been used for many years in human history, chemical pesticides occupy the largest place today.

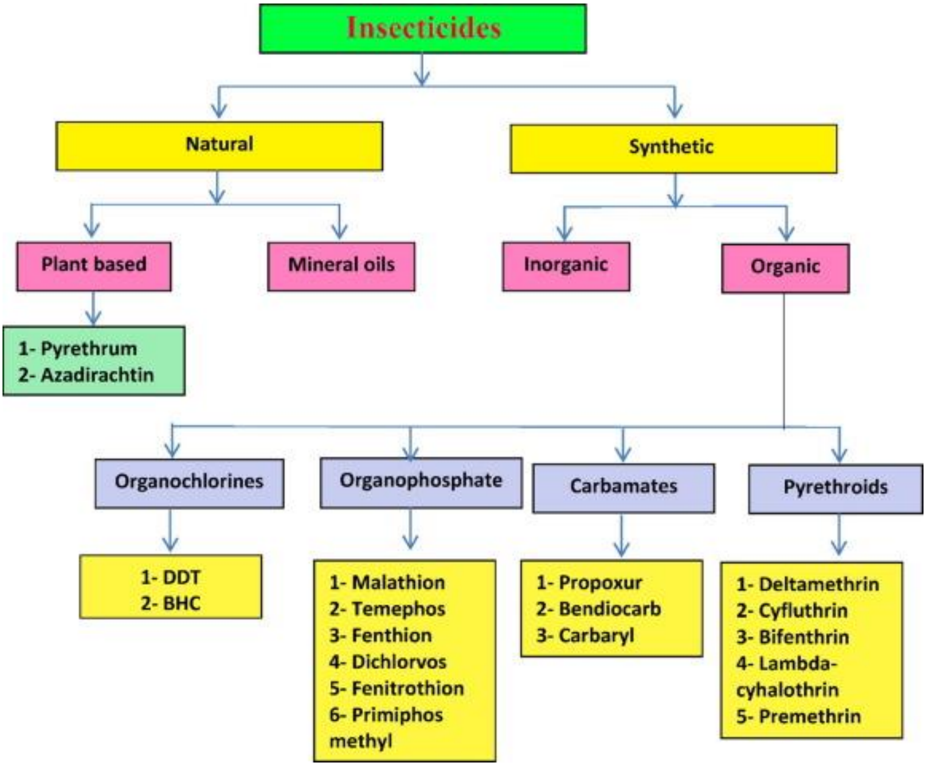

Figure 2. Insecticides Classification (Yadav & Devi, 2017).

Plant protection

Today, meeting the food needs of people is one of the most important issues that countries focus on. Despite all efforts, the world population is increasing and the surface area of the world is not increasing. In addition, agricultural areas are gradually decreasing due to erosion, opening of new settlements, industrial facilities and roads (Birdsall et al., 2001).

Since it is not possible to increase the amount of land, it becomes necessary to increase the amount of product obtained from the unit area by using modern techniques and inputs. Among the ways to increase the yield are irrigation, proper tillage, fertilization, improvement, appropriate harvest, establishment of producer associations, mechanization as well as the application of modern plant protection methods. We call "plant protection", in other words, "agricultural Control", all the processes that are carried out in order to protect plants economically from the damage of diseases, pests and weeds that limit plant production, and thus to increase agricultural production and improve their quality (Raio and Puopolo 2021).

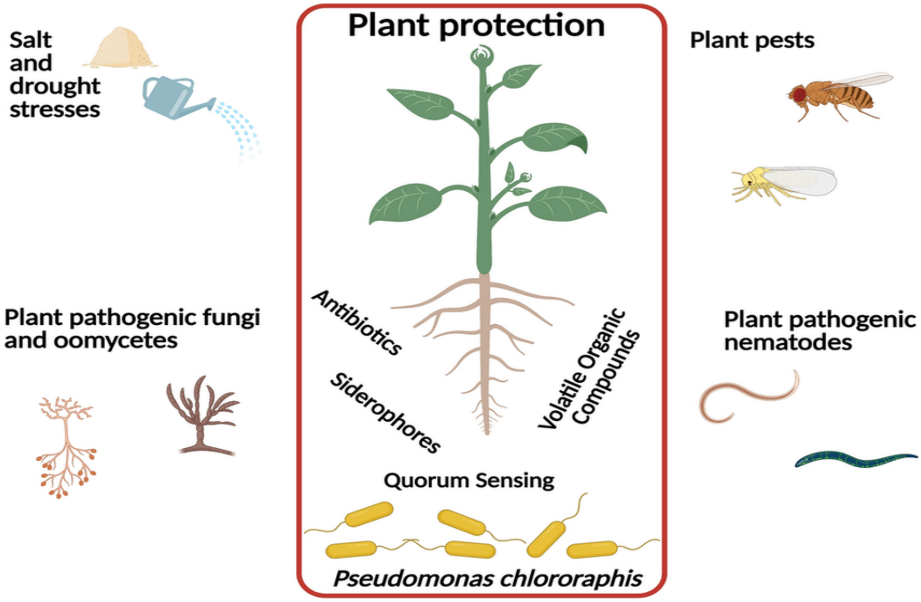

Figure 3. Plant Protection by *Pseudomonas chlororaphis* through multiple mechanisms active against abiotic and biotic stress factors. (Raio and Puopolo 2021)

Countries are faced with purchasing agro-industrial products to meet their food needs. Herbal products and various plant-derived substances are displaced from country to country, so that plants and herbal products are dispersed all over the world in a short time by crossing national borders. Today, there is a rapid and large-scale exchange of plants in the world. As a result of this, plant and plant product parts are dispersed to far distances in a short time. Along with these, very dangerous diseases, pests and weeds are distributed. If no precautions are taken, clean countries and regions are infected with harmful factors in a short time. These factors, which took a long time to spread before, are now contagious and dispersed in a short time. Today, there are 552 diseases, pests and weeds that cause economic damage in more than 100 cultivated plants grown in our country. People do not harvest what they sow, but what remains of diseases, pests and weeds, and some of them are lost to pests in the warehouses. Here, the duty of the Crop Protectionist should be to separate the least amount of these crop-reducing plant protection factors without disturbing the natural balance (Martin et al., 1969).

Methods Applied in Control Pests

Control Methods in Plant Protection If we talk about the classical control methods against plant protection factors, these are;

1- Cultural Control
2- Physical Control
3- Biotechnical Control
4- Biological Control
5- Chemical Control
6- Quarantine (Sherman, 2007)

Cultural Control

While agriculture is being done, it is called cultural control to suppress the harmful organisms in the environment with agricultural activity cultures, to prevent them from doing harm or to reduce their damage. Cultural Control; It can also be defined as the selection of seeds and place, the time and form of sowing and planting, the care, feeding, harvesting and storage conditions are adjusted to create minimum disease and pest pressure. The aim in cultural control is to use production techniques that will prevent the emergence of harmful organisms. Cultural control is one of the agricultural control methods that poses the least risk to the environment and human health (Aleinikova, 1962).

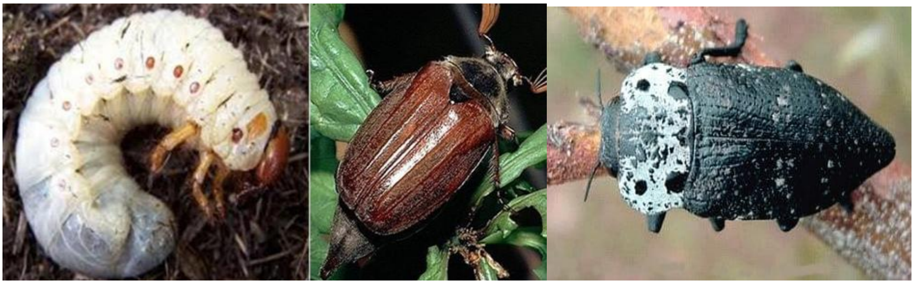

Figure 4. Harmful insect that can be control with cultural measures *Melolontha melolantha* and *Capnodis* spp.

Melolontha melolantha, (Coleoptera: Scarabaeidae), sapling bottom worm larvae are found in soil. Their larvae cannot survive in open air conditions. For this reason, it is possible to control these pest larvae by removing them to the soil surface by plowing and by ensuring that they die (Wright, 1984).

Physical Control

Physical and mechanical control such as collecting, pruning, hoeing, preventing pests from falling on the host, using caustic substances and sounds, and using radiation are environmentally friendly control methods, but there are difficulties in applying some of them (Walter, 1967).

It is a control method that involves killing insects by using heat and humidity and sterilizing insects by using electricity or radioactivity. It is a method mostly applied in agricultural areas.

Figure 5. Harmful insect that can be control with physical measures *Sitophilus* spp.

It is used to control pests in stored products by utilizing high temperatures. For example: *Sitophilus* spp., *Ephestia* spp. Warehouse pests such as are killed in ovens at 52–55 °C. Ensuring that pests die by using low temperatures and leaving them at -20 to -30 °C for a while. By using atmospheric gases, for example: If the O_2 rate in the tank is less than 1% or the CO_2 rate is more than 60% and this condition continues for a few weeks, the pests will disappear completely. Using light and color, traps, usually yellow, are used to collect insects (Hammond, 2015).

Ultraviolet rays are used to kill creatures such as mosquitoes and houseflies. By using the magnetic field, the magnetic field created by electric current can be used against mice and rats in places such as Home Depot, warehouse silo. Making use of sounds: It is a method especially aimed at attracting birds. However, with this method, birds can get used to the sounds. In electronic devices, the frequencies of the sounds can change in short intervals (Walter, 1967).

Utilizing radiation: Insects should be killed or sterilized with the rays emitted by these substances. The different doses of rays emitted by these radiation-emitting substances with the help of devices called irradiators cause mutations, sterilization and death in insects for example. *Ceratitis capitata* Wied. (Diptera: Tephritidae). Radiation is only used against pests in warehoused products (Salha, 2009)

Figure 6. Harmful insect that can be control with physical measures *Ceratitis capitata*

Mechanical Control

It is the attempt to destroy the pest or reduce its activities by changing the physical characteristics of the environment in which the pest lives. Collecting insects by various methods, ambushing, setting bait traps, using pheromones, food exchange, etc. It is a form of control carried out by means of It is a form of warfare using hands, tools or machines to destroy pests or prevent them from causing harm. Since the applications are made directly on the pest, they can be handled separately from cultural measures. The populations of some pests that are found in high density can be reduced by crushing them with wire or brush (Wik et al., 2007).

Figure7. Harmful insect that can be control with physical measures *Thaumetopoea pityocampa*

Especially pests that live in groups can be prevented from harming themselves by cutting and collecting them together with the plant organs they are found on. For example, pests such as *Thaumetopoea pityocampa* (Denis & Schiffermüller, Thaumetopoea) and *Euproctis chrysorrhoea* L. (Lepidoptera: Lymantriidae) are killed during the winter months by cutting off the bladders in which they are found in groups, along with the branches of the plants on them, burying them, removing them from the plants, or burning them. This method is the most effective method of control against these pests (Hammond, 2015).

Figure 8. Harmful insect that can be control with Biotechnical measures *Cydia pomonella*

Traps are catching tools developed to take advantage of insects' orientations and some behaviors. Traps are frequently used tools in plant protection studies. Traps are used to examine the biology of insects, determine their population densities, and monitor their migrations such as *Cydia pomonella* Lepidoptera; Tortricidae (Carter, 2006).

Traps are used to detect control time. For example, *Cydia pomonella* (L) (Lepidoptera: Tortricidae), *Lobesia botrana* D.S (Lepidoptera: Tortricidae). Adult flights of pests such as, *Bactrocera oleae* (Gmelin) (Lepidoptera: Tortricidae), *Ceratitis capitata* (Wied.) (Diptera: Tephritidae) is monitored with the help of traps to determine the most appropriate time to control against these pests. Traps are largely used in prediction and early warning studies.

Quarantine

Unfortunately, the legal measures taken to prevent the transfer of a harmful agent, which we call quarantine measures, from region to region or from country to country cannot be adequately implemented. If these legal measures were adequately implemented, overseas plant protection agents that might come to our country would be prevented from being harmful in our country. The process of reducing harmfulness levels by using human-friendly living agents, which are considered natural enemies against a harmful agent, is called biological control (Cayol, 1994). It refers to studies aimed at preventing harmful and disease factors that do not exist in our country from entering the country and preventing harmful and disease agents that do not exist in our country from being carried from one region to another.

Figure 9. Harmful insect that can be control with Quarantine measures *Cydia pomonella Rhagoletis pomonella* and *Spodoptera frugiperda*

Plant products or materials entering the country are checked by Agricultural Quarantine Directorates or Plant Protection Branch Directorates established in import and export centers. External quarantine measures for studies carried out against diseases and pests that are prohibited from entering the country. The transportation of harmful and disease agents from one part of our country to another is called internal quarantine measures (Armstrong et al., 1996)

Biotechnical Control

Methods applied by disrupting the normal characteristics of pests, that is, pests, by using some artificial or natural substances that have an effect on the biology, physiology and behavior of pests are called Biotechnical methods. It can make use of some synthetic and natural compounds to achieve this goal (Hammond, 2015).

Pheromones: As is known, there are two types of glands in insects: external and internal glands. Pheromones are important external secretions in determining the feeding, mating, defense, hiding, escape, etc. behaviors of insects (Frisvold and Reeves, 2010).

Figure10. Light and pheromone traps used in biotechnical methods.

- Mating or sex pheromones
- Alarm pheromones
- Pheromones that increase mating
- Aggregation pheromones, signaling pheromones
- Queen rearing pheromones in social insects

Among these, the most used against harmful insects are sex pheromones. Sex pheromones are secreted by the male or female insect. Sex pheromones can be used directly or indirectly (Vilcinskas, 2011).

Biological Control:

One of the most important sources of agricultural production is pest control methods. Biological control stands out as the most natural way to control living creatures that harm agricultural production by generally damaging soil, plants, vegetation or fruits. The aim of biological control is to suppress pests with the help of natural enemies present in nature (Hammond, 2015).

Hundreds of different species can be used as control agents in biological control. These factors can be examined in four main groups according to their functions: predators, parasitoids, pathogens and entomopathogens. Predators are fighting agents that destroy pests by hunting. Parasitoids are factors that live or reproduce on the pest and eventually cause the death of the pest. The group of pathogens refers to fungi, bacteria or viruses that kill or weaken pests (DeBach, P. 1974).

Figure 11. An important parasitoid for Türkiye is *Trissolcus semistriatus* (Hymenoptera; Sceolinidae) and its parasitized *Eurygaster integriceps* (Heteroptera;Scutelleridae) eggs.

Many of the microbial agents to be used in biological control are isolated from diseased insects found in nature. There are many microorganisms, originating from bacteria, nematodes, fungi, viruses or protozoa, that cause illness and death in insects in nature. These are known as entomopathogens (Wik et al., 2007). Entomopathogens in nature are of great importance in balancing insect populations. Many entomopathogenic microorganisms are used in the biological control of vectors and harmful insects that cause damage to field and garden plants, ornamental plants, plant species grown in protected areas in greenhouses, forest lands, stored products, veterinary and medical fields (Doutt, 1964).

Chemical Control

Chemical control; It is the control against harmful organisms that cause economic losses in plants by using synthetic or naturally obtained chemicals that have a killing effect (toxic effect) (Taylor et al., 2007)

These products, called pesticides (pest killers), kill the target organism by stopping respiration, blocking the nervous system, disrupting the digestive system, or inhibiting a natural process of metabolism such as molting or stopping metamorphosis. In addition to their benefits, it is also known that these chemicals can pose serious human, animal, plant and environmental health risks. For this reason, these chemicals, known as pesticides and technically called pesticides, are produced and sold subject to the most advanced control and inspection systems in the world (Thacker, 2002). The production and use of Plant Protection products is carried out according to some standards developed by the International Plant Protection Convention (IPPC) within the United Nations Food and Agriculture Organization (FAO).

In addition, there are Plant Protection Products Standards prepared by the European and Mediterranean Plant Protection Organization (EPPO), of which our country is a member, taking into account geographical and regional differences, developed with the participation of all relevant experts in the world and frequently updated according to the need (Himel C.M. 1969). Another important issue in pesticide use is the identification and management of health risks that may be reflected on the consumer. It should be known that in our country and in all developed countries of the world, there is no legal and administrative gap in the production, licensing, marketing and control of a chemical control product, on the contrary, a highly effective and strict systematic works (Thacker, 2002).

Integrated Management:

Integrated control, in its simplest and shortest form, can be defined as "effectively protecting plants from the effects of diseases, pests and weeds, and minimizing the negative effects on the environment and human health, by using all known methods in agricultural control together and balanced as much as possible" (Delen and al., 2005).

However, unfortunately, the most commonly used method among the methods mentioned above is chemical control using pesticides. Because when chemical control is applied in a conscious and controlled manner, it is more effective than other methods, gives faster results, can protect products from mycotoxin contamination, especially in field conditions, and can ensure that plant development is directed appropriately. Due to these advantages, pesticide production and consumption are increasing all over the world (Delen, 2005; 2009).

It is known that more than 3 million tons of pesticides are produced annually in the world today. Despite all these advantages, chemical control applied unconsciously and uncontrolledly leads to a decrease in the sensitivity of harmful organisms to pesticides, environmental pollution, health problems and a negative impact on agricultural product exports. In order to eliminate these problems that may arise from unconscious and uncontrolled chemical control, chemical control must be carried out in a conscious and controlled manner, in accordance with the integrated control view. However, many studies show that chemical warfare is carried out in a very unconscious and uncontrolled manner in Türkiye (Delen et al., 2005; Delen, 2005; 2009).

Plant Protection in Türkiye

Plant Protection Activities in Turkey According to Periods Changes and developments in the plant protection organization in Turkey can be examined in three periods;

1-The period before 1957,

2-1957–1984 period,

3-After 1984 and today's situation (Anonymous, 2002).

I. Period before 1957:

There were very few chemicals used in this period, and there was no widespread phytosanitary organization and no special phytosanitary legislation. Some chemicals were brought and used from abroad for the control of insects and grasshoppers, and chemical control was mostly applied by the state for harmful organisms causing epidemics and quarantine (Kadıoğlu, 2012).

Figure 12. The predatory insect *Rodolia cardinalis* Muls. (Coleoptera: Coccinellidae) is imported and used in biological control studies.

The first agricultural education in our country started in 1846, and agricultural control training started in 1928 at Halkalı Higher Agricultural School. In the Republic of Turkey, the Ministry of Agriculture was established in 1924 under the name "Agricultural Ministry" (Kadıoğlu, 2012).

Biological control studies were first started in the 1910s. *Rodolia cardinalis* Muls. (Coleoptera: Coccinellidae), a predatory insect brought from abroad in 1912, was released to the Chios Island to sutraggle the bagel pest in citrus fruits. Thanks to this predatory insect, which was later released to different parts of our country, today the bagelette problem has been taken under control (Anonymous, 2002). Again, in this period, herbicide efforts, especially against entomological factors, gained momentum, and immediately after the discovery of 2,4-D hormone-containing pesticide in the world, herbicide applications in cereals began in the 1950s (Kadıoğlu, 2012).

2.1957 – 1984 Period

With the entry into force of the Agricultural Control and Agricultural Quarantine Law No. 6968 in 1957, plant health studies were gathered under one roof. During this period, licensing of pesticide and devices related to chemical control began, and regulations were made regarding their manufacture, import, sale and use (Ecevit, et al. 1999).

It should be considered as the period when agricultural control was actively developed in Turkey and positive results were obtained. During this period, the "Agricultural Protection and Agricultural Quarantine Law No. 6968" was enacted in 1957 and the "General Directorate of Agricultural Protection and Agricultural Quarantine" was established based on this law (Anonymous, 2002).

With these practices, plant protection has been institutionalized, plant protection services have been gathered under one roof and managed by a single source, and chemical control has become more disciplined. In particular, pesticide research was supported to pesticide research institutes. In the established agricultural research institutes, studies have begun to be carried out, taking into account the requirements of the day, especially on chemical warfare, in accordance with the statutes and regulations issued based on Law No. 6968. Research projects were determined according to the needs of the day, and the above boards decided to support these projects according to the statutes and regulations (Kadıoğlu, 2012). These practices in the Pest Protection Research Institutes also served as an educational task within the hierarchical framework. Agricultural Control and Agricultural Quarantine Regional

Presidencies, Agricultural Control and Agricultural Quarantine Provincial Directorates and agricultural control organizations in the districts provided services to farmers according to the results of the research conducted in the research institutes (Türkoğlu, 2003).

3. 1984 and Later

This is the period when the General Directorate of Protection and Control was established. This period was a period in which the private sector in the field of plant protection became stronger in our country, many manufacturing and importer companies were established, a widespread dealer network was formed, and the state moved from the duty of publication and training on chemical control products to the duty of permitting, licensing and inspection (Kadıoğlu, 2012).

During this period, there was also a transition from state control to state aid control and from pesticide distribution to pesticide support. In this context, support continued to be given to producers using pesticides or associations control against olive fly until 1999.

During this period, pesticides were delivered to all parts of the country, the use of pesticides increased, and harmful organisms, especially *Tettigonia* spp. (Tettigoniidae Orthoptera), *Microtus* spp. (Rodentia: Muridae) and *Eurygaster integriceps* Put. (Heteroptera; Scutelleridae) were taken under control. Another important indicator of this period was the increase in the number of dealers, the development of the producer's awareness level in the use of chemical control, and the strengthening of the production, marketing and promotion network in the plant protection product sector (Kadıoğlu, 2012).

4. Period after 2005:

Limitation on exports from our country as a result of first detecting the presence of harmful organisms' subject to quarantine in fruit and vegetable exports from Turkey to the Russian Federation and the European Union (EU), and then detecting high residues in the analysis or determining that some active substances that are not licensed in the EU or Russia are used. and a ban was imposed. This situation has led to the questioning of the use of pesticides within the country and to some bans and restrictions in line with the EU (Kadıoğlu, 2012).

In this period, it is aimed to control and reduce the use of chemical control products, manage the risk of residues, and highlight other control methods in a way that protects consumer and environmental health (Kadıoğlu, 2012).

CONCLUSION

One of the most important problems that confront all countries today is to feed the rapidly increasing world population. The world population is increasing rapidly, but the surface area does not change, but erosion, the opening of new settlements, the establishment of new factories, and the expansion of existing roads in parallel with the increasing number of vehicles, opening of new roads, developing industry, technology, etc. For these reasons, areas suitable for agriculture are gradually decreasing.

Since the surface area of the world is limited, it is not possible to open new areas to agriculture for production that will meet this need. What needs to be done is to increase the amount of product obtained from the unit area. For this, using modern techniques and inputs is a necessity.

Today, in the world, the crop loss caused by diseases, pests and weeds that damage plants before harvest is approximately 35%, of which 14% is due to pests, 11% to diseases and 10% to weeds. After harvest; Insects, rodents, birds and harmful microorganisms cause an average of 14% (10-20%) additional damage. Thus, the total damage reaches 50%. Research shows that if there is no control, this loss can double. This situation can lead to an increase in diseases caused by food deficiency, famine, migration and humanitarian disasters such as war. Therefore, phytosanitary measures are extremely important to ensure food safety in a country.

Today, there is a rapid and large-scale plant exchange in the world. As a result, plant and plant product parts are dispersed to very distant places in a short time. Along with these, very dangerous diseases, pests and weeds are also spread. If precautions are not taken, clean countries and regions become infected with harmful factors in a short time. These factors, which used to take a long time to spread, now occur in a short time. Since any non-economic practice has no place in modern plant protection, the aim of agricultural control today is to increase the product and quality within the limits of economy. As it is known, economy includes the most fundamental values of our age. The concept of economy in modern plant protection includes protecting the environment and health, as well as preventing new problems, such as preventing new pests, diseases or weed species from becoming dominant, preventing the emergence of individual’s resistant to pesticides, and even preventing residue problems in agricultural product exports, through conscious and controlled practices.

Today, there are 552 diseases, pests and weeds that cause economic damage in more than 100 cultivated plants grown in our country. People harvest not what they planted, but what is left over from diseases, pests and weeds, and some of them are lost to pests in warehouses. The duty of the Plant Protection Officer should be to allocate the least amount of these product-reducing plant protection factors without disturbing the natural balance.

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CHAPTER 9

USE of AGRICULTURAL UNMANNED AERIALVEHICLES in AGRICULTURAL PRODUCTION

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1. INTRODUCTION

Rapidly increasing world population and uncontrolled industrialization process, unhealthy urbanization, regional wars, chemical substances such as pesticides used to increase efficiency, unconscious fertilization and detergents have increasingly started to pollute the environment, and as a result, highly polluted air, water and soil can be harmful to living things. has reached large sizes. With the industrial revolution, the increasing use of fossil fuels and the rapid destruction of forests have brought these negative effects to serious levels, almost unavoidable. Considering that approximately 85% of the world's current energy resources consist of fossil fuels (oil, coal, natural gas, etc.) (MacCracken, 2001), it can be said that the main cause of global warming is greenhouse gases in the atmosphere, especially carbon dioxide resulting from fossil fuels (Houghton, 2005). The increase in greenhouse gases in the atmosphere is largely due to the type of energy used to meet human needs such as industry, transportation and agriculture (Houghton, 2005). Science and technological developments offer the opportunity to design more environmentally friendly agricultural production processes and reduce the use of fossil fuels that cause climate change. In this sense, drone technology (Agricultural Unmanned Aerial Vehicle, AUAV), a new technology, is accepted as an alternative to reduce the use of fossil fuels in agricultural production processes.

2. CLIMATE CHANGE AND AGRICULTURAL PRODUCTION ACTIVITIES

Global warming has become a scientific and political issue that has occupied the world agenda in recent years and caused long discussions. Global warming can be defined as the increase in the concentrations of greenhouse gases (CO_2, CH_4, N_2O, etc.) in the atmosphere, causing these molecules to trap sunlight and increase the earth's temperature. Shortwave radiation reaching the surface of our planet from the sun heats the earth by converting from light into heat. The Earth reflects some of this radiation back into space as long-wave infrared radiation. While most of these long-wave infrared rays return to space, some of them are absorbed by greenhouse gas molecules such as water vapour, carbon dioxide and methane in the earth's atmosphere and trapped in the atmosphere, thus making the earth's surface and atmosphere warmer than they should be. The molecules act as glass and the heated air remains in the earth's atmosphere. This phenomenon is known as the natural greenhouse effect because it is likened to greenhouses that are heated by sunlight but do not release the heat inside. Although the greenhouse effect is an extremely important mechanism for keeping the world's temperature in balance, there has been an increase in the rate of these gases due to industrialization and the use of fossil fuels as a result of wrong practices in recent years, and therefore the greenhouse effect has become negatively associated with climate change. If there were no greenhouse effect in the atmosphere, the average temperature of the world would be 255 K or -18 °C and perhaps life on earth would not be possible. Due to this mechanism occurring in the atmosphere, a part of the long-wavelength reflection is retained and the world's average temperature is around +15 °C (King, 2005). Increasing air temperatures stand out among the climate changes occurring in Turkey and the World. It is estimated that this increase in air temperature will cause serious climate change in the world. Factors that climate change, sea level rise, displacement of climate zones, increase in severe weather events, more frequent occurrence of strong floods and floods, drought, erosion, desertification, epidemic diseases, agricultural pests, disruption of natural balance, arising from global warming pose a threat to human existence and are expected to cause significant problems, directly or indirectly, on socio-economic and ecological systems (Anonymous, 2001, 2002).

Due to the increasing earth temperature, the glaciers are melting and the sea level is rising due to irregular rainfall, which negatively affects the settlement of many coastal regions. In the projected projections, with a 100 cm increase in sea level, 6% of the Netherlands and 17.5% of Bangladesh will be under water, the USA's land loss will be 25,000 km^2, and many islands will either be completely or mostly under water. It is calculated that it will remain (Korkmaz, 2007The rise in seas will create major changes in coastal ecosystems, and new swamps will form in the low plains near the seas. In addition to the land losses that will occur as the sea advances over the land, there will also be an increase in coastal erosion. Considering that these negative effects will cause forced migrations and decreases in agricultural areas, the importance of being aware of the danger that will arise is once again highlighted. For example, in 2003, European agriculture suffered a major blow due to heat waves due to global warming, with France suffering a 20%

productivity loss and some other European countries suffering a 10-80% productivity loss (Şahin, 2007). The research of the International Climate Change Panel emphasizes that special attention should be given to Turkey due to its rich biodiversity and that the effects of climate change on Turkey should be carefully investigated. The fact that the region in which Turkey is located is faced with water scarcity, drought and soil erosion problems puts Turkey among the countries that will experience the harmful and severe effects of global warming first (Doğan, 2005).

The most important disaster that Turkey will experience due to global warming is drought. The decrease in rain and especially snowfall causes the groundwater level to decrease, thus causing the drying of streams and lakes. This will deal a great blow to agriculture, which is extremely important for Turkey's development and livelihood, and Turkey will face a great danger of hunger and drought. As we will clearly see the results of 2007, which will probably be the hottest year of all time, Çukurova and similar regions where irrigated agriculture is carried out will lose productivity due to drought. In developing countries such as Turkey, the decrease in the agricultural productivity of the land causes areas such as agriculture, pastures and forests to be used for purposes other than their intended purpose, leading to a decrease in sustainability and productivity. Therefore, the ongoing degradation process also reduces soil quality. Agricultural activities are responsible for approximately 20% of the increasing greenhouse gases in the world (Pathak and Wassmann, 2007). Especially CO_2, CH_4 and N_2O are held responsible for the increase in greenhouse gases as a result of agricultural activities (energy consumption, production, animal husbandry, fertilization, medicine, etc.) (Houghton, 2003). Agriculture is extremely important in terms of the negative effects of agricultural practices and production on global warming, as well as the healthy living of the increasing world population. As a result of agricultural activities such as incorrect land use and unconscious and excessive fertilization, greenhouse gas emissions from soils, which are carbon sources, increase (Lal, 2006).

In addition to the encouraging effects of agriculture on global warming, global warming also has negative effects on agriculture. In order to feed the world population, which is expected to reach 8.6 billion by 2030 (AA, 2017), current food production must be increased by 60% (FAO, 2023). Considering that the majority of this population lives in cities and that migration from rural areas to cities increases day by day due to financial difficulties, creating a production potential that will correspond to the increasing consumption rate is an important problem. Siqueira et al. (2001) stated that by 2050, there will be a 3-5 ^{o}C decrease in air temperature and an 11% increase in precipitation in Brazil, and this change will reduce the production of wheat by 30% and corn by 16%, while it will increase soybean production by 21%. They stated that this change would also increase erosion, negatively affect the productivity and quality of agricultural products by causing difficulties in agricultural operations (soil cultivation, irrigation, spraying, etc.), increase in diseases, and difficulty in controlling them, and that significant food shortages and hunger would occur. On the other hand, when other conditions are optimum, increasing CO_2 concentration in the atmosphere is expected to increase crop yields by 10-50% as it will encourage water use efficiency and photosynthetic activities of plants.

Although there are positive aspects of climate change increasing the general temperature level, its destructive effects are greater. Increasing temperature will generally have a negative impact on agricultural products and will cause diseases in plants. Therefore, farmers in arid regions will both irrigate more and use more pesticides. For example, increasing temperature will negatively affect the rice plant's increased transpiration rate, lack of vegetative development and grain filling period, and will negatively affect rice development and cause yield losses (Pathak and Wassmann, 2007). In addition, with increasing temperatures, it is inevitable that there will be a water shortage in the world. Goyal (2004) stated that even if the temperature increases by 1 ^{o}C in India, evapotranspiration will increase by 15 mm, which will create a large water need of 313.12 million cubic meters for the whole of India. Since the increasing water need cannot be met, especially in arid and semi-arid regions, it will cause significant productivity decreases, so preventing water losses, protecting water reserves and developing new plant varieties with low water sensitivity are extremely important in terms of ensuring productivity and sustainability. According to 2021 data, 844 million people in the world cannot access drinking water and cannot find clean water (Ministry of Agriculture and Forestry 2021), and according to FAO 1996 data, 800 million people suffer from nutritional difficulties (Gökten and Gökten, 2017). According to projections made by experts, it is thought that the food needs of the world's population will double in the next few decades (Zaimoğlu, 2019). As a result of climate change, productivity will increase in middle and high latitudes, while productivity will decrease significantly in tropical and subtropical regions. As a result, the majority of the rural population will be negatively affected. Infectious diseases and malnutrition will become important problems for people. Climate change will exacerbate the food shortage in middle belt regions such as India, Asia and Africa, and as a result, hunger and famine will seriously occur in these regions. By 2025, 61% of the world's population is expected to live in cities due to ongoing migration from rural areas. Environmental degradation, population growth and food shortage will cause migration for humans and animals, and as a result of these unhealthy migrations, diseases and deaths will increase (Khasnis and Nettleman, 2005).

3. TRADITIONAL METHODS IN AGRICULTURAL PRODUCTION

The rapid increase in human population necessitates an increase in efficiency and quality in agricultural production. Effective use of agricultural production areas, which are a scarce resource, requires using production methods that will provide the highest efficiency area. Studies carried out to increase productivity in crop production have yielded positive results and are still being improved. Organic fertilizers, which can be used instead of existing chemical products, increase the efficiency of plant production while also regulating the structure of the soil and creating positive results on the nutritional values in the soil. For this reason, correct fertilization, fertilization amount and time are very important in increasing the efficiency and quality of plant production (Saygı, 2022). A balanced fertilization is mandatory to ensure productivity increase and fruit quality (Saygı, 2022). Recently, the use of chemical fertilizers has increased in parallel with the increase in the world population. Understanding the problems caused by the unconscious use of chemical fertilizers and their negative effects on human health and the environment (Sayği, 2020) and considering that unconscious practices trigger global warming in the first degree, has led to the search for alternative plant nutrition opportunities in agricultural areas where intensive applications are made for sustainable agricultural production (Nicolopoulou-Stamati et al., 2016). The use of incorrect chemical fertilizers (nitrogenous and nitrate fertilizers) causes more nitrate accumulation in vegetables whose leaves are eaten. 80% of nitrate is taken by humans through food and 20% through drinking water. It has been reported that 70% of the nitrate taken with food comes from edible vegetables (Isermann, 1983). Nitrate accumulation has a toxic effect on human health. Excessive and unconscious use of chemical products causes the accumulation of nitrite and nitrate in plants and contaminates soil, water and plants through the water cycle (Saber, 2001). It has been reported that especially excessive amounts of nitrogen fertilization increases the amount of nitrite and nitrate in vegetables and negatively affects human health. Studies have shown that chemical fertilizers cause more nitrate accumulation in plants than organic fertilizers (Özgen and Sekerci, 2011).

Since the product is crushed in the area where spraying and fertilization is carried out with the tractor during the agricultural production process, access to the product becomes very difficult during these processes. Farmers prefer spraying and fertilizing with irrigation water, but excessive pesticides and chemical fertilizers mixed into irrigation water pose a great danger to the product and the environment. These inputs mix with water resources (lakes, rivers, groundwater) through water transformation, causing pollution and poisoning the living creatures that exist in this ecosystem and therefore people. As a matter of fact, research shows that traces of these agricultural inputs are found even in breast milk. Accordingly, the disadvantages of using chemicals with traditional methods in agricultural production are as follows:

3.1. Effect of pesticides used in agricultural production on human health

Some of the pesticides have immediate effect (acute), while some have chronic effect. Acute poisoning occurs when the pesticide is inhaled, ingested or comes into contact with the skin. As a result of acute poisoning, symptoms such as cessation or slowdown of the organism's activities, diarrhea, tremors, excessive sweating, nausea, and constriction of pupils are observed. Acute poisoning can occur as a result of careless use or misuse of the drug outside of agriculture. Poisonings caused by eating plant and animal foods containing pesticide residues are called chronic poisonings. Chronic poisoning occurs when low doses of the drug are taken continuously over a certain period of time. Chronic poisonings; It manifests itself with carcinogenic (cancer-causing substance), teratogenic (substance that causes abnormalities in the unborn child) and allergenic effects.

3.2. Effect of pesticides used in agricultural production on water

Pesticides reach the aquatic ecosystem through various means. During agricultural struggle, pesticides reach water through direct contact of plants or insects in or near water, washing of pesticides from treated plants and soil surfaces with rainwater, discharging pharmaceutical industry wastes into running or stagnant waters, washing application tools and empty packaging containers in water resources. In addition, water can be contaminated by carrying solid and liquid drug particles in the atmosphere to water resources. Contamination of water in dams that provide drinking and irrigation water with pesticides in different concentrations can create great dangers for humans, domestic and wild animals. A pesticide entering the aquatic ecosystem negatively affects the aquatic flora and fauna. The effects of pesticides on fish are very different. Apart from directly causing death, it can also be fatal in ways such as changes in the nutritional environment and decreased oxygen.

3.3. Effect of pesticides used in agricultural production on soil

Pesticides used against plant diseases and pests can indirectly reach the soil through factors such as rain and wind. Harmful insects, nematodes in the soil and chemicals applied to the seeds during seed spraying are directly contaminated with the soil. These pesticides accumulated in the soil reach humans, domestic animals and wildlife through consumed products, negatively affecting environmental health.

3.4. Effect of pesticides used in agricultural production on the atmosphere

Pesticides also pollute the environment through the air. The evaporation of the active substance causes harmful effects on all living things in the settlements around areas where intensive pesticide use is used. The issue is of great importance especially for people living in regions where intensive agriculture is practiced. For example, according to a study conducted in America in 1989, the effective substances of many pesticides were detected in the atmosphere in settlements.

3.5. Effect of pesticides used in agricultural production on plants

Intensive and unconscious use of pesticides gradually reduces the sensitivity of organisms to chemicals. In practice, the manufacturer tries to prevent organisms that begin to gain resistance by increasing the dose as sensitivity decreases. As the dose increases, tolerance manifests itself rapidly. The result is higher doses and more frequent spraying. Durability is an important problem for both pesticide manufacturers and applicators. Due to durability problems, fewer pesticides are released to the market every year with higher costs. This causes agricultural warfare to become increasingly expensive. Effects of pesticides on animals and nutrients • The pesticides used against plant diseases and pests have a certain period of time between the last application and harvest, depending on the degree of toxicity.

Pesticide residues found in farm animal meat, milk and dairy products, and poultry eggs can affect consumers. For this reason, animals should not be grazed in sprayed areas before the time specifically determined for each pesticide. The type of pesticides, the place and time of application, the dose used per decare, their permanence on the plants and the meteorological conditions on the days the pesticide is applied poison honey bees at different rates. Pesticides generally used during the flowering period of plants can cause the death of many bees. Faulty pest control applications and some unconsciously used pesticides have caused significant decreases in the number of some species, especially seed-eating birds. Medicines can be transported to great distances by mixing with surface waters and groundwater, into the seas, or by wind.

In order to minimize these negative conditions in agriculture, the idea of using a new technology, drone (AUAV), in all agricultural production processes has been developed and significant positive results have been achieved in practice. Especially spraying and fertilizing with a drone provides great convenience in terms of both time and cost. Agricultural Drone Technologies are developing day by day and the use of drones in agriculture is becoming widespread. Drone spraying and fertilization, which can be done at a more affordable cost compared to traditional methods, not only saves water, cost and time, but also prevents possible injuries to producers who have to work in rough terrain. With drone spraying, both agricultural production costs and environmental costs resulting from production (pollution and greenhouse gas emissions that cause climate change) will be reduced. 600 liters of medicine, which is applied in two hours with the traditional method by tractor, can be made in 15-20 minutes with AUAVs. In conclusion; It will save both labor, time and water.

4. USE OF TECHNOLOGY IN THE AGRICULTURAL PRODUCTION PROCESS (AUAV)

In recent years, countries around the world that have become aware of the reality of global warming have begun to include economic sectors such as energy, transportation and agriculture in their climate policies and sustainable development strategies. This shows that efficient energy use is possible with technology, thus the same level of development can be achieved with less energy use and less greenhouse gas emissions through technological tools. Many organizations working on global warming have reported that in order to prevent global warming, greenhouse gas emissions should be limited by making the necessary policy changes to reduce the use of fossil fuels in the energy, industry, transportation and agriculture sectors. In this sense, green energy, or as it is currently defined, utilizing renewable energy sources (solar, wind, thermal and nuclear energy) has come to the fore.

These resources can also be used effectively in the agricultural sector. In order to achieve this, studies should be carried out on renewable energy resources and their efficiency should be increased by using new technologies in the energy sector and the agricultural sector. Increasing the use of renewable energy resources will be beneficial in terms of protecting the natural balance such as air, soil and water and ensuring sustainability, as well as slowing down conventional energy applications, which will have significant positive effects on the environment. In addition, protecting forests, conscious agricultural practices (such as fertilization and spraying), and imposing taxes with serious sanctions to reduce greenhouse gas emissions can help reduce global warming.

Following agricultural technologies for a sustainable agricultural system has become inevitable in today's conditions. Many technological tools (from plough to sickle, sickle to scythe, scythe to plow) have been developed over time to increase productivity in agriculture in order to achieve more efficient agriculture according to the conditions of the period. In today's conditions, there are many technological tools that can be used in modern agricultural practices and one of these tools is AUAV.

4.1. Use of AUAV in agricultural production

AUAV, which is a relatively new technology used in many areas of agricultural production, is generally used to effectively apply liquid inputs. Spraying and fertilizing with AUAV not only reduces the amount of input used, but also reaches the product more effectively. Since it is an aerial spraying system, the product is not damaged, and since it allows effective spraying and plant nutrition, productivity is increased. The most preferred products for the use of AUAV in agricultural production are; They are listed as wheat, corn, barley, paddy, cotton, grapes, tea and seasonal fruits (Figure 1).

Figure 1. AUAV Spraying in Wheat

Thanks to its technology, AUAV reveals and analyzes the quality of the soil and its infertile parts from the air, and accordingly provides accurate information for spraying and fertilizing. The ability to monitor and examine large-scale areas with AUAV also provides a great advantage for the path to be followed in the long term.

AUAVs are very suitable for working with high efficiency, especially in large and rugged lands, and have a larger and wider spraying range compared to the spraying and fertilizing method done with tractors. In addition to these benefits, AUAVs are preferred by producers because they eliminate the damage that the tractor may cause to the crop and of course provide effective cost management. It offers the opportunity to spray and fertilize more land area in a shorter time compared to the backpack sprayer. The use of drones continues to become widespread in many different sectors, and the use of AUAVs is increasing, especially in agricultural production. We can list the areas or purposes of using AUAVs in agricultural production under the following 10 main headings.

- Crop yield prediction
- 3D data
- Planting seeds
- Weed control
- Insect presence control
- Relative biomass assessment
- Disease of crops
- Nutrient availability
- Number of plants
- Plant health

One use of AUAV imagery, which has already been introduced with great success, is for monitoring plant health. Equipped with special imaging equipment such as a thermal camera called Normalized Difference Vegetation Index (NDVI), AUAVs use detailed color information to indicate plant health, allowing farmers to monitor their crops as they grow, so that if there are any problems, the necessary measures can be taken early to save the plants (Figure 2).

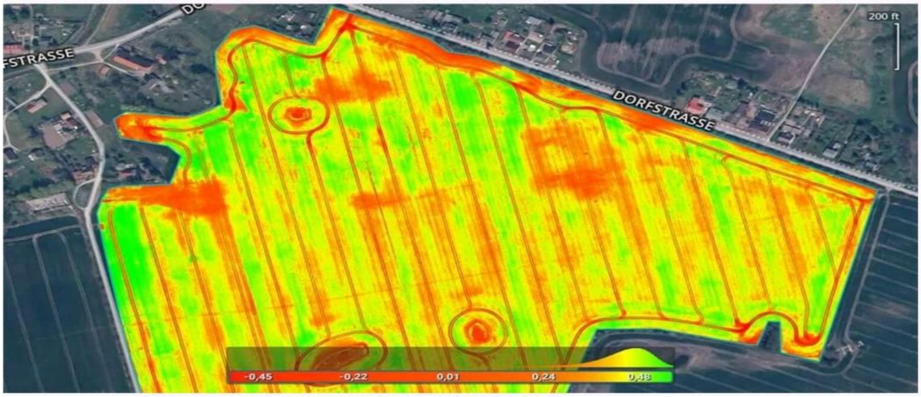

Figure 2. Vegetation Index Map (https://www.drone.net.tr/blog/zirai-insansiz-hava-araci-1275.html)

For example, as a result of checking a total of 1000 olive trees in 10 rows planted parallel to each other with AUAV, the diseased olive tree can be easily detected. With the POI (point of interest) method, it can be determined which tree in which row is diseased. Likewise, plant height and animal movements can be determined, and with this data it helps to make the following analyzes in the agricultural field.

- Phenology
- Phytophenology
- Floral Phenology

- Leaf area indexing
- Classification of trees
- Aging analysis
- Drought forecasts
- Yield monitoring
- Plant stress monitoring
- Field monitoring of nitrogen needs
- Monitoring the health of the crop

In addition, in order to produce more precise and faster agricultural solutions, very useful precise maps with “**orthomosaic”** images are created and used using AUAVs and agricultural software programs. These maps are used to help the farmer or agricultural engineer determine in advance the timing of agricultural production actions such as irrigation, fertilization and pesticide application. In general, the data provided by AUAVs has been tested and recorded by independent organizations that it significantly increases product yield.

With the approval of countries' aviation authorities, AUAVs can be equipped with large reservoirs that can be filled with fertilizers, herbicides or pesticides. The application of liquid inputs with AUAVs is much safer and lower cost in terms of production and the environment. AUAVs can be operated completely autonomously, for example, if there is a foreign plant in a particular part of the crop, they can be used to detect the problem, and can be programmed to operate on specific schedules and routes. With the speed at which AUAVs work, you can diagnose and treat potential crop problems before they become a widespread problem across the entire farm. While spot spraying of crops in the traditional system is a very difficult process and even if there are weeds or pests in the production area, the entire land must be treated. This is a huge waste of time and resources as someone would have to walk the entire area, plus there are the overall costs of pesticides and the associated environmental cost of chemical use. Spot spraying is possible with AUAVs and the process can be carried out in a shorter time with lower production and environmental costs.

Irrigation, which is difficult in some regions, can also be done with AUAVs. AUAVs can be used as a solution when water resources are scarce, water is difficult to access, or the area to be irrigated does not have normal conditions. AUAVs equipped with thermal cameras can help detect irrigation problems or areas receiving too little or too much moisture. With this information, crops can be better placed to maximize drainage, adhere to natural soil flow, and prevent waterlogging that can damage delicate crops. Water and irrigation problems are not only costly but can also disrupt crop yields. Thanks to AUAVs, these problems can be detected before they cause problems.

4.2. Advantages of Using AUAV in Agricultural Production

- **Safety:** Agricultural Drones protect farmers from poisoning when using harmful pesticides and sunburn when working in the fields in summer.
- **High efficiency:** 50-100 acres can be sprayed per day with the Agricultural Drone, which is 30 times more than traditional spraying methods.

- **Environmental protection:** With the fixed location and orientation method, water and soil pollution is significantly reduced.
- **Reducing waste:** 30% of pesticide savings are achieved with a high degree of atomization.
- **Water saving:** 90% water savings can be achieved compared to traditional spraying methods. This is only possible through the use of ultra-low volume drone spraying technology.
- **Lower cost:** There is a 97% reduction in cost compared to traditional spraying methods.
- **Wide range of applications:** It is not affected by the terrain and height of the crop, has an ergonomic and innovative remote control, easily manages flights at low altitudes and does not damage the crop.
- **Ease of use and maintenance:** It has a long life, low maintenance cost and easy to replace parts.

4.2. Evaluation of Traditional Disinfestation and Disinfestation with AUAV

4.2.1. Economically: A tractor with general features used in traditional spraying (average power 55 HP, average curb weight 2110 kg, average speed 15-20 kmh-1, which can be used at an average speed) consumes approximately 5 liters of fuel for 1 hectare of land (Vurarak and Bilgili, 2015). In this case, the fuel cost (1 liter of diesel fuel is approximately 40 TL as of 23.09.2023) is 200 TL/ha. In addition to this fuel cost, more input usage, lost working days due to unsuitable land conditions, and labor employment costs will also be added. In terms of time cost, while 1 ha of land can be sprayed in 1 hour with a tractor, this can be done in just 10 minutes with AUAV.

In spraying with AUAV, there will be no loss of working days due to unsuitable land conditions, no worker employment costs, and the use of agricultural input will be 40% less. Only the AUAV rental fee for spraying 1 ha of land is between 350 TL and 650 TL (these costs may vary depending on the size of the land). In terms of time cost, AUAV offers a greater advantage and 1 ha of land can be sprayed in just 10 minutes. According to 2022 data, 25 thousand ha of land was sprayed with AUAV and approximately 10 million TL was saved (Tarım Pusulası, 2022).

4.2.2. Environmental (greenhouse gas emission) effects: The most important environmental problem in spraying and fertilizing with tractors is the greenhouse gas emission of the type of energy (fossil fuels) used in tractors, which causes climate change. A general tractor used in traditional spraying causes the emission of greenhouse gases for 1 hectare of land (carbon equivalent CE) in the amount of approximately 0.7-2.2 kg CE/ha in herbicide spraying and 5.1-10.1 kg CE/ha in fertilization (Vurarak and Bilgili, 2015).

Since AUAVs use electrical energy, there is no greenhouse gas emissions that cause climate change. It is ensured that the pesticide input used is 40% less compared to the tractor (Tarım Pusulası, 2022). This is an important gain in terms of environmental costs for sustainable agricultural activities.

4.2.3. Effects of yield loss: Spraying and fertilizing caused by the tractor moving through the field causes a 5% yield loss. The time it takes to treat pests with a tractor, that is, spraying and fertilizing, is long, and sometimes pests cause great damage to the crop and loss of productivity because they cannot enter the land and work due to unsuitable land conditions.

With AUAVs, spraying and fertilization can be done regardless of field conditions. When pests are detected in the field, intervention can be made quickly, and with timely intervention, plant health can be protected and productivity losses can be prevented.

5. CONCLUSION

There is an interaction between agricultural production activities and climate change. While agricultural production activities are an important factor of climate change with the practices that cause climate change, it also has a structure that is most affected by these changes. On the one hand, variability in seasonal processes, drought, floods and adverse air quality caused by climate change directly affect the agricultural sector. On the other hand, the main factor causing climate change is the chemicals (chemical pesticides and fertilizers) used intensively in the agricultural production process and the release of greenhouse gases into the atmosphere due to the use of fossil fuels as the energy source used in the production process. It has now been understood by scientific circles and experiences that this situation poses a great threat to nature, living beings and human existence. AUAVs, which started to be used with the idea of using technology to solve the negative situations caused by these traditional production methods that have been used in agricultural production for a long time, have provided significant gains in agricultural production in terms of production and environmental costs. AUAVs contribute to sustainable agricultural activities by reducing input use in agricultural production, increasing product yield, preventing yield loss, saving time, rapid data collection from the production area and zero greenhouse gas emissions. In particular, spraying, fertilizing and irrigation with AUAV provides great convenience in terms of both time and cost. AUAV technologies are developing day by day and the use of drones in agriculture is becoming widespread.

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