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Impact of Urban Xenobiotics on Mycorrhizal Associations in Urban Plants

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ABSTRACT

Urban xenobiotics are a vital contamination phenomenon of urban plants in the overall country. They are a result of human activity due to growing urbanization and population growth. There are extensive sources of both natural (soil or rock erosion, fires, biodegradation, and volcanic eruptions) and anthropogenic (soil pollution, air, and herbicides). Currently, the demand for pharmaceuticals, compared to the growing population, has placed a risk on the urban plant. Additionally, the production of illegal drugs has caused the release of dangerous carcinogens into fungal activities, which will have an impact on plant health, microbial structure, and fungal interaction. Because of the harsh environment, higher temperatures, heavy metals, and higher N deposition, most urban trees suffer from stress conditions, and mycorrhiza is negatively impacted by plant conditions. Some mycorrhiza fungi are unable to sporulate and hyphal at higher xenobiotic concentrations in urban areas. This chapter takes a look at the sources and compounds of xenobiotics and their harmful impact on mycorrhiza; and its association with the urban plants.

INTRODUCTION

Urbanization has both positive and negative effects on the plant, but it is undoubtedly bringing about change. According to UN estimates, more than half of the world's population already lives in cities, and by the year 2050, that percentage will rise to 64% in developing countries and 86% in developed countries. The effects of climate change will be especially felt in urban areas because of how quickly urbanization grows globally (Bazaz et al. 2018). As a result, the temperature rise brought on by global warming is problematic for the ensuing decades because it will have a variety of effects on urban areas, which will have an impact on plant health, microbial structure, and fungal interaction. Urban pollution is a major challenge due to the steadily growing urban population. Human demand is rising as a result of the growing population, which has a negative impact on the urban area's plant environment (Liang et al. 2008). Although most urban xenobiotics come from natural sources, human-related emissions are the most dangerous. Cities frequently have worsened anthropogenic sources of xenobiotics, such as factories, industries, transportation, and so forth, because of the local concentration of people and human activity (Stefanac et al. 2021). For instance, fungus activity and the connection between fungi and plant roots affect xenobiotics in urban areas. Xenobiotics are chemicals or other substances that cannot be utilized by plants for the production of energy and are typically absent from ecosystems. Similar to other organisms in the environment, plants are constantly exposed to xenobiotics such as pesticides (such as atrazine, chlorpyriphos, cypermethrin, endosulfan, etc.), allelochemicals (such as cinnamic acid, benzoic acid), organic pollutants (such as trinitrotoluene, phenanthrene), heavy metals/metalloids (such as lead, cadmium, arsenic) (Zhang et al. 2007, Riechers et al. 2010). These xenobiotics can come from both anthropogenic (air and soil pollution, herbicides) and natural (fires, volcanic eruptions, soil or rock erosion, biodegradation) sources. Urban plants typically consist of tiny, isolated forest fragments and are subjected to very harsh environmental conditions (Ruddiman 2013). Urban forests experience higher temperatures than their rural counterparts because of heat island effects (Oke 1973), an increase in N deposition (Hosseini et al. 2015, O'Brien et al. 2012), and heavy metal buildup (Sun et al. 2009). Mycorrhizal fungi can be negatively impacted by specific environmental conditions present in most urban environments, despite the fact that plant-mycorrhizal associations appear to be very resilient to disturbances and can persist in the soil despite clear-cutting and weathering (Haug et al. 2013, Bhardwaj & Chandra 2016, Kumar et al. 2023). Mycorrhizal diversity was found to be lower in urban and highly disturbed soils, and Karpati et al. (2011) theorized that this change may be due to pollution and increased anthropogenic nitrogen deposition. According to Egerton-Warburton and Allen (2000), some AMF fungi fail to sporulate in high nitrogen environments, and hyphal growth is frequently inhibited by N deposition (Treseder & Allen 2000, Bhardwaj & Chandra 2017, Kumar et al. 2024). Additionally, mycorrhizal colonization can be hampered or reduced by heavy metals like zinc and lead (Yang et al. 2015). Another helpful mycorrhizal indicator is the fact that mycorrhizal communities are less diverse in soils with more recent physical disturbance and smaller soil aggregates (Duchicela 2013, Bhardwaj et al. 2023a, Kumar et al. 2022). Mycorrhiza is a symbiotic relationship between plant roots and soil fungi. About 80% of terrestrial plants can establish associations with mycorrhizal fungi (Smith & Read 2008, Chandra 2014, Bhardwaj et al. 2023b). Mycorrhizal fungi help plants acquire water, phosphorus (P), and other essential nutrients, and the colonizing fungi, in turn, obtain carbon from their host plant (Smith & Smith 2011, Chandra & Bhardwaj 2018). In this chapter, we focus on the xenobiotics that alter the soil's beneficial fungi for urban plants and identify the key urban xenobiotics that are primarily to blame for the decline in mycorrhizal associations.

XENOBIOTICS: SOURCES AND TYPES

The words "xenobiotic" come from Greek words that originally meant "foreign or strange" and "exotic," which means life. Xenobiotics are chemicals with peculiar structural characteristics (Fetzner 2002). Numerous xenobiotics have the potential to be harmful to organisms that come into contact with them in the environment. However, these bioavailable substances depend on the characteristics of the organism, the chemicals, and the environment. According to Maenpaa (2007), the bioaccumulation of chemical byproducts within the organism is correlated with the toxicity of any xenobiotic. Xenobiotics can linger in the environment for months or even years. For instance, the polymer structure of lignin or the components of a small number of fungi's cell walls (melanin polymers) may not break down quickly in the environment (Fetzner 2002). The same is true for hydrophobic pollutants in aquatic environments, which are eventually stored in sediments and turn dangerous when they come into contact with benthic organisms. Any exposure to xenobiotic-contaminated sediments may have an impact on the lower trophic levels. At higher trophic levels, it might also cause biomagnification or more harmful toxic effects (Landrum & Robbins 1990, Lee 1992, Streit 1992, Newman 1998).

Xenobiotics are a significant urban plant contamination phenomenon across the entire country. They are the result of human activity sparked by escalating urbanization and population growth. There are many anthropogenic and natural sources of pollution, including volcanic eruptions, biodegradation, soil erosion, and fires (soil pollution, air, and herbicides) (Musolff et al. 2010). Due to the imbalance between the demand for pharmaceuticals and the growing population, the urban plant is currently in danger. In addition, harmful carcinogens have been released into the metabolism of urban plants as a result of the production of illegal drugs. The release of these dangerous xenobiotics has an immediate and long-term effect on the urban plant (Brooks 2018). Plants growing in highly soil xenobiotics environments have disruptions in the physiology and biochemical processes like CO_2 fixation, gaseous exchange, nutrient absorption, and respiration (Fig. 1). These disturbances cause the urban plant to produce less biomass and grow more slowly.

As a result of technological development in the 20th century, a large number of substances that are used to improve daily life (such as antibiotics, pesticides, dyes, PCPs, and additives) either do not necessarily occur naturally in the environment or whose naturally occurring concentrations are very different from those caused by anthropogenic activity.

The main problem is their physicochemical structures, which make them difficult to identify, quantify, and eliminate (De Oliveira et al. 2020). These structures include small molecular size, ionizability, water solubility, lipophilicity, polarity, and volatility.

Xenobiotics are chemicals that exist in both the environment and living things but are not created there. When found in high concentrations in the environment, some naturally occurring chemicals (endobiotics) turn into xenobiotics (Soucek 2011). They are classified as pesticides, pharmaceutical compounds, personal care products, illicit drugs, industrial products, and nuclear waste (Kumar et al. 2020) and can be found in the air, soil, water, plants, animals, and humans, as shown in Fig. 2. According to WFD, priority substances are divided into 17 categories (organophosphorus polyaromatic, herbicides, hydrocarbons, chlorinated solvents, organochlorine insecticides, aromatic organochlorine compounds, PBBs, dioxins, BDEs, phthalate, metals, anti-fouling biocide, pyrethroid insecticides, alkylphenols, perfluorinated surfactant, quinoline fungicide, benzene, hexabromocyclododecane, and chloroalkanes), Substances on the watch list are divided into eight categories (hormones, antibiotics, pharmaceuticals, neonicotinoid

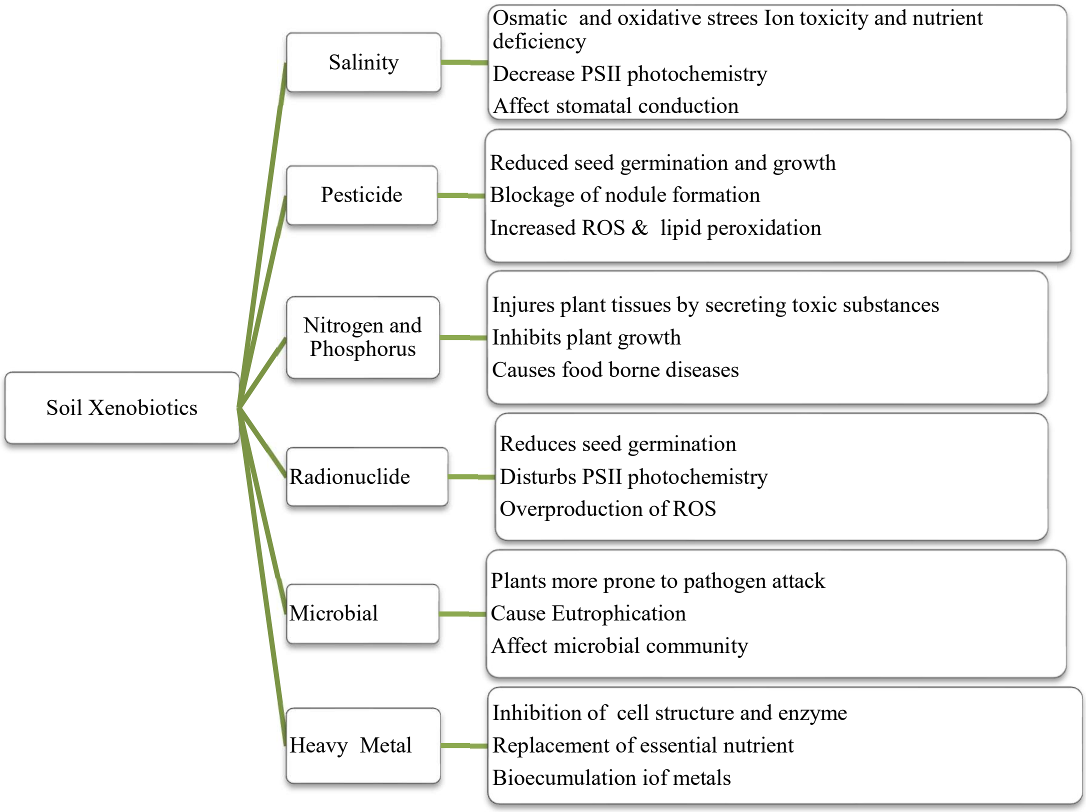

Fig. 1: Various soil xenobiotics influence the plant growth and physiology metabolism activity in plants.

insecticides, herbicides, antioxidant, carbamate insecticides, and sunscreen agent), and candidate substances, such as sulfonylurea herbicide, pyrethroid insecticides, organophosphorus insecticides, and metals and non-metals

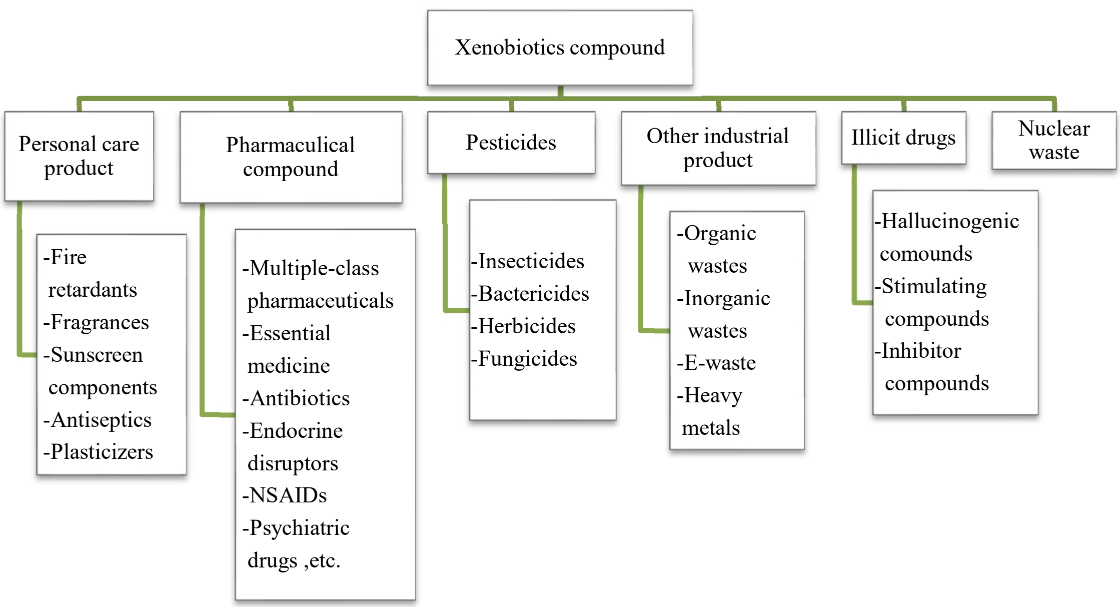

Fig. 2: Xenobiotics compounds (Kumar et al. 2020).

are present in traces. These are the different anthropogenic actions for entering xenobiotics into the environment, such as human consumption and excretion, livestock treatment and excretion, wastewater and sewage treatment plants, agriculture practices and industries, and production plants (Kumar & Chopra 2020). Pesticides are applied directly to the soil, where they are then washed into nearby rivers and groundwater, etc. When PPCPs are consumed by humans, they indirectly enter the environment because some of the metabolites cannot be completely metabolized and are, therefore, more toxic than the original compound. After excretion, they eventually find their way into sewage/wastewater treatment facilities, soil, groundwater, rivers, lakes, and oceans. Plants absorb PPCPs and pesticides, which then enter the food chain. Xenobiotic sources and substances can be categorized in Fig. 2 (Mathew et al. 2017).

XENOBIOTICS IN URBAN SOIL

Urban soil pollution can be caused by both man-made (industry, land-based farming, extractives, wastewater, waste, energy production, and transportation) and unnatural (soil geochemistry, landslides geology, and salt) sources (UNEP 2017). All systems, whether they are made by humans or the natural world, have soil as their foundation. The soil in urban areas serves two crucial functions: promoting urban development and sustaining parks and gardens, which are crucial for the environmental well-being of urban areas (Cachada et al. 2018).

The main factors causing soils used for urban development or transportation infrastructures to lose the majority of their functions are disrupted water, nutrient, and biological cycles (European Commission 2012). Depending on its intended use, soil quality is evaluated. Through the use of chemical, physical, and biological indicators, this assessment is carried out (Cachada et al. 2018).

URBAN MYCORRHIZA

Mycorrhizal symbiosis refers to the association of fungi with plant roots. This relationship is predominantly mutualistic, that is, with both partners benefiting from the association. There are seven types of mycorrhizal association, but common to all types is the net movement of carbon, generally (but not always) from the plant host to the fungus partner. In return, a fungus may confer increased nutrient supply, defense against pathogenic attack, and drought resistance to its partner plant. More than 90% of all plant families studied (80% of species) in both agricultural and natural environments form mycorrhizal associations, and they can be essential for plant nutrition. Mycorrhizas are found in a wide range of habitats, including deserts, lowland tropical rainforests, high latitudes and altitudes, and aquatic ecosystems. There are a few exceptions to the rule that mycorrhizas are found in all plant species that are economically important to man.

URBAN RHIZOSPHERE

The rhizosphere is the area of soil that surrounds plant roots. This region is characterized by root activity, including the related soil microbes and exudate production. The rhizosphere contains many microorganisms, which promotes their diversity, activity, and other interactions. This makes it a haven for a variety of organisms (Hinsinger et al. 2009). Rhizosphere processes include microbial colonization and biological, chemical, and physical changes caused by the plants' movement of water and minerals, which releases carbon dioxide, nutrients, and a variety of chemical compounds (Philippot et al. 2013). The secretion of chemical exudates into the rhizosphere region by the root cells is the process of rhizodeposition; these exudates are referred to as rhizodeposits (Hinsinger et al. 2005). Plants release a variety of substances into the soil around their roots, including organic acids, secondary metabolites, polysaccharides, amino acids, nitrogen (N), and organic carbon (Dennis et al. 2010, Baetz & Martinoia 2014). One of the key rhizosphere effect phenomena is the carbon released by germination-initiating seeds or plant roots, which permeates the soil and encourages microbial activity and proliferation (Farrar et al. 2003). Numerous studies have documented the effects of the rhizosphere on biotransformation for various compounds, such as improving plants' tolerance to phytotoxic elements in the soil because plants can encourage microorganisms that detoxify the xenobiotics (Dubey & Fulekar 2013, Agrawal & Dixit 2015).

Interactions between microbes and plants in the rhizosphere can be advantageous, neutral, or harmful depending on the particular host plant and the microbe involved in the current environmental conditions (Raaijmakers et al. 2009, Bais et al. 2006, Gianfreda 2015). While some pathogenic microbes, parasitic plants, and other harmful invertebrates associate with one another in the negative interactions, mycorrhizal fungi, rhizobacteria that encourage plant growth, and other beneficial microbes favor the positive interactions (Raaijmakers et al. 2009).

RHIZODEGRADATION IN URBAN AREA

Rhizodegradation is the process of influencing plant roots to accelerate soil's natural degradation processes, which can lead to the best detoxification of these organic pollutants. This process involves a variety of organic compounds, such as chlorinated solvents, petroleum hydrocarbons, pesticides, PAHs, surfactants, and polychlorinated biphenyls (Rentz et al. 2005). A few organic compounds that provide carbon and nitrogen are found in the root exudates of plants, which help the microorganisms that break down organic toxins grow and live longer. Additionally, studies revealed that plant roots stimulate the growth of microorganisms because they release certain organic compounds known as organic acids, enzymes, amino acids, sugars, and complex carbohydrates that are necessary for the development of microorganisms (Shim et al. 2000, Singer et al. 2003). Rhizospheric microbial populations contribute to the creation of substances that lessen plant stress, transport nutrients, protect against pathogens, and degrade pollutants (Gerhardt et al. 2009). As a result, certain plants and rhizospheric and endophytic microorganisms (bacteria) can work together to degrade poisonous organic compounds.

The density of microorganisms in the rhizosphere, which can be two to four times greater than the microbial population in the non-rhizospheric soil, promotes the degradation of polycyclic hydrocarbons (PAHs) in rhizospheric soils (Alkorta & Garbisu 2001, Anderson et al. 1994, Sheng-you et al. 2005). After annual plant growth, the PAH kills 100 times more microbial colonies in vegetated management than in unvegetated groups, according to research by Gerhardt et al. (2009). It was found that the degradation of phenanthrene is significantly accelerated by the addition of plant debris and root exudates (Miya & Firestone 2001).

The microbial community in the rhizosphere is influenced by a variety of factors, including the species of plant, root type, age of the plant, soil type, and previous exposure of the plant roots to xenobiotics. In general, gram-negative microbial communities predominate in the rhizosphere (Atlas & Bartha 1986). When compared to non-vegetated soil, the carbon dioxide concentration in the rhizosphere is typically higher, and the pH of rhizosphere soil is 1-2 units lower. The oxygen levels, moisture content, redox potentials, and osmotic potentials are some other variables that are affected by vegetation. Some characteristics of specific plant species are among the additional variables that affect these parameters. Physical and chemical changes that occur frequently at the root-soil interface lead to stable changes in the soil's structure and microbial community (Dzantor 2007).

Plant-microbe interactions lead to an increase in microbial biomass relative to soil bulk levels. The rhizosphere effect is typically defined as the ratio of organisms in rhizosphere-containing soil to those in rhizosphere-free soil. Although this ratio can be greater than 100, it typically falls between 5 and 20. The increased microbial activity and growth in the rhizosphere may be the cause of the increased metabolic degradation rate of different xenobiotic compounds. It is, therefore, intriguing to think about whether selecting plants with super-modulating roots, increasing root hairs, or breeding plants with roots that are more firmly set genetically would speed up the rate at which specific toxicants in the rhizosphere are broken down by microbes (Kidd et al. 2008).

CHANGES IN THE STRENGTH OF MYCORRHIZAL ASSOCIATIONS UNDER URBANIZATION

In urban areas, Shannon's diversity and Simpson's diversity of root AMF were significantly higher than in rural areas. Numerous studies have documented how important AM fungi are for increasing host plant resistance to heavy metal toxicity as well as host plant resistance to disease and insects (Hildebrandt et al. 2007, Khade & Adholeya 2008, Joy 2013, Schneider et al. 2016).

It is anticipated that plants in urban areas will rely more on mycorrhizal symbioses than plants in rural areas because of their increased exposure to biotic and abiotic stresses (Pourrut et al. 2011, Alzetta et al. 2012). As a result, when exposed to environmental stress, plants in urban areas with comparable biomass produce a wider variety of AM fungal communities.

In urban areas, trees increase the need for environmental stress tolerance while decreasing the need for nutrients. In urban areas, trees can be found with a range of fungal association compositions. Urbanization significantly increased the relative abundance of the Glomus Group II, which has a high degree of environmental adaptability and is frequently found in harmed ecosystems. Because of this, some environmental stress tolerance or resistance filters might encourage the growth of root mycorrhizal associations (Knapp et al. 2008). The patterns of significant plant-AM fungal links in the networks were very different in the urban area. The driving force behind niche differentiation is competition (Wright 2002). Urban xenobiotics in this study reduced the level of competition among AM fungi, as evidenced by a lower C-score value in the urban network. As a result, plants in urban areas may tend to work together with a variety of readily available, robust AM fungi to lessen the risk of species loss in ways other than through diffusion and host species selectivity.

CHANGES THE FUNGAL GROWTH

As xenobiotics contain a variety of potentially toxic additives, they can directly harm soil biota (Kim et al. 2020). Furthermore, a growing body of research indicates that organic xenobiotics like polycyclic aromatic hydrocarbons and organochlorines like DDT, as well as polychlorinated biphenyls, herbicides, pesticides, antibiotics, and trace metals, can all be absorbed by trees (Wang et al. 2019). Particularly, small xenobiotics particles or high concentrations can stimulate stress reactions, reproduction, and mortality of the plant and induce metabolic processes (Buks et al. 2020). Xenobiotics have the ability to significantly change the composition of the fungal communities (Kettner et al. 2017, Fei et al. 2020).

Xenobiotics, such as heavy metals or hydrocarbons, can have a negative impact on AMF, just like they can on other soil biota (Cabello 1997, Joner & Leyval 2003, Wang et al. 2020). Thus, we anticipate the direct effects of the additives or pollutants absorbed on the surface of the plant, which will ultimately be released upon degradation. Although heavy metals and hydrocarbons are tolerable to AMF and can even help reduce their toxicity to plants, they have adverse effects at high concentrations (Cabello 1997, Ferrol et al. 2016). AMF typically exhibits reduced root colonization and infectivity, decreased arbuscular and spore numbers, or cell damage in response to soil xenobiotics (Cabello 1997, Leyval et al. 1997, Desalme et al. 2012, Ferrol et al. 2016). Drugs like antibiotics can also be mycotoxic for AMF, reducing hyphal length and spore counts (Hillis et al. 2008). Additionally, changes in the AMF community structure can result from soil xenobiotics. For instance, in soils with high lead contamination, the relative abundance of Paraglomeraceae increased while the abundance of Acaulosporaceae and Glomeraceae decreased (Faggioli et al. 2019).

Xenobiotics can also affect AMF directly by producing breakdown byproducts. One recent study revealed that the diversity and composition of AMF communities were significantly altered by xenobiotics (Wang et al. 2020). The authors discovered that the type and concentration of xenobiotics affected the relative abundance of AMF taxa. For instance, Glomeraceae were less abundant in treatments with biodegradable polylactic acid (PLA) compared to the control and treatments with polyethylene (PE); OTU numbers of Ambispora and Archaeosporaceae were more abundant at higher application rates of microplastic (pollutant) (10% addition compared to 1% addition) under PLA and PE for Ambispora and only under PLA for Archaeosporaceae.

XENOBIOTICS INFLUENCE SEEDLING SURVIVAL

In some urban areas, xenobiotics have reduced seedling survival rates (Broshot 2007, Lehvavirta et al. 2014). This might be a result of the effects of drought and pollution, which have been well-researched in urban environments (Guerrero et al. 2013, Gillner et al. 2013, McDonald & Urban 2004). Even though the below-ground dynamics of urban forests are less well understood, a growing body of research indicates that they may be just as important to ecosystems as many changes seen on the surface (O'Brien et al. 2011, Horton et al. 1999, 2005). Possibly, Mycorrhizal fungi species and the degree to which they colonize plant roots may be influenced by the microclimate, soil nutrients or heavy metal accumulation, and restricted dispersal characteristics of urban environments (Treseder 2013, Fitter et al. 2004, Bainard et al. 2011). As mycorrhizal fungi are significant drivers of forest population dynamics, a better understanding of how plants and mycorrhizal fungi interact in urban environments will help assess and manage urban trees (Hetrick et al. 1989).

CONCLUSION

Mycorrhiza plays a vital role in the growth and development of urban plants. Currently, increasing urbanization is a major challenge for urban areas. The increasing population sharply increases xenobiotic substances like pollution, heavy metals, pharmaceuticals, insecticides, pesticides, etc. They impact plant health, microbial structure, and fungal association and sporulation in urban areas. Xenobiotics mostly affect the rhizosphere in the area; they mostly cause a decrease in the growth of mycorrhizal fungal growth and the interaction of the urban plant.

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