THE EFFECTS OF PLANT DIVERSITY ON SOIL IN URBAN ENVIRONMENTS

by

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DEDICATION

Dedicated to Austin who has supported me and my goals from the beginning. Thank you for accepting my crazy flower child personality, here's to you being a '2H'. You are my rock.

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Thank you to all my professors, lecturers, and instructors for teaching me and guiding me through many assignments. Thank you for responding to my countless emails and for your willingness to take on online education. Without your desire and passion to teach, I would not be writing this today.

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ABSTRACT

With the increase of urban areas across the United States, there is an increase in lawns, parks, and other green spaces. These green spaces are often monoculture grass environments. However, urban areas use fertilizers and pesticides to maintain picturesque yards. This management approach can result in leaching of both pesticides and fertilizers into waterways. Soil microorganisms assist plants in many ways and are an essential part of the soil microbiome. Therefore, my research aims to understand how plant diversity affects these soil microbes and if an increase in soil microorganism diversity aids in the reduction of water and fertilizer use. To understand the relationship between plant diversity and soil microbes, I examined 33 peer-reviewed articles from 2013 to 2023. I found that in 51% of articles reviewed soil microbes and microbial diversity not only improve plant-resource acquisition but also assist in periods of drought stress. The research identifies 24% of the articles reviewed detailing the consequences of conventional lawn management through the application of chemicals decreasing populations of soil microorganisms. Plant diversity led to an increase in microbial diversity and authors suggested increasing diversity of both plants and microbes could potentially assist in the reduction of fertilizers and irrigation frequency in urban areas. Although several management trends within urban communities promote urban plant diversification, more community education and research in urban areas would be needed to see diverse lawn plantings.

INTRODUCTION

Monoculture is the cultivation of a single species, typically seen in an agricultural setting, to increase crop production (Freedman, 2020). Urban areas are defined as areas that have at least 5,000 people or 2,000 housing units and make up 80% of the United States population (Ratcliffe, 2022). Urban areas use the practice of monoculture in areas such as lawns, parks, and golf courses by planting single species of grasses and removing all weeds from the area. Native grasslands rarely contain a single grass species. Instead, they are species-rich ecosystems with both above and below-ground diversity (Simmons et al., 2011). In 2005, urban turf grass areas were estimated to cover 1.9% of the continental United States (Milesi et al., 2005). This number will likely increase with the growth of urban areas within the United States with estimates of an 8.6% increase by 2060, double what was calculated in 2010 (Nowak & Greenfield, 2018). As urban areas across the United States increase, it is important to understand how the monoculture of urban areas impacts ecosystem functions and if increasing diversity aboveground correlates to other factors.

Turfgrass Monoculture in Urban Areas

Turfgrass is often overfertilized and overtreated with different pesticides to maintain a weed-free yard (Milesi et al., 2005). This overtreatment of fertilizer leads to harmful impacts on the environment because of off-site movement, such as algal blooms and the leaching of persistent herbicides into drinking water. Overfertilization of phosphorus in lawns results in an average of 75% of applied phosphorus entering runoff (Bierman et al., 2010). Phosphorus is not the only nutrient that is overused in lawns, nitrogen also contributes to the overfertilization

issues. A study that examined the relationship between soil characteristics and nitrogen leaching, turfgrass leaching ranged from 33 to 167 kg of nitrogen per hectare over 22 months depending on the fertilization and irrigation treatments (Barton et al., 2006).

This nutrient-high runoff causes harmful algae blooms in waterways, raising treatment costs for drinking water and creating toxic water for humans and other animals (US EPA, 2013a, 2013b). Algal blooms, or cyanobacterial blooms, impact urban communities such as Austin, Texas (Donith, 2021). The primary cause for these algal blooms is nutrient pollution, mainly the overuse of nitrogen and phosphorus (Lyons & Sarkis, 2021), and the effects may be exacerbated by irrigation (Campo et al., 2019). Nutrient runoff into waterways causes an excess growth of algae during the spring and summer months. When the algae die, they sink and begin to decompose. This process reduces the amount of oxygen available to aquatic life, creating a "dead zone" and has drastic impacts on ecosystems (US EPA, 2013a). Because of the nutrient pollution, ecosystems such as the Mississippi River Basin now have a "dead zone"- with an area of more than 6,000 square miles of hypoxia, where the oxygen levels are too low to sustain life. Hypoxia causes serious impacts on the ecosystem such as interruptions in nutrient cycles, decreases in biodiversity, and habitat loss for native marine life (US EPA, 2015).

Pesticides are often applied to keep the appearance of a "perfect" lawn by removing broadleaf weeds, pest insects, and other nuisances in urban areas. Overapplication or improper application of these pesticides leads to issues including leaching of chemicals into waterways. Products such as dicamba and 2,4-D, used to treat broadleaf weeds such as dandelions, have some of the higher percentages of mass lost after precipitation events occur, indicating that there is a high level of these products leaching into waterways (Kramer et al., 2009).

Soil Microorganisms and Plant Life

The use of soil microbes that increase plant nutrients (Anderson & Liberta, 1989; Delavaux et al., 2017) and water uptake (Delavaux et al., 2017; Delavaux & Bever, 2022) may reduce the use of fertilizers. This, in combination with managing fertilizer and chemical application results in less nutrient and chemical pollution runoff into waterways.

Soil microorganisms are an essential aspect of plant life. Microbial organisms, such as arbuscular mycorrhizal fungi assist plants in times of drought (Anderson et al., 1994; Anderson & Liberta, 1989; Delavaux & Bever, 2022). Grasses with a symbiotic relationship with soil microorganisms can take up more phosphorus (Anderson & Liberta, 1989).

If insufficient plant-available phosphorus is found in the soil, symbiotic relationships with mycorrhizal fungi provide nutrient support (Delavaux et al., 2017), reducing the need for high phosphorus applications. Symbiotic relationships between microorganisms, such as mycorrhizal fungi, and grasses may also benefit plant water uptake, chemical defense, soil aggregation, and disease resistance (Figure 1) (Delavaux et al., 2017).

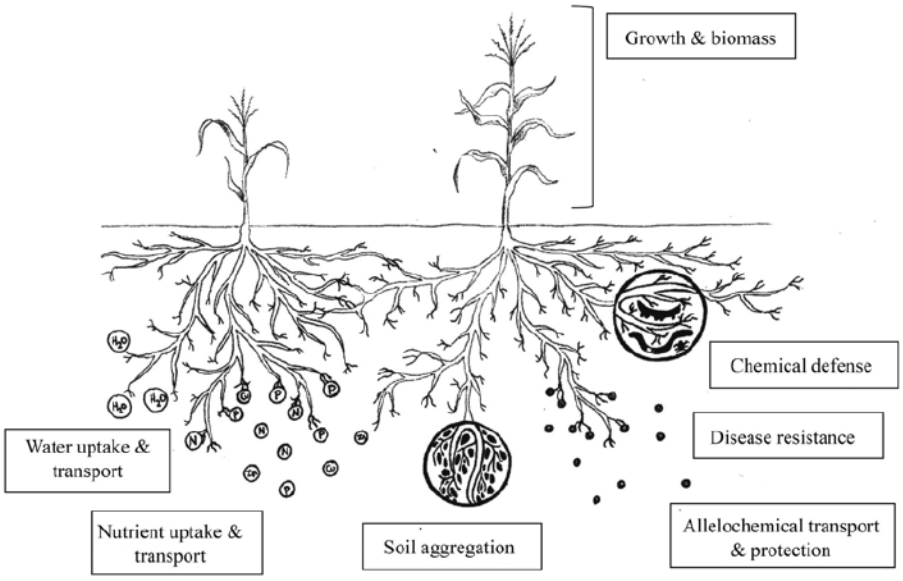


Figure 1. Impacts of mycorrhizal interactions with plants and soils. Multiple benefits such as chemical defense and disease resistance are received besides the commonly known benefits such as water and nutrient uptake. (Source: Delavaux et al., 2017)

The positive benefits of soil microorganisms are higher when there is a diverse grouping of plants as compared to monoculture (Schnitzer et al., 2011). Increased microbial activity aids with the disease resistance of grasses. Root colonization of *Piriformospora indica* in crops improves the resistance to fungal diseases, including several strains of the genus *Fusarium* (Harman & Uphoff, 2019).

The relationship between the bacterial family Rhizobia and plants in the Fabaceae family is another example of a positive relationship between soil microorganisms and plant life. Rhizobacteria form nodules on the roots of plants and allow atmospheric nitrogen to be fixed into the soil in a plant-available form (Harman & Uphoff, 2019). Although this relationship is host-specific, it is not limited to legume plants, and the nitrogen-fixing benefits provided are

highly beneficial to the host plant. The symbiotic relationship between grasses and soil microorganisms could be beneficial in an urban area as it could reduce the use of chemical applications and irrigation. Increasing plant diversity in urban environments fosters a positive environment for increased diversity in the soil microbiome.

RESEARCH GOALS

My paper seeks to a) understand if an increase in the diversity of soil microorganisms in urban environments assists in reducing water, fertilizer, fungicide, and pesticide application, and if so, b) whether greater soil microbial diversity can be achieved through diversification of grass species.

First, I conducted a literature search to examine how the symbiotic mutualistic plant-microbe relationship and soil microbial diversity affect plant resource acquisition and growth. Based on the literature review, I detailed the consequences of conventional lawn management, using monoculture and application of fertilizer and other chemicals. I examined if greater soil microbial diversity can improve the resource acquisition by plants. Finally, I discuss the possibility of plant-microbe interactions as a method to reduce urban nutrient pollution and water use, potential issues for homeowners in diversifying grasses, application of plant diversification in urban communities, and future steps to be taken.

METHODS

I performed a literature search utilizing a modified PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to retrieve, select, and combine research results that would provide evidence for the goals of this paper. The modifications include, the papers include based on the suggestion of Y. Yano at the end and not did not remove duplicates from search results. I retrieved articles by first using keywords such as "soil microorganisms AND plant water use", "soil microorganisms AND monoculture", "soil microorganisms AND grasses", and "microbial diversity AND soil AND irrigation" (Tables 1, 2). Search platforms used for these searches were Google Scholar and Montana State University Library the number of results returned for each search is listed in Table 1. Of the results found, only publications published in the last 10 years and peer-reviewed journals were considered for selection (Table 2).

Table 1: Search keywords and corresponding results from three different library sources from 2013 to 2023. The library sources used were Montana State University (MSU) and Google Scholar (Google).

Search	MSU	Google
soil microorganisms AND plant water use	3482	16800
soil microorganisms AND monoculture	763	18000
microbial diversity AND soil AND irrigation	642	19700
Soil microorganisms AND grasses	1778	17400
Grass rooting depths	197	17900
Soil nutrients AND microbes	6158	31900

Table 2: Search keywords and corresponding results from three different library sources from 2013 to 2023. The library sources used were Montana State University (MSU) and Google Scholar (Google).

Search - Peer-reviewed	MSU	Google
soil microorganisms AND plant water use	2687	28900
soil microorganisms AND monoculture	673	4230
microbial diversity AND soil AND irrigation	542	16900
Soil microorganisms AND grasses	1480	16600
Grass rooting depths	156	16000
Soil nutrients AND microbes	4188	21100

The search results display the substantial amount of research being published on these topics. For each search the first 50 results, equaling one full page of results, were examined, and papers were selected to read and to determine if any of the research questions were answered. After completing all six searches, 84 articles were selected for further review based on the abstract, title, and keywords. After a full-text review, 33 articles were selected. (Figure 2). Additional articles were added based on the recommendation from Y. Yano (personal communication).

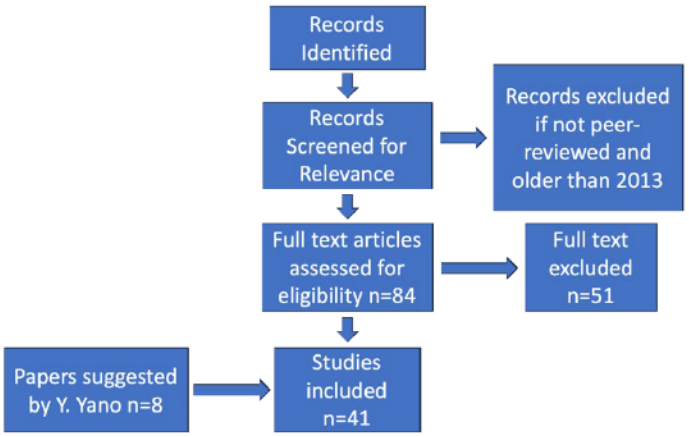


Figure 2: Flow chart detailing how articles were chosen for the literature review.

The first research objective is to understand how an increase in the diversity of soil microorganisms can affect water use, pests, weeds, and fertilizer needs. This was categorized into two sections. The first section discusses how microbes influence resource acquisition in plants, for which were 21 articles identified. The second section examined the consequences of using modern methods, such as chemical and fertilizer use, for lawn upkeep: 13 articles were identified. The second research objective focused on the effects of plant diversity on soil microorganisms and other aspects of productivity: 11 articles were identified. There is some overlap between article use and research objectives. These articles were then used as primary data for the literature review analysis. These numbers do not include the articles suggested by my advising professor. The articles identified in the above search and through recommendations are listed in Table 3 in Appendix A.

LITERATURE REVIEW

Increasing plant diversity leads to an increase in soil microbial populations. The symbiotic relationship formed between plants and soil microbes increases plant's ability to acquire nutrients and withstand drought stress. Guo et al. (2019) investigated the long-term fertilization impacts on soil organic carbon and found that 11 bacteria phyla accounted for 85% of the microbial communities studied. Each microbe species has a different part to play in the soil nutrient cycle. Most microbes act as a biofertilizer to the plant with which it has a symbiotic relationship by helping the plant acquire nutrients that may not have been in a usable form (Miransari, 2013; Morgan & Connolly, 2013).

Microbial Effects on Resource Acquisition

There are numerous nutrients found in the soil, but the nutrients are not always plant-available (Miransari, 2013). Soil microbes can be useful for plants providing different interactions and benefits to plants and helping plants with functions such as seedling growth and nutrient uptake (Solans et al., 2022). For example, *Actinomycetes* spp. is a soil bacterium that has the unique ability to solubilize phosphorus and has been associated with different plant species in the Monte Desert. These bacteria assist in the seedling survival of three plant species *Atriplex lampa, Grindelia chiloensis,* and *Gutierrezia solbrigii* (Solans et al., 2022). Although the enhanced seedling growth of all three plant species could be attributed to other factors, the same level of growth was not observed in the control seedlings that were not inoculated with the bacteria (Solans et al., 2022). The specific relationships between plants and soil microbes are useful in restoration projects as well as in the establishment of new plants. Microbe genera, such as the *Actinomycetes* bacteria, interact differently and have different functions with plants allowing plants to receive different benefits from different microbes (Solans et al., 2022; Xun et al., 2021). Microbial diversity is beneficial to the health and functioning of ecosystems through resource acquisition for the three native plant species studied, *A. lampa, G. Chiloensis,* and *G. solbrigii* (Solans et al., 2022).

The rhizosphere has the potential to be one of the most important dynamic biogeochemical zones (Rupp et al., 2021). Microbes that dwell in the rhizosphere assist in the active cycling of carbon and nitrogen, benefiting both the plant and the microorganisms with necessary resources (Rupp et al., 2021; Zhao et al., 2021). Microbial communities that reside in the rhizosphere populations fluctuate throughout the plant's development (Zhao et al., 2021).

This fluctuation is commonly attributed to the shifts in root exudate, or plant root fluid, profile with the faster-growing phases of a plant having more root exudates present for microbes to attach. Zhao et al. (2021) showed that changes in the root profile could drive the diversity of soil microorganisms present. The microbial communities within the rhizosphere directly impact and shape the plant's nutrient demands (Zhao et al., 2021). Root exudates increase potential soil microbe communities leading to further benefits for the plant in later growth stages (Zhao et al., 2021). Sedges and grasses are known to produce root exudates that foster fungal root endophytes in their roots. This relationship would increase disease resistance in the host plants in addition to nutrient assistance (Rupp et al., 2021).

Symbiotic microbial relationships are limited by soil resources such as carbon and nutrients. Soil microbial diversity peaks under high phosphorous relative to carbon or nitrogen (Delgado-Baquerizo et al., 2017). Cui et al. (2019) suggested that microbial communities are limited by carbon and phosphorus. Although carbon is a limiting nutrient, phosphorous is the primary limiting nutrient (Cui et al., 2019). Plant exudates are essential for microbial diversity and function due to the exudate's ability to reduce the resource limitations of microbes.

Drought is a prominent stressor on plants in arid and semi-arid regions (Marulanda et al., 2009). Extreme conditions, such as drought, reduce microbial activity and encourage the establishment of non-native plants (Meisner et al., 2013). Indigenous bacteria may have adapted to various levels of drought stress in the soil. This adaptation positively affects plant development during drought conditions (Marulanda et al., 2009). Lau and Lennon (2012) examined fruit production when grown under drought stress with either wet or dry climate microbes (Lau & Lennon, 2012). The plants that were grown with wet-climate microbes had a

59% decrease in production while the plants grown with dry-climate microbes had a 19% decrease in production (Lau & Lennon, 2012). Plants that are grown with drought-adapted microbes are more fit under drought stress (Lau & Lennon, 2012).

Plants such as *Encephalartos natalensis*, a cycad, demonstrate the exchange between plants and indigenous microbes, which includes members from the family Burkholderiales, a microbial family that contributes significantly to nitrogen fixation (Figure 2) (Ndlovu et al., 2023). Indigenous microbes such as Burkholderiales seem to increase the bioavailability of phosphorus and nitrogen in nutrient-poor soil (Ndlovu et al., 2023). The use of native microbes extends to grasslands as well. Verrucomicrobia is a keystone phylum of bacteria in prairie systems. These microbes not only assist in obtaining needed nutrients for prairie plants and carbon sequestration, but they can be modeled to assist scientists with monitoring the functional capabilities of a prairie. This is due to the large amount of bacteria that live in prairie soils (Fierer et al., 2013). By sampling different soils from different grasslands, Fierer et al. (2013) modeled the taxonomic and functional diversity of soil bacteria communities that had a greater than 50% accuracy for predicting grassland plant diversity based on microbial diversity. This improves understanding of what native microbes are present in the grasslands, aiding in restoration practices (Fierer et al., 2013; Koziol et al., 2018).

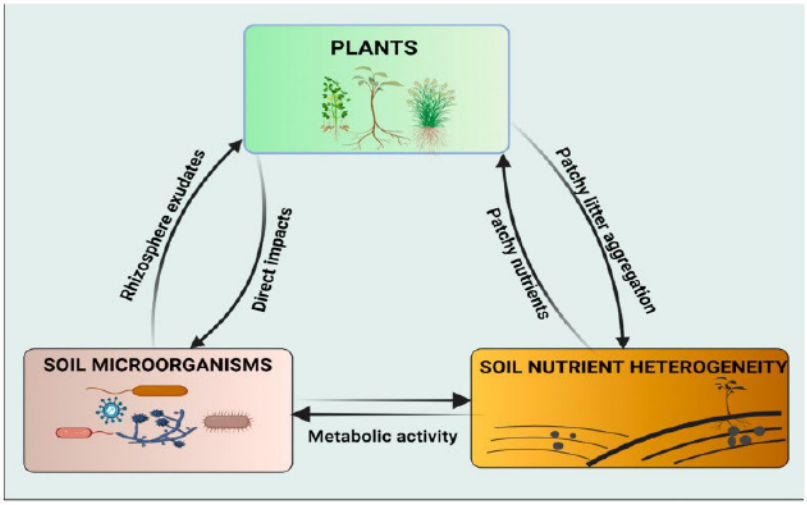


Figure 3: Interaction between soil microorganisms, plants, and soil nutrient heterogeneity. Source:(Adomako et al., 2022).

Native mycorrhizal fungi are suggested to assist in the restoration of grasslands by accelerating succession (Koziol et al., 2018), encouraging larger plant growth (Delavaux & Bever, 2022; Koziol et al., 2022), and improving the establishment of native host plants (Koziol et al., 2022). Anthropogenic disturbances may alter the natural microbiome and encourage novel plant-microbial interactions (Delavaux & Bever, 2022; Koziol et al., 2022). In a study of four native plant species, the ones planted in post-agriculture land contained more mycorrhizal colonization from new, non-native mycorrhizae (Delavaux & Bever, 2022) as compared to native plant species that were planted in undisturbed grasslands that had overall less colonization but more native mycorrhizae (Delavaux & Bever, 2022). The native plants responded more positively in terms of growth to native mycorrhizal fungi than to non-native mycorrhizae (Delavaux & Bever, 2022) which suggests that anthropogenic disturbances may lead to an evolution of plant-microbe interactions.

In restoration practices, the inclusion of native mycorrhizae assists in the establishment of later successional native plants that are often difficult to successfully establish. Using native mycorrhizal fungi in restoration practices influences the reestablishment of other native soil microbes and reduces the establishment of non-native plant species (Koziol et al., 2022). Koziol et al. (2018) examined the benefits of utilizing native mycorrhizal fungi in restoration practices. Grasses often have a very early or early response to inoculation with native mycorrhizal fungi that are beneficial for quick establishment and resistance to invasive species (Koziol et al., 2018). Non-native plants can negatively affect mycorrhizal fungi density and other factors such as soil aggregation and native plant establishment (Koziol et al., 2018). Koziol et al. (2018) suggest that for this reason, inoculating native plant species with native mycorrhizae could assist native plant species' survival.

It is assumed that mycorrhizal fungi evolved with plants (Adomako et al., 2022; Delavaux & Bever, 2022). This evolution allows for an ecologically cost-effective system (Adomako et al., 2022). This system of nutrient availability through hyphal systems relies on three factors: plants, soil microorganisms, and soil nutrient heterogeneity (Adomako et al., 2022). The soil microorganisms have diverse impacts on plants, such as mineralization and exploitation of nutrients, partially due to the foraging characteristic of soil microorganisms and to the microbes constantly seeking out needed nutrients for the plants (Adomako et al., 2022). This impacts the length of plant rooting length as the hyphae seek nutrients instead of the plant roots (Mendoza et al., 2016).

When grasses grow with legumes, the foraging benefits of soil microorganisms are enhanced (Mendoza et al., 2016). However, the addition of legumes to a grass area allows for a

20% increase in available nitrogen in the soil due to N-fixing Rhizobacteria's symbiotic relationship with legumes (Adomako et al., 2022; Mendoza et al., 2016). The diversity of plant mixes assists in increasing the soil nutrient availability.

Diversity of soil microorganisms leads to functioning ecosystems, through nutrient acquisition, nitrogen fixation, and decomposition, making it easier for plants to adjust to global changes in ecosystems and environments (Adomako et al., 2022). High microbial diversity leads to an increase in nutrient uptake, this high microbial diversity is often found in areas with five to six plant species present (Sahib et al., 2020). Sahib et al. (2020) explored the Biodiversity and Ecological Functioning theory, which states that diverse soil and plant populations experience more benefits due to the high diversity. When there was a higher plant diversity per pot, they observed a greater uptake in micro- and macro-soil nutrients. These results were mainly seen in pots featuring five to six plant species (Sahib et al., 2020). The results from this study supported the Biodiversity and Ecological Functioning theory (Sahib et al., 2020). This idea is further explored by Prommer et al. (2020) with the discussion of including plant species richness in grasslands in Jena, Germany as part of the Jena experiment. This area is an upland floodplain and is a part of one of the longest-running biodiversity experiments (Max Planck Institute for Biogeochemistry, n.d.; Prommer et al., 2020). In this study, an increase in plant species richness led to an increase in plant carbon inputs, and therefore, an increase in microbial biomass (Prommer et al., 2020).

Microbial diversity is important in times of drought. Drought reduces arbuscular mycorrhizal fungi colonization, depending on the strain of fungi (Compant et al., 2010). Different microbes can assist in plant survival. Ectomycorrhizal fungi survive better than

arbuscular mycorrhizal fungi in times of drought (Compant et al., 2010). This allows plants that are inoculated with ectomycorrhizal fungi to better survive drought stress. Plant growth-promoting bacteria aid in drought stress by enhancing plant water and nutrient uptake by increasing the amount of root hairs on the plant and decreasing the distance between the hairs and the root tip (Compant et al., 2010).

Overall, 15 papers discussed the positive impact of soil microbes on soil nutrient acquisition, four papers discussed the neutral impacts of soil microbes on soil nutrient acquisition, and one discussed the negative impacts of soil microbes on nutrient acquisition.

The Consequences of Conventional Lawn Management Through the Addition of Chemicals and Fertilizer

Excessive nutrient addition negatively impacts soil nutrients. Overfertilization of phosphorus in the soil negatively affects mycorrhizal fungi density (Koorem et al., 2014). This negative correlation did not impact plant biomass (Koorem et al., 2014), suggesting that since phosphorus was high and present in the soil, there was no reliance on mycorrhizal fungi to obtain the nutrients. These relationships suggest that plants anticipate differing levels of association with mycorrhizal fungi and rely on microbial symbiosis when nutrient levels are low (Koorem et al., 2014). Plants, therefore, modify their reliance on microbes versus root growth according to nutrient availability (Mendoza et al., 2016). Mendoza et al. (2016) examined the root length, diameter, and surface area of grasses and legumes planted together. Although there was an increase in plant root biomass when both nitrogen and phosphorous were present in the soil, there was little growth of the mycorrhizal fungi nodules inoculated to the grassroots (Mendoza et al., 2016). Phosphorous is not limiting and instead mediates the biomass level of arbuscular

mycorrhizae (Mendoza et al., 2016). Briefly, plants either embrace or repress the relationship with microbial communities depending on the resource availability via exudates (Mendoza et al., 2016).

To achieve a green lawn, many homeowners rely on chemical fertilizers to add the nutrients needed to achieve the desired look. An estimated 60% of urban households applied chemical fertilizer to their lawn in 2004 (Martini et al., 2015). Although Martini et al. (2015) did not reveal a singular reason behind the motivation to fertilize lawns, the impacts of chemical fertilization are clear. Over time, the impacts of over-fertilization changed in soil properties, such as lower pH, soil organic carbon, and total nitrogen (Guo et al., 2019). There is evidence of underdevelopment of root length and reduction of nitrate uptake (van Delden et al., 2016). Another ecological issue resulting from excessive fertilization is nitrogen loss leading to environmental pollution (Frey et al., 2023; van Delden et al., 2016). Excessive nitrogen contributes to a lower pH due to the urea often used in lawn fertilizers acidifying the soil over time (Frey et al., 2023). An increase in nitrogen fertilization modifies the nitrogen cycle by accelerating nitrogen turnover, which in turn increases N_2O emissions (van Delden et al., 2016). Frey et al. (2023) illustrate the importance of pH for the microbial community. Soil pH is one of the primary components of shaping a soil microbial community, drastically changing the pH leads to different microbial structures (Frey et al., 2023). Excessive fertilizer containing nitrogen, potassium, and phosphorus over 22 years changes the soil nutrient balance and disrupts the population size of the naturally occurring soil microbial community, both positively and negatively (Guo et al., 2019).

Soil microbes use poorly soluble organic sources and are fundamental to biochemical processes, such as soil organic carbon mineralization and mobilization of phytate (Guo et al., 2019; Velasco-Sánchez et al., 2023). As previously stated, phosphorus is a key nutrient for soil microbes. Even in a "well-balanced" bag of fertilizer, there is a significant amount of phosphorous that is added when fertilizing a lawn. Over time, excessive phosphorous becomes immobilized in the soil and is no longer available for plant use. Phytic acid makes up approximately 70% of the organic phosphorous pool and is largely unavailable to plants. Soil microbes play a crucial role in the use of different forms of phosphorous, microbes act by releasing organic acid allowing for a soluble form of phosphorous to become plant-available (Brucker et al., 2020; Velasco-Sánchez et al., 2023). These immobile forms of phosphorous resulting from overfertilization cannot be used by plants without certain soil microbes or the introduction of carbon to the soil (Brucker et al., 2020; Velasco-Sánchez et al., 2023).

The use of pesticides is common in urban environments. These pesticides impact both plants and soil microbes. Pre-emergent herbicides such as prodiamine, a common treatment for annual weeds such as crabgrass, can affect root length density. Although this can be impacted by soil type, the use of pre-emergent pesticides on bermudagrass resulted in a substantial reduction in root length density (Jones et al., 2013). Pesticides negatively impact soil microbes. After a treatment of two different pesticides, indaziflam and prodiamine, toxicity was observed with both bacterial and fungal soil microorganisms (García-Delgado et al., 2019). Irrigation increases the negative impacts of pesticides through the leaching of pesticides through the soil profile (García-Delgado et al., 2019). Irrigated plots, or plots with a 38% increase from non-irrigated plots studied, lowered the relative abundance of both the gram-negative and gram-positive soil

bacteria that were examined in this study when treated with pesticides (García-Delgado et al., 2019). Although these toxic pesticide results do not seem to be permanent, they are persistent for approximately two months (García-Delgado et al., 2019). Additionally, the continued use of fertilizer and pesticides can reduce soil fertility and organic matter, leading to fewer populations of soil microorganisms (Lynn et al., 2021).

A general rule of thumb is that plants that do not receive as much water have longer roots (Bristiel et al., 2019). Although this was disproven by Bristiel et al. (2019), plants with longer roots had enhanced growth and drought resistance (Bristiel et al., 2019). This is a reoccurring pattern found in other studies: deeper rooting distribution leads to more water uptake and is typically unaffected by drought conditions (Bristiel et al., 2019; Kulmatiski et al., 2020). Most of the time, a relationship with mycorrhizal communities is beneficial for nutrient uptake but decreases the plant root biomass (Mendoza et al., 2016). However, shorter roots tend to have more access to nitrogen as nitrogen occurs closer to the surface (Kulmatiski et al., 2020). When it comes to irrigation, time of year and location tend to be the most key factors in determining plant root lengths. Bristiel et al. (2019) theorize that different species have different root lengths that could be linked to the native climate.

10 articles discussed the negative consequences of fertilizers and pesticides on soil microbes and three discussed the neutral consequences. There were no positive articles found.

The Effects of Plant Diversity on Microbial Diversity and Other Aspects of Productivity

Even though there is not a single microbe species that can do everything needed for the plant, 80% of plant families are dependent on mycorrhizal fungi (Tanner & Gange, 2013; Zhang

et al., 2022). Soils that have more grass species tend to have higher levels of fungal pathogens (Heinen et al., 2020). When compared with bacterial communities, changes in fungal communities tended to be longer-lasting than those in bacterial communities (Heinen et al., 2020). Mycorrhizal fungi are often controlled by the plant based on limited resources that the plant needs. This manipulation of fungal microbes via rhizodeposition (or exudates) creates unique microbiomes and establishes new communities (Heinen et al., 2020; Preece & Peñuelas, 2016). For instance, soil fungal communities are shaped over time by plants with which there is a symbiotic relationship formed (Heinen et al., 2020). In times of drought, there is evidence that plants may have some control over the regulation of the rhizodeposition. Plant species richness increases soil microbial growth, turnover, and respiration (Prommer et al., 2020).

Conversely, monocultures have negative impacts on soil microbes and plant life. As previously mentioned, 80% of plant species rely on mycorrhizal fungi for growth and nutrient acquisition. Large monocultures of non-native plants slowly deplete the mycorrhizal fungi levels leading to lower shoot biomass and growth of native species when grown in soil invaded by non-native species (Tanner & Gange, 2013). This depletion of mycorrhizal fungi gradually removes the native plant species from a natural prairie setting. There are cases, such as with non-native invasive plant spotted knapweed, where mycorrhizal fungi assist in their colonization and growth (Tanner & Gange, 2013). Monocultures lead to lower soil organic matter, changes in pH, and low levels of phosphorous which eventually leads to lower levels of microbial activity (Arafat et al., 2019; Lynn et al., 2021). Soil organic matter is important as it increases biological diversity and nutrient availability which is why there are low levels of microbial activity in monocultured areas (Lynn et al., 2021). Continuous monoculture can decrease productivity in crops such as tea,

potato, apple, and soybean (Arafat et al., 2019). Furthermore, plant communities that contained both legumes and C_4 grasses had greater opportunity for nitrogen uptake, resulting in a more efficient conversion from nitrogen into biomass, essentially increasing plant productivity (Mueller et al., 2013). There is a positive correlation between the decrease of all observed fungal levels in the soil and the increase in the number of cropping years (Arafat et al., 2019).

Monoculture affects rooting depth. In a 12-year study, Mueller et al. (2013) examined rooting depth and diversity and found a positive correlation between plant species richness and root biomass. Species richness had a positive impact on deep root biomass with as much as seven times more root biomass found in diversified plots than those examined in monoculture plots. Microbial diversity does not always impact the rooting depth of plants. *Bromus inermis*, or smooth brome, is a foraging grass whose roots reach the B Horizon in soil. *Bromus inermis* has a strong relationship with the soil microbial community and is known to alter nutrient cycling. This relationship is hypothesized to be due to the deep root depth but is not likely as there is little microbe diversity in lower soil levels (Li et al., 2018). However, *B. inermis* has a lateral root system that extends along the A Horizon, which is where most of the microbial communities were found for *B. inermis* (Li et al., 2018). Plant roots are foragers, using long thin roots to explore the soil for needed resources (Vries et al., 2021). When a mutualistic relationship is formed with microbes, roots do not need to forage for resources and form shorter and thicker roots (Vries et al., 2021).

Although there is much literature available on monoculture crop fields, there is little discussing the biodiversity found in urban environments. In a four-season study, Borowy and Swan (2022) investigated the function of native plant communities in these urban environments

and demonstrated that native species can establish and grow in urban environments regardless of soil conditions and respond to changes in the environment. Native grasses grew taller and had higher aboveground biodiversity (Borowy & Swan, 2022). They hypothesize that in abandoned urban areas, the lack of native species is based on dispersal limitations, such as buildings, rather than the inability of the native plant species to thrive in the area.

One article had a negative outcome discussing monoculture impacts on soil microbes, six articles had a positive outcome discussing impacts on plant diversity on soil microbes, and four articles had neutral outcomes discussing root length and other impacts on plants by soil microbes.

DISCUSSION

Is it Important to Increase Plant Diversity in Urban Environments?

Increasing plant diversity increases microbial diversity in soils. Microbes are beneficial in aiding plants in nutrient acquisition that may not have been in a plant-available form. This is done by making nutrients available to plants or encouraging root hair growth to benefit plants in seasons of drought. Increased microbial diversity allows for more plants to form symbiotic relationships with these microbes, increasing the plant's ability to acquire nutrients. But how does this benefit homeowners and land managers in an urban environment?

As most urban environments contain one species of grass, the soil microbes have a lower population density. This leads to changes in the soil pH and lower organic matter (Arafat et al., 2019; Lynn et al., 2021). Both factors are crucial to microbial productivity and habitat. By

diversifying the plant species, urban environments would increase the microbial population density. This diverse ecosystem would reduce the need to fertilize frequently because of the increased nutrient acquisition provided by the diverse microbial life. The need for water often would be reduced as the microbial relationship would assist in times of drought. The reduction of fertilizer application and irrigation would assist in the reduction of phosphorus becoming immobile in the soil or nutrients running off into waterways. Reducing nutrient runoff, such as phosphorous, lowers the risk of algal blooms in a community. More research is needed to see if there is a correlation between increasing microbial populations and the frequency of algal blooms in a community. Increasing plant diversity increases microbial diversity which allows the plants to acquire the needed resources without human intervention through irrigation and chemical application.

Potential Issues in Plant Diversification in Urban Environments

If plant diversification provides so many benefits belowground through increasing microbial diversity, such as the potential to reduce irrigation and excessive nutrient use, why have more homeowners and land managers not utilized the native plants available? Several different thoughts could play into this issue. For one, homeowners and park managers may not want to let the grass grow tall and therefore frequently mow the area. This could hurt the plant biomass as they are not traditionally mowed frequently. Plant species would have to be chosen based on the ability to be cut down to approximately three inches repeatedly.

Other issues include the durability of the plant species to high traffic. Parks, playgrounds, and lawns often have high foot traffic, and plant species that cannot be repeatedly trampled upon would not fare well over time. Similarly, the feel of the plant species could cause issues in lawns

as homeowners choose the grass that feels comfortable. Often, the homeowners choosing comfortable grass leads to monocultured lawns. Diversification of plant species means a diversification of plant textures but also a diversification of soil microbes.

One example of plant diversification in an urban community is "The Meadow" at Kansas State University. This is an area of Kansas State University campus that has been used for researching and teaching about different ecoregions. This plot of land has become a place to experience diverse plants and allow the community to participate through art classes and volunteer opportunities (Freeman, 2020).

Next Steps

More research is needed to fully examine the impacts of increasing diversity in urban environments. There is a lack of peer-reviewed evidence involving the correlation between plant diversification and microbial diversity in urban environments. Although the evidence stated above does not change based on the environment where the plants are located, there is a need to see if other factors such as mowing or high traffic could negatively impact the soil microbial populations.

Education of the public is also necessary. Using the Extension services provided through land-grant universities could be a method to encourage the diversification of plants within an urban environment. For homeowners, certain lawn seed businesses are marketing diverse native grass mixes as "no-mow" mixtures. These mixes are often marketed as drought tolerant as well. These mixes could be the start of increasing plant diversity in lawns. Another movement that could assist with changing the mindset away from monoculture lawns is the pollinator movement. Trends such as "No Mow May" and "Bee-Lawns" within homeowner and gardening

groups encourage letting the dandelions grow and planting additional plant species, such as Dutch white clover so that the pollinators have additional food sources. Movements such as these assist the soil microbial ecosystem through the increase of diversity in plants.

CONCLUSION

The goals of my paper were to understand how increasing the diversity of soil microorganisms in urban environments assists in reducing water and chemical use, such as fertilizers and pesticides, and if increasing microbial diversity can be achieved through the diversification of grasses. There is significant research detailing the benefits of increasing plant diversity and the mutualistic relationship that many plants have with soil microbes. Benefits include increasing plant resource acquisition, drought stress resilience, and plant productivity. Microbial diversity is directly correlated with the diversity of plants.

Urban environments could benefit from the diversification of the green spaces in their communities. Diversification of plant species in these spaces, increases soil microbial diversity, increasing plant ability to obtain resources, increasing plant biomass and overall health. Research is needed to understand how daily human activity could impact the plant and microbial population within urban communities. Education in urban communities is essential to increasing the diversity of plants in these areas. These communities may want to assist in reducing water use or fertilization but do not know that it could be as simple as diversifying their lawn. Allowing homeowners to feel empowered to make a change is the easiest and quickest way to make a difference, either positive or negative, in an ecosystem.

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APPENDICES

APPENDIX A

TABLE 3. PAPERS USED IN LITERATURE REVIEW

Title	Author	Is Part Of	Positive (+), negative (-), or neutral (N) outcome
Potential Roles of Soil Microorganisms in Regulating the Effect of Soil Nutrient Heterogeneity on Plant Performance	Adomako, Michael Opoku; Roiloa, Sergio; Yu, Fei-Hai	Microorganisms (Basel), 2022, Vol.10 (12), p.2399	+
Long-Term Monoculture Negatively Regulates Fungal Community Composition and Abundance of Tea Orchards	Arafat, Yasir; Tayyab, Muhammad; Khan, Muhammad Umar; Chen, Ting; Amjad, Hira; Awais, Saadia; Lin, Xiangmin; Lin, Wenxiong; Lin, Sheng	Agronomy (Basel), 2019, Vol.9 (8), p.466, Article 466	-
The effects of local filtering processes on the structure and functioning of native plant communities in experimental urban habitats	Borowy, Dorothy; Swan, Christopher M.	Ecology and evolution, 2022, Vol.12 (10), p.e9397-n/a	**N**
Coping with drought: root trait variability within the perennial grass Dactylis glomerata captures a trade-off between dehydration avoidance and dehydration tolerance	Bristiel, Pauline; Roumet, Catherine; Violle, Cyrille; Volaire, Florence	Plant and soil, 2019, Vol.434 (1/2), p.327-342	**N**
Release of phosphorus and silicon from minerals by soil microorganisms depends on the availability of organic carbon	Brucker, Emanuel; Kernchen, Sarmite; Spohn, Marie	Soil biology & biochemistry, 2020, Vol.143, p.107737, Article 107737	-
Climate change effects on beneficial plant-microorganism interactions	Compant, Stéphane; van der Heijden, Marcel G.A; Sessitsch, Angela	FEMS microbiology ecology, 2010, Vol.73 (2), p.197-214	-
Natural grassland as the optimal pattern of vegetation restoration in arid and semi-arid regions: Evidence from nutrient limitation of soil microbes	Cui, Yongxing; Fang, Linchuan; Guo, Xiaobin; Han, Fu; Ju, Wenliang; Ye, Luping; Wang, Xia; Tan, Wenfeng; Zhang, Xingchang	The Science of the Total Environment, 2019, Vol.648, p.388-397	**N**
Evidence for the evolution of native plant response to mycorrhizal fungi in post-agricultural grasslands	Delavaux, Camille S.; Bever, James D.	Ecology and evolution, 2022, Vol.12 (7), p.e9097-n/a	+
It is elemental: soil nutrient stoichiometry drives bacterial diversity	Delgado-Baquerizo, Manuel; Reich, Peter B.; Khachane, Amit N.; Campbell, Colin D.; Thomas, Nadine; Freitag, Thomas E.; Abu Al-Soud, Waleed; Sørensen, Søren; Bardgett, Richard D.; Singh, Brajesh K.	Environmental microbiology, 2017, Vol.19 (3), p.1176-1188	**N**
Reconstructing the Microbial Diversity and Function of Pre-Agricultural Tallgrass Prairie Soils in the United States	Fierer, Noah; Ladau, Joshua; Clemente, Jose C.; Leff, Jonathan W.; Owens, Sarah M.; Pollard, Katherine S.; Knight, Rob; Gilbert, Jack A.; McCulley, Rebecca L.	Science (American Association for the Advancement of Science), 2013, Vol.342 (6158), p.621-624	+

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