# Soil Health and Ecosystem Services in Ohio State University's Chadwick Arboretum

Ohio State University

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Undergraduate Honors Thesis

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# Abstract

This work aims to examine soil health and ecosystem services in the Chadwick Arboretum on Ohio State University's Columbus campus. Healthy soils serve as a foundation for plant and tree health, as well as helping to provide many ecosystem services, such as carbon sequestration and stormwater control. As a 62-acre public arboretum, Chadwick is intensively managed by a team of horticulturalists since 1980, while having relatively few disturbances to soils (compared to an agricultural system). However, Chadwick is also an urban space, and urban soils often deviate from undisturbed soil profiles and properties due to anthropogenic influences and land use history.

To assess soil health in the arboretum presently and determine what management practices may be beneficial, soil samples were pulled from each sub-area of the Learning Gardens and Lane Avenue Gardens. A literature review was also done to determine gaps in the urban soils literature and management practices at other arboreta. Soil chemical analyses including pH, major cations (K, Mg, Ca), cation exchange capacity (CEC), and phosphorus (P) were performed by Penn State Extension labs. Results show good soil chemical properties in the areas tested and show no major concerns to soil health. Additional tests planned included total soil carbon and nitrogen and bulk density every 20cm to 1m depth.

Unfortunately, due to limited lab access because of COVID-19, some data could not be collected. However, the original plan for data collection will still be presented. Despite the unforeseen changes, this work still hopes to build a framework for understanding, valuing, and managing soil health and ecosystem services in a large urban greenspace, and contribute to an understanding and valuing of urban soils in the research literature.

# Background and Literature Review

## Introduction

Urban environments are under increasing pressure from population increases, expansion, environmental challenges like stormwater problems, the urban heat island effect, etc., many of which will be worsened with the progression of climate change.  Over 80% of the U.S. population lives in urban areas, according to the 2010 Census. Many studies have examined the urban environment, often focusing on the carbon sequestration and cooling benefits of urban trees. Less studied are urban soils and the benefits they can provide if managed for soil health and ecosystem health.  Understanding and maximizing the ecosystem services that the urban environment can provision is increasingly important, but many gaps remain in the research literature.

Healthy soils serve as a foundation for plant and tree health, as well as helping to provide many ecosystem services, such as carbon sequestration and stormwater control. As a 62-acre public arboretum, Chadwick is intensively managed by a team of horticulturalists, while having relatively few disturbances to soils (compared to an agricultural system). This would lead to the expectation that Chadwick should be a very healthy, functional ecosystem. However, Chadwick is also an urban space, and urban soils often deviate from undisturbed soil profiles and properties due to anthropogenic influences and land use history.

Intensively managed urban greenspaces have a high potential for ecosystem services including carbon sequestration, but benefits may be undercut by hidden costs as well, such as energy costs involved in mowing or irrigation.  Interest in natural climate solutions is growing, such as in Ohio State University's own recent Climate Action Plan, which calls to "Expand campus land management techniques to maximize, and account for, carbon sequestration and additional ecosystem services."  Relatively few studies have looked specifically at urban soils and their ecosystem services, despite the fact that soils store as much carbon to 1m depth as trees and vegetation store aboveground. Thus, it's important to understand and value urban soils and the services they provide, as well as the benefits and drawbacks of management practices in order to protect urban soils and improve the health of the environment.

## Objectives and Expectation

This work aims to set a baseline understanding of soil health in the Chadwick site presently and make recommendations for management.

To do this, soil samples were pulled from sites in the arboretum in September 2019 and chemical analyses of soil properties performed. In addition, a review of the research literature on urban soils, soil health and ecosystem services is presented to determine what some of the gaps in understanding are.

Based on the results of the chemical analyses, it wouldn't be expected to find many significant differences between the different areas of the arboretum. As the site is relatively undisturbed since its founding in 1980, with the benefits of good management over time, the site would be expected to have overall good soil health metrics and contribute positively to the local environment.

If carbon data were to be taken to 1m depth, it's expected that the site would be a dense carbon storage site due to its intensive management and relatively undisturbed state for 40 years. However, as the site is urban, there would likely be signs of disturbance in the soil profile, such as compaction or presence of foreign materials (ex. asphalt or concrete from past nearby construction). Soil carbon residence time would be a lingering question as well, and soil respiration could be taken to determine how quickly organic matter is being degraded. Long term monitoring of the site could help determine how carbon stocks change over time compared to other land uses.

## Soil Health and Carbon

Soil health is the idea of “the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans” (*Soil Health | NRCS Soils*, n.d.). Generally, soil health assessments look at soil physical, chemical, and biological properties to determine overall functioning of the soil. These properties work together to create the soil’s ecosystem and ecological properties. Physical properties can include bulk density, pore space, hydraulic conductivity, soil strength; chemical properties can include pH, cation exchange capacity (CEC), the presence of contaminants, electrical conductivity; biological properties can include microbial biomass, earthworm activity, enzymatic activity, among others. These properties work in tandem to support soil strength and fertility and support vegetative growth. The soil’s ecosystem services are based on these three categories of properties.

The Millenium Ecosystem Assessment defines ecosystem services simply as “the benefits people derive from ecosystems” (*Millennium Ecosystem Assessment*, n.d.). Healthy soils can provision a wide range of ecosystem services, like retaining and provisioning nutrients for vegetative growth, retaining more water and filtering pollutants from water helping to improve water quality and improve stormwater control, sequestering carbon from the atmosphere, and many other benefits. Carbon / organic matter is key to many of these properties as well, as it helps to improve soil strength, retain nutrients, etc. Increasing carbon in soils is beneficial for climate change, but it has more direct benefits on the local environment as well, such as increasing soil strength helping prevent compaction, improving water holding capacity reducing the risk of drought, or retaining more nutrients for plant growth.

In discussions of natural carbon sequestration for climate change mitigation, trees and vegetation generally get more attention than soils (Lorenz, 2015; Pouyat et al., 2015). However, soils are estimated to contain 1500 to 2400 Pg of organic carbon to 1m depth, while living biomass estimates range from 450 to 700 Pg (Ussiri & Lal, 2017), meaning that soils contain more of the world's carbon than trees or other living organisms. Thus, soil management is worthy of discussion and can play a critical role in climate mitigation efforts. In general, more carbon in soils means that soils are stronger, can grow more vegetation, can filter more water, store more nutrients, etc., as well as help play a role in climate mitigation. For soil health, 5-6% organic matter is about the maximum unless the soil is in a wetland environment (Moebius-Clune et al., 2016).

## Urban Soils and Ecosystem Services

Related to the concept of soil health, and important for understanding this specific site is the study of urban soils. Urban land use is growing rapidly – as of the 2010 U.S. Census, 81% of the population lived in urban areas, meaning many people are in part dependent on urban ecosystem services. Soil ecosystem services like stormwater control and water quality, nutrient retention and provisioning, contaminant recycling, among many others, are vital to the environmental quality of life in urban areas. However, urbanization has a range of impacts on soil properties and structure, and urban soils are highly variable, meaning their properties and services aren't well understood (Burgos Hernández et al., 2019)

Urban soils are characterized by the domination of anthropogenic activities (ex. surface removal, contamination, fill material) over natural processes (*Urban Soils | NRCS Soils*, n.d.). This can result in soils deviating in structure and function from what would be expected given the natural environment. The specific anthropogenic properties are dependent on the land use history of the site in question (Ziter & Turner, 2018), and thus urban soils can vary greatly from each other and from an undisturbed soil profile, necessitating further study.

Compaction and loss of organic matter are two of the most common issues with urban soils due to the impacts of construction – heavy machinery, topsoil removal, erosion, etc. (Chen et al., 2013). Other issues, such as the presence of heavy metals or other toxins, are dependent on the land use history of the site and the areas around it. Because of their complex history, urban soils are unique and necessitate further study to understand their properties and the influence that human activity has had on them. One study done on the Ohio State University campus found evidence of disturbance within even seemingly undisturbed areas of campus (Burgos Hernández et al., 2019), indicating that most if not all soils in urban environments have been altered, just to varying degrees and with different impacts on soil functions.

Studies concerned with carbon dynamics in urban areas are most often concerned with carbon stored and sequestered in vegetation, often omitting the study of soil carbon dynamics (Baró & Gómez-Baggethun, 2017). Urban soils, as discussed, have complex histories and often bear evidence of anthropogenic disturbance, altering their functions. However, urban environments are also intensively managed, meaning that they have the potential to support a high level of ecosystem services (Lal, 2012). Thus, urban carbon storage in soils is complex, and warrants further detailed study.

One study on urban soil carbon storage looked at carbon in cities based on existing data for tree biomass, land use, and land cover (Pouyat et al., 2006) and storage density ranged from 8.3-10.8 kg/m^2. However, little data was from green spaces specifically and measurements in general were limited. Residential lawns had high carbon density, and in general, urban soils showed high potential to sequester carbon in soil, again, likely due to intensive management practices and lack of annual disturbances, such as tilling in agroecosystems.

Another study showed that the effects of management (i.e. anthropogenic influences) were more important than environmental factors in determining urban soil structures (Pouyat et al., 2015). Other factors to consider in determining carbon sequestration include soil respiration rates, which can help determine how stable the organic matter is from microbial degradation.

Other reviews have shown that natural climate solutions and ecosystem services are limited or uncertain in their ability to offset carbon emissions, reduce heat stress, and reduce air pollution on a large scale (city, region), but can have a higher impacts at smaller scales like streets and greenspaces (Baró & Gómez-Baggethun, 2017). This suggests that due to all the variation in urban ecosystem services and the scale of the problems on a city or regional scale, it's more useful to assess urban ecosystem services on a smaller, site-level scale.

In general, soil carbon sequestration is dependent on the net balance of organic matter entering the soil (ex. from biomass amendments, net primary productivity (NPP) of vegetation) and the organic matter leaving the soil (ex. disturbances, erosion, decomposition). Urban environments have a high potential for carbon sequestration due to intensive management regimes (fertilization, irrigation, mowing, etc.) which supports high levels of vegetative growth, as well as few annual disturbances such as tilling in agroecosystems (Lal, 2012). However, urban environmental management also has hidden costs that reduce the net carbon sink value, such as energy costs for mowing or irrigation. (Lal, 2012).

Ultimately urban soils, soil health, and ecosystem services tie together to support a case for further study on urban ecosystem management. To understand ecosystem services in urban environments, land use history must be considered, as well as measurements of the properties on site to understand the influence of anthropogenic activities. Then, considerations for maximizing the benefits of urban greenspaces can be considered, and management recommendations can be considered.

## Ohio State Climate Action Plan and Land Management

Chadwick's land management activities have a potentially larger implication for OSU's Climate Action Plan (CAP) (*Ohio State's Path to Carbon Neutrality: University Accelerates Climate Action | Ohio State Sustainability Institute*, 2020). The plan, released originally under President Gee in 2008 and updated under President Drake in April 2020, strives to make Ohio State University carbon neutral by 2050. The plan primarily looks at energy sourcing and efficiency measures as those make up the majority of OSU's emissions, but discusses the role of natural climate solutions like tree and soil-based carbon sequestration on campus property as part of the carbon budget calculation.

One recommendation from the CAP is to "Expand campus land management techniques to maximize, and account for, carbon sequestration and additional ecosystem services." The question then is how much carbon campus landscapes can reliably and measurably store through land use management practices and tree canopy increases, what the potential for sequestration is, and how to maximize sequestration via best management practices. It's also important to consider how OSU can leverage existing resources (extension, community connections and initiatives, research initiatives and funding, etc.) to disseminate those best practices and expand impact beyond the borders of campus.

The CAP estimates soil carbon sequestration rates from studies of forest, crop, and grazing land. But, given the complexities of urban carbon sequestration, does that accurately reflect urban greenspace on campus?

Under these scenarios, the sum of the sequestration across all campuses is:

| Scenario | CO2e Metric Tonnes Sequestered | Percentage of Total Emissions |
|---|---|---|
| Current | 7,750 | 1.25% |
| Potential I | 21,000 | 3.4% |
| Potential II | 46,250 | 7.5% |

*Figure 16: Carbon Sequestration Potential Comparison*

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*Figure 1. Summary of scenarios for natural carbon sequestration on Ohio State campuses. From* Ohio State's Path to Carbon Neutrality: University Accelerates Climate Action | Ohio State Sustainability Institute, *(2020).*

The CAP considers two scenarios for sequestration: Potential 1 = no land use change, just beneficial land management practices ("Ex. fertility management, local manure, improved and native plant species, erosion reduction, longer crop rotations, partial cutting vs. clear cuts") while Potential 2 = land use change is considered as a possibility. The results of these scenarios is presented in Figure 1. It estimates that by simply implementing better land management practices into Ohio State green spaces and agricultural fields, the amount of carbon sequestered in campus lands could approximately triple, a substantial return on investment with additional benefits for the local environment.

Given that Chadwick Arboretum is a relatively large urban greenspace on campus (62 acres / 1904 total acres for Columbus campus) it has potential to serve as a testing grounds for best management practices and maximizing ecosystem services from campus lands in accordance with CAP goals. And although the sequestration potential for the arboretum and for campus is relatively small compared to emissions (max. about 7.5%  of OSU emissions, according to Scenario II in the CAP), there's a potential to demonstrate best management practices and expand the impact beyond just campus. Even if the changes in carbon are relatively minor compared to the CAP projections, the co-benefits of improving management of urban soils are beneficial in themselves, such as other local ecosystem services, the potential for partnerships with community businesses, possibilities of further research and experimentation on campus, the investment in a peaceful, natural space for students and staff, is valuable apart from the potential climate benefits. Given the benefits of carbon to soil health, and potentially to the OSU climate plans, the question then is how to consider best management practices for a public urban greenspace.

## Best Management Practices for Urban Greenspaces and Arboreta

Due to their intensive management and public access, arboreta and other urban greenspaces face unique considerations when implementing sustainable practices compared to other land use types. It's necessary to balance the public areas like event spaces with ecological concerns, like soil compaction from traffic, native vs. ornamental plantings, or determining which areas may be candidates for no-mow meadows and which should be kept short. Arboreta in general are also very visible to the public, and can serve as an educational resource through signage, workshops, online resources, and other means.

The Harvard Arnold Arboretum is one example of an arboreta working on more sustainable management practices. Starting in 2018, the arboretum partnered with a local coffee shop and a local brewery to use their coffee grounds and spent grains to make compost for the arboretum grounds (Blackwell, 2019). This allowed the local businesses to dispose of organic waste more easily, and for the organic materials to be recycled into the landscape, improving soil health and carbon. In addition, the Arnold Arboretum formed a Soils Advisory Committee to outline objectives for sustainable management of the arboretum.  Staff horticulturalist Conor Guidarelli explained more about the decision-making considerations via email. The main considerations were how organic materials were managed (ex. weeds, leaves), how soil fertility impacts selection of plant species, how to balance public space and natural habitat in the landscape, and how new plantings are maintained and assessed for health issues (C. Guidarelli, personal communication, November 6, 2019). Some specific management practices that came out of that study included no driving off road or using protective compaction mats to reduce pressure on soils, introducing no-mow meadows to reduce mowing costs and provide more native habitat, reducing soil erosion as necessary by stabilizing areas, additional soil sampling and measurement efforts, and limiting traffic on wet soils, again to reduce compaction.

Again, every greenspace is unique and will have unique management considerations, but the recommendations from Harvard are good examples of specific actions arboreta and other greenspaces can take. Maximizing net carbon sequestration is about managing inputs and fertility to maximize net primary productivity of vegetation, while minimizing disturbances like compaction, tilling (Lal, 2012). Practices to limit compaction of soils, for example, are important for areas that have been compacted by past development, or have high traffic from the public. The Harvard Arboretum was the primary example found of an arboretum doing specific soil health-oriented management, although there are almost certainly others that just haven't been as public about what they're doing. Regardless, this is one good example of an arboreta valuing and managing soil health on its grounds.

### Summary

Currently Chadwick already employs some of the practices Guidarelli discussed the Harvard Arboretum implementing. Weeds and other herbaceous materials removed from the landscape are composted and reapplied to garden beds, and woody materials are mulched and used as topdressing for beds, helping with weed control and helping to cover soil and retain water. In addition, Com-Til (a composted biosolid product from the City of Columbus) was applied to some of the lawn areas around Kottman hall last September with the hopes of improving soil structure and available water capacity issues in the area.

However, there's always room for improvement in any land management activity. The soil sampling activities performed for this thesis are intended to set a baseline for Chadwick's soil health management practices and determine what best management practices could be most beneficial for implementation in this campus greenspace in alignment with CAP recommendations for best management practices for campus lands.

## Site Background

Chadwick Arboretum is a large urban greenspace located on the Ohio State University Columbus campus. It covers 62 acres and features include a catch and release lake, extensive collections of perennial and annual flowers and shrubs, a green roof on Howlett Hall, and a wide range of tree species. It's split into three areas: Arboretum North, where the lake and a more natural forested area are located, the Lane Avenue gardens, stretching along the north border of campus and primarily made up of tree and shrub collections, and the Learning Gardens, made up primarily of dense perennial and annual planting beds. Lane Avenue was the original section of the arboretum, founded in 1980. In 2003, the arboretum expanded to include the Learning Gardens (*About Us | Chadwick Arboretum & Learning Gardens*, n.d.)

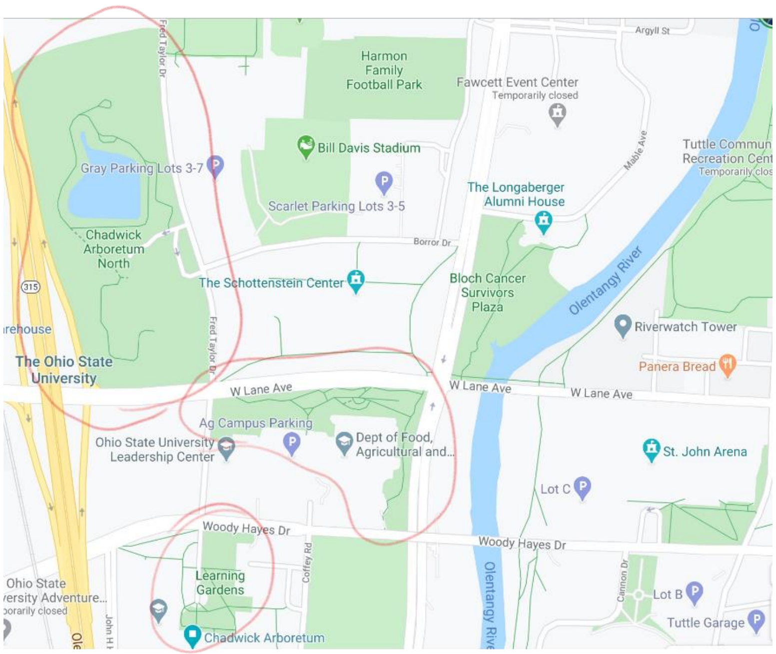


*Figure 2. Map of Chadwick Arboretum, with relevant areas circled in red. Image from Google Maps, July 2020.*

This study focused on sampling the two smaller areas of the arboretum – Lane Avenue and the Learning Gardens – as they are the more intensively managed of the areas. Based on arboretum maps and records, the areas were never the site of any buildings prior to their usage as gardens. However, they may have been disturbed in development regardless due to their proximity to several other campus buildings.

## Methodology

Soil samples were taken in September of 2019 from each of the garden and lawn areas in the learning gardens and Lane avenue sections of the arboretum. Samples were taken from randomized points throughout each garden area at a depth of 20cm and aggregated in a single sample per area to get a representative sample for each area. A total of 12 samples were sent to Penn State Extension labs for chemical analysis. Each area of the garden was classified based on its primary makeup of vegetation – flower, lawn, or tree/shrub.

Each sample was measured for pH, phosphorus, potassium, magnesium, and calcium levels, as well as CEC (cation exchange capacity). pH was measured using the 1:1 soil to water method, nutrients were measured using the Mehlich 3 test, and CEC was calculated from the summation of cations ($K^+$, $Mg^+$, $Ca^{2+}$) measured.

Total carbon and nitrogen every 20cm to 1m depth, as well as bulk density would have also been collected for each sample site in the arboretum, but unfortunately couldn't be collected due to lab access issues from COVID-19.

# Results

## Chemical Results

Table 1 below summarizes the chemical results of the soil testing by area of the garden. For each sample the high level of Ca indicated the presence of soluble calcium, so the CEC was calculated using a maximum level of 15 meq/100g, so the CEC may not be a direct sum of the measurements of each cation. pH, phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and cation exchange capacity (CEC) were measured in the analysis.

| Name | Area | Type | pH | P (lb/A) | K(meq/100g) | Mg (meq/100g) | Ca(meq/100g) | CEC |
|---|---|---|---|---|---|---|---|---|
| Van Fossen | Learning Garden | Flower | 7.4 | 214 | 0.4 | 3.4 | 19.7 | 18.9 |
| Kleinmaier | Learning Garden | Flower | 7.6 | 824 | 0.5 | 3.9 | 20.9 | 19.4 |
| Still Garden | Learning Garden | Flower | 7.6 | 346 | 0.3 | 3 | 17.5 | 18.4 |
| Forget me not | Lane Ave | Flower | 7.5 | 192 | 0.5 | 3.6 | 18.4 | 19.1 |
| Labyrinth | Lane Ave | Tree/Shrub | 7.8 | 114 | 0.4 | 3 | 16.8 | 18.3 |
| Phenology | Lane Ave | Tree/Shrub | 7.7 | 100 | 0.5 | 4 | 14.8 | 19.3 |
| Lawn NW of founder's rock | Lane Ave | Lawn | 7.5 | 130 | 0.45 | 3.78 | 13.73 | 18 |
| Trial garden lawn | Learning Garden | Lawn | 7.8 | 176 | 0.54 | 2.92 | 24.09 | 18.5 |
| Lawn SW of Rose | Learning Garden | Lawn | 7.5 | 208 | 0.57 | 3.66 | 19.29 | 19.2 |
| Kottman SW Lawn | Learning Garden | Lawn | 7.5 | 282 | 0.58 | 2.78 | 19.64 | 18.4 |

*Table 1. Summary of chemical data by area of garden.*

## Discussion

Overall, the chemical data doesn’t show any major signs for concern with regards to soil health.  pH is slightly high in some areas but given the calcareous subsoil of the area, this is to be expected. The high levels of soluble Ca support this idea. Tree and flower species should be chosen that will grow well in these slightly alkaline soils to minimize the inputs necessary to maintain plant health. Figure 3 shows that there’s little correlation between pH and calcium levels in the gardens, as the $R^2$ value is very low. However, this inconsistency may be due to inconsistent sampling depths and amounts of subsoil material in the tested samples. Regardless, the pH is still within a healthy range for most plant growth and is not a cause for concern.

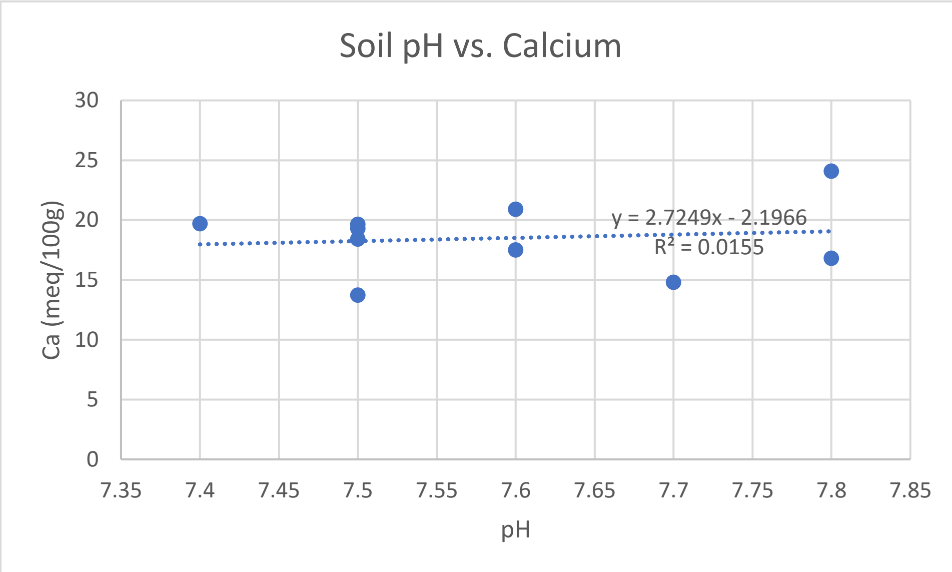


*Figure 3. pH vs. Ca levels in the gardens*

Overall cation exchange capacity across the gardens is fairly high and consistent, there are no major areas of low nutrient capacity shown in these samples. The P-level in the Kleinmaier garden is a significant outlier compared to the other P data samples. However, this garden recently had compost applied, and this is the likely source of the high P levels, and so is not a cause for concern.

Table 2 below shows the average of each measured property by the type of planting present in the area. Average P is calculated without the significant outlier of the Kleinmaier garden, which as discussed had compost applied shortly before sampling occurred, skewing the measurement. Overall chemical data is consistent across the three planting types. The main difference between the three planting types is how frequently new plantings are brought in and how those are maintained – the flower beds are mostly perennial, some annual plants, and so would be expected to be higher in P due to the more frequent compost/fertilizer amendment to help establish new plants. The tree/shrub areas are planted less frequently, and so would be expected to be lower in nutrient levels due to fewer inputs. Lawn areas are more intensively managed with frequent fertilizer and irrigation usage, and so P and K levels are expected to be higher there, consistent with the results.

| Type | Avg. pH | Avg. P (lb/A) | Avg. K (meq/100g) | Avg. Mg (meq/100g) | Avg. Ca (meq/100g) | Avg. CEC |
|---|---|---|---|---|---|---|
| Flower | 7.525 | 280 | 0.425 | 3.475 | 19.125 | 18.95 |
| Tree/Shrub | 7.75 | 107 | 0.45 | 3.5 | 15.8 | 18.8 |
| Lawn | 7.575 | 199 | 0.535 | 3.285 | 19.1875 | 18.525 |

*Table 2. Average of soil chemical properties by planting type.*

One difference between the planting areas is in the pH of the tree/shrub areas, which is slightly higher than the flower or lawn areas, but lower in calcium. This goes against the idea that the raised pH is from the calcareous, alkaline subsoil. However, as the tree/shrub data is only from two data points, and the difference is relatively minor and still within a healthy range, this difference is little cause for management concerns. The variations in pH and Ca amounts may be due to inconsistencies in the sampling depth, resulting in different amounts of subsoil collected in the samples.

## Recommendations

Based on the literature review and the data, several recommendations can be made. The establishment of a no-mow meadow area would help to reduce energy costs from frequent mowing, as well as reduce compaction on the soil, increase organic carbon inputs from the meadow plant roots, and provide habitat for pollinators and other living organisms. Another recommendation would be to limit vehicle traffic on soils in general, but especially after watering or rain, when soils are particularly vulnerable to compaction. The arboretum already does a good job at using compost made from pulled weeds in garden beds, but incorporating compost or Com-Til into more compacted, dry areas of the arboretum, such as around the lake, could be beneficial to improve soil strength and increase available water capacity, as well as increasing soil carbon.

Aside from the more specific recommendations for the arboretum, some general recommendations for urban land management would be to limit vehicle and human traffic on compacted soils, incorporate compost or other organic matter source on a regular basis (ex. leave leaves on the ground during the fall so they can decompose, allow grass clippings to collect on the ground instead of being bagged). Understanding the local environment and soil conditions is important as well, to choose species that will do well in that environment without a great deal of costly management interventions – ex. choosing plants that will do well in the soil's pH. More ornamental plants are popular with many gardeners but finding ways to incorporate both native and ornamental varieties of plants would be beneficial to local pollinators and environments.

In addition, Ohio State and other organizations interested in climate mitigation and adaptation should consider all the ways to invest in decarbonization efforts. Highly technical solutions often get much of the attention, but lower-tech solutions like green roofs, better land management in urban greenspaces and agricultural areas, and energy efficiency efforts can all be a big part of the solution despite not being as flashy as carbon capture technology, for example.

Although this report does not go into detail on agricultural soil carbon sequestration specifically, Ohio State should consider using existing agricultural fields on Ohio State campuses to implement best management practices for soil carbon sequestration. This would benefit local carbon budgets outlined in the Climate Action Plan, as well as serving as a very public example of the value of investing in soil management practices. Ohio State has the potential to make a large difference in how environments are managed in Ohio. The university should set an example not only for land best management practices, but other climate actions, like investing in renewable energy sources, implementing more energy efficiency measures, and not building additional fossil fuel infrastructure. Actions such as these would be beneficial not only for OSU, but for surrounding communities and others in Ohio.

## Conclusion

Overall, no major issues were found in the chemical data for Lane Ave or the Learning Gardens, indicating good soil chemical functioning. Unfortunately, due to time and lab constraints from COVID-19, much of what this report aimed to analyze remains theoretical – current carbon storage estimates compared to other urban areas, physical properties and restraints on soil health, etc. However, there is a strong case for studying urban ecosystem services on a local site scale and considering the impact of the management decisions that go into these lands. Urban greenspaces face unique challenges in their management based on land use history and alterations to soil functioning, but they also have the potential to be dense carbon sinks and provide a great deal of ecosystem services. OSU should value the arboretum as a place of peace and beauty, as well as a place that can support local ecosystem services. Opportunities to expand public knowledge of the environment should include the urban environment and should include topics like soils that often get overlooked by policymakers and the general public.

Given more time, additional research should be done on understanding intensively managed urban greenspaces across time, across specific land uses and management considerations within a specific site, and to consider ecosystem services. Relatively few studies have been done looking at ecosystem services in depth in a specific site with management considered. More work should be done to understand and communicate the value of greenspaces in urban environments, and to advocate for their investment and protection as public resources and educational tools.

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