Final Research Report

Slope restoration on urban freeways

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16. Abstract

Diverse plantings along freeway roadsides can be beneficial to surrounding areas in many ways, such as improved driver safety, increased biodiversity, and improved aesthetics. Unfortunately, establishing these plantings can be difficult for a variety of reasons. To improve the success of future plantings, we investigated the impacts of site preparation and plant selection on the success of roadside plantings. The objective of the study was to evaluate the effect of site preparation (tillage and addition of compost) on establishment of roadside plantings and to identify suitable plants for roadside plantings. We conducted a large-scale field study at two locations (Warren, MI and Roseville, MI) along I-696 near Detroit, MI. We installed 16 selections of shrubs and perennials into sites with four different site preparation treatments. In a separate trial on the site, we evaluated 16 additional selections of shrubs and perennials to identify additional plants suitable for roadside plantings. In the site preparation experiment, compost application had positive effects on plant growth and plant coverage (% ground cover) in 2019 and 2020, irrespective of tillage. Soil surface tillage had no effect on overall plant coverage, plant growth and plant survival for most species. Evaluation of plant moisture stress and plant nutrition suggests that the addition of compost improved plant growth and establishment through improved soil nutrient content rather than improved moisture availability. Overall, the compost only site preparation treatment was the most successful in improving plant establishment and aesthetics. Plants grown in plots with 4 in compost as a top-dress, followed by 3 in of mulch grew as well or better than plants in other treatments. This site preparation method is consistent with current MDOT standards. These results emphasize the need for contractors to adhere to standards during plant installation. Based on the results of this project, site preparation and plant selection guidelines were updated and incorporated in a new Plant Selection Manual for the state of Michigan.

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Executive Summary

Establishing landscape plants such as shrubs, herbaceous perennials, and ornamental grasses can increase the diversity of highway roadside plantings. Landscape plantings along roadsides provide a range of benefits including slope stabilization, improved aesthetics, increased biodiversity and pollinator habitat, reduced need for mowing, and improved driver awareness and safety. However, highway roadsides are difficult sites on which to establish plants, particularly on sloped roadsides in urban areas. Plants on these sites are often subjected to poor soil conditions such as alkaline soils, low organic matter and loss of soil structure due to site disturbance during construction. Roadside plants also face above-ground stresses including elevated temperatures associated with urban heat island effects and increased wind exposure due to nearby traffic and wind tunnelling effects of sloped freeways. In 2013 the Michigan Department of Transportation (MDOT) installed 14 linear miles of landscaping along I-696 in the metro Detroit area. The purpose of the project was to reduce erosion along the sloped roadsides, reduce mowing frequency, and improve the aesthetics of the area. However, initial plant establishment was poor along some sections of the plantings.

We undertook this research project with the long-term goal of improving success of establishing roadside plantings in urban areas. Based on the literature and experience, we focused on site preparation and plant selection, as these are two key drivers of successful plant establishment and are factors over which roadside managers have control. We established a large-scale field experiment on two sites along I-696, one near Warren, MI and one near Roseville, MI in summer and fall 2018. The experiment had two main objectives. The first objective was to evaluate the effectiveness of site preparation through tillage and/or compost addition in improving plant establishment. We hypothesized the tillage would improve plant establishment by reducing compaction and that compost would improve plant performance by improving soil nutrient retention and reducing plant moisture stress. We further hypothesized that combining tillage and compost would provide additive benefits to plant establishment. The second objective was to evaluate the performance of several different selections of plants. In particular, we evaluated shrubs, ornamental grasses and herbaceous perennials, which can contribute aesthetic, structural and biological diversity to roadside plantings. To accomplish this, we evaluated plant establishment as percent ground cover, plant survival and growth for two years after planting in plots with four different site preparation treatments: 1) control, 2) tillage only, 3) top-dress with 4 in of compost and 4) compost + tillage. All plots received a final top-dress with 3 in of ground hardwood bark mulch. We evaluated 16 plant selections as part of the site preparation experiment and evaluated 16 additional plant selections under one site preparation condition (compost + tillage). To understand the mechanisms by which the site preparation treatments affected plant establishment and survival, we evaluated plant physiological responses and environmental parameters for each site preparation treatment.

Site preparation affected plant establishment, as indicated by percent ground cover and plant growth, two years after establishment. Contrary to our original hypotheses, however, compost was the primary driver of the site preparation response while tillage had little effect on plant growth or percent cover

and there was no additive benefit of combining compost and tillage. Addition of compost reduced soil pH and increased soil nutrient content and plant foliar nutrient concentration, suggesting the primary benefit of compost on plant establishment was due to improved nutrient availability and reduced soil pH. Contrary to our hypothesis, the addition of compost did not reduce plant moisture stress.

Plant establishment varied among plant selections. Overall survival and plant cover (% ground area in plant cover) was very good among most shrub selections, particularly *Cotoneaster, Diervilla, Physocarpus* and *Cephalanthus* selections. Plots with these selections had over 60% plant cover when planted with compost. Among herbaceous perennials, *Amsonia, Hemerocallis, Nepeta* and *Allium* selections had 50% coverage or better with compost. Plant cover was relatively poor for grass selections; only *Deschampsia cespitosa* 'Bronzeschleier' and *Panicum virgatum* 'Rotstrahlbush' averaged more than 50% plant cover. Plant selections with dense foliage and a spreading habit were often the most successful plants at this site.

These results indicate that top-dressing with compost followed by mulch was the optimal site preparation treatment as it resulted in plant establishment that was as good or better than any other treatment, without the additional effort and expense of tilling the site. The compost + mulch top-dress protocol is consistent with current MDOT specifications. Prior to the current study, we inspected some of the planting sites on I-696 on which earlier plant establishment was poor. In several instances we found that compost and/or mulch had been greatly over-applied. The results of our experiment demonstrate the MDOT specification of 4 in compost followed by 3 in mulch resulted in excellent plant establishment. We recommend that MDOT emphasize training for contractors and oversight to ensure that the specification is maintained during roadside plant installations. The dramatic response of plants on the roadside sites to addition of nutrients in compost suggests several lines for further investigation. These include examination of common compost types to determine if plant response varies by compost type and investigation of other site amendments that may impact plant nutrient availability such as fertilization.

Introduction

Roadside plantings that include woody plants and perennials can provide a myriad of benefits (AASHTO, 1991; Baldauf, 2017). When designed appropriately, roadside plantings can reduce road noise (Balduf, 2016), reduce the urban heat island effect (Edmondson et al., 2016; Shashua-Bar and Hoffman, 2000) and improve the aesthetic quality of an area. Roadside plantings can improve the safety around a site as well. For example, sites that have well managed landscapes have significantly reduced crash rates when compared to areas with poorly managed or no landscapes (Mok et al., 2006). Biodiverse roadside plantings not only benefit humans, but also provide habitat for pollinators and urban wildlife, which can aid restoration efforts (Hopwood, 2008; Wigginton and Meyerson, 2018). In addition, urban and roadside plants benefit the surrounding environment because they have the potential to improve air quality by filtering and sequestering pollutants from the surrounding environment (Baldauf, 2017; Dzierzanowski and Gawronski, 2011; Weber et al., 2014). Lead and sulfur dioxide, common pollutants from car exhaust, as well as particulate matter from wear of tires and brakes can be effectively filtered from the air by plants (Singh et al., 1995). The efficacy of particulate matter collection is dependent on plant morphological features such as foliage density, leaf hairs, leaf area and height (Balduf, 2016; Dzierzanowski and Gawronski, 2011; Weber et al., 2014).

While the benefits of roadside plantings are of interest to many communities and transportation agencies, highway roadsides are difficult environments to establish plantings (Bary et al., 2016). Human activity often degrades urban soils, which leads to increased bulk density, low organic matter content and loss of soil structure (Craul, 1985; Scharenbroch et al., 2005). These factors can restrict root growth of woody plants (Alberty et al., 1984), reduce the amount of available water and air in the soil (Jim and Ng, 2018), and reduce the amount of nutrients in the soil (Craul, 1985). Roadside soils are also subject to pollution from heavy metals (Khalid et al., 2018; Nagajyoti et al., 2010; Ndiokwere, 1984), which can affect the development and growth of plants when they accumulate in the soil (Balsberg-Påhlsson, 1989; Nagajyoti et al., 2010; Sanità Di Toppi and Gabbrielli, 1999).Additionally, roadside plants face challenges not related to soil conditions. Although roadside plants have been shown to benefit the surrounding environment by sequestering aerial pollutants, excessive buildup on of particulate matter on leaves can result in plant damage (Grantz et al., 2003) or reduce photosynthetic efficiency (Popek et al., 2018).

In order to address the challenges of the roadside environment, proper site preparation is important to the establishment of roadside plantings and can mitigate some of the factors that make establishment difficult. During construction, grading and other activities often remove topsoil leaving subsoils with little organic matter (Craul, 1985). A popular way to resolve this problem is amending soil with compost or other commonly available organic materials. The addition of organic amendments can significantly increase tree growth and tree biomass of roadside plantings (McGrath and Henry, 2016; Scharenbroch et al., 2013). McGrath and Henry

(2016) attributed the improved growth of roadside trees associated with compost addition to improved soil physical properties, particularly bulk density. Incorporation of organic matter via tillage also decreases soil bulk density and can result in increased water holding capacity (Sax et al., 2017). Organic amendments also can improve soil nutrition. Soil amended with organic matter had increased amounts of phosphorus and nitrogen, which was associated with increased ground cover and height of turfgrass (Brown and Gorres, 2011). When compared to trees grown in greater amounts of compost, roadside trees grown in topsoil that contained 25 % compost by volume had the greatest increase in height (McGrath et al., 2020), suggesting that compost additions should be optimized for site conditions and desired plant species. Excessive application of compost can result in significant settling, waterlogging and salt accumulation in the soil (Cogger, 2005).

In addition to reducing organic matter, construction activities can increase compaction and reduce soil structure of urban soils (Alberty et al., 1984; Craul, 1985). Compacted soils can restrict root growth of woody plants at bulk densities between 1.40 and 1.65 g/cm^3 or above (Alberty et al., 1984). For plants to have successful root systems, the soil must be loose enough for root penetration (Alberty et al., 1984; Kuhns et al., 2004). Guidelines from Pennsylvania State University recommend that soils on roadside planting sites be loosened as deeply and in as large of an area as possible (Kuhns et al., 2004). Tillage of compacted soil increased infiltration rates of water by 3 to 4 times compared to soils that were not tilled (Mohammadshirazi et al., 2017). Increased infiltration rates reduce runoff, increase plant available water, and improve growth of plants (Mohammadshirazi et al., 2017). Tillage also allows for increased incorporation of amendments into the soil and can make plant installation easier for planters. Incorporation of compost via tillage mitigates re-compaction from mower traffic (Mohammadshirazi et al., 2017). Furthermore, incorporation of compost via soil tillage can improve water infiltration rates and reduce stormwater runoff (Rivers et al., 2021). However, improved soil physical properties associated with the incorporation of organic amendments into soil via tillage does not always translate into improved plant growth (Bary et al., 2016; Rivers et al., 2021).

Along with site preparation, appropriate plant selections are essential to the success of roadside plantings. The effects of pollution, poor soil quality, and the urban heat island effect cause roadside plantings to require plants that are both adapted to the local climate and resilient to extreme conditions. The American Association of Highway Transportation recommends that plant selection be based on the climate, soils, and topography in natural areas close to the planting site (AASHTO, 1991). Many municipalities have created updated guidelines for roadside plantings that both maximize establishment and the benefits that roadside plantings provide (Jones et al., 2007). As part of this overall project we developed a list of plant selections that are suitable for roadside plantings along highways in Michigan. This plant selection guide, along with accompanying plant specifications have been prepared as a separate deliverable for MDOT from this project

In the research study we investigated the effect of site preparation practices and plant selection on the establishment of roadside plantings along Interstate-696 (I-696), a major interstate highway near Detroit, MI USA. In 2013 the Michigan Department of Transportation

(MDOT) installed 14 linear miles of landscaping along I-696 in the metro Detroit area (Lawrence, 2015). The purpose of the project was to reduce erosion along the sloped roadsides, reduce mowing frequency, and improve the aesthetics of the area (MDOT, 2021). However, some sections of the plantings did not survive after two years (Lawrence, 2015). Poor plant survival of plants along roadsides may be due to range of factors, some of which highway departments and their contractors can control and some which are beyond their control. As noted earlier, two key factors in roadside planting success are site preparation and plant selection. Existing MDOT planting specifications require top-dressing sites with 4 in of compost prior to planting. MDOT also noted a need for updated roadside planting guidelines in Michigan. The latest set of plant selection guidelines that MDOT has on file are from the 1970s and need to be updated (Nanette Alton, MDOT, personal communication). This experiment had two main objectives. The first objective was to evaluate the effectiveness of tillage and compost in improving plant establishment. The second objective was to evaluate the performance of several different selections of plants. We evaluated shrubs, ornamental grasses, and herbaceous perennials, which can add aesthetic, structural and biological diversity to roadside plantings. To accomplish this, we evaluated plant establishment as percent ground cover, plant survival and growth. To understand the mechanisms by which the site preparation treatments affected plant establishment and survival, we evaluated plant physiological responses and environmental parameters for each site preparation treatment.

Literature review

Establishing Vegetation Along Urban Highways: Benefits, Challenges and Opportunities

As the public grows more concerned about climate change and sustainability, many municipalities have been looking for practical and cost-effective ways to reduce their environmental impact. One way they can meet their goals is establishing roadside plantings along major roadways. Roadside plantings not only provide aesthetic benefits to an area, but also benefit the surrounding ecosystems (Singh et al., 1995). Unfortunately, roadside environments present several challenges to plant establishment, such as pollution, poor soil quality and other environmental stresses (Mills et al., 2020). These barriers to establishment may discourage municipalities from dedicating funding to roadside planting projects. However, proper plant selection and site preparation can improve plant establishment and the longevity of roadside plantings (Barwise and Kumar, 2020; Bochet and García-Fayos, 2015). The requirements for plant selection and site preparation will vary by region, therefore many departments of transportation have created manuals that outline proper installation and design and maintenance for a given region. In this review I will review the benefits roadside plantings provide, discuss the challenges to the establishment roadside plantings, and discuss approaches to overcoming those challenges. This review will largely focus on examples from North America and Europe.

Benefits of Roadside Plants

Roadside plantings can improve biodiversity and provision of ecosystem services for humans who are present in an area. Pollinators and other urban wildlife benefit from the additional habitat and food sources that roadside plantings can provide (Hopwood, 2008; Way, 1977). The health of humans and wildlife also benefit from the reduction of polluted runoff and particulate matter that roadside plantings can provide. Finally, roadside plantings can require less maintenance than turf covered areas, saving both money and time (Bretzel et al., 2009; O'Sullivan et al., 2017). When compared to urban areas with shade trees, turf by itself required large amounts of water, and provided very little cooling benefit (Shashua-Bar et al., 2009).

Reduction of the Urban Heat Island Effect

Due to the large heat capacity and conductivity of common construction materials, like concrete or asphalt, urban areas are unable to dissipate heat effectively overnight. The poor heat dissipation combined with the effects of increased CO_2 and other human activity results in an urban heat island effect where urban areas have warmer surface temperatures than surrounding rural areas (Bornstein, 1968). The urban heat island has implications for human health, such as increased frequency and severity of heat waves that can result in heat stress (Tan et al., 2010). Fortunately, the urban heat island effect can be reduced by planting trees and shrubs in urban areas. In a study in Leicester UK, soil surface temperatures beneath urban tree and shrub plantings were 5.7 degrees cooler on average than areas with no plantings (Edmondson et al., 2016). Moderate canopy coverage over urban streets can also offset the heating effects of heavy vehicle traffic (Shashua-Bar and Hoffman, 2000).

Benefits to Wildlife

Urban plantings and urban roadside plantings can make developed areas more hospitable not only to humans, but also provide habitat for urban wildlife. Increased species and floral abundance led to increased bee abundance and species richness in urban plantings (Hopwood, 2008). In general, plants with large and abundant flowers were the most beneficial to generalist pollinators. However, many pollinators prefer specific flower structures and species. For example, hummingbirds prefer tubular shaped flowers like those found on *Salvia* (Wojcik and Buchmann, 2012). Butterflies, in contrast, need different plants depending on what part of their lifecycle they are in. Adult butterflies need various sources of nectar, while larvae need foliage to shelter from predators and for food (Wojcik and Buchmann, 2012). Because of this, plantings designed to increase pollinator populations should use a diverse selection of plants in order to appeal to as many pollinator species as possible.

Programs to increase pollinators along highways have been popular in various states in the US. In the late 1990's the Indiana Department of Transportation (INDOT) started their Hoosier Roadside Heritage Program, which incorporates native wildflowers into roadside plantings. This benefitted INDOT not only by reducing maintenance costs and time, but also by reducing the amount of herbicide applied to roadsides. Additionally, the wildflowers provided both food and habitat for pollinators and other wildlife (INDOT, n.d.). Reducing mowing and practicing passive habitat restoration creates useable habitat for wildlife (Wigginton and Meyerson, 2018). The Virginia Department of Transportation (VaDOT) began a similar program in 2015 called the Pollinator Habitat Program. This program focuses on creating "Pollinator

Waystations” in rest areas and parking lots. Through this program, VaDOT aims to reduce both mowing and erosion, while also providing habitat for wildlife (VaDOT, n.d.).

Pollution reduction

Ecosystems and humans alike can also benefit from the ability of roadside plantings to reduce or sequester pollutants from the surrounding environment. Urban and roadside plants have the potential to filter pollutants, especially those that are found in car exhaust. Both lead and sulfur dioxide are common pollutants from car exhaust that can be effectively mitigated by roadside plants (Singh et al., 1995). Morphological structures such as leaf hairs and foliage density affect the amount of particulate matter that leaves of various trees species can collect (Dzierzanowski and Gawronski, 2011). Dzierzanowski and Gawronski (2011) compared five tree species and found that silver birch (*Betula pendula*) had the highest level of particulate removal, removing 80 percent of particulates from the air. This mirrors the conclusions reached in a related study that focused on herbaceous plants, which found that particulate matter immobilization is dependent on both plant height and leaf traits (Weber et al., 2014). Plants that had a greater number of leaf hairs were the most effective at particulate matter immobilization, and the authors suggest that plants that are structurally diverse and have large leaf area would be the most effective in trapping pollutants (Weber et al., 2014). Weber et al. (2014) also postulate that because herbaceous vegetation is often closer to roadways than trees or shrubs it can maximize particulate matter absorption in a roadside planting.

Based on numerous studies confirming that roadside plantings can improve surrounding air quality, the Environmental Protection Agency (EPA) released a publication in 2016 recommending the creation of roadside plantings that improve air quality. The EPA recommends plants with hairy leaf surfaces and increased surface area. However, the EPA goes further and considers both seasonal effects and a plant’s tolerance for urban conditions. For maximum air quality improvement, the EPA recommends planting coniferous or evergreen plants that are tolerant of urban environments (Balduf, 2016). This bulletin also recognizes that roadside plantings can benefit an area by reducing noise and mitigating runoff.

Roadside Plantings Increase Safety

As stated before, many DOTs have replaced turf covered areas with more diverse plantings to reduce maintenance costs and time. Reducing the amount of time an employee is mowing along roadsides may also reduce related accidents and traffic. In addition, roadside plantings may help to encourage safer driving. Varied landscapes help keep drivers alert compared to more homogeneous ones (AASHTO, 1991; Antonson et al., 2009; Nelson, 1997). Antonson et al. (2009) found that semi-forested areas have a positive effect on drivers’ safety, and postulate that roadside plantings could help make roads safer by influencing drivers to steer in a certain direction. Using plants to signal a change in road direction is a technique that is endorsed by the American Association of Highway and Transportation Officials (AASHTO, 1991). AASHTO (1991) also recommends the use of dense roadside plants to reduce headlight glare and drift from snow or sand, mitigating those hazards from roadways.

Furthermore, Mok et al. (2006) found that while there is no clear cause, sites with managed roadside landscapes had significantly reduced crash rates when compared to sites that did not have managed landscapes. It is possible that the improved landscapes decreased stress of those driving by the site as viewing greenery and natural features can calm the viewer and reduce stress (Parsons et al., 1998). Parsons et al. (1998) exposed subjects to a mild stressor and then showed videos of different driving routes from the perspective of a car passenger, all with varying roadside environments. Subjects that viewed the videos from more vegetated environments had lower blood pressure, and other somatic factors that indicated these subjects were significantly more relaxed than those who viewed the videos of other environments (Bary et al., 2002).

Challenges to establishing roadside vegetation

While roadside plantings provide ecosystem services and improve aesthetics and driver well-being and safety, roadsides are not ideal environments for plants to grow. As a result, the use of diverse plantings along urban highways and roadways is still relatively rare. Roadside plantings are subjected to pollution, compacted and degraded soils, and reflected heat; all of which negatively affect establishment and growth of plants.

Roadside and Urban Climates

The water and energy balances of urban areas are different than natural environments due to the presence of built terrain and other human activity (Gebert et al., 2019; Oke, 1982). Although roadside plantings help to mitigate this urban heat island effect, these altered microclimates are a source of stress for plants (Czaja et al., 2020; Gillner et al., 2014; Kjelgren and Clark, 1992a). The presence of buildings and other built features along roadways create urban canyons, which cause altered wind and airflow patterns (Hunter et al., 1990; Nakamura and Oke, 1988). Wind that skims over the top of a canyon perpendicular to the roadway can cause air to form a vortex within the canyon, pulling air from the ground to the top of the buildings (Hunter et al., 1990; Oke, 1988). The orientation of these canyons influences the microclimate within the canyon. Urban canyons that run in a North-South or Northeast-Southwest direction are have been observed to be cooler than those that run East-West or Northwest-Southeast (Zaki et al., 2020). Plants in these canyons, particularly those that run north to south, often receive limited amounts of solar radiation throughout the day due to shadows from buildings (Gebert et al., 2019; Kjelgren and Clark, 1992a). This limited sunlight results in shade acclimation responses in street trees planted in these urban canyons (Kjelgren and Clark, 1992a). Shade intolerant plants such as *Liquidambar styraciflua* can become chronically stressed from this limitation of sunlight (Kjelgren and Clark, 1992b). Increased temperatures and evaporative demand has also been observed in urban canyons when compared to other urban and rural sites (Gebert et al., 2019).

As discussed before, the urban heat island effect causes urban areas to be warmer than more rural areas (Bornstein, 1968). When compared to a vegetated lawn, soil temperatures beneath asphalt can be up to 16 ^{o}C higher (Celestian and Martin, 2004). Consistent high soil temperatures negatively affect a plant's photosynthetic process and the water content in leaves (Nóia Júnior et al., 2018). Higher air temperatures and decreased relative humidity that result from the urban heat island effect affect plants as well. Elevated temperatures increase the rate of respiration in plants and can be linked with higher carbon dioxide emissions (Czaja et al., 2020; Reich et al., 2016). The urban heat island effect also results in a lower relative humidity in the affected areas and therefore an increased vapor pressure deficit (Wang et al., 2011). This vapor pressure deficit causes an increase in transpiration rate and negative effects on plant growth (Wang et al., 2020). Micro-climatic factors can also interact with pollutants in urban areas, causing more deleterious effects on plant growth (Wang et al., 2011, 2020).

Heavy Metals and Particulate Matter

Vehicle emissions and wear from vehicle components can release heavy metals and particulate matter in the surrounding environment (Thorpe and Harrison, 2008; Thorpe et al., 2007). Particulate matter released from vehicle wear accumulates in roadside environments, and can become re-suspended in the air in high traffic areas (Handler et al., 2008; Thorpe and Harrison, 2008). Vehicle emissions can contain heavy metals such as cadmium, chromium, copper, lead, and zinc, which can build up in soil near roadways and on the surface of plant tissue (Handler et al., 2008; Ndiokwere, 1984; Thorpe and Harrison, 2008). Vehicle emissions also contain sulfates, ammonium, and nitrates (Fraser et al., 1998). Pollutants from vehicle wear usually come from brakes and tires in the form of particulate matter (Thorpe and Harrison, 2008). This particulate matter also contains heavy metals and also can contain man-made materials such as rubber (Thorpe and Harrison, 2008). Accumulation of these pollutants in roadside environments can have negative effects on roadside plantings.

While some heavy metals, like iron or copper, are essential for plant life, excessive concentrations are damaging to plants. Other heavy metals, such as lead, only have negative effects on plant life (Nagajyoti et al., 2010). Heavy metal concentrations in plants are highest when plants are close to the source of contamination, such as roadsides (Khalid et al., 2018; Nagajyoti et al., 2010; Ndiokwere, 1984). Vegetables grown in high traffic areas of Berlin had higher concentrations of trace metals, such as cadmium, lead, nickel and chromium than vegetables grown in other areas (Säumel et al., 2012). Säumel et al. (2012) also found that stem and root vegetables had the highest metal concentrations compared to other types of vegetables. Over 50% of the produce sampled by Säumel et al. exceeded the EU standards for lead concentration in food crops, meaning the vegetables were not considered safe for consumption. Certain concentrations of heavy metals can prevent nutrient uptake by damaging root tips, as well as interrupt metabolic processes and growth (Balsberg-Påhlsson, 1989; Sanità Di Toppi and Gabbrielli, 1999).

In addition to pollutants in the soil, roadside plantings can be affected by particulate matter that is distributed through the air. As discussed before, roadside plants have been shown to be effective in collecting particulate matter that could be hazardous to human health. However, the process of intercepting particulate matter can result in deleterious effects on plants like abrasion and radiative heating (Grantz et al., 2003). In addition, particulate matter can negatively affect photosynthetic rates by clogging the stomata on leaves (Popek et al., 2018). Because of this issue, Popek et al. (2018) recommend that species that are sensitive to particulates should be planted further from emission sources (Popek et al., 2018). In practice, this would result in the use of plants that are tolerant of air pollution and other urban conditions.

Urban Soils

Degradation of urban soil can impede establishment of roadside plantings in urban areas. Human activity is the primary cause of the degradation of urban soils (Craul, 1985). During urbanization and construction, topsoil is often removed and stockpiled, and different soils or layers of the soils can be mixed together causing soil structure to be lost or modified (Craul, 1985; Scharenbroch et al., 2005). The loss of soil structure can lead to compaction and erosion (Craul, 1985). Because of this degradation, urban soils can contribute to the urban heat island effect, and decreased storm water mitigation (Craul, 1985; Pavao-Zuckerman, 2008; Scharenbroch et al., 2005). Increased soil bulk density, decreased organic matter, and exposed sub-soil layers that result from urbanization can promote the establishment of invasive species, which can make ecological restoration difficult (Pavao-Zuckerman, 2008). Haan et al. (2012) examined survival of native plants along roadsides near Ann Arbor, Michigan. When examining the factors that caused mortality, they found that some clay soils at their study sites had bulk densities of 1.5 g/cm^3 (Haan et al., 2012). Bulk densities between 1.40 and 1.65 g/cm^3 restrict the root growth of woody plants (Alberty et al., 1984; McGrath and Henry, 2015). Soil compaction also reduces soil porosity, which decreases the amount of available soil water and air (Jim and Ng, 2018).

Haan et al. (2012) and Mills et al. (2020) reported that soils on their study sites were much more alkaline than non-roadside soils in the region. Craul and Klein (1980) found that soil samples taken from roadsides had pH values that were at the upper limit of the pH range of undisturbed soils in Syracuse, NY. Urban soils commonly have higher pH values than their undeveloped counterparts, most likely because the release of calcium from construction materials and deicing agents (Craul, 1985; Craul and Klein, 1980). Soil pH values of 7 or greater cause soil nutrients such as nitrogen, phosphorus, manganese and iron to be less available to plants, which could cause nutrient deficiencies (Fernández and Hoeft, 2009).

Creating Successful Roadside Plantings

Hopkinson et al. (2016) suggests that challenges related to establishment are mainly related to site preparation. The combination of particulate matter pollution and poor soil quality can result in poor survival and establishment of roadside plantings. The proper establishment of plants is critical to the long term success of a roadside plantings (AASHTO, 1991). To mitigate the effects of urban roadside environments and improve plant establishment, the principal tools available to designers and contractors include site preparation, irrigation and plant selection. Appropriate plant selection, plant handling, site preparation, and maintenance can improve establishment of trees and shrubs along roadsides (Kuhns et al. 2004; McGrath, 2016). Because of varying climates and conditions across the country, there is a need for regionally specific guidelines for the creation of roadside plantings.

Site Preparation via Tillage

In order to improve the establishments of root systems of roadside plants, the soil at the site must be loose enough to allow for root penetration (Alberty et al., 1984; Kuhns et al., 2004; McGrath and Henry, 2015). Because of the prevalence of compacted soils in urban and roadside environments, loosening the soil in roadside plantings site via tillage has become a prevalent site preparation technique. A bulletin from Penn State University concerning tree and shrub plantings along roadsides recommends that the soil at a site be loosened as deeply and in as large of an area as possible (Kuhns et al., 2004). If only small areas are tilled, root growth could stop at the untilled areas, leading to plants becoming root bound (Jim and Ng, 2018). The water infiltration rate of urban soil is significantly increased by tillage (Mohammadshirazi et al., 2017). Tilling the soil also has the benefit of incorporating organic matter or other amendments to the soil, further improving the quality of soils at the site.

Although tillage is often recommended for roadside plantings, as noted above, the effects of tillage are not consistent. Rivers et al. (2021) reported that tillage alone did not increase infiltration rate, and that tillage did not reduce stormwater runoff from roadsides. Additionally, vegetation cover was negatively affected by tillage (Rivers et al., 2021). Bary et al. (2016) observed that incorporating organic amendment by tilling into the soil did not improve plant survival or growth, implying that surface application of organic material was sufficient.

Site Preparation via Compost

One of the most common site preparation techniques is the addition of organic material to urban soils. Urban soils often have decreased organic matter content because the surface layers are often removed during construction (Craul, 1985; Pavao-Zuckerman, 2008). The amount of organic matter is often correlated with the amount of vegetation coverage in roadside plantings (Hopkinson et al., 2016). Low quality topsoil can be amended with organic materials to create a more ideal soil for most plants (AASHTO, 1991). Increasing soil organic matter can improve plant performance in several ways including reducing soil bulk density, increasing soil cation exchange capacity (CEC), increasing soil water holding capacity, and providing plant nutrients. The addition of compost significantly improved the growth of roadside trees in Ontario, Canada (McGrath and Henry, 2016). Improved tree growth was attributed to decreased soil bulk density in the treatments with compost amendments (McGrath and Henry, 2016). Incorporation of organic matter via tillage has been shown to reduce the bulk density and improve the water holding capacity within urban soils (Sax et al., 2017). However, incorporating compost into urban soil showed no significant plant growth benefit when compared to surface application of compost, suggesting a top dressing of compost is sufficient for plant success (Bary et al., 2016).

In addition to compost, amending soils with biosolids and biochar have been shown to increase tree growth and tree biomass (Scharenbroch et al., 2013). Organic amendments can also improve both soil and plant nutrition in roadside plantings. A turf-based study tested the effectiveness of using yard compost and biosolids as soil amendments in roadside environments. Sites treated with both organic amendments had increased amounts of soil nitrogen and phosphorus than those without (Brown and Gorres, 2011). Brown and Gorres also observed that overall, the turf in those same treatments had increased ground cover and height compared to the control treatment (Brown and Gorres, 2011). The authors inferred that the turf responded positively to the increased amount of nutrients in the soil. The Minnesota Department of Transportation (MnDOT) recommends the use of compost in roadside plantings citing benefits such as salt alleviation, enhanced growing environment and wildlife mitigation (Johnson, 2008). The benefits associated with organic amendments are often dependent on the amount organic material added to urban soils. Recommended application rates vary between crops and location (Cogger, 2005). Exaggerated application of compost could result in a soil becoming waterlogged, settling significantly, and accumulating salt (Cogger, 2005). McGrath et al. (2020) found that roadside trees had the greatest increase in height when the topsoil at the planting site contained 25% compost by volume and trees did not benefit from higher additions.

Organic amendments come in many different forms and can have different plant available nutrients. Simply adding straw can greatly increase the amount of available carbon, and add some available nitrogen to the soil (Siedt et al., 2021). Like straw, biochar can add some plant available nitrogen to the soil, but has a very low amount of available carbon (Siedt et al., 2021). Compost adds both nitrogen and carbon to a soil, but the nitrogen is released slowly over time (Nelson, 1997; Siedt et al., 2021). While the nutrient availability of compost can be lower than other fertilizers, it can release nutrients over a long period of time (Cogger, 2005). To know more about the quality of a compost, Bary et al. (2002) recommends that the carbon to nitrogen ratio, electrical conductivity, NH_4 content, NO_3 content, moisture content, and organic matter content be analyzed. These factors give insight into a compost's stability, nutrition content and nutrient availability (Bary et al., 2002). Stable compost is often thought of as compost with low amounts of plant available organic matter, which slows microbial activity and therefore slows the decomposition of compost (Hue and Liu, 1995). Compost age or maturity often determines its suitability for use and is often closely related to stability (Cooperband et al., 2003; Hue and Liu, 1995). While there is no specific measure to determine what makes a compost mature, older composts generally released lower amounts of carbon and nitrogen into stormwater runoff, implying that these nutrients were immobilized (Al-Bataina et al., 2016). Cooperband et al (2003) determined that individual measures of compost stability or maturity were not correlated with plant growth, however pH changes over time and NO_3-N/CO_2-C ratios could be. Higher ratios were associated with nitrogen and carbon mineralization and plant nutrient uptake (Cooperband et al., 2003).

Compost quality can be an important consideration in municipal projects as many state agencies have specific quality specifications for compost (Brinton, 2000). European countries have more comprehensive guidelines and certifications related to compost quality (Brinton, 2000) than the U.S. These guidelines often contain specifications related to a compost's composition, heavy metal content, maturity, and concentration of other potentially hazardous materials (Brinton, 2000). Potentially hazardous materials that could be contained in compost are weeds, weed seeds, pesticides and herbicides (Brinton, 2000; Cogger and Sullivan, 2009). All of these materials could have an effect on plant growth (Brinton, 2000).

Irrigation Considerations

In addition to organic amendments and tillage, installing irrigation can be a consideration during the creation of roadside plantings. In a Florida study, irrigating palm trees via a permanent drip system improved tree establishment, however the presence of irrigation had no significant effect on the establishment of other types of trees (Blair et al., 2019). Relatively few studies have considered the effectiveness of long-term irrigation on roadside plant establishment, possibly because of the added installation and maintenance expenses irrigation would bring to a project. While proper irrigation is important during initial establishment, temporary irrigation techniques, like irrigation bags, are often sufficient (Kuhns et al., 2004). If permanent irrigation systems are necessary, they should be designed to be easily maintained and minimize water spraying on the roadway (AASHTO, 1991).

Plant Selection

Even with improvements to the site, plants selected for roadsides need to be tolerant of urban conditions, adapted to the local climate, and fit in with municipal maintenance plans. Because of the varied climates across the United States, the best way to determine what plants are appropriate for a site is to examine the plant life in natural areas that have similar topography, soils, and climate (AASHTO, 1991). While the plant selection process is complex, landscape architects are mainly influenced by cost of plants, the amount of maintenance a plant requires, and the overall structure of a plant when selecting plants for roadsides (Guneroglu et al., 2019). In their recent roadside planting manuals, the Florida Department of Transportation has begun to implement a “right plant in right place” philosophy (FDOT, 2014). The manuals of several other states, such as Minnesota, Washington and Texas mirror this (Jones et al., 2007). Other states, like New York and Massachusetts, have goals to improve their sustainability by designing low input and low maintenance roadside plantings (Jones et al., 2007). These goals affect the plant selections for projects in these areas.

Selecting Plants Based on Urban Stressors

Many roadside planting manuals have begun incorporating “natural landscaping”, which can refer to the practice of using native plants or natural materials into the designs of roadside plantings, and minimizing the amount of fertilizing, watering, weeding and mowing done after planting (Jones et al., 2007). Reducing the number of inputs to roadside landscapes often results in increased exposure from adverse environmental conditions, such as drought and low nutrient availability. Selecting plants that are tolerant of these stresses can improve the success of a roadside planting project.

A plant’s native habitat can be indicative of its tolerances and success on roadsides. A study in Freising, Germany evaluated the growth of six different tree species under drought conditions designed to resemble roadside conditions. Some of the trees selected were considered to be “low-resource” because they originate from drier climates, including *Acer campestre*, *Ostrya carpinifolia,* and *Tilia tomentosa* ‘Brabant’. These “low resource” species used water more conservatively in drought conditions, and had higher growth rates than plants from wetter climates (Stratópoulos et al., 2018).

Plant selection Based on Project Goals

Certain plant morphological structures can be selected based on the goals of a roadside planting project. If reduced maintenance is desired, plant architecture and morphology that is conducive to covering and shading the ground, such as dense foliage or creeping habit, helps to reduce the need for weed control and reduces the amount of weeds in an area over time (Eom et al., 2005; Weston and Eom, 2008). *Alchemilla mollis, Nepeta* x *faassenii*, *Phlox subulata*, and *Solidago sphacelate* suppressed weed growth in managed and un-managed plots (Eom et al., 2005). Some groundcovers, like *Nepeta* x *faassenii* emit allelopathic chemicals that inhibit weed growth (Weston and Eom, 2008).

Some projects may be more focused on the cooling effects roadside plantings provide, which can be dependent on plant morphology and the location of plantings (Morakinyo et al., 2020; Tan et al., 2010). Dense plantings of trees that produce large amounts of shade are often the most effective in cooling urban areas (Tan et al., 2010). However, this effect may be dependent on the surrounding environment. Urban canyons with low amounts of shading from buildings received the most cooling benefit from trees that had high foliage density and shorter trunks (Morakinyo et al., 2020). In contrast, sites that received greater amounts of shade from surrounding buildings received the most cooling benefit from taller trees with moderate foliage density (Morakinyo et al., 2020). Projects that focus on cooling need to also consider the availability of water at their proposed site. Plants that have better water use efficiency and drought tolerance may have less of a cooling effect due to lower transpiration rates (Stratópoulos et al., 2018).

Other projects may be more focused on pollution mitigation. Plants with thick epicuticular wax, dense foliage and leaf hairs are often more efficient in capturing airborne particulate matter (Dzierzanowski and Gawronski, 2011). Having a diverse plant pallet that contains a variety of species, plant architectures and morphologies allows for a wide range of particulate matter to be captured (Weber et al., 2014). Stormwater treatment can be another possible project focus, which relies heavily on selecting resilient plants that are efficient in removing nitrogen and phosphorus from runoff (Read et al., 2009). Plants that have high biomass, extensive root systems and rapid growth rate are the most effective in removing nutrients from runoff (Payne et al., 2018).

Conclusions

Roadside plantings have numerous benefits to the urban landscape, including filtering out airborne particulate matter, providing habitat to urban wildlife, and dissipation of the urban heat island effect. There is even evidence that well landscaped roadsides can reduce crash rates, possibly due to reduced driver stress. Incorporating low maintenance plantings can also reduce maintenance costs when compared to turf plantings due to the reduced need for mowing. Unfortunately, establishing roadside plants can be challenging because of the effects of poor urban soils and pollution, which can cause municipalities to be hesitant to fund these projects. Proper site preparation and plant selection can drastically improve the success of these roadside plantings. The addition of compost can improve soil nutrition and reduce the bulk density of urban soils, which allows for better root growth and improved plant nutrition. The bulk density of urban soils can further be reduced by tillage. When selecting plants for roadside sites one should not only consider the local climate, but also a plant’s tolerance for urban conditions and pollution. Incorporating proper plant selection and site preparation into municipal planting manuals may result in better outcomes for future roadside planting projects.

Methodology

Location

Site description

The study was installed on two sites along Interstate 696 (I-696), also known as the Walter P. Reuther Freeway, an east-west running highway located near Detroit, Michigan, USA. Two sloped roadsides along I-696 were selected for this experiment (Figure 1). The first site was located in Roseville, Michigan, near I-696 exit 28 and a residential neighborhood (Figure 2). The research blocks at this site are on a south facing slope situated between westbound I-696 and westbound East Eleven Mile Road and were installed in October of 2018. In 2020, the annual average daily traffic (AADT) at this site was 41,022 vehicles travelling west (lanes closest to study site). In 2019, the westbound AADT was 51,324 vehicles. The second site was located in Warren, Michigan near I-696 exit 24, retail shops, and other commercial buildings (Figure 3). The research blocks at this site are on a north facing slope situated between westbound I-696 and westbound East Eleven Mile Road were installed in June 2018. In 2020, the AADT at this location was 52,582 vehicles travelling east. In 2019, the eastbound AADT was 62,227 vehicles. These two locations are approximately 5 km apart and both locations were the sites of failed plantings from the initial I-696 project. On average, the soil within 6 in of the surface at these sites consisted of 33.10% sand, 31.35% silt and 38.27% clay (clay loam texture). The average soil pH was 8.2, and the average soil bulk density was 1.58 g/cm^3. Each block had a slope between 30 to 40%.

Climate

The study area is within USDA plant hardiness zone 6B (mean annual minimum temperature –5 to 0 ^{o}F). The metro Detroit area has warm summers and cool winters, but extreme heat or cold weather is uncommon due to the proximity of the Great Lakes. The mean daily maximum temperature at the Coleman A. Young airport (located approximately 5.8 mi from the Warren site) between 1981 and 2010 was 57.9 ^{o}F, the mean daily minimum temperature during this period was 42.8 ^{o}F (Table 1). The average yearly precipitation between 1981 and 2010 was 31.3 in.

Experimental Design

This study was installed as a split-plot in a randomized complete block design with site preparation treatment (site prep) as the main plot factor and plant selection as the sub-plot factor (Figure 4).

Main plot: Site Prep

We installed three complete blocks with four main plots within each block at each location. Each main plot measured 20 ft wide and 56 feet long. We randomly assigned one of four site preparation treatments to each main plot: control, compost only, tillage only, and compost + tillage. Before construction of each block, existing plant material, mulch and compost were cleared from the site down to mineral soil. Plots assigned to the *compost only* treatment were top-dressed with a 4 in deep layer of compost. Plots assigned the *tillage only* treatment were mechanically tilled to a 8 in depth using a rotary tiller attached to a skid-steer tractor. Plots assigned the *compost + tillage* had a 4 in deep layer of compost applied, which was then mechanically tilled into the soil to a 8 in depth. All plots were subsequently top-dressed with a top layer of 3 in of twice-ground hardwood mulch (TDE Enterprises Inc., Commerce Township, Michigan). Compost consisted of composted municipal yard waste (C:N ratio = 8:1, %K=0.88, %P=0.2) (Advanced Disposal, Northville, Michigan).

Sub-plot: Plant Selection

Each main plot was divided into 16 sub-plots (Figure 5). The subplots were arranged in two rows with larger sub-plots located at the top of the slope measuring 8 ft wide and 12 ft long, and contained 6 individual plants each (Figure 6). Smaller sub-plots were located at the bottom of each main plot and measured 8 ft by 6 ft, and contained 9 plants (Figures 6-8).

Within each sub-plot, contract crews planted one of 16 selections of ornamental plants; these included 7 shrubs, 5 herbaceous perennials and 4 ornamental grasses (Table 2). All plants were obtained from commercial nurseries in the area and arrived in #3 (3 gal) or #1 (1 gal) nursery containers. The *Baptisia*, *Cephalanthus*, *Cornus, Diervilla*, and *Physocarpus* selections were planted in the larger 8 ft by 12 ft sub-plots. All other plant selections were planted in the smaller 8 ft by 6 ft subplots

Plant Evaluation Study

Proximate to each block, one additional plant evaluation plot was constructed to allow evaluation of additional plant selections without replicating the entire site preparation study. These evaluation plots were the same size and layout of the main plots and contain 16 additional plant selections. Within each evaluation plot, contract crews planted 16 selections of ornamental plants; this included 7 shrubs, 6 herbaceous perennials and 3 ornamental grasses (Table 3). All plants were obtained from commercial nurseries in the area and arrived in #3 (11.4 L) and #1 (3.8 L) nursery containers. The *Baptisia*, *Cotoneaster*, *Deutzia* 'NCDX2'*, Diervilla*, and *Physocarpus* selections were planted in the larger 8 ft by 12 ft sub-plots. All other plant selections were planted in the smaller 8 ft by 6 ft subplots

Site Management

Weed Control

To reduce competition from weeds, each planting site was treated with a pre-emergent herbicide (Snapshot 2.5 TG Dow Agrosciences, Indianapolis, IN) at 100 lb/acre after compost application and before mulching according to MDOT 2012 Standard Specifications for Construction. This application was repeated in the spring of 2019. We were unable to apply pre-emergent herbicide in spring 2020 due Covid-19 travel restrictions. During the growing seasons, weeds were removed from each site by hand or by spray application of glyphosate (Prosecutor, Lesco, INC. Cleveland, OH) as a 2% a.i. solution.

Environmental Monitoring

Initial monitoring

After initial construction, a rain gauge (All-Weather Rain Gauge, Productive Alternatives, Fergus Falls, Mn) was installed on a 5 ft tall post on the top of the slope in block five at the Warren location. We also installed a tipping bucket rain gauge and temperature sensor (Hobo RG3, Onset, Inc. Bourne MA) in this location. Near the roadside, a weatherproof temperature and relative humidity data logger (HOBO Pro V2, Onset, Inc., Bourne, MA) was installed.

MSU Enviroweather Station

During the summer of 2020 we installed two weather stations with the assistance of the MSU Enviroweather Team. One station was installed close to block one at the Roseville location approximately 15 feet from the roadside. The other station was installed between blocks five and six at the Warren location approximately 15 feet from the roadside. Each station was outfitted with a wind sentry set (model 03002-L, Campbell Scientific, Logan, UT), solar radiation sensor (model LI200x, LI-COR INC. 4647 Lincoln, NE), HygroVUE10 Temp/Rh sensor (model HygroVUE10, Campbell Scientific, Logan, UT), metric rain gauge (model TE525MM-L, Campbell Scientific, Logan, UT) and datalogger (model CR1000, Campbell Scientific, Logan, UT). In addition, each station was outfitted with four soil moisture sensors (model CS616, Campbell Scientific, Logan, UT) and four thermocouple probes (model 105T, Campbell Scientific, Logan, UT). At each location, soil moisture sensors and thermocouples were installed at 6 in and 12 in depths at locations within a research block and under the weather station. Soil temperature, soil moisture, solar radiation, air temperature, relative humidity, and total precipitation were logged every hour. Wind speed and temperature were logged every five seconds.

Plant Evaluation

Growth and Mortality

In 2019 we measured plant heights and plant widths in two perpendicular directions on all plants in June, July and October with a meter stick. Plant survival was also noted during this time. In August 2020 we measured plant height only as the crown of many plants had begun to overlap, making width determination impractical. We also assessed mortality and plant cover at this time. Plant cover was evaluated by visual estimation of percentage of plant cover within each sub-plot. Within a block, the same observer estimated plant cover.

Plant Nutrition

Foliar nutrition samples were collected from mature leaves on the upper third of each plant on a subsample of plant selections in the 2019 and 2020 growing seasons between June and July of each year. Within each main plot, we collected foliar samples from Artic Sun® Red Twig Dogwood*,* Summer Wine® Ninebark, Show Off® Starlet Forsythia, Kodiak® Black Diervilla, Red Switch Grass, 'Happy Returns' Daylily, Bronze Veil Tufted Hair Grass. Due to resource limitations foliar samples were collected on a subsample of block 2 and 5 only for Six Hills Giant Nepeta, Halfway to Arkansas Narrow Leaf Blue Star, Slender Deutzia, Little Blue Stem, Sugar Shack® Buttonbush, Dwarf Bush Honeysuckle. Foliar samples were collected from all selections within the plant evaluation plots (Table 3) and pooled together by selection. All foliar samples were dried in an oven and sent to a commercial analytical laboratory (Waters Agricultural Lab, Camilla, GA) and were analyzed for nitrogen, phosphorus, potassium, magnesium, calcium, sulfur, boron, zinc, manganese, iron and copper concentration via inductively coupled plasma analysis.

Photosynthetic Gas Exchange

We measured photosynthesis and stomatal conductance on a sub-sample of selections in the Site Prep plots (Artic Sun® Red Twig Dogwood*,* Summer Wine® Ninebark , Sugar Shack® Buttonbush, 'Happy Returns' Daylily, and Red Switch Grass) using a portable photosynthesis system (LI-6400XT LI-COR INC, Lincoln, Nebraska USA). Four plants per sub-plot were measured in July and August of 2019 and 2020. We measured one fully expanded leaf in the upper third of the crown from each plant. These measurements were taken between 10 am and 2 pm. The settings for the portable photosynthesis system included 400 ppm CO_2 as the reference CO_2 and 1500 µmol PPFD. The measurements in 2019 occurred between 3 July and 11 July, and between 8 August and 20 August. In 2020 these measurements occurred between 7 July and July 14, and 5 August and 12 August. Stability of gas exchange readings was assessed by tracking photosynthetic rate, stomatal conductance and total CV using the Li-6400’s real-time graphing feature. Readings were logged when net photosynthesis and conductance appeared stable and total CV was less than 5%, which was usually achieved within 1.0–1.5 min of placing leaves in the chamber.

Chlorophyll Content Index

Chlorophyll content index of Artic Sun® Red Twig Dogwood, Show Off® Starlet Forsythia, Summer Wine® Ninebark, Kodiak® Black Diervilla, Red Switch Grass, Halfway to Arkansas Narrow Leaf Blue Star, 'Happy Returns' Daylily and Bronze Veil Tufted Hair Grass were measured with a Chlorophyll meter (SPAD-502, Konica Minolta Sensing Americas, Inc, Ramsey, NJ). Six plants per subplot were measured in July and August of 2019, and in July of 2020. One fully expanded leaf from the upper crown of each was measured.

Leaf Water Potential

Mid-day Leaf water potential (Ψ_l) of Summer Wine® Ninebark and Sugar Shack® Buttonbush was measured using a portable pressure chamber (Model 1000, PMS Instrument Company, Albany, OR). The measurements in 2019 occurred between 3 July and 11 July, and between 8 August 8 and 20 August. In 2020 these measurements occurred between 7 July and 14 July, and 5 August and 12 August. This data was collected between 10:00 and 14:00 h. Within each sub-plot, three mature leaves were selected randomly from three different plants. Water potential sampling was limited to two selections due to time and logistical constraints. We did not collect pre-dawn water potential readings due to safety considerations of working in darkness on steep slopes near the freeway roadside.

Soil Evaluation

During each growing season soil samples were collected in each main plot and evaluation plot. Before collection, mulch and compost top-dressing were removed from each sampling area. Using a soil sample probe we took 5 to 7 samples from various locations within each plot at approximately 6 in depth. Samples from each plot were combined, dried in an oven to a constant weight, and sent to a commercial analytical laboratory for nutrient analysis (Waters Agricultural Lab, Camilla, GA). Samples were analyzed for available phosphorus, exchangeable potassium, magnesium, calcium, zinc, manganese, iron, copper, and boron, soil pH, Cation Exchange Capacity (CEC), and Percent Base Saturation of cation elements. Elements were extracted by the Mehlich-3 extraction method and analyzed via inductively coupled plasma analysis. In addition to this, bulk density samples were taken in both 2019 and 2020 using a 8.7 in^3 bulk density ring. Before sampling, mulch was removed from the soil surface. In July of both years, one bulk density sample was collected from the soil surface of each main plot. In 2019 an additional sample was taken from each main plot 6 in below the soil surface. All bulk density samples were then dried in an oven and weighed.

Statistical Analysis

Data were analyzed using SAS version 9.4 software. PROC MIXED was used to conduct an analysis of variance (ANOVA) for all variables, and tested the effects of site location, compost, tillage. The main plot factors (compost and tillage) were analyzed as 2 × 2 factorial. Block and subplot effects were treated as random factors. Soil nutrition and bulk density were analyzed for main effects only. Plant coverage, and foliar nutrition were analyzed as sub-plot means. Plant growth, photosynthetic rate, chlorophyll content, and water potential were analyzed at the individual plant level. Means separation using Tukey's HSD was performed in the LSMEANS prompt of PROC MIXED.

Findings

Site Prep Experiment

Plant Coverage

Among main plot effects, compost affected plant coverage more than tillage. Compost treatments increased plant coverage for shrub ($p<0.05$) and perennial ($p<0.001$) groups (Table 3), whereas tillage did not affect cover for either plant group. Species x Compost interaction reflected increased coverage for *Cornus*, *Forsythia*, and *Diervilla* selections and *Amsonia*, *Chleone*, *Hemerocallis* and *Nepeta* selections in response to compost. (Figure 9). All other species had no observable effects that could be attributed to compost treatment. Differences in coverage between locations were observed in certain shrub ($p<0.05$) and perennial ($p<0.001$) species (Table 3). The *Cephalanthus*, *Cornus*, *Physocarpus,* and *Diervilla* selections all had greater plot coverage at the Warren site (Figure 10). Tillage had no effect on plant cover of most species, and did not have any interaction effects (Table 3). Sub-plots with *Diervilla lonicera* had less coverage in tilled treatments. Increases in coverage were observed for the *Deschampsia* and *Carex* selections in tillage treatments ($P<0.05$). *Cephalanthus*, *Physocarpus*, *Diervilla rivularis*, *Diervilla lonicera*, *Amsonia, Hemerocallis, Nepeta*, and *Panicum* had over 50% average plot cover in composted treatments.

Plant Growth

Compost increased overall plant height of both groups of plants in both 2020 ($P<0.05$) and 2019 ($P \leq 0.001$), however effects varied between species and years (Table 3). In both years, compost additon resulted in increased growth of *Cornus, Forsythia,* and both *Diervilla* selections ($P<0.05$) (Figure 11). Tillage did not increase average plant height or have any overall effect for most species in the shrub group in both years. The only observable effects tillage had on plant growth was decreased average height of *Baptisia* in 2019 ($P<0.05$) and increased average height in *Diervilla lonicera* in 2020 ($P<0.05$). As with the shrubs, compost increased overall plant height of grasses and perennials in both 2019 ($P<0.001$) and 2020 ($P<0.05$). Compost increased mean plant height of *Panicum*, *Nepeta*, *Hemerocallis* and *Chleone* in 2020 ($P<0.05$) when compared to those planted in non-compost treatments (Figure 12). Compost treatments increased the average heights of *Panicum*, *Schizachrium*, and *Chelone* in 2019 ($P \leq 0.05$). Tillage did not affect the overall growth of shrubs, perennials or grasses in either year. However, the average height of *Carex* in tillage treatments was greater in 2019 ($P \leq 0.05$). Location did not affect overall plant height in either year. The only plant selection affected by location was *Carex,* which was taller at the Warren location ($p<0.05$) in both years (Figure 13).

Plant Survival

Location affected survival of shrubs in 2019 (<0.05), but not in 2020 (Table 3). In general, shrubs in Roseville had a higher rate of survival than those in Warren. Compost by itself had no overall effects on the survival of shrubs in 2019, but in increased rates of survival ($p<0.05$) of shrubs in 2020 (Figure 13). Compost and location interactions were observed ($p<0.05$) in 2019 and 2020 (Table 3). However there does not seem to be a clear trend. *Baptisia* in Roseville had increased survival with no compost but decreased survival with compost in Warren (Figure 13). Similarly, *Forsythia* in non-composted treatments located in Warren had lower rates of survival ($p<0.05$) than those in either treatment in Roseville or those in composted treatments in Warren (Figure 13). Tillage negatively affected survival of Baptisia and *D. Lonicera*, but positively affected *forsythia*.

Compost generally had a positive effect on survival of perennials in 2019 ($p<0.001$), but did not affect survival in 2020 (Table 3). *Chelone* survival was greater in composted treatments in both years ($p<0.05$) (Figure 14). *Panicum* and *Deutzia* did not benefit from compost treatments, as their survival rates in compost treatments were lower in 2020 ($p<0.05$) (Figure 14). Plant survival in response to compost varied by location ($p<0.05$). In Warren, the first-year survival of *Nepeta* and *Chleone* in composted treatments was higher ($p<0.05$) than those without compost. *Carex* in non-composted treatments in Roseville had lower survival ($p<0.05$) than all other groups. Tillage had no overall effect by itself in perennial survival rates, but Deutzia in treatments with soil tillage had reduced ($p<0.05$) survival in 2019. Tillage and location interactions existed in 2019. When in tilled treatments, *Carex* had a much lower survival rate ($p<0.05$) in Roseville than in Warren in both years. *Carex* in untilled treatments had similar survival rates in both years. Location effects in 2019 were also seen in the perennial group ($p<0.001$) (Table 3). However, different species had higher rates of survival at different locations. *Carex* and *Deutzia* had increased overall survival in Warren ($p<0.05$), *Panicum, Chleone,* and *Schizachrium* had increased survival in Roseville ($p<0.05$) (Figure 15).

Foliar Nutrition

In both years, compost application increased foliar nitrogen, phosphorus, potassium, calcium and magnesium, regardless of tillage . In general, compost did not influence any other micronutrient concentrations. The only observed differences in micronutrients concentrations were for *Amsonia, Forsythia* and *Diervilla* selections. In 2019, compost treatments increased foliar Cu concentrations in *Forsythia* and *Diervilla* . *Amsonia* in compost treatments had decreased levels of Zn in 2020. Tillage decreased overall foliar iron content in 2020, these differences were significant ($p<0.05$) in *Hemerocallis*.

Chlorophyll Content

Overall, compost increased SPAD chlorophyll index (<0.001) in both years. In 2019, SPAD values from *Amsonia*, *Diervilla*, *Hemerocallis*, and *Panicum* were higher in compost treatments ($p<0.05$). There was an overall compost and tillage interaction in 2019. The addition of tillage treatment decreased chlorophyll content in *Diervilla* and *Hemerocallis* selections ($p<0.05$) even if these plants were treated with compost. Tillage and location effects were not significant in either year. In 2020, compost treatments increased the SPAD values of *Cornus*, *Diervilla*, *Hemerocallis*, *Forsythia*, *Panicum*, and *Physocarpus* ($P<0.05$).

Photosynthesis and Conductance

Site preparation treatments did not affect the photosynthetic rate of the *Cornus, Cephalanthus, Hemerocallis,* and *Physocarpus* selections in 2019. In July of 2020, *Cornus* and *Cephalanthus* selections showed lower rates of photosynthesis when in compost treatments. The photosynthetic rates of these two species were also affected by location, but exact effects varied by species. *Cephalanthus* plants in Warren had higher photosynthetic rates in August of 2020 while *Cornus* plants in Roseville had higher rates in July of 2020.

Water Potential

Compost and tillage did not affect ($p>0.05$) water potential (Ψ_l) in *Cephalanthus* plants. Compost treatment decreased midday Ψ_l in *Physocarpus*, however compost treatment did not have any other negative effects for this species (Figure 16). Location also affected midday Ψ_l of both species as plants in Warren had higher midday Ψ_l than plants in Roseville in both years ($P<0.05$) (Figure 17).

Soil Properties

Soils in the composted treatments had improved soil nutrition. Soils treated with compost had increased phosphorus and potassium in both 2019 ($P < 0.001$) and 2020 when compared to those that were not treated with compost (Table 4). In addition to this, compost reduced soil pH in both 2019 ($P<0.001$) and 2020 ($P<0.001$). Application of compost also increased other soil nutrients such as magnesium, boron, zinc, manganese, iron and copper (Table 4). Site preparation treatments did not affect calcium content of the soils at either site. Tillage had no effect on soil nutrient content.

Soil bulk density taken at the soil surface (0-6 in.) in 2019 was decreased in composted treatments and was not affected by tillage or location. Tillage, compost and location did not affect soil bulk density taken 6 in. below the soil surface. Soil bulk density taken at the surface decreased in all treatments in 2020, but was unaffected by compost, tillage or location. Compost application resulted in lower soil pH values in both years ($P<0.001$) . All site preparation treatments had lower pH in 2020 than in 2019 (Figure 18). Tillage had no effect on soil pH in either year. Compost treatments increased soil CEC in 2019 ($P<0.05$) and 2020 ($P<0.001$) (Figure 18). In 2020, tillage treatments decreased CEC when compared to untilled treatments ($P<0.05$), this effect was not seen in 2019.

Supplemental Plant Evaluation Experiment

Growth and Coverage

Data from the supplemental plant evaluation blocks were combined with those from the comparable treatment in the site preparation study (Compost + Tillage) in order to develop an overall evaluation of all selections studied. Survival of all eight ornamental grass species was lower in 2020 than in 2019 (Table 5). Only one grass species, *Panicum virgatum* 'Rostrahlbush', had greater than 60 percent plot coverage (Figure 19). Survival of perennials remained relatively steady between the two years (Table 5). The exception was *Deutzia gracilis* 'Nikko' as the average survival rate declined from 83 percent to 28 percent (Table 5). Perennials with 60% average coverage were Nepeta, *Amsonia hubrichtii*, *Hemerocallis* 'Stella de Oro' and *Hemerocallis* 'Happy Returns' (Figure 19). Shrub survival rates were high overall and similar between both years (Table 1.5). The shrub group had the most selections with 60% or greater coverage. These include *Diervilla sessilfolia* 'Butterfly', *Diervilla rivularis* 'Kodiak Black', *Diervilla rivularis* 'Kodiak Orange', *Physocarpus opulifoluis* 'Summer Wine', *Cephalanthus* and *Cotoneaster* (Figure 19).

The Urban Microclimate

Comparing North and South Aspects

Site differences soil moisture, soil temperature, solar radiation, and relative humidity between the two sites between August 2020 and February 2021 were relatively small. For most of this period, monthly precipitation totals were similar between the two sites. Between October and December 2020, the Warren site had warmer average air temperatures than Roseville. Additionally, overall wind direction trends matched up with traffic direction. The Warren site faces the eastbound lanes of I-696, and winds blowing east were observed most of the time. In contrast, the Roseville site faces the westbound lanes of I-696 and winds blowing west were observed a majority of the time.

Roadside climates vs non roadside climates

Monthly average (Figure 20) and maximum temperatures at the Warren site were most often higher than those at the Detroit city airport between July 2018 and February 2021. During the summer months, maximum extreme temperatures at the roadside were often higher than those observed at the airport.

Distance from the roadside

Temperatures at the top of the roadside slope and the roadside in Warren showed differences in temperature extremes during the fall and winter months. Minimum temperatures at the top of the slope were much cooler than those by the roadside. Maximum temperatures by the roadside remained consistently higher than temperatures at the top of the slope between September 2019 and February 2020.

Discussion

Proper site preparation and plant selection are two factors that are critical to successful plant establishment in roadside environments (Brown and Gorres, 2011; Mohammadshirazi et al., 2017; Weston and Eom, 2008). Often, urban soils are compacted and have little plant available nutrients (Craul, 1985). Past studies suggest application of compost improves soil nutrition, and can improve overall soil quality when incorporated into the soil which improves plant establishment and results in increased plant growth (Brown and Gorres, 2011; McGrath et al., 2020; Mohammadshirazi et al., 2017). Tilling roadside soils may reduce soil bulk density, allowing more water infiltration, increased stormwater capture and increased root growth (Alberty et al., 1984; Mohammadshirazi et al., 2017; Rivers et al., 2021). In our study, we hypothesized that both tillage and compost would improve plant establishment, and that when these two treatments were combined their effects would be additive. However, we observed that compost was the main factor that affected plant establishment and growth. Tillage and the interaction of compost and tillage had little to no effect on plant performance at this site.

Effects of Compost

Compost was beneficial to overall plant growth and plant coverage for both shrubs and perennials. We observed that plants that covered over 50% of the subplot often had little to no issues with weed competition. Increased ground coverage and dense canopies allows plants to out-compete weed species, which can reduce costs associated with weed control (Eom et al., 2005; Weston and Eom, 2008). McGrath and Henry (2016) attributed the success of plants in compost-amended soil to lowered soil bulk density. In 2019, we observed decreased soil surface bulk density in both the compost only, and compost and tillage treatments. However, compost application did not affect surface bulk density from 2020. Based on previous work, we hypothesized that compost would improve plant establishment by reducing plant moisture stress and improving soil nutrition. While we observed some increases in water stress in *Physocarpus opulifolius* 'Seward' that were planted in the compost treatments, this did not a ffect overall plant establishment, growth, or aesthetics. Increases in plant growth and plant coverage can most likely be attributed to the increased soil nutrition that resulted from compost application. Soils with compost contained more phosphorus, potassium, magnesium, boron, zinc, manganese, iron and copper than soils without compost. These increases in nutrients were reflected in foliar nutrition in both years. In addition, compost application resulted in lower soil pH, which allows more nutrients contained in the soil to become available to the plants (Fernández and Hoeft, 2009). The chlorophyll content analysis also provides evidence for improved foliar nutrition. Plants in compost treatments had higher SPAD values than those without.

While compost benefit was seen in this study, it is possible that the benefits can be maximized with proper application levels, techniques, and quality. The type and quality of organic amendments used in roadside plantings can also influence the nutritional benefit compost provides. Brown and Gorres (2011) found that turfgrass treated with biosolids created from treated sewage had increased ground coverage than turfgrass treated with compost made from municipal yard waste.

Effects of Tillage

Tillage did not influence overall plant survival, plant coverage or plant growth. When tillage effects existed in certain species, it was often negative. For example, *Diervilla lonicera* 'Michigan Sunset', *Duetzia gracillis* 'Nikko' and *Baptisia australis* had lower rates of survival when planted in tillage treatments than those in untilled treatments. *Carex pensylvanica* was the only species that benefited from tillage treatment. Incorporating compost into the soil via compost did not change any soil properties. Since there is no overall benefit, soil tillage cannot be recommended at this site at this time. Similar to our study, Bary et al. (2016) observed that while incroporating organic material into the soil reduced soil bulk density below the surface, there were not any signifigant benefits to plant survival.

While we did not see any benefit to incorporating compost with tillage, others have concluded that incorporation of compost into the soil via tillage reduces soil bulk density and reduces future soil compaction (Mohammadshirazi et al., 2017). Similar to our study, Mohammadshirazi et al. incorporated compost created from municipal yard waste with a rotary tiller. Mohammadshirazi et al (2017) observed that in roadside sites with sandy clay or clay loam soil, plots that were tilled to a 12 in depth and had compost incorporated into the soil had reduced bulk densities when compared to the plots that had received the tillage only or control treatments. These differences were observed for over two years. Different tillage methods have also produced long term benefits for soil and plant health. Siedt et al. (2021) observed long term improvements to urban soils using the scoop and dump method, where top 18 in of the soils were fractured and amended with compost using a backhoe. McGrath et al. (2020) tilled soil by deep ripping to a depth of 3 ft, which resulted in varying levels of benefits to plants depending on the amount of compost added. In that study, amending the soil with 25% compost by volume resulted in the most benefit for tree establishment and growth (McGrath et al., 2020). It is possible that a deeper tillage depth, alternate techniques, or incorporating greater amounts of compost could benefit our study site.

Soil type may also be a factor in the magnitude of tillage effects. The sites used in the study by Bary et al. (2016) had a gravelly sand texture and reduced bulk density reduction following tillage was observed to only 6 in. Mohammadshirazi et al (2017) did not see any differences between the soil bulk density of tilled an untilled treatments at their mountain site after 30 months. The mountain site had soil that was a silty clay loam texture.

Location Effects

Several shrub selections planted in the Warren site had greater ground coverage than those in Roseville. *Physocarpus opulifolus* also planted in Warren had decreased water stress. In addtion, *Carex pensylvanica* planted in Warren were taller on average than those planted in Roseville. There are a few reasons that could explain this phenomenon. Plants in Warren were on a north aspect, where as plants in Roseville were on a south aspect. The Warren location also had warmer monthly average temperatures than the Roseville location between October 2020 and December 2020. It is likely the difference in plant perfrmance between the two sites are at least in part a result of different planting times and location effects seen in this study are confounded with planting date. The research blocks in Warren were planted in June of 2018. Plants for the Roseville site remained in a temporary nursery site due to construction delays and were not planted until October of 2018. It is possible that since the Warren plants were planted earlier, they had more time to establish roots before the winter. The plants reserved for the Roseville site may have been subjected to more stress while in the containers than if they had been planted immediately.

Plant Selection

We evalauted plant coverage and survival for 32 plant selections in this study. Fifteen species had both high average rates of survival and high amounts of average plant coverage. Shrubs that were most successful in this study based on plant coverage and survival were *Physocarpus opulifolius* ‘Seward’, *Physocarpus opulifolius* ‘SMPOTW’, *Diervilla lonicera* ‘Copper’, Diervilla rivularis ’SMNDRSF’, *Diervilla* ‘G2X885411’, *Diervilla* ‘G2X88544’, *Diervilla sessilifolia* ‘Butterfly’, and *Cephalanthus occidentalis* ‘SMCOSS’. Perennials that were successful in this study were *Nepeta* x *faassenii* ‘Six Hills Giant’, *Hemerocallis* ‘Happy Returns’, *Hemerocallis* ‘Stella De Oro’, *Amsonia hubrichtii* ‘Halfway to Arkansas’, *Panicum virgatum* ‘Rotstrahlbush’, *Allium tanguticum* ‘Noneuq’*, Allium tanguticum* ‘Summer Beauty’. All the mentioned plant selections would be good choices for roadside plantings in Michigan.

Conclusions

Diverse roadside plantings improve air quality, provide habitat for pollinators and reduce the urban heat island effect (Baldauf, 2017; Barwise and Kumar, 2020; Hopwood, 2008; Shashua-Bar et al., 2009). The results of this study indicate that compost is more beneficial to plant establishment and growth than tillage. Based on these results, the optimum site preparation treatment is to apply a 4 in top-dress of compost, which is the current MDOT specification. For benefits to be observed, compost needs to be applied in proper amounts. Inspections of the original I-696 plantings revealed that compost had been applied to depths up to 12 in. Because of this observation, it is important that these plantings are inspected during and after construction to ensure that all plantings are meeting standards. Plant selection is another important factor in the success of roadside plantings. We observed that most of the shrubs in this study had high rates of survival and ground coverage. Perennials and ornamental grasses with dense foliage and a spreading habit were successful as well. Recommended plant selections and guidelines for the state of Michigan can be found in the MDOT Plant Selection Manual.

The results of this study open more research questions. Since most of the compost benefit appears to be a result of increased nutrition, it is possible that simply adding chemical fertilizer could provide similar benefits. Additionally, application of different organic amendments, like biosolids or biochar, could influence plant growth and establishment. The effect of slope aspect is also another topic that warrants further study. We did observe some location effects on plant ground cover, water stress, and air temperature, but since slope aspect was confounded with location and planting date, formal conclusions about slope aspect cannot be made.

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Appendix

Table 1. Plant selections planted in Site Preparation Experiment

Scientific name	Common name	Plant Type	Plants per subplot	Container size
Cephalanthus occidentalis 'SMCOSS'	Sugar Shack® Buttonbush	Shrub	6	#3
Cornus sanguinea 'Cato'	Artic Sun® Red Twig Dogwood	Shrub	6	#3
Deutzia gracilis 'Nikko'	Slender Deutzia	Shrub	9	#3
Diervilla lonicera 'Michigan Sunset’	Dwarf Bush Honeysuckle	Shrub	6	#3
Diervilla rivularis 'SMNDRF'	Kodiak® Black Diervilla	Shrub	6	#3
Forsythia x 'Minfor6'	Show Off® Starlet Forsythia	Shrub	6	#3
Physocarpus opulifolius 'Seward'	Summer Wine® Ninebark	Shrub	6	#3
Carex pensylvanica	Pennsylvania Sedge	Grass	9	#1
Deschampsia cespitosa 'Bronzeschleier'	Bronze Veil Tufted Hair Grass	Grass	9	#1
Panicum virgatum 'Rotstrahlbush'	Red Switch Grass	Grass	9	#1
Schizachyrium scoparium 'The Blues'	Little Blue Stem	Grass	9	#1
Baptisia australis	Blue False Indigo	Perennial	6	#1
Chelone lyonii 'Hotlips'	Hot Lips Turtle Head	Perennial	9	#1
Hemerocallis 'Happy Returns'	Happy Returns Daylily	Perennial	9	#1
Nepeta x *faassenii* 'Six Hills Giant'	Six Hills Giant Nepeta	Perennial	9	#1
Amsonia hubrichtii 'Halfway to Arkansas'	Halfway to Arkansas Narrow Leaf Blue Star	Perennial	9	#1

Table 2. Plant selections planted in plant evaluation experiment.

Scientific name	Common name	Plant Type	Plants per subplot	Container size
Cotoneaster dammeri 'Coral Beauty'	Bearberry Cotoneaster	Shrub	6	#3
Deutzia gracilis 'Duncan'	Chardonnay Pearls® Deutzia	Shrub	6	#3
Deutzia 'NCDX2'	Yuki Cherry Blossom® Deutzia	Shrub	6	#3
Diervilla sessilifolia ‘Butterfly’	Southern Bush-honeysuckle	Shrub	9	#3
Diervilla 'G288544'	Kodiak® Orange Diervilla	Shrub	6	#3
Diervilla 'G2X885411'	Kodiak® Red Diervilla	Shrub	6	#3
Physocarpus opulifolius 'SMPOTW'	Tiny Wine® Ninebark	Shrub	6	#3
Carex vulpinoidea	Fox Sedge	Grass	9	#1
Deschampsia cespitosa 'Goldstaub'	Goldstaub Tufted Hair Grass	Grass	9	#1
Panicum virgatum 'Shenandoah'	Shenandoah Switch Grass	Grass	9	#1
Schizachyrium scoparium 'Little Arrow'	Little Arrow® Little Blue Stem	Grass	9	#1
Allium tanguticum 'Balloon Bouquet'	Balloon Bouquet Ornamental Chive	Perennial	9	#1
Allium tanguticum 'Summer Beauty'	Summer Beauty Ornamental Chive	Perennial	9	#1
Baptisia ‘Solar Flare’	Solar Flare Prairieblues™ Indigo	Perennial	6	#1
Hemerocallis 'Stella de Oro'	Stella de Oro Daylily	Perennial	9	#1
Amsonia tabemontana	Blue Star	Perennial	9	#1

Table 3. Summary of analysis of variance (p values) for plant cover, survival and plant growth of shrubs, herbaceous perennials and grasses planted at two locations along an urban freeway near Detroit, MI.

Shrubs

		Cover	Plant survival		Total height	
Source	df	2020	2019	2020	2019	2020
Location (L)	1	<0.05	<0.05	ns	<0.05	<0.05
Compost (C)	1	<0.05	ns	<0.05	<0.001	<0.05
Tillage (T)	1	ns	ns	ns	ns	ns
C x T	1	ns	ns	ns	<0.05	ns
L x C	1	ns	<0.05	<0.05	ns	ns
L x C x T	1	ns	ns	ns	ns	ns
Species (S)	6	<0.001	<0.001	<0.001	<0.001	<0.001
S x C	6	<0.05	ns	ns	<0.001	<0.001
S x T	6	ns	ns	<0.05	<0.05	<0.001
L x S	6	<0.05	ns	ns	<0.001	<0.001
S x C x T	6	ns	ns	ns	ns	ns
L x C x S	6	ns	ns	ns	<0.05	ns
L x T x S	6	ns	ns	ns	ns	ns
L x T x C x S	6	ns	ns	ns	ns	<0.05

Grasses and herbaceous perennials

		Cover	Plant survival		Total height	
Source	df	2020	2019	2020	2019	2020
Location (L)	1	ns	ns	ns	<0.05	ns
Compost (C)	1	<0.05	<0.001	ns	<0.001	<0.05
Tillage (T)	1	ns	ns	ns	ns	ns
C x T	1	ns	ns	ns	<0.01	ns
L x C	1	0.05	ns	ns	ns	ns
L x T	1	ns	ns	ns	ns	ns
L x C x T	1	ns	ns	ns	<0.05	ns
Species (S)	8	<0.001	<0.001	<0.001	<0.001	<0.001
S x C	8	<0.001	ns	<0.001	<0.05	<0.001
S x T	8	<0.05	<0.05	ns	<0.05	ns
L x S	8	<0.001	<0.001	<0.001	<0.001	ns
S x C x T	8	ns	ns	ns	ns	ns
L x C x S	8	<0.05	<0.05	ns	ns	<0.05
L x T x S	8	ns	<0.05	<0.05	<0.05	ns
L x C x T x S	8	ns	ns	ns	ns	ns

Table 4. Mean soil nutrient concentrations from 2019 and 2020.

2019 Soil Nutrients

Site prep treatment	P (lb ac^{-1})	K (lb ac^{-1})	Mg (lb ac^{-1})	Ca (lb ac^{-1})	B (lb ac^{-1})	Zn (lb ac^{-1})	Mn (lb ac^{-1})	Fe (lb ac^{-1})	Cu (lb ac^{-1})
Control	29.83 b	378.31 b	781.45 b	11165.91 a	2.43 b	19.47 b	160.49 a	450.47 a	15.38 a
Tillage only	38.16 b	372.97 b	698.28 b	10583.45 a	2.73 b	21.43 b	145.66 a	473.13 a	15.07 ab
Compost only	343.30 a	1113.92 a	1448.40 a	11058.25 a	5.47 a	43.35 a	96.00 b	449.47 a	11.25 ab
Compost and tillage	253.15 a	1235.09 a	1341.24 a	11208.91 a	5.47 a	39.03 a	106.00 b	467.47 a	9.00 b

2020 Soil Nutrients

Site prep treatment	P (lb ac^{-1})	K (lb ac^{-1})	Mg (lb ac^{-1})	Ca (lb ac^{-1})	B (lb ac^{-1})	Zn (lb ac^{-1})	Mn (lb ac^{-1})	Fe (lb ac^{-1})	Cu (lb ac^{-1})
Control	32.67 c	287.81 b	654.12 c	10104.32 a	3.02 b	20.57 b	178.49 a	419.14 a	6.13 a
Tillage only	32.33 c	348.81 b	558.63 c	9862.50 a	2.73 b	19.57 b	165.49 a	401.80 a	8.52 a
Compost only	451.64 a	860.27 a	1534.06 a	11275.91 a	6.18 a	42.48 a	103.49 b	441.97 a	12.72 b
Compost and tillage	275.65 b	876.11 a	1163.92 b	10015.15 a	5.15 a	36.58 a	106.17 b	440.80 a	14.48 b

Means within a column for a given year followed by the same letter are not different at $P<0.05$. Mean separation by Tukey’s HSD test.

Table 5. A comparison of the survival rates of perennial selections from the site preparation experiment, and the supplemental plant evaluation experiment. Survival rates of selections from the site preparation experiment were calculated from the compost and tillage treatment only.

		Survival Rate	
Species	Experiment group	2019	2020
A. hubrichtii	Site Preparation	100.0	100.0
H. 'Stella de Oro'	Plant Evaluation	100.0	100.0
H. 'Happy Returns'	Site Preparation	100.0	100.0
D. 'Bronzeschleier'	Site Preparation	100.0	98.2
Chelone	Site Preparation	94.4	92.6
P. 'Rotstrahlbush'	Site Preparation	100.0	90.7
A. 'Summer Beauty'	Plant Evaluation	94.4	88.9
Nepeta	Site Preparation	87.0	88.9
A. tabemontana	Plant Evaluation	94.4	87.0
D. 'Duncan'	Plant Evaluation	100.0	79.6
A. 'Balloon Bouquet'	Plant Evaluation	87.0	77.8
P. 'Shenandoah'	Plant Evaluation	100.0	68.5
S. 'The Blues'	Site Preparation	83.3	68.5
D.'Goldstaub'	Plant Evaluation	100.0	61.1
C. vulpinoidea	Plant Evaluation	81.5	53.7
C. pensylvanica	Site Preparation	59.3	44.4
D. 'Nikko'	Site Preparation	83.3	27.8
S. 'Jazz'	Plant Evaluation	40.7	24.1

Table 6. A comparison of the survival rates of shrub selections from the site preparation experiment, and the supplemental plant evaluation experiment. Survival rates of selections from the site preparation experiment were calculated from the compost and tillage treatment only.

		Survival Rate	
Species	Experiment group	2019	2020
D. 'Butterfly'	Plant Evaluation	100	100
Cotoneaster	Plant Evaluation	100	100
D. Kodiak Black	Site Preparation	97.2	97.2
P. 'Tiny Wine'	Plant Evaluation	97.2	97.2
P. 'Summer Wine'	Site Preparation	97.2	97.2
Cephalanthus	Site Preparation	97.2	97.2
Cornus	Site Preparation	100	97.2
Forsythia	Site Preparation	97.2	97.2
D. Kodiak Orange	Plant Evaluation	100	93.1
Deutzia	Plant Evaluation	100	91.7
D. Kodiak Red	Plant Evaluation	100	90
D. lonicera	Site Preparation	88.9	80.6
B. 'Solar Flare'	Plant Evaluation	97.2	75
Baptisia	Site Preparation	72.2	58.3

Table 7. Foliar nutrition results of plants in compost treatments and plants in treatments without compost in 2019.

		2019									
Species	Compost	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	B (ppm)	Mn (ppm)	Zn (ppm)	Fe (ppm)	Cu (ppm)
Amsonia	N	1.51*	0.14	1.10*	0.35	1.31*	98.64*	409.55*	232.18*	300.45	6.45
	Y	2.03	0.19	1.45	0.33	0.99	167.83	345.25	164.83	252.50	5.92
Cornus	N	2.13*	0.33	1.04*	0.64*	3.11*	38.33*	24.58	19.25	99.83	6.50
	Y	2.41	0.32	1.39	0.73	2.63	61.42	19.92	18.75	103.92	7.08
Deschampsia	N	1.97*	0.24	1.83*	0.26	0.69	13.83	96.67*	38.75	189.17	7.58
	Y	2.24	0.31	2.07	0.26	0.63	19.75	48.17	39.83	161.50	8.50
Diervilla	N	1.58*	0.51*	1.10*	0.34	1.40*	54.17*	35.33	71.92*	133.67	3.75*
	Y	2.03	0.63	1.70	0.33	1.09	92.67	32.67	96.92	124.83	5.33
Forsythia	N	1.44*	0.23*	1.27*	0.25	1.00*	34.73	124.00*	22.27	85.64	5.36*
	Y	2.07	0.33	1.76	0.27	0.78	41.27	84.45	27.09	93.45	12.91
Hemerocallis	N	1.61*	0.19	1.86*	0.39*	1.82*	32.25	50.17	37.92*	379.42	4.75
	Y	2.29	0.37	2.77	0.44	1.50	38.17	42.92	57.00	404.17	5.17
Physocarpus	N	1.41*	0.23	0.90*	0.35	1.34*	24.67	28.33	23.92	188.67	5.42
	Y	1.71	0.24	1.16	0.35	1.06	24.25	19.67	26.25	185.25	5.83
Panicum	N	1.49*	0.12*	1.20	0.14	0.50	10.27	20.45	16.55	145.45	5.91
	Y	1.82	0.16	1.38	0.17	0.45	16.00	18.82	18.73	134.55	6.91

* indicates that means are significantly different at P<0.05.

Table 8. Foliar nutrition results of plants in compost treatments and plants in treatments without compost in 2020.

		2020									
Species	Compost	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	B (ppm)	Mn (ppm)	Zn (ppm)	Fe (ppm)	Cu (ppm)
Amsonia	N	1.58*	0.14	1.33*	0.29	1.02*	80.45*	226.09*	142.18*	156.45	4.82
	Y	1.95	0.20	1.26	0.30	0.85	92.50	108.42	90.83	173.00	5.50
Cornus	N	1.99*	0.29	1.32	0.57	2.68*	38.55	23.55	20.18	83.27	6.82
	Y	2.37	0.31	1.31	0.59	2.26	42.58	21.33	19.25	82.58	6.92
Deschampsia	N	1.69*	0.34	1.50	0.31	1.08	31.92	35.67	50.17	176.83	7.42
	Y	1.90	0.39	1.56	0.32	1.03	41.33	26.42	53.08	189.83	8.25
Diervilla	N	1.64*	0.37	1.28	0.37	1.22	56.36	29.00	78.18	128.09	4.64
	Y	2.15	0.41	1.26	0.34	1.07	63.83	23.83	73.42	138.83	6.08
Forsythia	N	1.83*	0.24	1.60	0.25	0.88	39.33	66.83*	32.25	81.50	15.08*
	Y	2.07	0.27	1.55	0.28	0.76	40.00	42.67	33.42	90.67	17.50
Hemerocallis	N	1.74*	0.24*	2.15*	0.32*	1.53	62.42	32.17	42.42	383.42*	6.17
	Y	2.23	0.35	2.19	0.38	1.50	65.00	34.58	39.08	268.67	6.00
Physocarpus	N	1.75*	0.21*	1.20	0.33	1.19	42.67	24.25	27.33	147.67	8.83
	Y	2.20	0.27	1.20	0.36	1.07	40.33	25.50	29.58	164.50	9.75
Panicum	N	1.57*	0.20*	1.72*	0.19*	0.78	24.50*	18.42	25.50	180.58	6.25
	Y	1.98	0.29	1.68	0.26	0.80	45.11	19.67	28.89	138.11	6.56

* indicates means are significantly different at P<0.05.

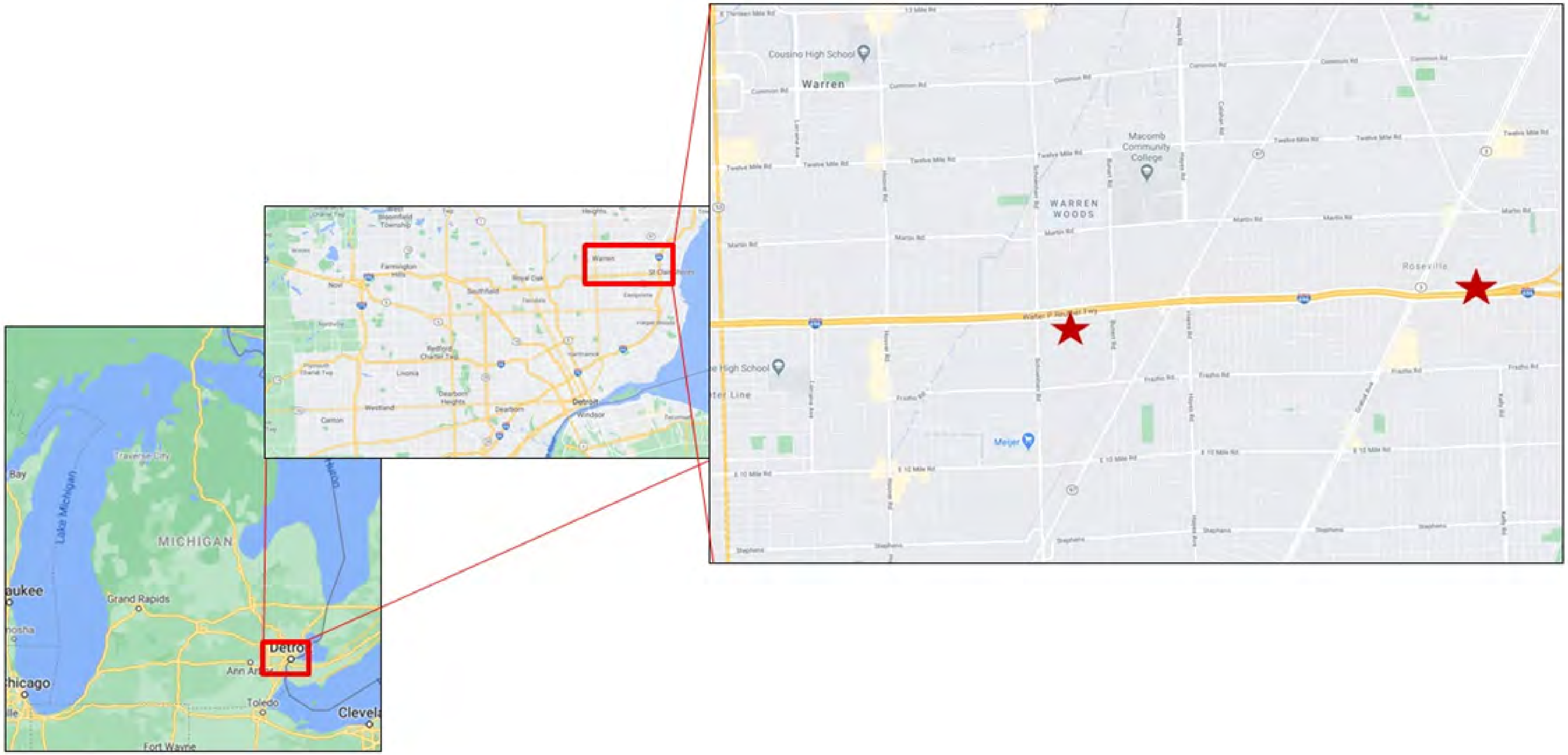


Figure 1. Location of the two studies sites is suburban Detroit, MI USA.

Figure 2. Photo indicating location of blocks at the Roseville site along I-696. Blocks with an “A” are the plant evaluation plots.

Figure 3. Photo indicating location of blocks at the Warren site along I-696. Blocks with an “A” are the plant evaluation plots.

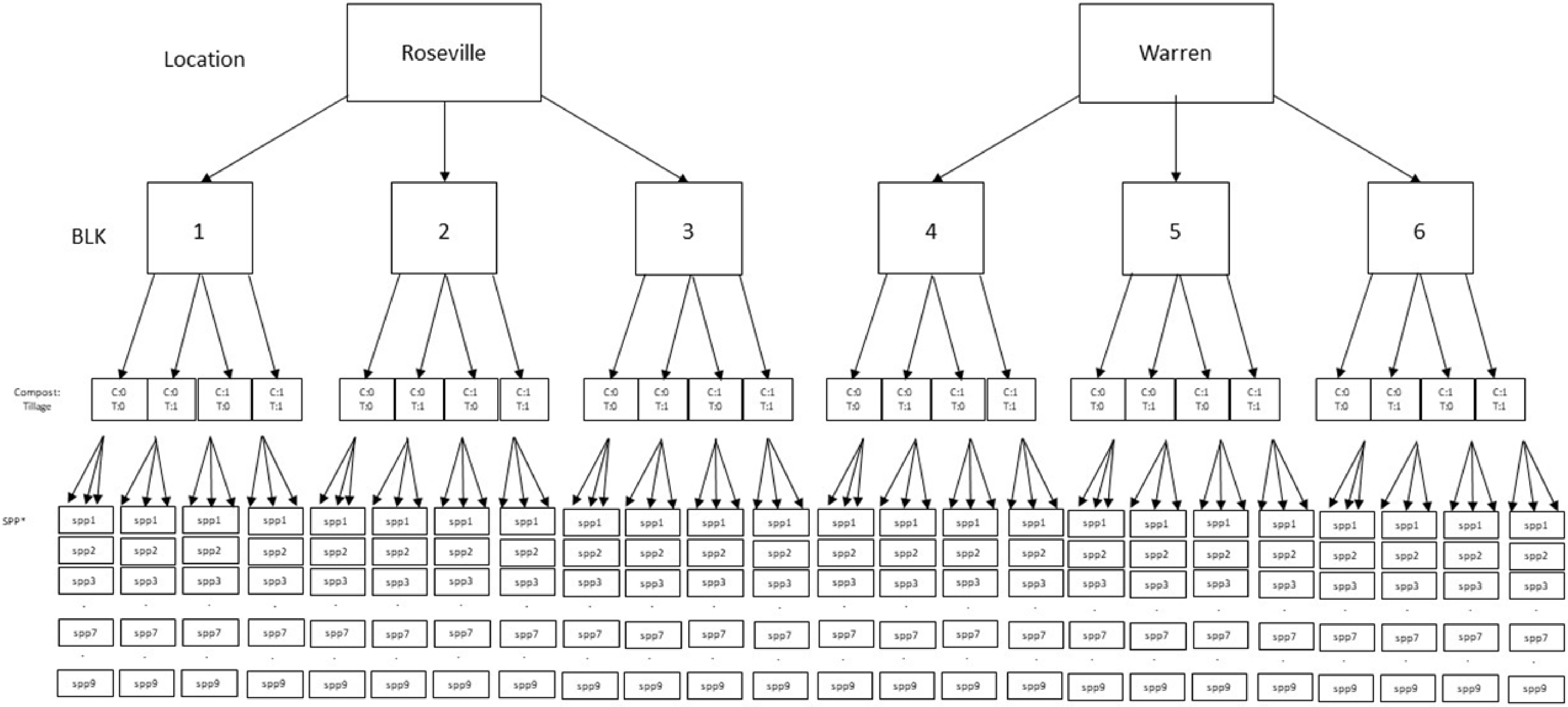


Figure 4. Schematic illustration of the study design indicating main plots (compost:tillage) and subplots (SPP).

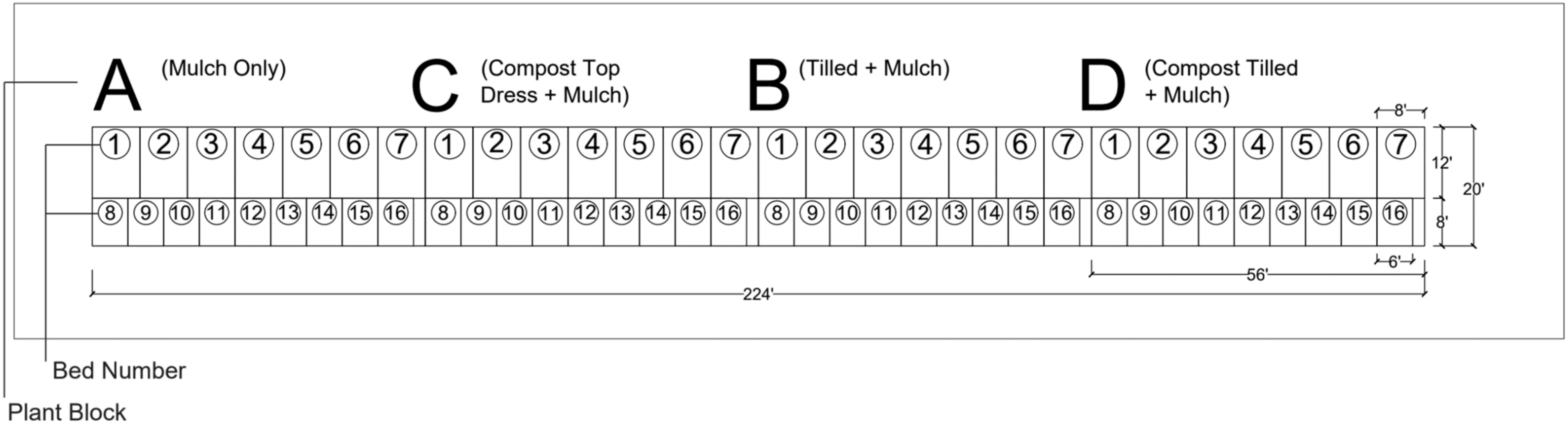


Figure 5. Schematic illustration of a single block indicating layout of main plots and subplots

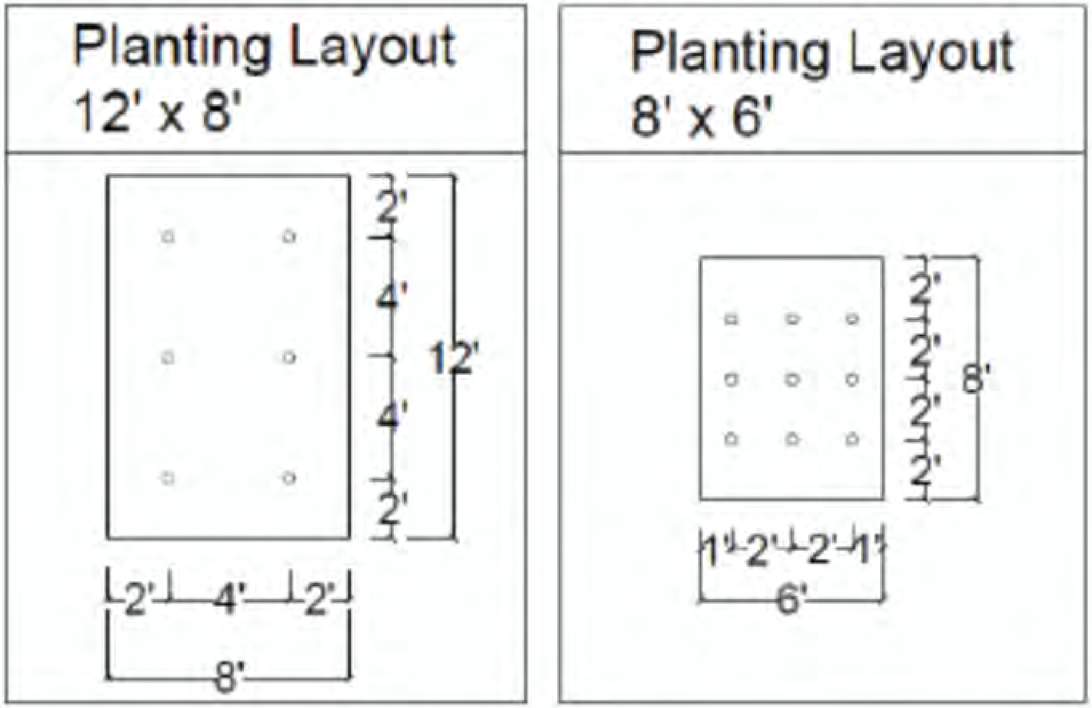


Figure 6. Schematic illustration of the two subplot sizes

Figure 7. Plot layout of the four treatments (Control, Tilled Only, Compost only, and Compost and Tilled) within a block before plant installation.

Figure 8. A single treatment plot after plant installation.

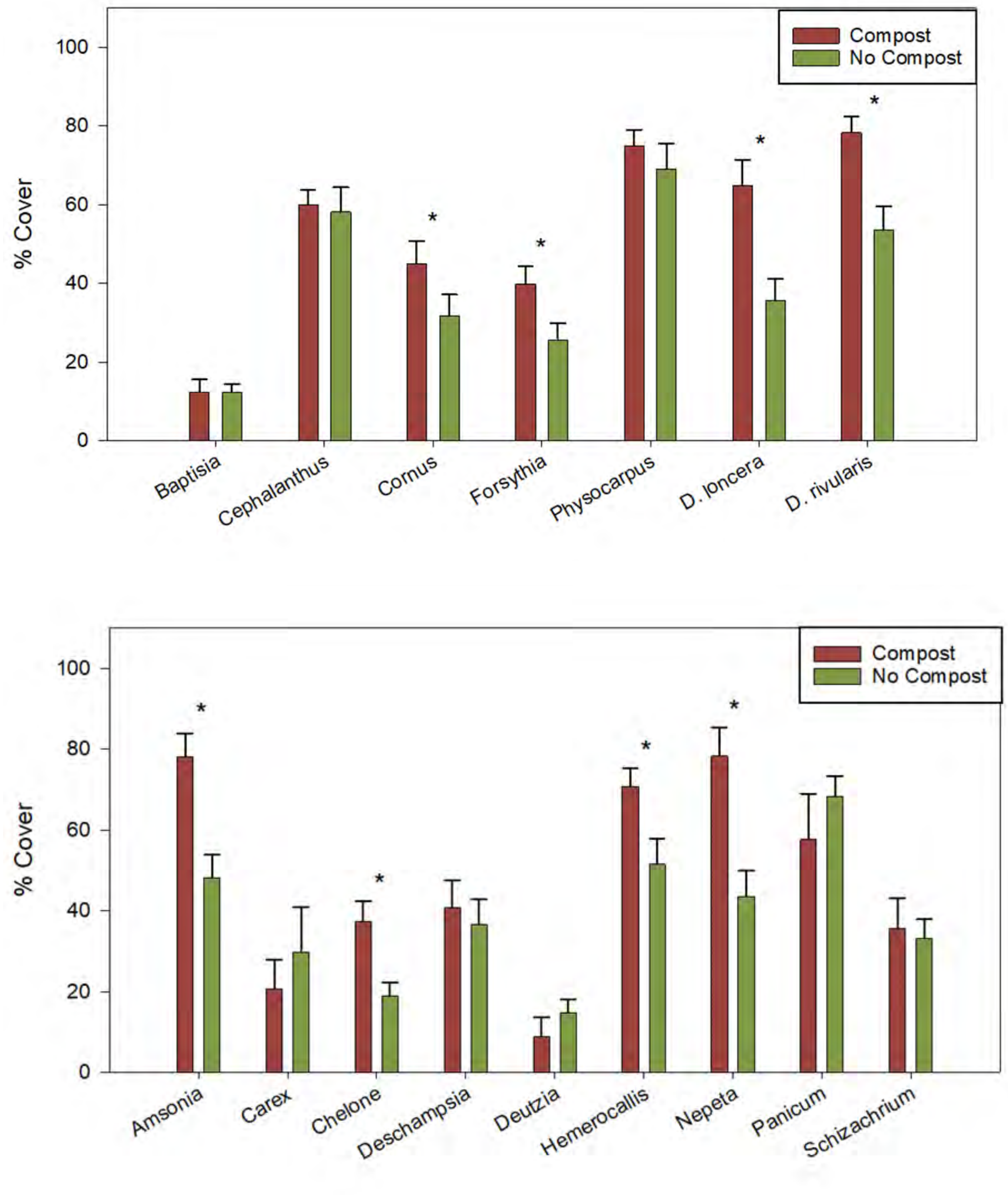


Figure 9. Mean (± SE) subplot coverage (%) of plants species at each study location subjected to compost treatment and no compost treatment along roadsides near Detroit, MI. * indicates that means are significantly different at $P \leq 0.05$.

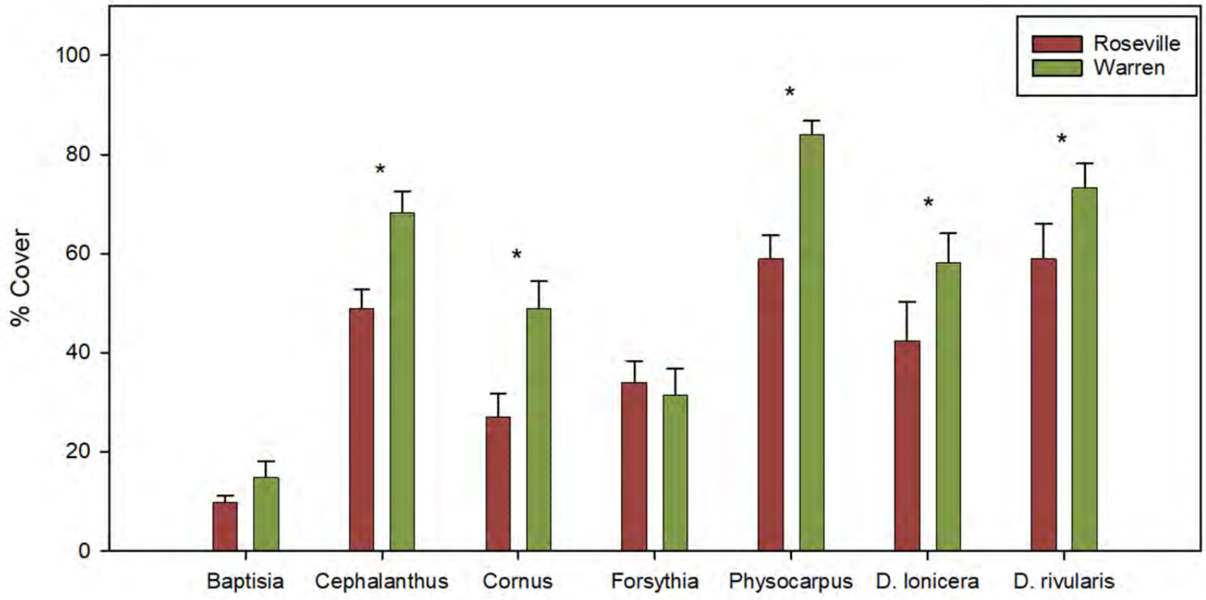


Figure 10. Mean (± SE) subplot coverage (%) of plants of 7 shrub species at two locations along roadsides near Detroit, MI. * indicates that means are significantly different at $P \leq 0.05$.

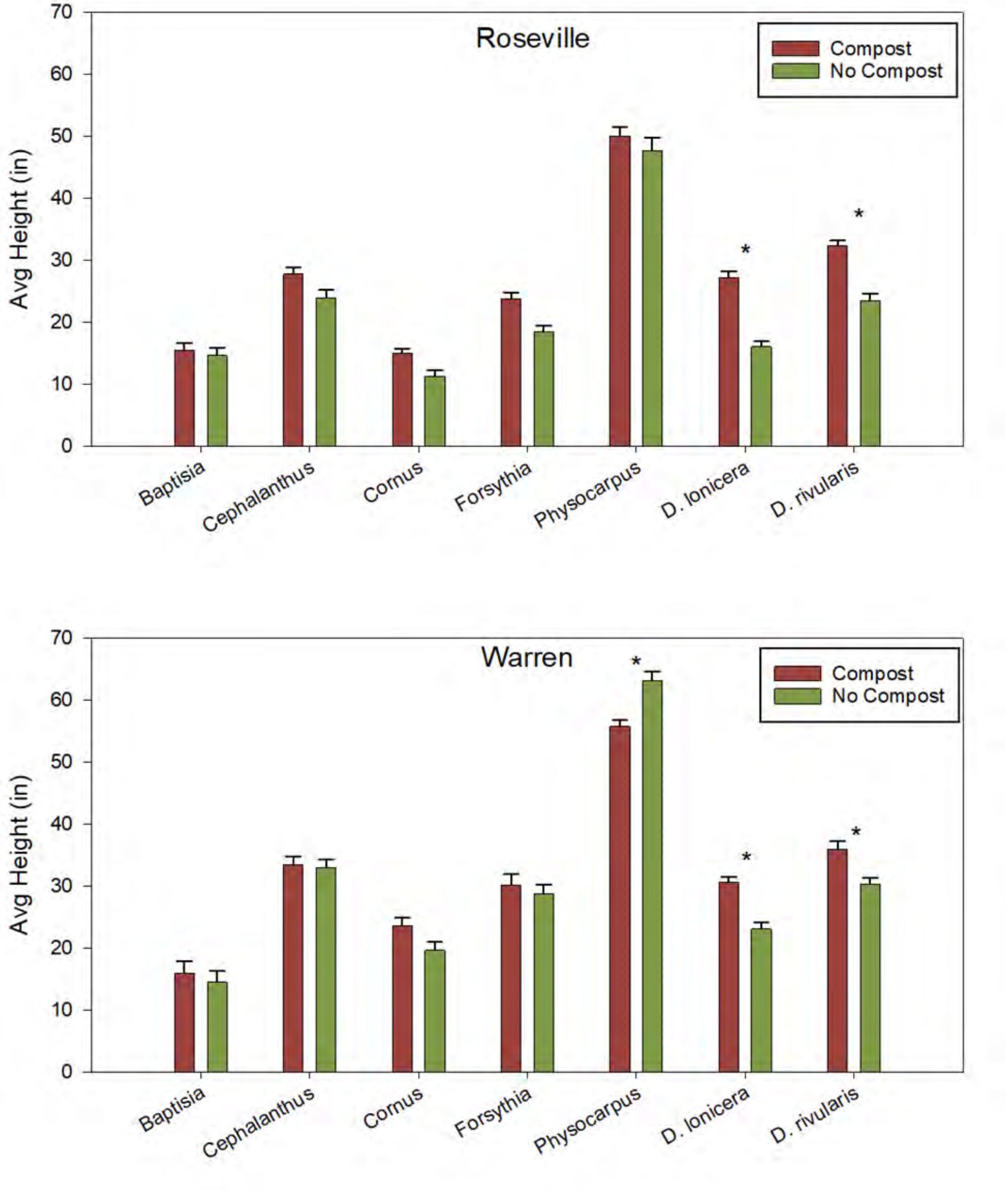
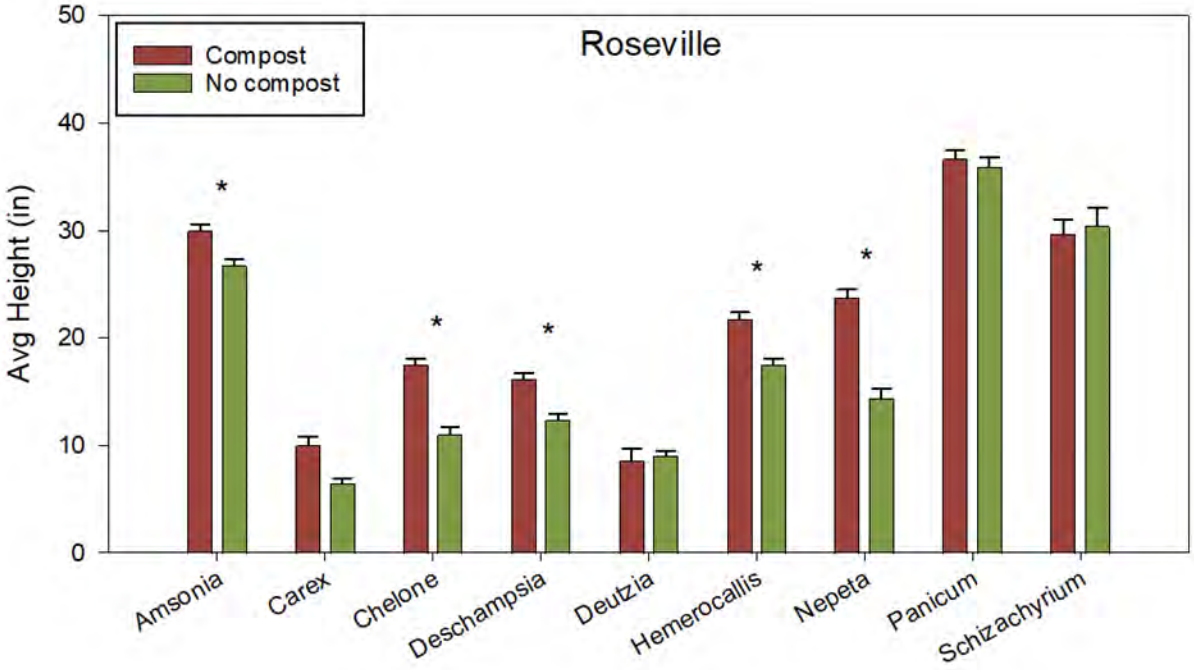
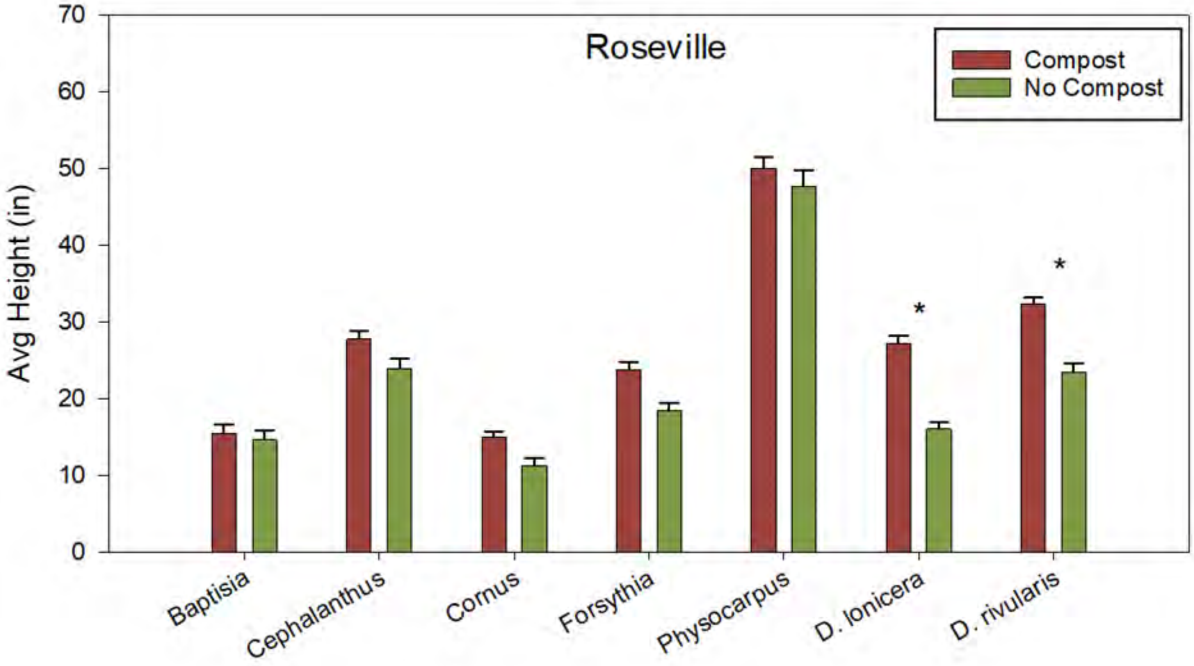


Figure 11. Mean (± SE) plant heights of 7 shrub species at each study location subjected to compost treatment and no compost treatment along roadsides near Detroit, MI. * indicates that means are significantly different at $P \leq 0.05$.


Roseville
Compost
No compost
Avg Height (in)
0
10
20
30
40
50
Amsonia
Carex
Chelone
Deschampsia
Deutzia
Hemerocallis
Nepeta
Panicum
Schizachyrium
*
*
*
*
*


Roseville
Compost
No Compost
Avg Height (in)
0
10
20
30
40
50
60
70
Baptisia
Cephalanthus
Cornus
Forsythia
Physocarpus
D. lonicera
D. rivularis
*
*

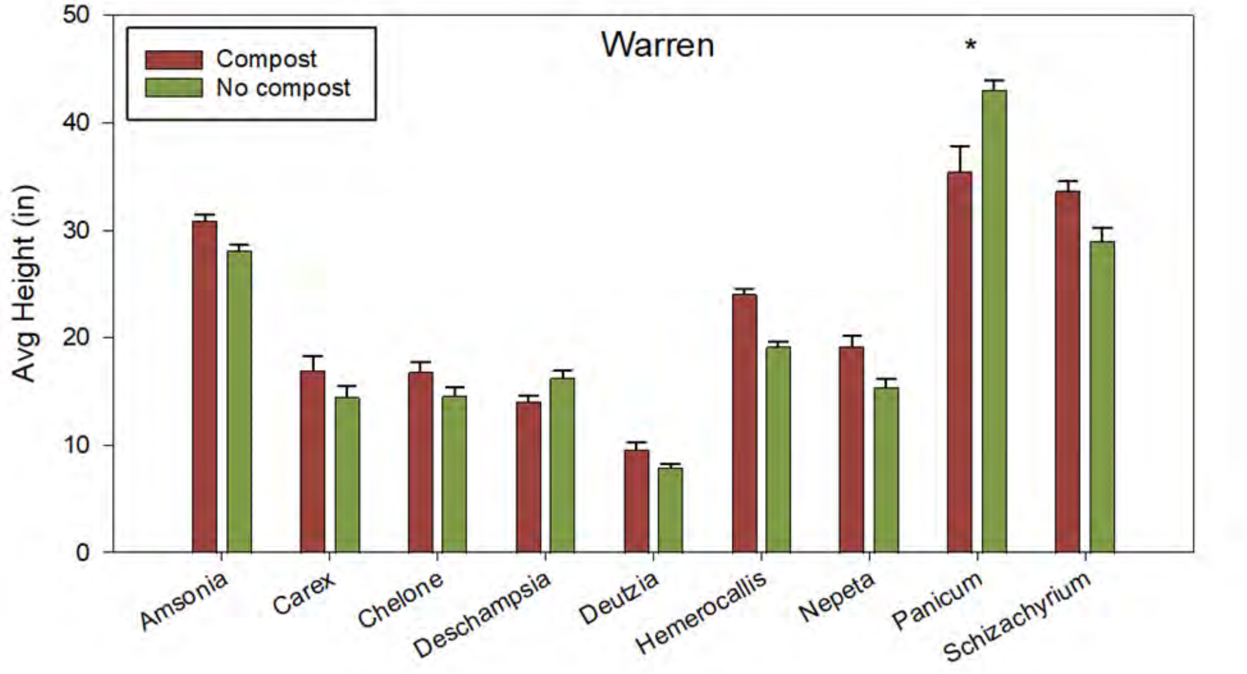


Figure 12. Mean (± SE) plant height 9 species at each study location subjected to compost treatment and no compost treatment along roadsides near Detroit, MI. * indicates that means are significantly different at $P \leq 0.05$.

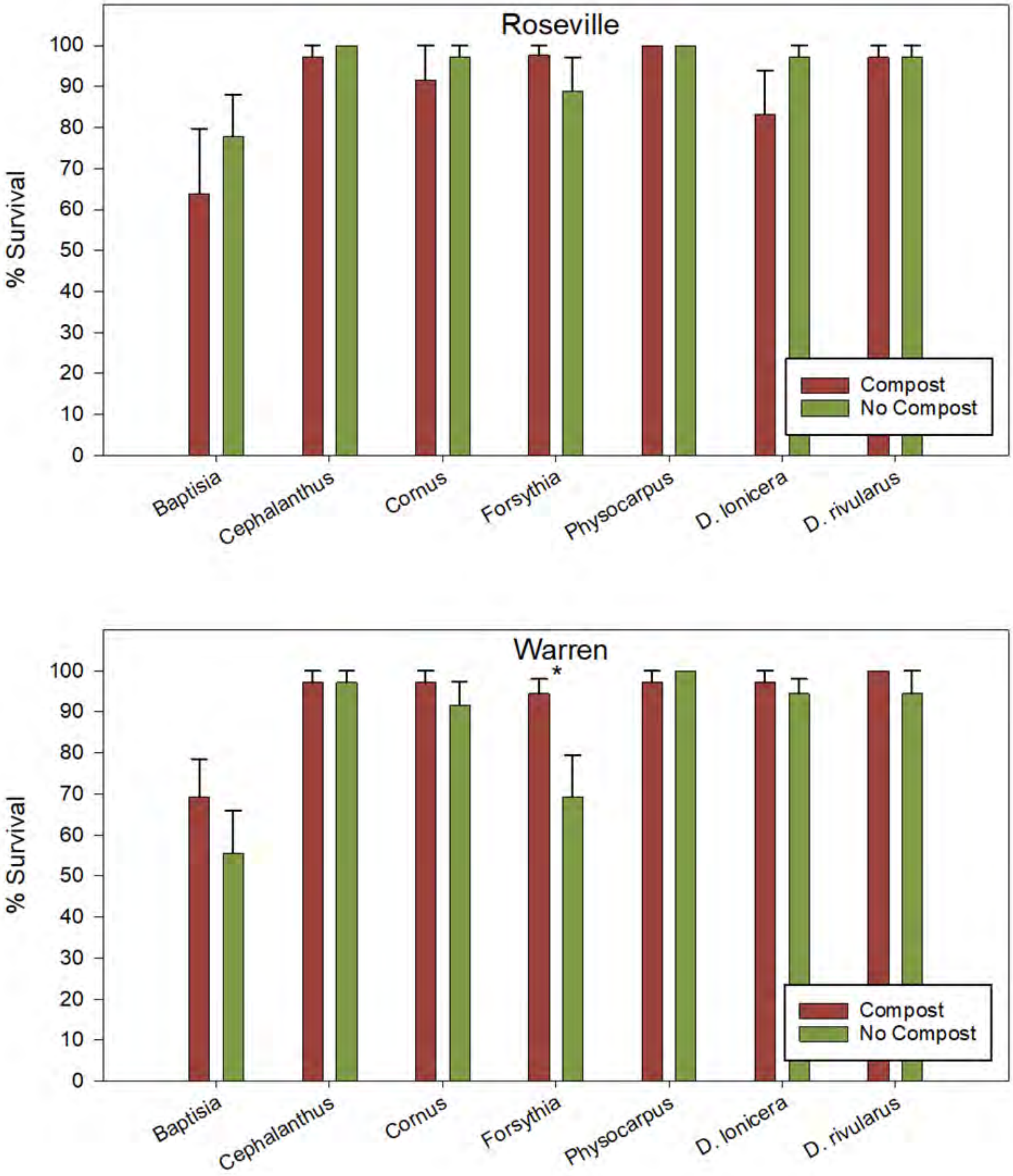


Figure 13. Mean (± SE) survival (%) of plants of 7 shrubs species at the Warren and Roseville locations subjected to compost treatment and no compost treatment along roadsides near Detroit, MI. * indicates that means are significantly different at P ≤ 0.05.

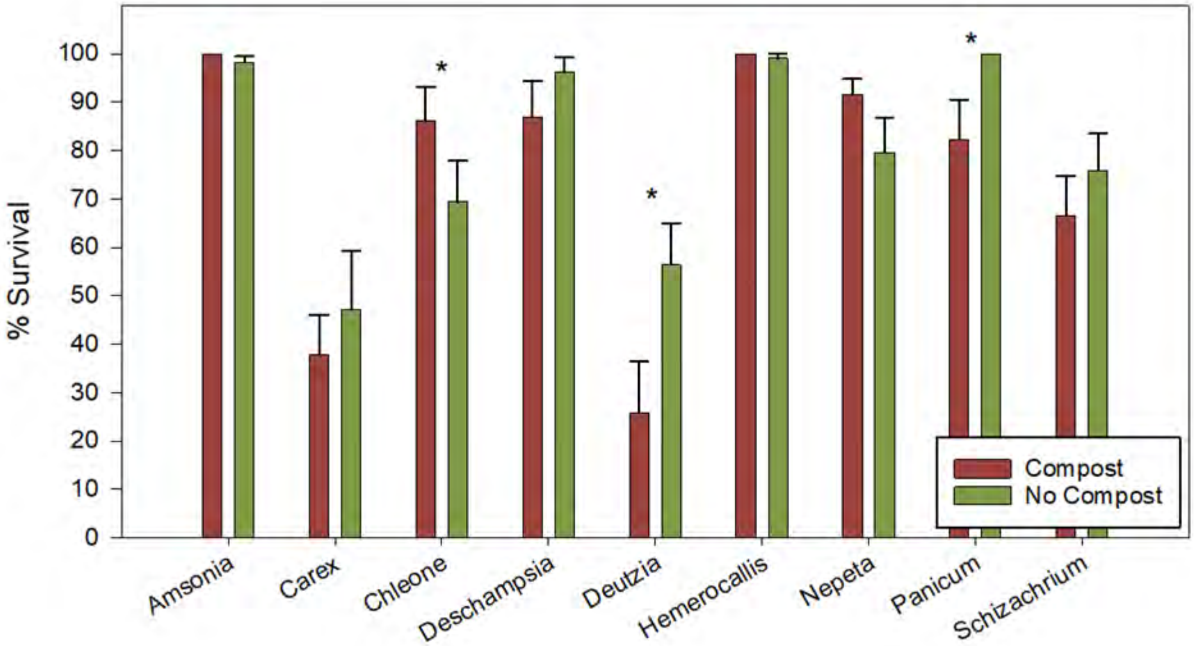


Figure 14. Mean (± SE) survival (%) of plants of 9 perennial species at the Roseville site subjected to compost treatment and no compost treatment along roadsides near Detroit, MI. * indicates that means are significantly different at $P \leq 0.05$.

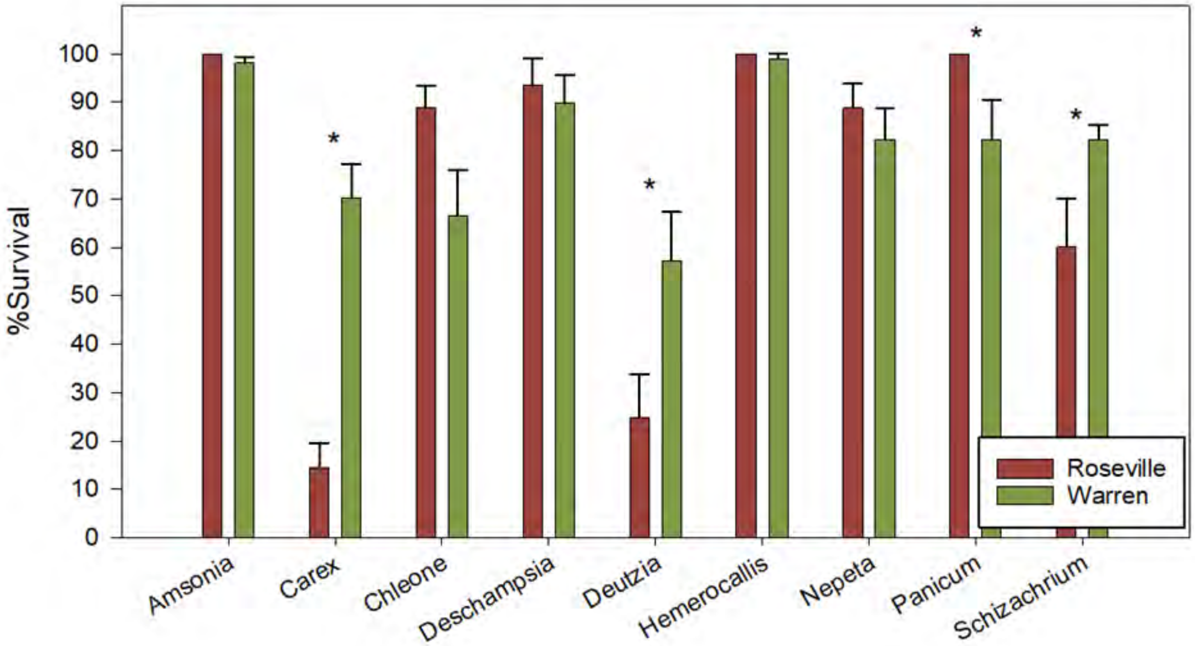


Figure 15. Mean (± SE) survival (%) of plants of 9 perennial species in the Roseville and Warren locations along roadsides near Detroit, MI. * indicates that means are significantly different at $P \leq 0.05$.

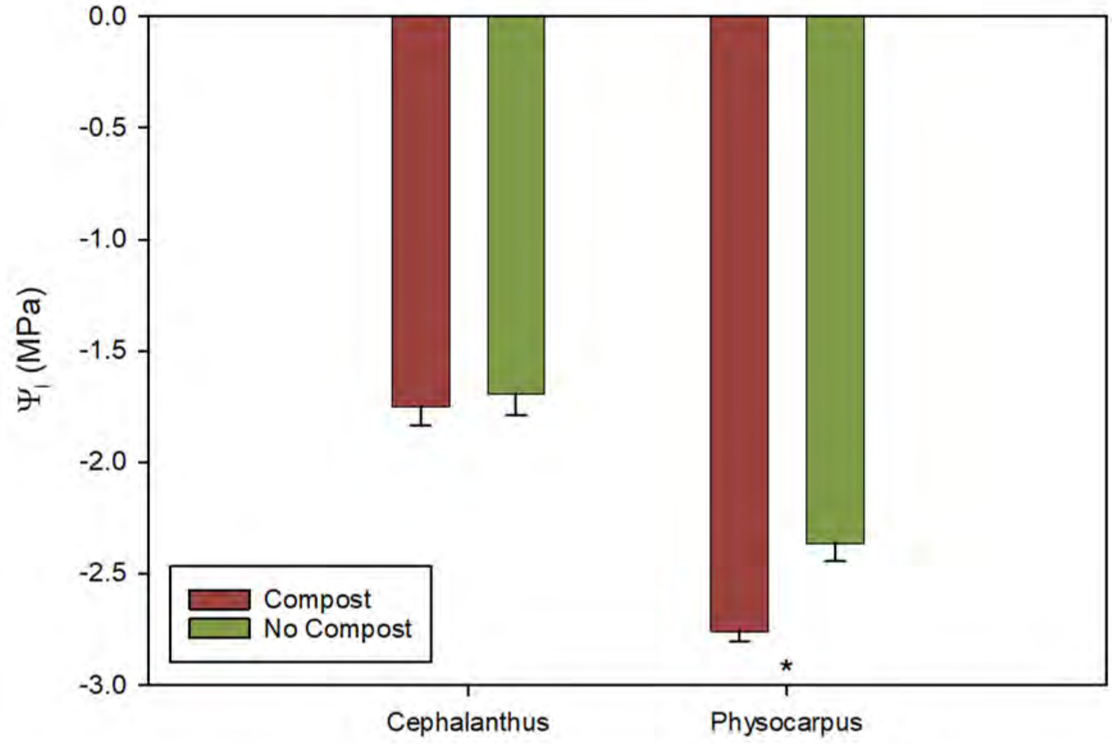


Figure 16. Mean (± SE) midday Ψ_l of Summer Wine® Ninebark and Sugar Shack® Buttonbush in July of 2020 subjected to compost treatment and no compost treatment along roadsides near Detroit, MI. * indicates that means are significantly different at $P \leq 0.05$.

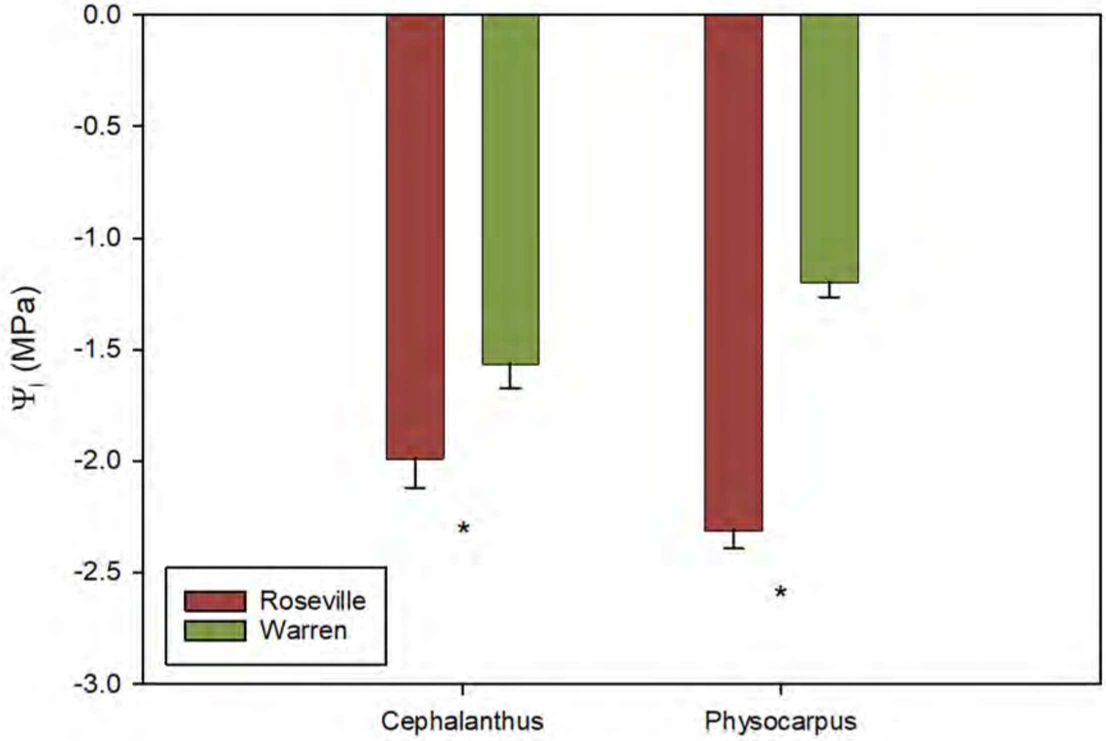


Figure 17. Mean (± SE) midday Ψ_l of Summer Wine® Ninebark and Sugar Shack® Buttonbush in August 2019 along roadsides near Detroit, MI. * indicates that means are significantly different at $P \leq 0.05$.

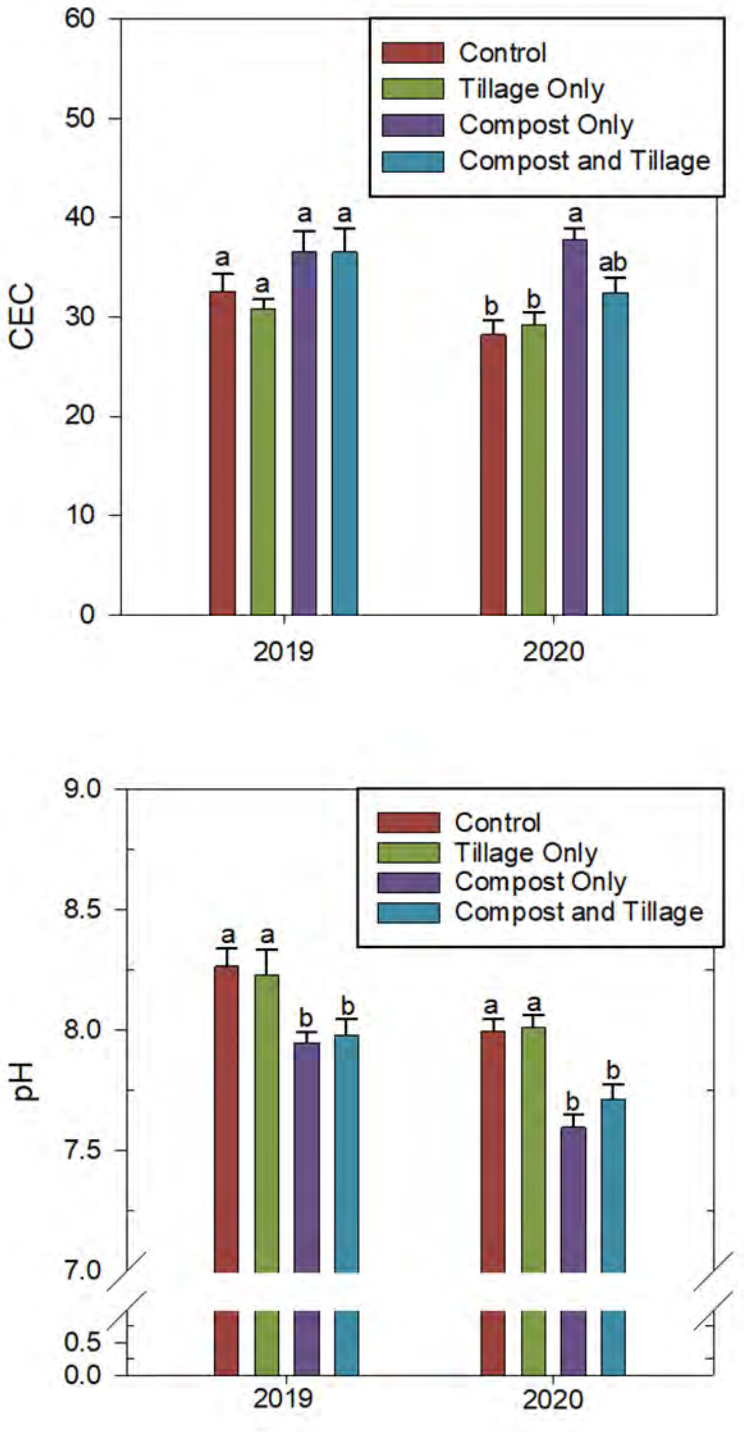


Figure 18. Mean (± SE) soil pH and CEC of the control, tillage only, compost only and compost and tillage treatments in 2019 and 2020 along roadsides near Detroit, MI. Means within a year indicated by the same letter are not different at $p \leq 0.05$. Mean separation by Tukey's HSD test.

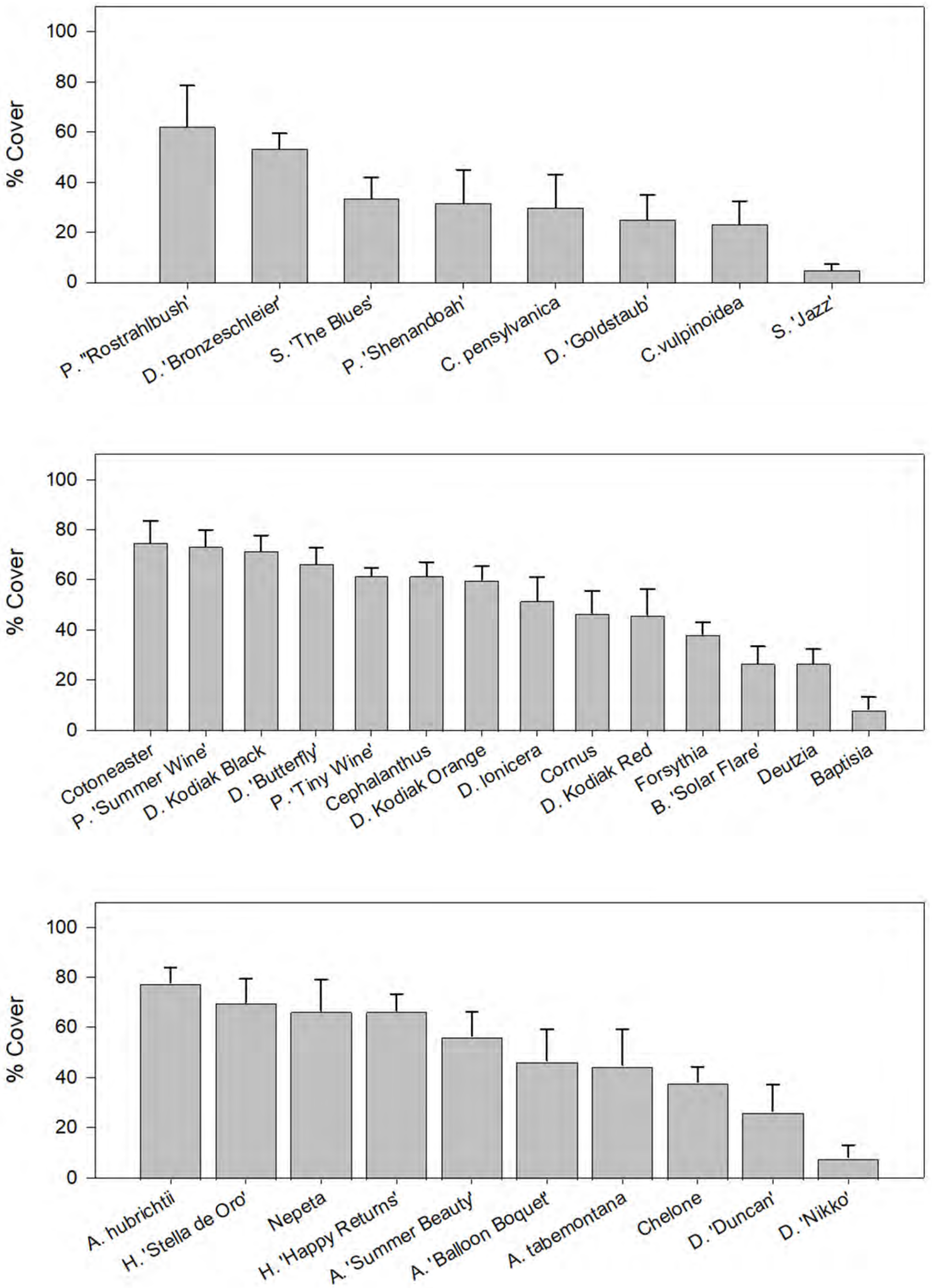


Figure 19. Mean (+- SE) ground cover (%) of plants of all selection in the site preparation and supplemental plant evaluation studies. Means of selections from the site preparation study were taken from plants in the compost and tillage treatment.

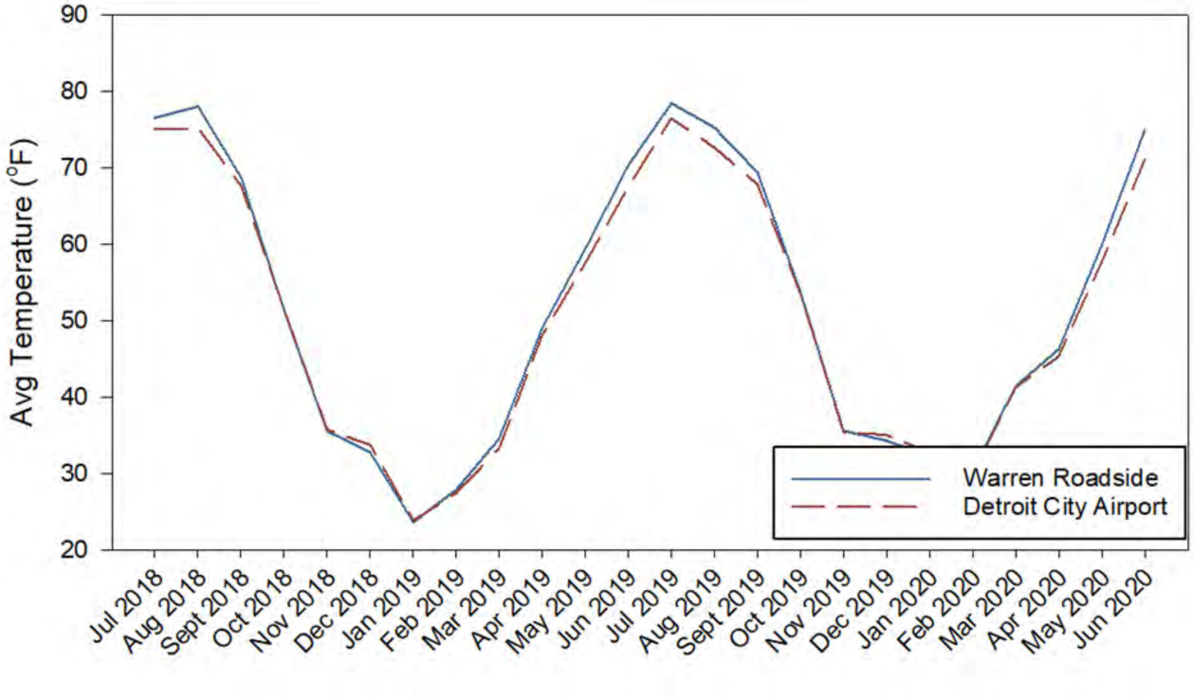


Figure 20. Mean monthly temperatures at the Warren roadside and the Detroit City (Coleman A. Young) airport.