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Illinois Department of Transportation's Seeding Standards and Best Management Practices

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16. Abstract

To provide evidence-based revisions to Section 250 of the Illinois Department of Transportation roadside specifications manual, we conducted a literature review, an experimental planting, and a survey of previously planted roadsides. We created newly designed native seed mixes and field tested these mixes in comparison with existing IDOT mixes. After one year of growth in lawn, roadside, and slope areas, we found overall positive effects on native species cover using the newly designed native mixes. We surveyed 34 native species plantings along roadsides in Indiana and Illinois and evaluated several variables to determine which factors led to long-term establishment, finding cover by seeded native species and native species overall increased with distance from road and decreased with increasing soil nitrate and phosphorous. We further found that number of native species and seeded native species increased with distance from road and greater seed mix diversity, whereas richness of non-native, non-seeded species was greater at shorter distances from the road. Across all sites, 84 of the 150 native species seeded at sites were never observed in our surveys, but 28 native species were observed at more than half of the sites in which they were seeded. Our results suggest native plantings can persist on roadsides for several years after planting, but that specific site-level factors increase the likelihood of long-term success.

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EXECUTIVE SUMMARY

If successful, native plantings in roadside rights-of-way provide many benefits, including slope stabilization, pollinator resources, sediment and pollutant sequestration, and scenic value. To make recommendations for improved native seeding practices for the Illinois Department of Transportation (IDOT), we assessed the native species seeding requirements of Midwestern DOT roadside specifications manuals, conducted comparison trial experiments between existing IDOT seed mixes and high-diversity, fully native mixes, and assessed the status of native species plantings along roadsides in Indiana and Illinois.

We conducted experimental seed mix trials for lawn, roadside, and northern and southern Illinois slope mixes, comparing existing IDOT mixes against newly designed, fully native mixes. After one year of growth, we determined how native mixes compared to IDOT mixes based on seeded cover, bare ground reduction, native species cover, native species richness, and reduction of introduced (non-native, non-seeded) species cover and richness.

We surveyed vegetation in 34 previously planted sites across Indiana and Illinois. All but one of these sites had been planted using one or more native seed mixes, and five sites in Indiana also contained areas of turfgrass plantings. We estimated cover of plant species in 0.25 m^2 (2.7 ft^2) quadrats arrayed at different distances from the nearest road. We also collected soil cores at each quadrat, which were analyzed for key soil components, measured soil compaction, and assessed surrounding land cover within 100 m (328 ft) of each site. Data collected were used to determine which factors affected the cover and richness of native seeded species, all native species, and non-native, non-seeded species via linear mixed-effects modeling.

In experimental seeding trials, after the first year of growth, native species richness and often cover were significantly higher for the native mixes, particularly in roadside and northern slope trials. However, overall plant cover as well as cover and richness of non-native, non-seeded species were generally equal between mix types. We anticipate more pronounced effects of mix types after additional growing seasons.

In surveys of previously planted roadsides, native seeded cover increased with greater distance from the road and higher soil magnesium and lower nitrate and phosphorous. High overall native species cover was best predicted by greater distance from the road, higher soil magnesium, lower nitrate and phosphorous, and increased proximity to developed land. Native seeded richness and overall native richness both increased with greater distance from the road, high seed mix diversity, and proximity to developed land. Increased cover by non-native, non-seeded species was associated with higher soil calcium, cation exchange capacity, pH, and soluble salt concentrations. Richness of non-native, non-seeded species was greater at shorter distances from the road and with increased proximity to developed land.

Across all sites, 84 of the 150 native species seeded were never observed in our surveys, but 28 native species were observed at more than half of the sites in which they were seeded. Five of these 28 species were present in 100% of seeded sites, and five other species were found in at least 10

sites, including some in which they were not seeded according to planting lists from the Illinois and Indiana DOTs.

These data, along with information from the literature, have many implications for updates to seeding work for managers concerned with roadside vegetation. Overall, our results suggest that many elements of different Midwestern DOT native seeding practices can be implemented by IDOT, that native seed mixes may persist well in certain areas after proper sowing and maintenance, and that native plantings can persist on roadsides for several years after planting, but that specific site-level factors increase the likelihood of long-term success. A key unknown in this research is maintenance regime, which likely has significant impacts on success. We make specific recommendations for updating IDOT's standard specifications for seeding mixes, roadside planting, and roadside vegetation management.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: LITERATURE REVIEW

INTRODUCTION

The Midwestern United States has undergone significant land cover transformation since the 19th century, with large-scale conversion of forest, prairie, savanna, and wetland ecosystems to agricultural land. Although some of the forested area in the Midwest has been reforested through natural means (Graham et al., 1963; Williams, 2003), prairie and savanna ecosystems continue to be lost due to persistent agriculture and development pressures (Wright and Wimberly, 2013). Illinois' Grand Prairie ecosystem, which covered approximately 61% of land area in 1820, now occupies around 0.01% of its original area. Iowa has seen a 99.9% decrease of presettlement prairie habitat (Houseal and Smith, 2000). These land-cover and land-use changes have caused irreversible losses of nutrients, biodiversity, and wildlife habitat (Fitzpatrick et al., 1999; Sala et al., 2000). This degradation also increases rates of erosion, sediment displacement, and nutrient runoff into waterways, causing widespread eutrophication of wetlands and waterbodies, with effects extending over 800 km (500 mi) to the mouth of the Mississippi River (David et al., 2010). Furthermore, this land-use shift allows invasive species to take hold of large swathes of disturbed land, furthering the rate of degradation (Christen and Matlack, 2009; Skultety and Matthews, 2017).

Although agriculture is the most influential driver of land change in the Midwest, roadway development has also caused large changes. All public roads in the Midwest amount to over 3,331,000 km (2,070,000 mi). At a conservative estimate (assuming two-lane roads at 3.66 m [12 ft] per lane [FHWA, 2024]) this represents a paved road area of 2,439,000 ha (6,025,000 ac). For highway miles (centerline miles) alone, eight Midwestern departments of transportation operate more than 162,000 centerline km (101,000 mi) of highways (IDOT, 2024; IaDOT, 2024; INDOT, 2021; MDOT, 2024; MnDOT, 2024a; MoDOT, 2024; ODOT, 2024; WisDOT, 2024). A conservative estimate of the unpaved right-of-way (ROW), consisting of interchanges, medians, and roadside margins, excluding roads themselves is 445,000 ha (1,100,000 ac) given 15.24 m (50 ft) medians and 6.10 m (20 ft) shoulders. This estimate does not include the area of "cloverleaf" interchanges on highways, each lobe of which can be 4 ha (10 ac) or more.

With the declared UN Decade on Ecosystem Restoration in full swing (Eisele and Huang, 2019), the roadways of the Midwest are well positioned for a transition to native habitat, increasing ecosystem services and reducing maintenance costs. In this chapter, we synthesize the environmental effects of restoring native vegetation to roadways and detail best practices for sowing and maintenance. Specifically, we address the following questions: What evidence is there in literature for the viability and effects of native species on roadsides? What are the most used and successful methods for establishing roadside native assemblages?

NATIVE SPECIES VIABILITY AND EFFECTS ON ROADSIDES

Standard practice on most roadsides in the United States is to plant non-native, Eurasian cool season grasses (generally species and cultivars of fescue [*Festuca*], ryegrass [*Lolium*], and bluegrass [*Poa*]), due to their perceived fast establishment compared to native species and their ability to remain green in cooler seasons (Bennett, 1936). However, due to shorter root systems, these species are less effective at preventing weed growth than native assemblages (Simmons et al., 2011) and only remain "verdant" if they receive consistent surface watering (Tinsley et al., 2006; Alvarez et al., 2007). Given recent and projected droughts expected in the Midwest from climate change (Cook et al., 2018; Erler et al., 2019), native prairie species can be favorable replacements for Eurasian turfgrasses. Additionally, native species can be planted as a control measure without fertilizers, as nutrient additions to soil often favor weed growth over native establishment (Brejda, 2000).

Roads and the vehicles that drive them carry invasive plant material to prime areas for colonization (von der Lippe and Kowarik, 2007). However, native species planting can be an effective means of invasive management. Assemblages of native herbaceous plants can inhibit the establishment of invasive and noxious weeds and outcompete some non-native turfgrasses on roadsides (Tinsley et al., 2006; Schuster et al., 2018). Planting natives on roadsides near remnant prairies can insulate the remnant area from colonization by non-natives, especially if using local ecotypes of planted species (Rowe, 2013). Further, the routine mowing needed for non-native grasses can result in greater spread of invasive species like crownvetch (*Securigera varia*) and teasel (*Dipsacus* spp.) in addition to being costly and polluting (Cheesman, 1998; Rector et al., 2006; Losure et al., 2009).

Midwestern native species can aid many ecosystem services if planted in highway ROWs. These plantings benefit populations of pollinating insects (like Monarch butterflies [*Danaus plexippus*]), birds, and mammals by providing habitat, forage sources, and corridors linking fragmented areas to each other (Underhill and Angold, 2000; Murray et al., 2009; Noordijk et al., 2011; Wojcik and Buchmann, 2012; Hopwood et al., 2015; Reppert and de Roode, 2018; Kaul and Wilsey, 2019). Cover provided by taller herbaceous species may also reduce the risk of deer-vehicle collisions by precluding the need for deer to sprint in exposed areas (Liu et al., 2018).

A native plant community can have many beneficial impacts on soil and soil faunal assemblages. Native plantings sequester carbon in soil at higher rates than non-native grasses or tilled crops (Purakayastha, 2008). Even in nutrient-poor soils, many native prairie species fare better than non-native crops and grasses because their deeper root systems can access nutrients in lower soil strata (Wilsey and Polley, 2006). Further, native species can enrich deeper layers of soil than shorter rooting non-native species by bolstering soil invertebrate populations and arbuscular mycorrhizal fungi (Zajicek et al., 1986; Wodika et al., 2014). Native species can remove and sequester additives like fertilizers and pesticides, preventing them from entering waterways and contributing to eutrophication or pollinator decline (Hernandez-Santana et al., 2013; Zhou et al., 2014; Prosser et al., 2020; Tatariw et al., 2021). As such, they are especially well suited to planting near agricultural areas often encountered along Midwestern highways, where these additives are highest (Cale and Hobbs, 1991; Schilling et al., 2018).

There are also roadway safety and economic benefits to planting with native species. Trees near highways pose risks to motorists from impacts or falling branches. However, establishment of a community of native grasses and forbs can prevent the growth of woody species by outcompeting their seedlings for resources while maintaining visual interest for drivers and preventing fatigue-related accidents (Cackowski and Nassar, 2003; de Blois et al., 2004; Parwathaneni, 2016). While initial costs of seeding with native prairie species are generally higher than non-native turfgrasses, long-term savings arise due to reduced fuel costs from less frequent mowing, and fewer work hours needed for maintenance, especially after the first year of establishment (Turk et al., 2017). The deep roots of native prairie species reduce slope failure risk and the need for costly resurfacing work (Drake, 1980). For example, in Florida, the value of ROW ecosystem services (runoff prevention, carbon sequestration, pollination and other insect services, air quality, invasive species resistance, and aesthetics) was estimated to double with a complete conversion to native plant species (Harrison, 2014).

BEST PRACTICES FOR SEED MIX DESIGN

Planting roadsides from seeds instead of plugs is standard practice given scale and cost concerns for most projects. Roadways are highly disturbed areas with poor soil characteristics and frequent chemical inputs, including automotive fluids, salts, and microplastics from tires and litter, that are harmful to most organisms (Khan and Kathi, 2014; Sommer et al., 2018; Walker et al., 2021). Thus, selecting species for a successfully establishing roadside seed mix is a complex process based on many attributes. Considerations include, but are not limited to, cost, plant type (graminoid, legume, forb), growth height, bloom phenology, attractiveness, and species tolerances of soil moisture, salinity, and disturbance.

Cost is naturally a consideration for seed mix design, as native species' seeds tend to be more expensive than commercially widely used non-natives, especially turfgrasses. While research has shown that long-term benefits usually outweigh the upfront costs of seeds (Harrison, 2014; Turk et al., 2017), it can still be a daunting process to source native species for a mix when a European turfgrass mixture can be sourced for pennies per pound. Fortunately, the cost of native seed is constantly decreasing as more species are being used and seed stocks rise concurrently with native harvest and propagation programs like the state-level ecotype projects underway in Iowa and Missouri (Houseal and Smith, 2000; Erickson and Navarrete-Tindall, 2004). The graminoid species that are the primary groundcover of most mixes (such *as Bouteloua* spp., *Elymus* spp., *Andropogon* spp., *Sporobolus* spp., *Carex* spp., and *Eragrostis* spp.) are some of the cheapest native species available and can be seeded as a much higher proportion of a mix relative to forbs and legumes if on a tighter budget (Zinnen and Matthews, 2022).

Planting a variety of species with different functional traits will keep the planting diverse over time and allow the assemblage to weather different environmental stressors (Meissen et al., 2020; Barak et al., 2022). Plantings should consist of at least nine species, with no individual species seeded at greater than 15% of the total weight, and annuals and biennials should not be seeded at greater than 10% of the total weight of the mix (USDA NRCS, 2015). The ideal seeding rate should be a total of 60–70 pure live seeds (PLS) per ft^2 (Bartow, 2021) to prevent weed encroachment. A key consideration of a mix should be the pure live seed count ratio of graminoids (grasses, sedges, and rushes) to forbs (non-graminoid, non-legume flowering plants) to legumes (nitrogen-fixing plants in the family Fabaceae). When selecting species, managers should consider relative seed size to be a proxy for seed germination rate. Larger seeded species tend to establish better than smaller seeds if properly sown, although this may have cost impacts (Moles and Westoby, 2004). For many roadside plantings, quick (and cheap) cover is a priority. Roadside managers generally consider 75% plant cover in the first year to be a successful seeding from bare ground (IDOT TRP members, pers. comm, online meeting, Feb. 21, 2023). A rapid cover mix should have a higher proportion of graminoid seeds relative to forb and legume seeds, as high as 3:1, graminoids:forbs and legumes. This will result in fewer blooms and less soil nitrogen fixation but will be an inexpensive, rapidly covering mix appropriate for most highway ROW conditions. To achieve a ratio most like a reference prairie ecosystem, which could be used near a remnant or around areas of restoration interest, managers should seed a diverse mix of 1:1. If managers need a showier mix for an area where drivers pass by more slowly, the ratio can be adjusted as high as 1:3. However, a mix with fewer graminoids is likely to allow for more invasive species due to patchier overall ground cover (Meissen et al., 2020). Legumes provide the benefit of fixing nitrogen in soil but are not necessarily wanted in large quantities relative to other forbs, and generally make up about 5%–10% of the species in a mix because too much soil nitrogen can allow non-natives to colonize (Brejda, 2000).

One safety consideration is growth height. On ROW areas like merges where unimpeded sight lines are vital for drivers, short-growing species are non-negotiable. However, in areas of high weed pressure, selecting species that grow taller than the weeds of concern will help prevent weed reestablishment by outcompeting them for light access. These taller species are beneficial along stretches of highway road shoulder where visibility over and through the plants is not important. As plant height is positively correlated with root depth (Tumber-Dávila et al., 2022), managers should select taller plants when erosion control or slope failure is a concern. However, these species may take years to reach maximum root depth, so faster rooting and shorter species should also be employed. Reference prairie and savanna ecosystems often include shorter species not usually included in seed mixes (Ladwig et al., 2020). Therefore, some of these species and families (*Dicanthelium* spp*.,* Ericaceae, Violaceae, Caprifoliaceae, and Boraginaceae) may be worthy of consideration in a ROW mix pending experimental evidence of growth in those conditions.

Bloom phenology and public perception of attractiveness are nonstructural but no less important attributes to consider in a planting. If the goal of a mix is to provide pollinators with nectar resources, it is important to include species like golden Alexander (*Zizia aurea*) that bloom early in the spring and asters (*Symphyotrichum* spp.) that bloom late in the summer and into the fall so pollinators have access to forage resources throughout the growing season (Zinnen et al., 2025). This has the added benefit of providing scenic views to motorists for a longer period of the year. Although public perception of native plants can be that they are “unattractive” compared to selectively bred, non-native flowers (Beckwith et al., 2022), a diverse assemblage of native flowering plants and grasses can be eye catching, especially if it attracts butterflies and birds. Including more native plants on the roads many people travel daily can increase public awareness and interest in native gardening (Wandersee and Schussler, 1999). Moreover, many native plants do have classically eye-catching blooms, including coneflowers (*Echinacea* spp*., Ratibida* spp*., Rudbeckia* spp.), silphiums (*Silphium* spp.), asters (*Symphyotrichum* spp.), and beardtongues (*Penstemon* spp.).

Moisture tolerance is a vital consideration for roadway seed mixes. Selecting species based on their Wetland Indicator Value (WIV) is a straightforward means of choosing species that will persist with the given moisture conditions of a site (United States Army Corps of Engineers, 2020). The five WIV categories, from hydric to xeric, are OBL: obligate wetland, FACW: facultative wetland, FAC: facultative, FACU: facultative upland, and UPL: upland. Most sloped areas on a roadway will do best with UPL and FACU species because these areas are unlikely to experience high soil moisture. For drainage ditches, culverts, and stormwater retention ponds, OBL and FACW species should be seeded because these are fundamentally wetland plantings, though ditches that may often dry out completely should include some drought-tolerant species in the mix to provide coverage in dry seasons. FAC species may be employed to great success in either condition, depending on the species and the benefits it provides to the mix.

Salinity tolerance is especially important for Midwestern roadsides in temperate regions due to road-salt application in winter. This is difficult to address due to limited evidence of salt tolerance among most Midwestern native plants and invasion by aggressive, salt-tolerant plants, like *Phragmites australis, Bassia scoparia,* and *Solidago sempervirens* (Fennessey, 2021). Saline soils often inhibit germination of native seeds, but once an individual has germinated and matured, salinity rarely results in mortality (Kim et al., 2012; Wang et al., 2011). A number of wild-type native graminoids or their cultivars have been shown to have salinity tolerance sufficient to survive roadside conditions, including prairie Junegrass (*Koeleria macrantha*), prairie cordgrass (*Spartina pectinata*), buffalograss (*Buchloe dactyloides*), side-oats grama (*Bouteloua curtipendula*), switchgrass (*Panicum virgatum*), and big bluestem (*Andropogon gerardii*) (Pessarakli, 1999; Kim et al., 2012; Wang et al., 2011; Schmer et al., 2012). Additionally, the fast-establishing native annual legume partridge pea (*Chamaecrista fasciculata*) has shown increased adaptation to salinity over successive generations of plants (Goldsmith and Nashoba, 2021). A mix of salt-tolerant native species is therefore encouraged closer to roadways to give the assemblage the greatest chance of persisting and adapting over time. Because salinity decreases with distance from road (Walker et al., 2021), a higher diversity of less salt-tolerant species can be successfully seeded further from the road edge.

A species' tolerance of disturbance is a key attribute for any high-traffic roadside given the high winds, poor soils, litter, and mechanical disturbances from mowers and other vehicles. Starting a planting from bare soil on a roadway means that the seed mix needs to contain disturbance-tolerant and fast-establishing species to provide rapid cover and improve conditions for other species in the mix to germinate in the following years. One good metric of a species' ability to weather disturbance is its coefficient of conservatism (CC) score (Freyman et al., 2016). CC scores range from 0 to 10, and species with lower CC scores are both more tolerant of anthropogenic disturbance and considered better able to establish in disturbed and sparsely vegetated sites. CC values are state specific and may be higher or lower across different parts of a species' range, though they rarely vary by more than two across the range. Many forbs including milkweeds (*Asclepias* spp.), evening primrose (*Oenothera biennis*), yarrow (*Achillea millefolium*), smartweeds (*Polygonum* spp.), and black-eyed Susans (*Rudbeckia hirta*) have low CC values and are great candidates for early establishing roadside plants.

BEST PRACTICES FOR SEEDING METHODS AND MANAGEMENT

Although hand broadcasting can be an effective way to sow seed into existing vegetation, a hydroseeding unit should be used when seeding onto bare ground, especially sloped areas. Hydroseeding involves a water tank containing a mix of seeds, water, and a tackifying agent that is sprayed onto roadsides in fall. This is the most effective seeding method, especially for sloped areas not easily reachable with a seed drill and tractor (Bochet et al., 2010). Drill seeding with a rangeland drill that has multiple boxes for different seed sizes is ideal for larger sites that are not heavily sloped. Additionally, granivorous animals are often a concern with restoration from seed, so drilling or hydroseeding should be employed where possible to protect seed from consumption (Linabury et al., 2019). Depending on weed pressure, a cover crop of annual, fast-growing graminoids may be beneficial. Typical cover crops are *Avena sativa* for spring planting and *Lolium perenne* or *Triticum aestivum* for fall planting, although they can persist in an assemblage. Other cover crops to consider are native *Elymus canadensis* and *Elymus virginicus*, although these native C3 cool-season grasses may lead to fewer warm-season C4 natives persisting (Herget, 2020; Kaul and Wilsey, 2022). Some fast-growing annual forb and legume species like *Rudbeckia hirta, Oenothera biennis, and Chamaecrista fasciculata* can be employed as elements of a cover crop mix as well to provide functional diversity, aesthetics, and pollinator benefits.

The most effective weed-management technique for prairie assemblages is a prescribed burn every 3–5 years (Panzer, 2002; Van Dyke et al., 2004). However, this type of management is infrequently used by most DOTs due to public concern and a lack of trained employees (Harrington, 1994; IDOT staff, pers. comm., online meeting, Feb. 21, 2023). With training, intelligent application of fire during cool spring or fall days with minimal wind is an inexpensive and effective method of prairie management, even on roadsides. A lack of prescribed fire is a primary reason for native species loss from prairie remnants (Leach and Givnish, 1996). Burning also increases the extent and depth of prairie plant roots, enriching soil, sequestering carbon, and preventing erosion (Kitchen et al., 2009). A burn can be especially beneficial in early spring (after the emergence of stem-overwintering insects), because it reduces pressure from undesirable species, clears dead plant material that prevents new growth, and adds bioavailable nutrients in the form of ash. While spring is generally a good time for burning, different species can be controlled by burning at different times of year based on the invasive species' phenology. Annual burns have been shown to control numerous invasive species, including *Bromus inermis, Elymus repens,* and *Phalaris arundinacea*, in a Midwestern prairie restoration (Betz et al., 1996). Although most invasive species can be controlled by prescribed burns, some species like *Lespedeza cuneata* may tolerate and thrive in burned areas; therefore, it is not a catch-all technique (Cummings et al., 2007).

If burning is infeasible, mowing or string trimming and removal of cut plant material can be a functional alternative (Busby, 2014). Although there are not many native prairie species that can withstand mowing at the typical rate of Eurasian turfgrasses, most native grasses and forbs are adapted to annual grazing and can, thus, tolerate some mowing. Few native tallgrass graminoids can form a typical turf, but shorter *Bouteloua, Buchloe,* and *Carex* species can form a tightly knit sod, especially in a polyculture (Simmons et al., 2011). The most effective way to keep invasive species from returning to an area after mechanical or chemical removal is to deliberately seed native species, as stressors and habitat fragmentation often inhibit natural native species regeneration (Schuster et al., 2018; Collings et al., 2023). In areas where ungulate pressure is high, mowing or burning should be conducted in early spring as the regrowth of vegetation is less palatable than vegetation cut in summer or early fall (Rea, 2003).

CHAPTER 2: NATIVE AND IDOT SEED MIX COMPARISON EXPERIMENT

INTRODUCTION

Roadside vegetation planting and management is an important, if often overlooked, consideration for highway construction and maintenance. Right-of-way (ROW) vegetation is meant to prevent erosion and inhibit invasive species and woody vegetation from colonizing these areas that need to be accessible for emergency vehicles, construction equipment, or motorists in the event of an accident. Aesthetics for motorists are also a consideration but are a lower priority than driver safety.

Roadside ROWs are typically seeded after construction, although plugs generally establish better on roadways overall (Gallagher and Wagenius, 2016; Young et al., 2017). Seeding roadsides presents several significant challenges. Roadsides are highly disturbed areas with poor soil characteristics and chemical inputs, which impact vegetation growth (Khan and Kathi, 2014; Sommer et al., 2018; Walker et al., 2021). These disturbed spaces are prime colonization areas for hardy, disturbance-tolerant invasive species (von der Lippe and Kowarik, 2007).

Although roadsides are typically planted with cool-season Eurasian grasses, seeding with native plants provides several benefits for wildlife and ecosystem services. Native plantings benefit populations of pollinating insects, birds, and mammals by providing habitat, forage sources, and corridors linking fragmented areas to each other (Underhill and Angold, 2000; Hopwood, 2008; Murray et al., 2009; Noordijk et al., 2011; Wojcik and Buchmann, 2012; Hopwood et al., 2015; Reppert and de Roode, 2018; Kaul and Wilsey, 2019). Native species can remove and sequester additives like fertilizers and pesticides, preventing them from entering waterways and contributing to eutrophication and insect decline (Hernandez-Santana et al., 2013; Zhou et al., 2014; Prosser et al., 2020; Tatariw et al., 2021).

Despite numerous benefits, many considerations are required to successfully establish native species. Seeding method, seasonality concerns, maintenance practices, site preparation, and picking the right species for a seed mix are all important aspects of roadside seeding. Most DOTs seed different mixes for different purposes, including lawns, roadsides, erosion-prone slopes, and drainage areas, which require different species and seeding methods. These elements are further complicated by the slow first-year growth of many native species. Despite these challenges and considerations, the benefits of native roadside seeding are highly impactful.

Our objective was to determine if fully native seed mixes can perform as well or better than currently listed partially to entirely non-native IDOT seed mixes for lawns, roadsides, and slope areas in northern and southern Illinois in their first growing season. Specifically, can deliberately designed native mixes provide effective plant cover and greater native species cover compared to existing IDOT mixes? An additional objective was to determine which seeded species effectively established and had the greatest cover over the first growing season. We measured first-year seeded species cover, native cover, and non-native cover, along with species richness and proportion of seeded species established. We hypothesized that a diverse native assemblage would reach higher cover and lower non-native cover than existing DOT mixes over time, although this may not be the case in the first year of establishment. We further hypothesized that native richness would be higher in the first year for newly designed native mixes even when compared against current IDOT slope mixes that contain native species.

METHODS

Site Selection

Four study site locations were determined in coordination with IDOT staff. At each study site, five paired plots were established. One plot in each pair was seeded with an existing IDOT seed mix, and the other plot was seeded with a newly designed native-only seed mix. The lawn and roadside experiments were conducted in IDOT District 5 at the Farmland Rest Area Eastbound in Farmer City, Illinois (Figure 1) and along I-74 eastbound leading up to the Farmland Rest Area Eastbound (Figure 2), respectively. The lawn plots were paired plots of 4 × 4 m (13 × 13 ft). The roadside plots were paired plots of 4 × 20 m (13 × 66 ft) and were oriented parallel to the roadway in a northwest–southeast orientation. The north slope experiment was conducted in IDOT District 2 in a cloverleaf lobe of the US 20/IL-251 intersection in Rockford, Illinois (Figure 3). The north slope plots were north–northwest-facing paired plots of 4 × 5 m (13 × 16 ft) with slopes between 15° and 20°. The south slope experiment was in IDOT District 2, along an inslope ditch in the IL 13/I-57/The Hill Avenue intersection in Marion, Illinois (Figure 4). The south slope plots were east-facing paired plots of 4 × 5 m (13 × 16 ft) with slopes between 18° and 22°. From correspondence with IDOT staff, all sites were previously seeded with an IDOT turfgrass mix of *Festuca arundinacea*, *Festuca rubra*, *Festuca brevipila*, and *Poa pratensis.* The south slope site was also seeded with the native legume *Desmanthus illinoensis* prior to the experiment to control erosion and rilling at the site. Unvegetated rills are still present south of the southernmost paired plot.

Seed Mix Design

We tested three newly designed, fully native seed mixes against current IDOT mixes for usage in lawns (Class 1), roadsides (Class 2), and slope areas (Class 3 and 3a for northern and southern Illinois slopes, respectively). We designed new mixes with high functional and phylogenetic diversity to increase the chances that plantings would remain diverse, persist well in varied conditions, and reduce overall maintenance costs (Meissen et al., 2020; Barak et al., 2022). Much of the initial restructuring of these mixes was informed by two previous studies on the use of native species on Illinois roadsides, which provided information on availability, disturbance tolerance, and pollinator value of some Illinois native plants (Busby, 2014; Sivicek, 2021).

We designed three experimental mixes (lawn, roadside, and slope) to have as many native species as possible given desired parameters, general availability in Midwestern nurseries (Zinnen and Matthews, 2022), and species availability from a native plant vendor (Prairie Moon Nursery, 2025). We also designed mixes to be salt tolerant and require minimal maintenance by being generally slow growing and weed excluding. We selected flowering species so that multiple species would be in bloom across as much of the growing season as possible (Lady Bird Johnson Wildflower Center, 2024). Though the mixes were composed of mostly slow-growing species, all mixes included several quickly establishing species to provide cover for other species to grow while preventing undesirable weeds from colonizing.

We added one or more legumes to each mix to provide some natural nitrogen fixation without over-nitrifying soil, which could reduce native species success by favoring weed growth (Fornara et al., 2012). Each mix contains *Chamaecrista fasciculata*, an annual legume, which has shown promise at adapting to roadside salt conditions and is a fast-establishing species (Goldsmith and Nashoba, 2021). Several common native forbs were omitted from these mixes due to various unsuitable growth characteristics, which could require more frequent maintenance. We excluded species with a height of greater than 1.5 m (5 ft) because they could affect roadside sightlines (e.g., *Andropogon gerardii*, *Sorghastrum nutans*, and many *Helianthus* species). Similarly omitted were species with rapid-spreading, weedy tendencies (e.g., *Heliopsis helianthoides*, *Eryngium yuccifolium*, *Solidago canadensis*, and most *Symphyotrichum* spp.) and woody growth forms (e.g., *Amorpha canescens*, *Senna hebecarpa*, *Ceanothus americanus*, and *Cephalanthus occidentalis*).

We determined seeding rates based on existing literature on species' ability to thrive in poor and disturbed soils, their coefficient of conservatism (Freyman et al., 2016), and the number of seeds per oz and cost of seed from vendor specifications (Prairie Moon Nursery 2025). Coefficient of conservatism (CC) is a measure of a species' fidelity to natural, low-disturbance habitat. Species with higher CC were seeded at greater rates to allow a greater chance of establishing a higher quality community and give less disturbance-tolerant species a greater likelihood of germination and persistence.

Each mix was designed to achieve roughly 535 germinated seedlings per m^2 (50 seedlings per ft^2). Total desired seedlings per ft^2 for each species was multiplied by the species' Illinois CC to yield a general experimental seeding baseline. Several species were reduced in seeding rate from that baseline if seeds were exceptionally large, expensive, or the species demonstrates spreading growth habits. Others were slightly increased if higher early cover of that species was desired.

The three native mixes were seeded at higher rates than is typical for restoration of native species onto bare soil from seed. Generally, about 535–1,070 seeds per m^2 (50–100 seeds per ft^2) are seeded in bare ground seeding restoration (Smith, 2010). However, our mixes were seeded at roughly 2,140 seeds per m^2 (200 seeds per ft^2). This was because these experiments represented an industrial control process for highly disturbed highway areas and not traditional ecological restoration projects. In highway ROW seeding, a high percent cover is paramount in the first year of seed establishment to prevent soil erosion and suppress unwanted species. A high seeding rate also serves as a hedge against seed predation by granivorous animals. Despite this, new mixes were 2–6 times less by weight per acre compared to existing IDOT mix counterparts (Tables 1–4).

The first experimental mix (Experimental Lawn Mix 1) was a replacement for IDOT Class 1, 1A, and 1B mixes as a minimal maintenance, salt-tolerant lawn mixture. This also replaces the Class 4A Low-Profile Native Grass mix, because all species are native and grow to heights of under 0.9 m (3 ft) if unmowed. Experimental Mix 1 consisted of seven native sedges and grasses and one annual legume (Table 1). The second experimental mix (Experimental Roadside Mix 2) was a replacement for IDOT Class 2 and 2A mixes, creating a low-maintenance, salt-tolerant roadside mix for road shoulders and right-of-way areas. Experimental Mix 2 consisted of 20 species of grasses, sedges, legumes, and forbs (Table 2). The third experimental mix (Experimental Slope Mix 3) was a replacement for IDOT Class 3 and 3A mixes for northern and southern Illinois slope stabilization, respectively. Experimental Mix 3 consisted of 38 native grasses, sedges, forbs, and legumes (Table 3 for IDOT Mixes 3 and 3A, Table 4 for experimental mix), and was designed to include deep-rooted species that are also tolerant of Imazapic (Plateau) herbicide. This was to make it easier for road managers to target noxious weeds selectively without damaging the planted native community or jeopardizing slope stability. This mix includes every native species listed in IDOT Mixes 3 and 3A apart from *Dalea candida*, which was unavailable from the native seed vendor at the time of purchase. Experimental Slope Mix 3 is close to the theoretical optimum for grassland seeding rate and diversity (Barr et al., 2017). The IDOT Slope Mix 3 that we received from our IDOT seed mix vendor had an unanticipated addition of 54 kg (120 lb) of four turf grasses (*Festuca rubra*, *Festuca arundinacea*, *Poa pratensis*, *Pucinellia distans*) that are not in the pure IDOT Mix 3 specifications in the IDOT specifications manual. We seeded these plots at the correct rate of application for the stand-alone IDOT Mix 3 with the inclusion of these turf grasses. The decision was made not to include a cover crop for any mixes (generally for a fall seeding, *Triticum aestivum* is used by IDOT [2024]) as we wanted to assess the first-year cover and introduced (non-native, non-seeded) species control potential of these seed mixes unimpeded by cover crops.

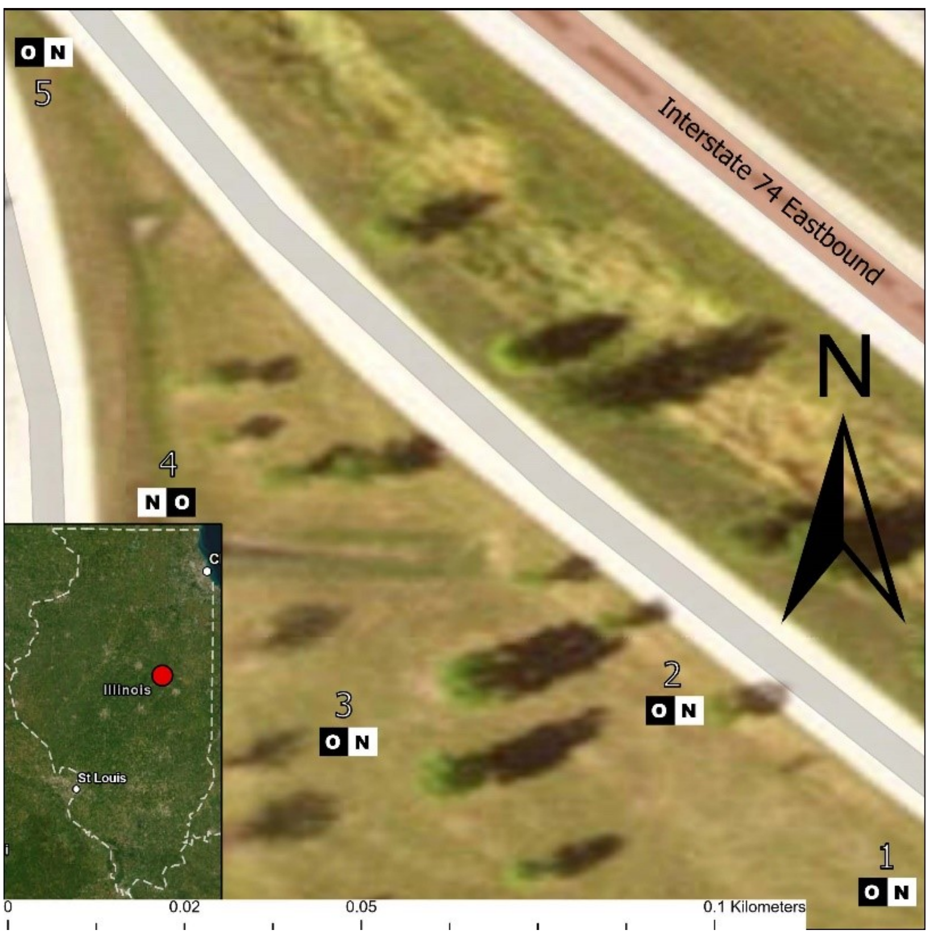

Figure 1. Map. Paired plot placements for lawn seed experiment (O: IDOT Mix 1a; N: Experimental Lawn Mix 1).

Table 1. Mixes for low-maintenance, salt-tolerant lawn experiment

Experimental Lawn Mix 1 (88.2 lb/acre, 8 species)			IDOT Mix 1a Salt-Tolerant Lawn Mix (180 lb/acre, 5 species)		
Common name	**Scientific name**	**Seeding rate (lb/acre)**	**Common name**	**Scientific name**	**Seeding rate (lb/acre)**
Broomsedge	*Andropogon virginicus*	0.2	Red Fescue	*Festuca rubra*	20
Side-Oats Grama	*Bouteloua curtipendula*	19.0	Hard Fescue	*Festuca brevipila*	20
Buffalograss	*Bouteloua dactyloides*	37.8	Perennial Ryegrass	*Lolium perenne*	20
Blue Grama	*Bouteloua gracilis*	3.4	Bluegrass	*Poa pratensis*	60
Plains Oval Sedge	*Carex brevior*	2.3	Salty Alkaligrass	*Puccinellia distans*	60
Fox Sedge	*Carex vulpinoidea*	0.6			
Partridge Pea	*Chamaecrista fasciculata*	7.6			
Slender Wheatgrass	*Elymus trachycaulus*	17.4			

Figure 2. Map. Paired plot placements for roadside seed experiment (O: IDOT Mix 2a; N: Experimental Roadside Mix 2).

Table 2. Experimental roadside mix 2 for low-maintenance, salt-tolerant roadside plantings

Experimental Roadside Mix 2 (69.6 lb/acre, 22 species)			IDOT Mix 2a Salt Tolerant Roadside Mix (200 lb/acre, 5 species)		
Common name	**Scientific name**	**Seeding rate (lb/acre)**	**Common name**	**Scientific name**	**Seeding rate (lb/acre)**
Broomsedge	*Andropogon virginicus*	0.2	Tall Fescue	*Festuca arundinacea*	60
White Sage	*Artemisia ludoviciana*	0.1	Hard Fescue	*Festuca brevipila*	30
Side-Oats Grama	*Bouteloua curtipendula*	19.0	Red Fescue	*Festuca rubra*	30
Buffalograss	*Bouteloua dactyloides*	18.9	Perennial Ryegrass	*Lolium perenne*	20
Blue Grama	*Bouteloua gracilis*	1.7	Salty Alkaligrass	*Puccinellia distans*	60
Plains Oval Sedge	*Carex brevior*	1.9			
Fox Sedge	*Carex vulpinoidea*	0.5			
Partridge Pea	*Chamaecrista fasciculata*	3.0			
Showy Ticktrefoil	*Desmodium canadense*	2.5			
Pale Purple Coneflower	*Echinacea pallida*	7.3			
Canada Wild Rye	*Elymus canadensis*	1.0			
Slender Wheatgrass	*Elymus trachycaulus*	3.2			
Virginia Wildrye	*Elymus virginicus*	6.2			
Purple Lovegrass	*Eragrostis spectabilis*	0.1			
Foxglove Beardtongue	*Penstemon digitalis*	0.2			
Slender Mountain Mint	*Pycnanthemum tenuifolium*	0.1			
Yellow Coneflower	*Ratibida pinnata*	0.4			
Black-Eyed Susan	*Rudbeckia hirta*	0.2			
Little Bluestem	*Schizachyrium scoparium*	0.9			
Sand Dropseed	*Sporobolus cryptandrus*	0.1			
Prairie Dropseed	*Sporobolus heterolepis*	1.7			
Hoary Vervain	*Verbena stricta*	0.4			

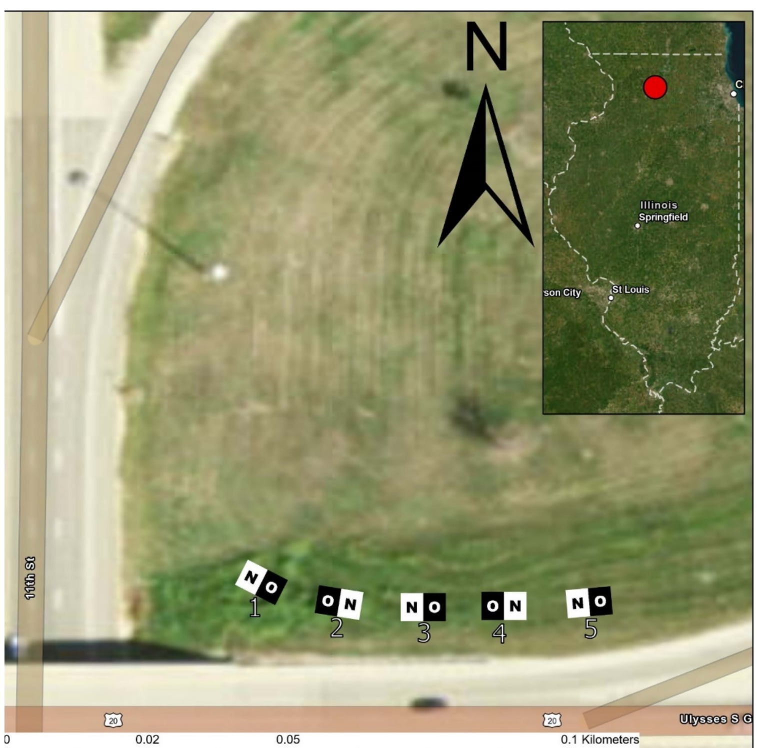

Figure 3. Map. Paired plot placements for north slope seed experiment (O: IDOT Mix 3; N: Experimental Slope Mix 3). Plot size and position to scale.

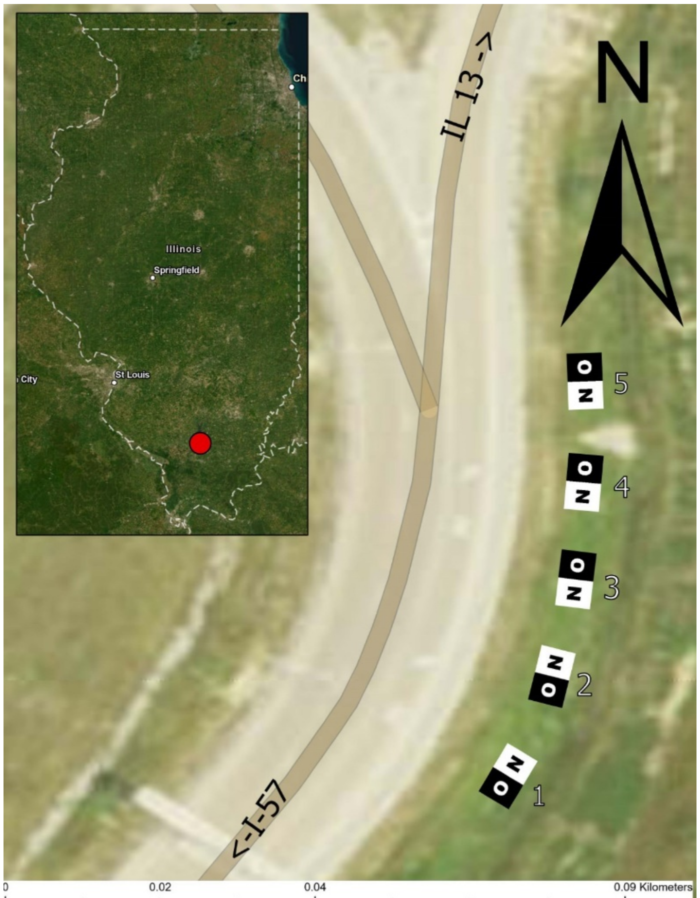

Figure 4. Map. Paired plot placements for south slope seed experiment (O: IDOT Mix 3a; N: Experimental Slope Mix 3).

Table 3. IDOT north and south slope mixes

IDOT Mix 3 North Slope Mix (293 lb/acre†, 14 species)			IDOT Mix 3a South Slope Mix (132 lb/acre, 8 species)		
Common name	**Scientific name**	**Seeding rate (lb/acre)**	**Common name**	**Scientific name**	**Seeding rate (lb/acre)**
Spring Oats	*Avena sativa*	50	Spring Oats	*Avena sativa*	50
Side-Oats Grama	*Bouteloua curtipendula*	20	Side-Oats Grama	*Bouteloua curtipendula*	10
Buffalograss	*Bouteloua dactyloides*	5	White Prairie Clover	*Dalea candida*	5
Illinois Bundleflower	*Desmanthus illinoensis*	1	Canada Wild Rye	*Elymus canadensis*	20
Canada Wild Rye	*Elymus canadensis*	10	Perennial Ryegrass	*Lolium perenne*	20
Slender Wheat Grass	*Elymus trachycaulus*	5	Switchgrass	*Panicum virgatum*	10
*Tall Fescue	*Festuca arundinacea*	50	Black-Eyed Susan	*Rudbeckia hirta*	5
*Red Fescue	*Festuca rubra*	30	Little Bluestem	*Schizachyrium scoparium*	12
Annual Ryegrass	*Lolium multiflorum*	15			
Perennial Ryegrass	*Lolium perenne*	40			
*Kentucky Bluegrass	*Poa pratensis*	10			
*Salty Alkaligrass	*Puccinellia distans*	30			
Little Bluestem	*Schizachyrium scoparium*	25			
Alsike Clover	*Trifolium hybridum*	2			

†Stand-alone mix in IDOT specification manual is 173 lb/acre.

*Denotes species added to IDOT mix by seed vendor.

Table 4. Experimental slope mix 3 for low-maintenance, salt-tolerant slope stabilization

Experimental Slope Mix 3 (49.4 lb/acre, 38 species)		
Common name	**Scientific name**	**Seeding rate (lb/acre)**
Broomsedge	*Andropogon virginicus*	0.1
White Sage	*Artemisia ludoviciana*	0.1
Common Milkweed	*Asclepias syriaca*	1.0
White Wild Indigo	*Baptisia alba*	4.8
Side-Oats Grama	*Bouteloua curtipendula*	4.8
Buffalograss	*Bouteloua dactyloides*	1.9
Blue Grama	*Bouteloua gracilis*	0.2
Plains Oval Sedge	*Carex brevior*	0.4
Fox Sedge	*Carex vulpinoidea*	0.1
Partridge Pea	*Chamaecrista fasciculata*	3.0
Lanceleaf Tickseed	*Coreopsis lanceolata*	1.0
Illinois Bundleflower	*Desmanthus illinoensis*	2.6
Showy Ticktrefoil	*Desmodium canadense*	2.5
Pale Purple Coneflower	*Echinacea pallida*	3.7
Canada Wildrye	*Elymus canadensis*	1.0
Slender Wheat Grass	*Elymus trachycaulus*	1.6
Virginia Wildrye	*Elymus virginicus*	1.6
Purple lovegrass	*Eragrostis spectabilis*	0.1
Prairie Junegrass	*Koeleria macrantha*	0.1
Prairie Blazing Star	*Liatris pycnostachya*	3.0
Wild Bergamot	*Monarda fistulosa*	0.3
Common Evening-primrose	*Oenothera biennis*	0.1
Rigid Goldenrod	*Oligoneuron rigidum*	0.2
Switchgrass	*Panicum virgatum*	0.8
Foxglove Beardtongue	*Penstemon digitalis*	0.1
Slender Mountain Mint	*Pycnanthemum tenuifolium*	0.1
Yellow Coneflower	*Ratibida pinnata*	0.7
Black-Eyed Susan	*Rudbeckia hirta*	0.1
Little Bluestem	*Schizachyrium scoparium*	0.9
Compass Plant	*Silphium laciniatum*	6.9
Oldfield Goldenrod	*Solidago nemoralis*	0.1
Showy Goldenrod	*Solidago speciosa*	0.3
Sand Dropseed	*Sporobolus cryptandrus*	1.0
Prairie dropseed	*Sporobolus heterolepis*	1.7
Silky Aster	*Symphyotrichum sericeum*	0.4
Ohio Spiderwort	*Tradescantia ohiensis*	1.5
Hoary Vervain	*Verbena stricta*	0.3
Golden Alexander	*Zizia aurea*	1.5

Site Preparation and Maintenance

All sites were marked with reflective poles prior to site preparation. The planting method used for all mixes was based on recommendations for native seeding in the Minnesota DOT *Seeding Manual* (MnDOT, 2024b). All plots were cleared of existing vegetation via a round of low-height mowing, glyphosate application, and another round of mowing one to two weeks later beginning in mid-September and continuing until late October 2023. Seeding was conducted in mid-November (when soil temperatures reached ~4.4°C [40°F]). Plots were lightly raked, seeds were evenly hand broadcast onto the dead, cut material already present, rolled with a 13.6 kg (30 lb) weighted packing wheel to increase soil contact, and then covered with M-Binder Plantago Psyllium Husk Tackifier powder at a rate of 156 kg/ha (140 lb/ac) and wetted with fresh water at a rate of 748 L/ha (80 gal/ac). Psyllium Husk tackifier is listed for use by the MnDOT and is the easiest to apply on a small scale without industrial machinery. Because we seeded into plant material and not bare soil, we did not use additional straw mulch or fertilizer. In the first growing year, all plots were mowed once or twice, depending on vegetative growth. Lawn and roadside plots were mowed on June 6 and August 21, 2024. North slope plots were mowed only once on August 14 due to limited vegetation pressure after the May survey. The south slope sites were mowed on May 1 and August 23.

Survey Methods

Prior to site preparation and seeding, we collected percent cover data for all vascular plant species in all plots. These pre-preparation surveys were conducted in 2023 on June 7 for lawn sites, August 2 for roadside and north slope sites, and August 16 for south slope sites. For each plot, every species was identified to the nearest 5% cover, with species closer to 1% than 5% receiving a 1%. For all pre-preparation surveys, incidences of *Festuca arundinacea*, *Festuca rubra*, *Festuca brevipila*, and *Poa pratensis* were considered “seeded” species and all others were considered “non-seeded” “native” or “non-native” species.

May surveys were conducted in 2024 on May 29 for lawn, roadside, and north slope sites and May 30 for south slope sites. August surveys were conducted in 2024 on August 6 for north slope sites, August 12 for lawn and roadside sites, and August 13 for south slope sites. Posttreatment surveys were conducted following the same methods used in the pre-preparation surveys. Some species could only be identified to genus level if distinguishing species characteristics were not present. For other species we were unable to identify past genus, we consulted the seed mix sown at each site and assigned species based on listed planted seed. *Carex* spp. found in sites where both *Carex brevior* and *Carex vulpinoidea* were sown were assumed to be one of the two. *Carex* spp. fruits did not reach identifiable maturity during any survey.

Cover and Richness Analyses

For each experimental plot and each sampling event, we calculated cover of non-vegetated, bare ground as well as relative cover of seeded species, native species, and (non-seeded) non-native species. We also calculated richness of native and non-native species. We used paired t-tests, separately for each experiment and sampling date, to determine if mean response variables differed between the two seed mix treatments. All analyses were conducted in R (RStudio, 2024).

Seeded Species Observations

To determine which seeded species germinated in the first year of seeding, we reviewed all seeded species for observation in posttreatment sites. If a species was present in either the May or August 2024 surveys of a plot, we considered it present at that plot.

RESULTS

Pre-preparation Vegetation Surveys

Prior to site preparation and planting, there were no significant differences in any measured variables between IDOT mix plots and experimental mix plots in any experimental site, suggesting all subsequently observed differences resulted from seeding treatments (Table 5, Figures 5–8). After site preparation and seeding, non-vegetated (bare ground or plant litter) cover increased at experimental sites except the south slope plots compared to the pretreatment surveys (Figures 5–8).

Lawn Seed Mixes

Seeded cover in lawn plots increased for both mixes over the first growing season (Table 5), and by August 2024, the IDOT mix had a significantly higher mean seeded cover than Experimental Lawn Mix 1, although neither mix approached the > 75% seeded cover from the pretreatment survey (Figure 5, Table 5). In the lawn plots, bare ground cover after seeding was generally higher for Experimental Lawn Mix 1 compared to IDOT Mix 1a, although it was below 25% in all plots (Figure 5, Table 5). Mean native cover increased for posttreatment lawn plots. Mean native cover was stable across the first growing season for Experimental Lawn Mix 1 but decreased from May to August for the IDOT mix. In August 2024, native cover was significantly higher for the fully native experimental mix (Figure 5, Table 5). Mean non-native cover increased compared to the pretreatment survey but remained relatively stable for both mixes over the first growing season. Mean native richness increased posttreatment and was significantly higher for the experimental mix compared to the IDOT mix in August 2024 (Figure 5, Table 5). Mean non-native richness increased from pretreatment through the first growing season but did not differ between seeding treatments (Figure 5, Table 5).

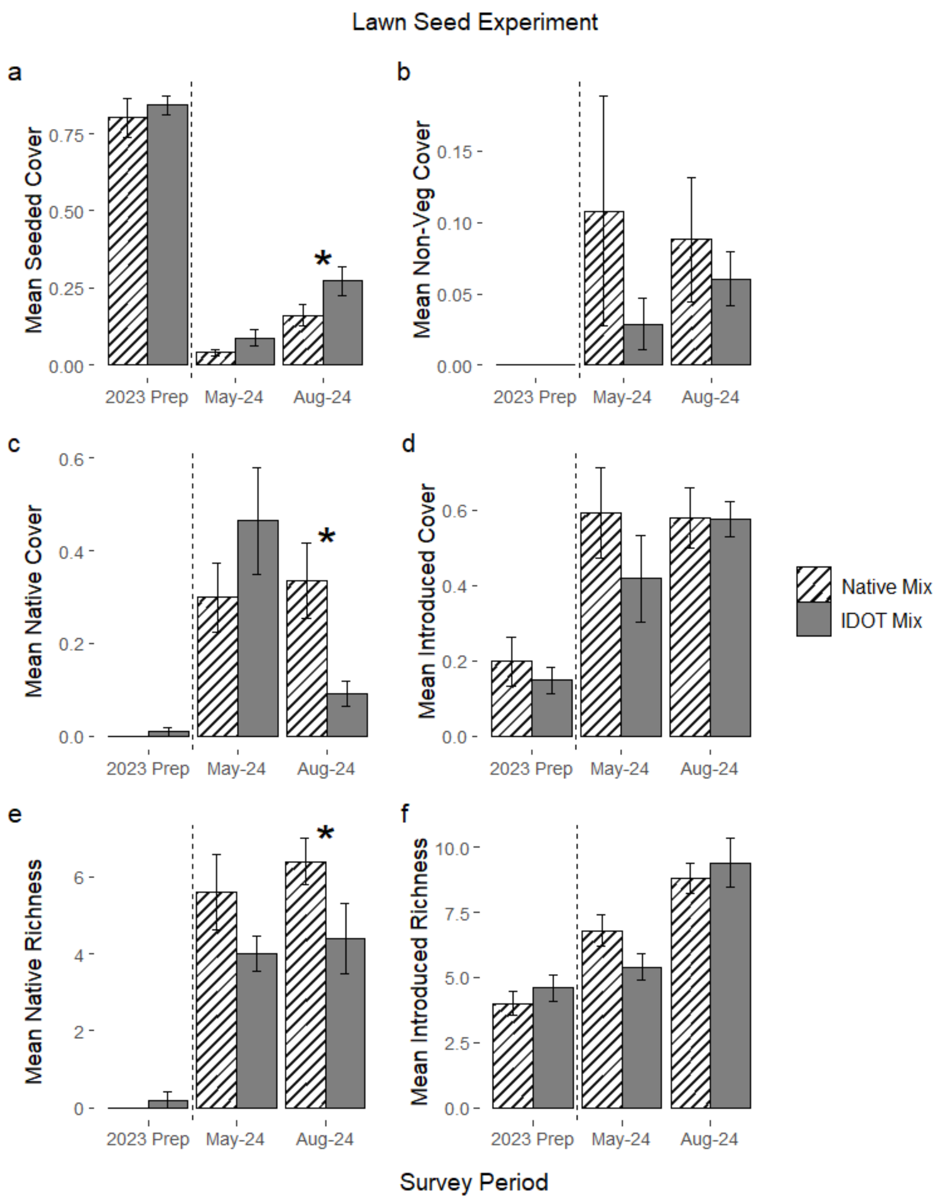

Figure 5. Graph. Plant cover, richness, and bare ground in lawn experimental plots. Bars are mean values, and error bars are one standard error margin. Vertical dashed line distinguishes between pre- and posttreatment surveys. Asterisk (*) above bars denotes significant difference ($p < 0.05$) between mixes from paired t-test.

Roadside Seed Mixes

Mean seeded cover in roadside plots was significantly higher for IDOT Mix 2a than Experimental Roadside Mix 2 in May 2024 (Table 5, Figure 6), but by August 2024, IDOT Mix 2a seeded cover had decreased and Experimental Roadside Mix 2 seeded cover had increased to roughly even (Figure 6). The majority of seeded cover for IDOT mix plots in May 2024 was made up by *Poa pratensis,* but by August, this species was less abundant. Non-vegetated cover in roadside plots was higher posttreatment compared to pretreatment, and non-vegetated cover was higher for the experimental mix plots compared to the IDOT mix plots in May 2024, but non-vegetated cover decreased to near pretreatment levels by August for both mixes (Figure 6). Mean native cover increased compared to pretreatment levels and was significantly higher for the fully native experimental mix plots compared to IDOT mix plots in August 2024 (Table 5, Figure 6). Mean non-native cover increased through the posttreatment surveys, and by August 2024 was higher, although not significantly, for the IDOT mix than the experimental mix plots (Figure 6). Mean native richness was near pretreatment values in May 2024 for both mixes but was higher in August and significantly higher for the experimental mix plots compared to the IDOT mix plots (Table 5, Figure 6). Mean non-native richness was similar to pretreatment values for May 2024 but was much higher for both mixes in August (Figure 6).

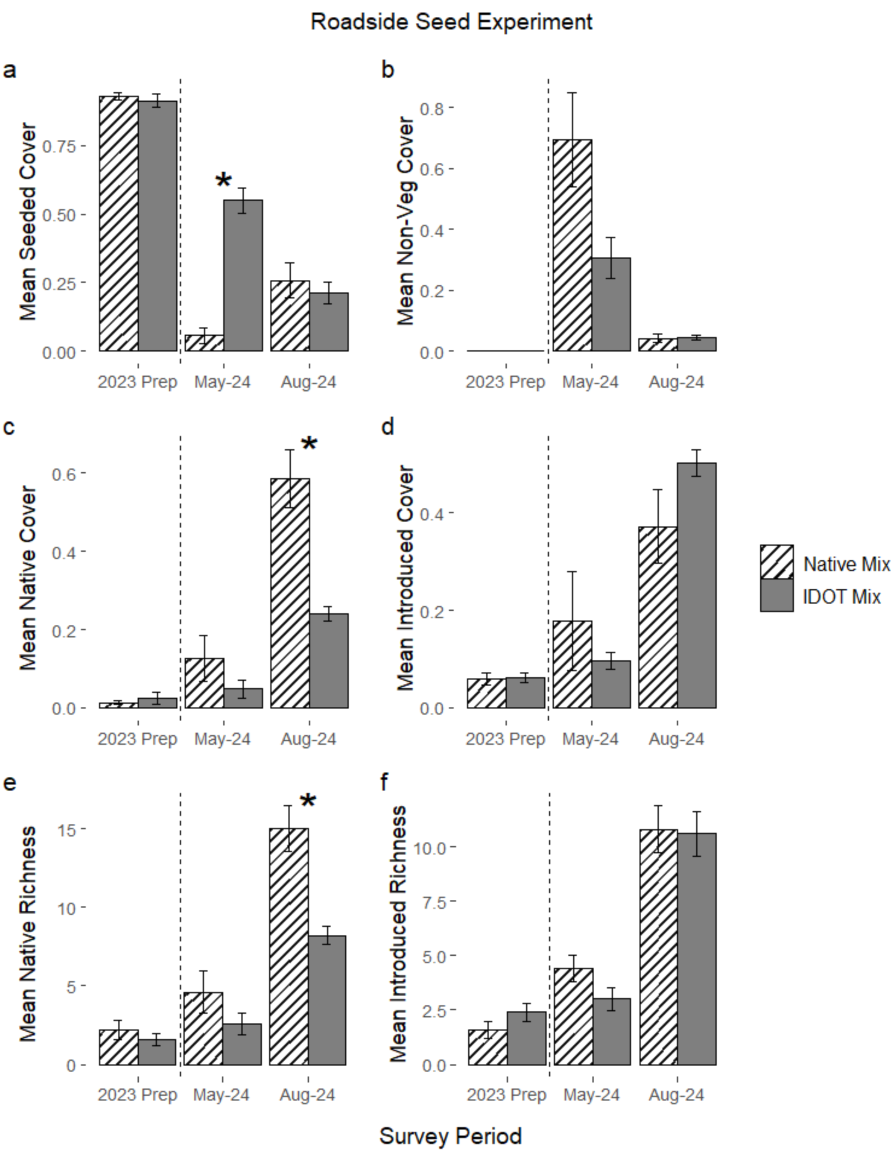

Figure 6. Graph. Plant cover, richness, and bare ground in roadside experimental plots. Bars are mean values, and error bars are one standard error margin. Vertical dashed line distinguishes between pre- and posttreatment surveys. Asterisk (*) above bars denotes significant difference ($p < 0.05$) between mixes from paired t-test.

North Slope Seed Mixes

Mean seeded cover in the north slope experimental plots decreased compared to pretreatment levels but was significantly higher for Experimental Slope Mix 3 compared to IDOT Mix 3 by August 2024 (Table 5, Figure 7). Non-vegetated cover in north slope plots was very high in May 2024 but declined to near pretreatment levels for both mixes by August 2024 (Figure 7). Mean native cover was near pretreatment levels for May 2024 but significantly higher for experimental mix plots compared to the IDOT mix plots for this survey (Table 5, Figure 7). By August 2024 native cover for both mixes had increased considerably, but native cover in the experimental mix plots was still significantly higher than in the IDOT mix plots (Table 5, Figure 7). Non-native cover was relatively unchanged for the May 2024 survey compared to the pretreatment surveys for both mixes but increased by August 2024 for both mixes, although it was generally higher for the IDOT mix (Figure 7). Mean native richness increased for both mixes compared to pretreatment surveys and increased over the first growing season (Figure 7). However, the experimental mix was significantly higher than the IDOT mix in both May and August 2024 (Table 5, Figure 7). Mean non-native richness changed little from the pretreatment survey but did increase slightly by August 2024 for both mixes (Figure 7).

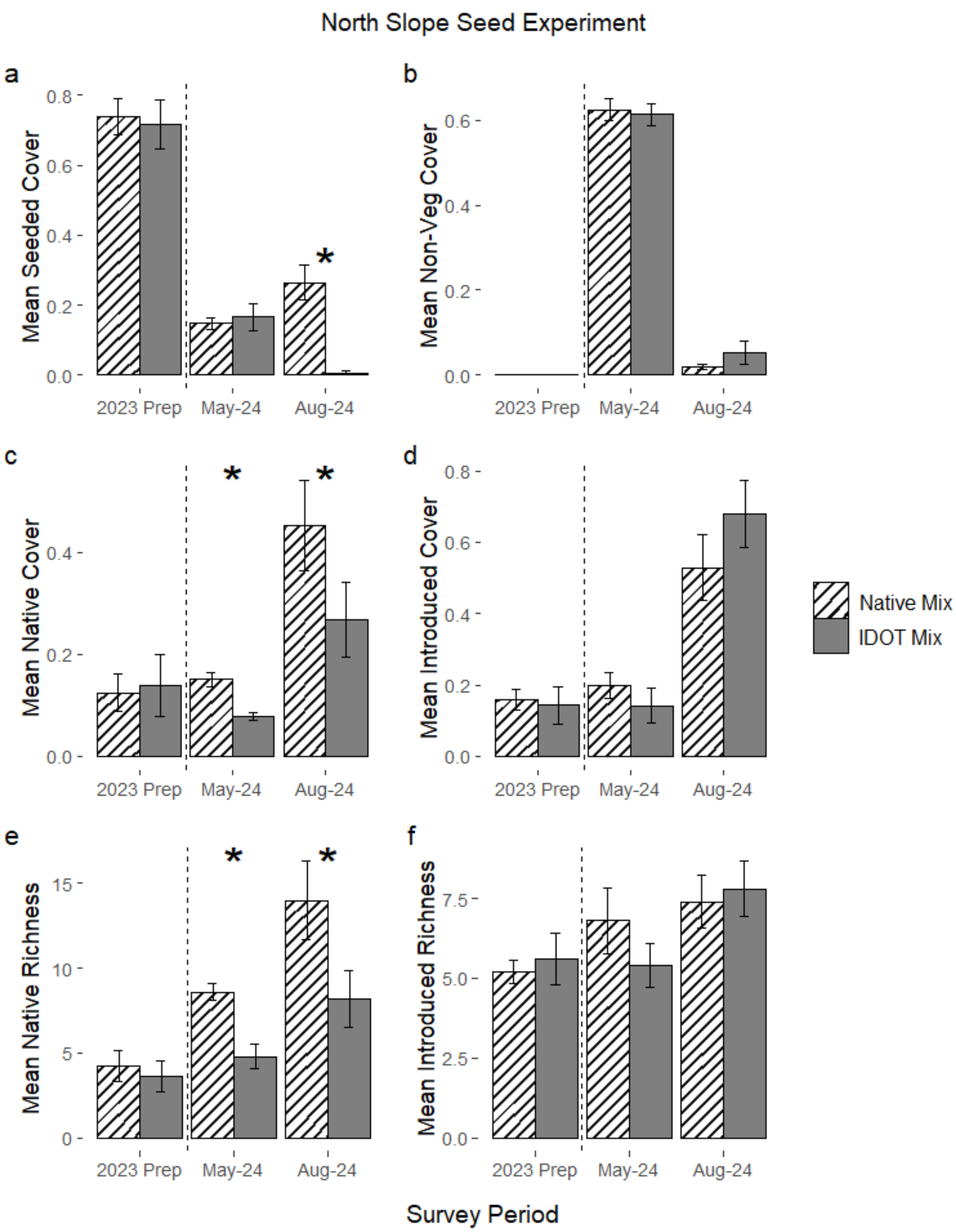

Figure 7. Graph. Plant cover, richness, and bare ground in north slope experimental plots. Bars are mean values, and error bars are one standard error margin. Vertical dashed line distinguishes between pre- and posttreatment surveys. Asterisk (*) above bars denotes significant difference ($p < 0.05$) between mixes from paired t-test.

South Slope Seed Mixes

Seeded cover remained low at all south slope experimental plots throughout the first growing season (Figure 8). Non-vegetated cover at south slope plots decreased for Experimental Slope Mix 3 posttreatment but remained relatively stable for the IDOT Mix 3a plots from pretreatment through the first growing season (Figure 8). Native cover increased for both seed mixes into the first growing season but did not reach the pretreatment cover (Figure 8). Non-native cover was high for posttreatment surveys for both mixes and was higher than pretreatment (Figure 8). Native richness was significantly higher for the experimental mix plots compared to the IDOT mix plots by August 2024 (Table 5, Figure 8). Non-native richness increased somewhat from May to August 2024 but was near pretreatment conditions for both posttreatment surveys (Figure 8).

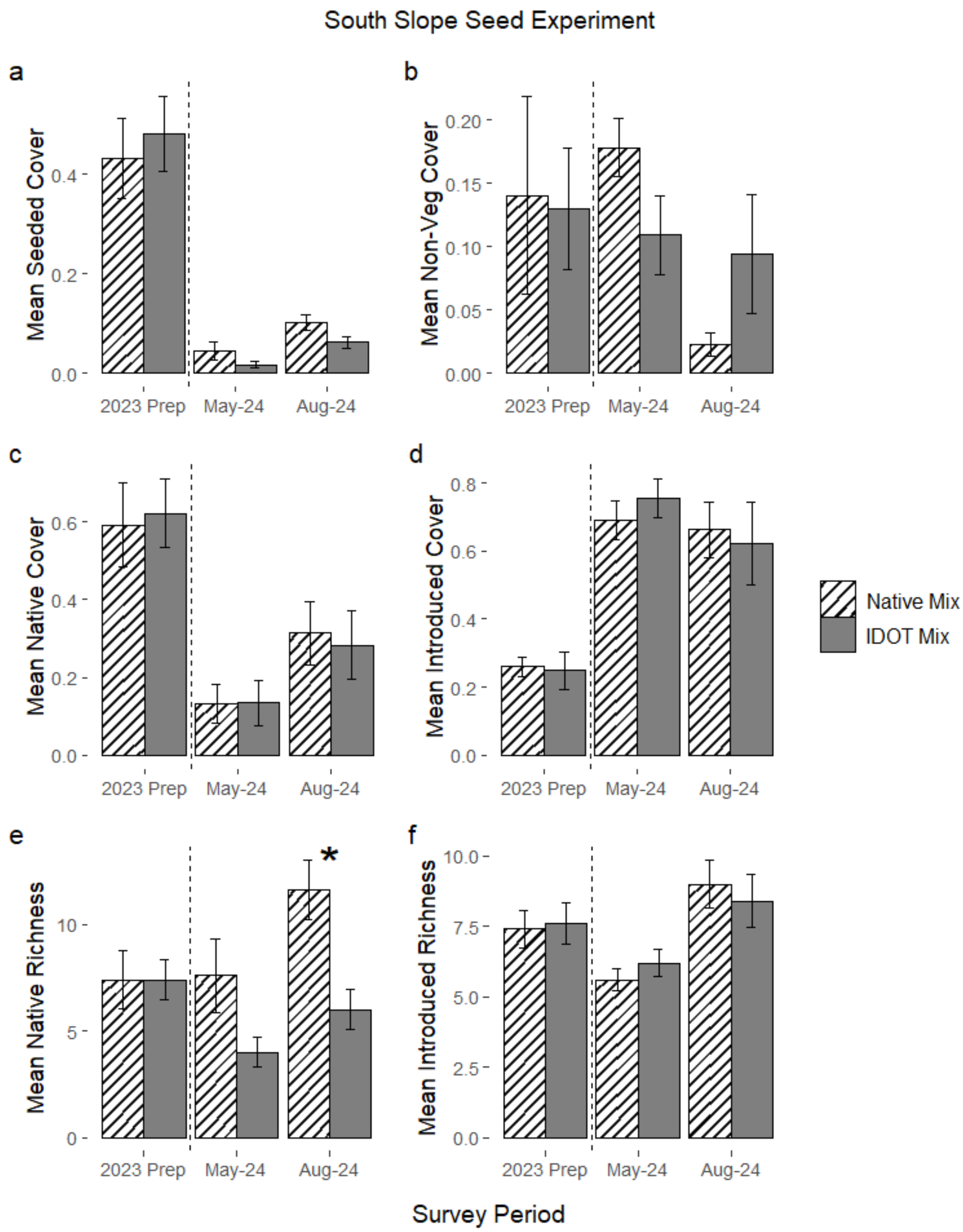

Figure 8. Graph. Plant cover, richness, and bare ground in south slope experimental plots. Bars are mean values, and error bars are one standard error margin. Vertical dashed line distinguishes between pre- and posttreatment surveys. Asterisk (*) above bars denotes significant difference (p < 0.05) between mixes from paired t-test.

Table 5. T-statistics from paired t-tests for all experiments and survey dates

Experiment	Survey date	Seeded cover	Non-native (non-seeded) cover	Bare/ litter cover	Native cover	Native richness	Non-native (non-seeded) richness
Lawn	2023 Prep	0.75	−1.00	0.00	1.00	1.00	1.18
	May 2024	1.78	−1.38	−0.91	2.21	−1.63	−1.51
	August 2024	**2.80***	−0.03	−0.86	**−3.56***	**−2.83***	0.50
Roadside	2023 Prep	−0.81	0.47	0.00	0.80	−2.45	2.14
	May 2024	**7.87****	−0.75	−2.02	−1.22	−1.41	−1.87
	August 2024	−0.77	1.66	0.35	**−5.55****	**−6.11****	−0.13
North slope	2023 Prep	−0.38	−0.28	0.00	0.35	−0.53	0.59
	May 2024	0.46	−1.38	−0.30	**−4.73****	**−3.92***	−1.16
	August 2024	**−5.10****	2.06	1.42	**−3.31***	**−3.64***	0.59
South slope	2023 Prep	1.75	−0.33	−0.31	0.47	0.00	0.23
	May 2024	−1.54	0.76	−1.76	0.02	−1.72	1.00
	August 2024	−2.49	−0.92	1.60	−1.11	**−5.44****	−0.50

*$p < 0.05$, **$p < 0.01$

Germinated Seeded Species

Table 6 lists observation rates of all seeded species across all four experiments. Fifteen of 48 species were never observed. Non-native seeded species *Poa pratensis*, *Festuca rubra*, and *Festuca arundinacea* were observed in between 60%–100% of all sites in which they were seeded. Eleven native species (including indistinguishable *C. brevior* and *C. vulpinoidea*) were found in ≥ 50% of seeded plots. Of these 11 native species, five are not currently in use in any IDOT standard specifications manual seed mix (IDOT, 2024). These were *Asclepias syriaca*, *Carex brevior* (potentially), *Chamaecrista fasciculata*, *Oenothera biennis*, and *Verbena stricta.*

Elymus virginicus had the greatest percentage of seeded plot observations (47%) of any native graminoid. Although only present in 37% of seeded sites, *Bouteloua curtipendula* made up a large proportion of native cover for most of those plots and had the greatest cover of any seeded native grass. Legumes *Chamaecrista fasciculata* and *Desmanthus illinoensis* were observed at 80% and 73% of seeded plots, respectively.

Table 6. Observations of seeded species in seeded plots and in plots where the species was not seeded, in order of highest to lowest seeded plot observation percentage. Underlined scientific names are non-native species seeded in one or more IDOT mix.

Scientific Name	Total plots seeded	Seeded plots observed	Other plots observed	% seeded plots observed
*Poa pratensis**	10	10	21	100%
Coreopsis lanceolata	10	9	0	90%
*Festuca rubra**	10	9	11	90%
Asclepias syriaca	10	8	5	80%
Chamaecrista fasciculata	20	16	1	80%
Desmanthus illinoensis	15	11	5	73%
Echinacea pallida	15	11	1	73%
*Festuca arundinacea**	15	9	13	60%
Oenothera biennis	10	6	8	60%
Zizia aurea	10	6	3	60%
Verbena stricta	15	8	1	53%
Carex brevior/C. vulpinoidea†	20	10	5	50%
Elymus virginicus	15	7	0	47%
Liatris pycnostachya	10	4	0	40%
Ratibida pinnata	15	6	1	40%
Rudbeckia hirta	20	8	1	40%
Bouteloua curtipendula	30	11	0	37%
Silphium laciniatum	10	3	0	30%
*Lolium perenne**	20	5	0	25%
Elymus canadensis	25	6	0	24%
Oligoneuron rigidum	10	2	0	20%
*Trifolium hybridum**	5	1	0	20%
Schizachyrium scoparium	25	4	0	16%
Andropogon virginicus	20	3	0	15%
Artemisia ludoviciana	15	2	0	13%
Desmodium canadense	15	2	0	13%
Elymus trachycaulus	25	3	0	12%
Monarda fistulosa	10	1	2	10%
Tradescantia ohiensis	10	1	0	10%
Panicum virgatum	15	1	7	7%
Penstemon digitalis	15	1	0	7%
Bouteloua dactyloides	25	1	0	4%
*Avena sativa**	10	0	0	0%
Baptisia alba	10	0	0	0%
Bouteloua gracilis	20	0	0	0%
Dalea candida	5	0	0	0%
Eragrostis spectabilis	15	0	0	0%
*Festuca brevipila**	15	0	0	0%
Koeleria macrantha	10	0	0	0%
*Lolium multiflorum**	5	0	0	0%
Puccinellia distans	10	0	0	0%
Pycnanthemum tenuifolium	15	0	0	0%
Solidago nemoralis	10	0	0	0%
Solidago speciosa	10	0	0	0%
Sporobolus cryptandrus	15	0	0	0%
Sporobolus heterolepis	15	0	0	0%
Symphyotrichum sericeum	10	0	0	0%

*Non-native species

†*Carex brevior* and *Carex vulpinoidea* observations were combined because they could not be distinguished in the first year.

Common Non-seeded Native Species

We also evaluated occurrences of non-seeded, native species that recruited into plots posttreatment, which may suggest these species could be considered for deliberate seeding. *Eupatorium* spp. (*E. altissimum* and *E. serotinum*) were found in 22 plots. *Hordeum jubatum* was found at 20 plots. *Solidago canadensis* was found in 17 plots. *Asclepias verticillata* was found in 15 plots. Native *Euphorbia* spp. (*E. dentata* and *E. corollata*) were found in 15 plots.

DISCUSSION

Given the general assumption that native species take several years to fully establish from seed, along with the fact that our native seed mixes were seeded at much lower rates than IDOT mixes, it was encouraging that there was significantly higher native richness for all native mixes by August of the first growing season (Table 5) and that all experiments except the south slope trials showed significantly higher native cover by August. The north slope trials showed significant increases in native cover and richness even earlier during the May survey, highlighting the effectiveness of the native experimental mix compared to the IDOT North Slope Mix 3, which had an additional 54 kg (120 lb) of turfgrass seed inadvertently added by our vendor. It is also noteworthy that high-diversity native mixes did not significantly impact non-native, non-seeded species cover or richness. However, in most sites by August 2024, non-native, non-seeded cover and richness were somewhat higher for IDOT mixes compared to experimental native mixes. Further data collection in the second growing season may provide stronger signals for these and other results.

The lawn trials had the lowest recruitment of any trial. This was also the lowest diversity native mix of any trial, and a more diverse mix with higher functional group diversity may improve results. High non-vegetated (bare ground/litter) cover may be a result of the seeding mixes or an artifact of the relatively exposed gravelly nature of some of our plots in this trial. High non-native, non-seeded species cover and richness suggests high invasion pressure at this site, which may be exacerbated by edge effects of small plots. By August 2024, the highest native covers were *Carex* spp. (likely seeded *Carex vulpinoidea* or *Carex brevior*) and *Bouteloua curtipendula. Chamaecrista fasciculata* was also present in most seeded plots. We found one incidence of *Achillea millefolium* that was present before treatment and persisted throughout the trials. This disturbance-tolerant, short-growing herbaceous species may be a worthy inclusion in a lawn mix.

The roadside trial showed near complete coverage (low non-vegetated cover) by August 2024, which is encouraging. We believe the change in IDOT mix seeded cover was due to the high *Poa pratensis* cover from May 2024 being reduced by a maintenance mow between surveys. Non-native, non-seeded cover and richness continued to increase over the first growing season and was generally higher (although not significantly) for the IDOT mix. High August 2024 cover for native mix plots was due mostly to *Bouteloua curtipendula*, *Chamaecrista fasciculata*, *Elymus virginicus*, and *Panicum virgatum. Panicum virgatum* was not seeded in this mix but was likely seeded nearby as part of a prior seeding project at the nearby rest area. There was also moderate recruitment of *Echinacea pallida* and *Verbena stricta* at these sites, though cover of both was very low.

The north slope trials had the most significant results of any experiment. The result of almost no non-vegetated cover by August is encouraging generally, but one especially interesting result is that by August, the experimental native mix plots had significantly more seeded cover than the IDOT mix plots, which had almost no seeded cover at all. This may suggest the IDOT mix was crowded out by naturally recruited native and introduced species. Considering these plots had the heaviest seeding rate of any plots in all four trials (due partially to the inclusion of 54 kg [120 lb] of turfgrass seed), and contained a number of native species, it is noteworthy that a high-diversity, fully native mix, seeded at a lower rate, was more successful. Further research and surveys into the following growing season would be beneficial. The significantly higher native cover and richness in experimental slope mix plots in May and August also highlights the value of native mixes in these areas. Many of the 38 seeded native species in this mix did not establish in year one, and if shown to not establish in year two, they could be removed from this seed mix, potentially lowering costs. Most of the non-native cover was due to *Daucus carota*, a roadside weed that is common in early restoration plantings but manageable through mowing until the stand establishes (David Almy, IDOT pers. comm., online meeting, Aug. 31, 2024).

Compared to the north slope trials, the south slope trials resulted in fewer differences between the experimental mix and IDOT Mix 3a. By August 2024, the native mix plots had reached significantly higher native richness than the IDOT mix plots. Seeded cover remained low across the growing season, and non-vegetated cover was much higher (albeit not significantly) for the IDOT mixes by August 2024. Non-native, non-seeded cover and richness were high across the growing season. Both plot types had high cover of *Sorghum halapense* and *Bromus inermis*. It is possible this trial was less successful than the northern slope mix for several reasons. This trial was situated in a high-erosion area, which may have resulted in more loss of seeds than the north slope site. There are soil rills present at the site, and erosion control was the main reason that IDOT previously overseeded this area with *Desmanthus illinoensis* (Mike Fuhrhop, IDOT, pers. comm., online meeting, March 30, 2024). This site was also closer to a high-traffic road than the north slope site. Plots were less than 3 m (10 ft) from the road edge here, whereas they were 6 m (20 ft) from the edge of the nearest road in the north slope site. This site, situated in the south of the state, has a longer and wetter growing season than the north slope site, which may encourage invasive species cover.

Despite mostly encouraging first-year results, we believe a number of factors could improve the success, richness, and cover of native mixes. Future work to seed native species mixes in similar areas could employ larger plots than ours to mimic typical DOT planting areas. Invasive species propagule pressure from plot surroundings may be lessened by seeding larger areas, reducing the edge effect of the planting (Stringham and Lockwood, 2021). It is feasible that much of the seed sown by our hand broadcasting method was lost to erosion or granivory, which could have been controlled using different seeding techniques. Suitable seeding techniques include use of a rangeland seed drill designed to place seeds at the proper soil depth, or a hydroseeder, a device which sprays a mixture of seed, water, and an adhesive tackifier onto bare ground. This machine allows for rapid seed application, avoids tillage and erosion concerns, and may result in the greatest overall success for roadside plantings (Bochet et al., 2010). We also chose not to include any non-native cover crops in the seeding work. Many native species show success as short-term cover crops including *Elymus canadensis*, *Elymus virginicus*, *Chamaecrista fasciculata*, and *Oenothera biennis* (Morris, 2012;

Herget, 2020; Kaul and Wilsey, 2022). These and other fast-growing native species may have greater cover when seeded in mixed functional group plantings due to complementarity effects (Fargione and Tillman, 2005). The short duration of this study was also a limitation. It is possible that differences between mix types would be stronger after a second growing season, and we intend to survey these plots again in the early summer of 2025.

From the assessment of species observations (Table 6), *Chamaecrista fasciculata* established well from seed in the first year. However, based on data presented later in this report, *C. fasciculata* does not appear to persist over time in plantings, illustrating it is an early colonizing native species with good cover benefits. Similarly, both *Coreopsis lanceolata* and *Oenothera biennis* established well and should be implemented for use on ROWs as early cover annuals. *Bouteloua curtipendula* also established well and developed high cover where it was seeded. As a short-statured, attractive, upland grass, *B. curtipendula* is an excellent candidate for ROW seeding. Seeding of *Carex brevior* and/or *Carex vulpinoidea* appeared to be successful, based on observations of *Carex* spp. in most seeded plots. Good establishment of *Zizia aurea* suggests this species should be seeded often to provide early spring pollinator resources and visual appeal (Zinnen et al., 2025). *Desmanthus illinoensis* established well in seeded plots, but this may be an artifact of the *D. illinoensis* already seeded at the south slope site. Species observed in no or few plots should not be considered unworthy of inclusion in mixes because they may not germinate until the following growing season or might better germinate with different seeding methods. Naturally recruited species—namely, *Asclepias verticillata*, *Eupatorium altissimum*, *Eupatorium perfoliatum*, and *Hordeum jubatum*—are also strong candidates for inclusion in a disturbance-tolerant mix.

The findings of these experiments show that native mixes can establish as well or better than existing IDOT mixes in many circumstances, even in environments typically assumed to be too harsh for a native community. Improvements to seeding methodology, including use of a drill or hydroseeder, seeding larger areas, and including more native cover crops may further increase success of a native mix in these areas. Several species seemed especially well suited to these environments, and those should be incorporated into more mixes and used in more areas.

CHAPTER 3: SURVEY OF PREVIOUSLY PLANTED ROADSIDES

INTRODUCTION

Since the development of wheeled vehicles, roads have covered large swaths of Earth's surface and have had tremendous impacts on the planet in the process. In the contiguous US alone, over 6,800,000 km (4,200,000 mi) of roads traverse the country (FHWA, 2022). Often, the work to clear, construct, and maintain roadways, along with their routine use by vehicles, negatively impacts native habitats, preventing unassisted reestablishment of native vegetation and loss of ecosystem services (Fitzpatrick et al., 1999; Sala et al., 2000; von der Lippe and Kowarik, 2007). Reestablishment of native vegetation may confer many benefits to the local ecosystem and improve infrastructure. Midwestern native species can aid many ecosystem services if successfully planted in highway ROWs (Underhill and Angold, 2000; Murray et al., 2009; Noordijk et al., 2011; Wojcik and Buchmann, 2012; Hopwood et al., 2015; Reppert and de Roode, 2018; Kaul and Wilsey, 2019).

Unfortunately, despite the advantages, there are numerous challenges that inhibit the successful establishment of a roadside native plant community. Roadways are highly disturbed areas with poor soil characteristics and frequent biologically harmful chemical inputs that include automotive fluids, fertilizers, salts, and microplastics from tires and litter (Khan and Kathi, 2014; Sommer et al., 2018). Many native species are unable to germinate or persist in these areas due to specialized establishment requirements or an inability to tolerate pollutants (Walker et al., 2021). Many of these inputs decline or increase with distance from the road and with differences in watershed characteristics (Cale and Hobbs, 1991; Phillips et al., 2021). Roadside soils are often highly compacted due to construction, by mowing vehicles, and by emergency vehicle stops on roadsides (Das et al., 2023). Roads are also prime areas for hardy, disturbance-tolerant invasive species to colonize from surrounding areas, inhibiting growth of native species (von der Lippe and Kowarik, 2007). Generally, surrounding land cover, such as nearby agricultural or urban areas, can also be an important indicator for stressors on a site (Bedford, 1999). These and other factors possibly have large impacts on the success of a native planting.

The Illinois Department of Transportation is interested in increasing the usage and success of native species seeding in the finishing of new construction projects, with the overall goals of increasing ecosystem services and reducing maintenance costs. Here, we report on a field study to assess which native species tolerate right-of-way conditions and recommend improvements to IDOT seed mixes, methods, and maintenance protocols for native areas. To determine which species are best suited for roadside seeding and identify which factors improve or inhibit seed mix success, we surveyed areas in Indiana and Illinois that have previously been seeded by DOT crews or contractors. Our specific research questions were as follows: (1) Which factors, including distance to road, soil chemical and physical properties, surrounding land cover, slope, and year since planting, are most likely to foster high cover of seeded native species and native species generally? (2) Which frequently planted species are most and least likely to persist when planted on roadsides?

METHODS

Site Selection

We surveyed plant communities at 34 previously planted roadside locations across Illinois and Indiana (from approximately 37°56′ to 42°12′ latitude and −85°30′ to −90°54′ longitude). Sites were selected in consultation with staff from IDOT and INDOT. Of the 27 sites provided to us in Illinois that were within 100 m (328 ft) of a nearby road, 11 sites were omitted from survey work upon visiting the site due to inaccessibility, recent mowing, or dangerous conditions that made access and movement unsafe. Most sites were provided by IDOT staff in IDOT Districts 2, 3, and 5. The remainder of sites were located based on a previously conducted survey of native plantings statewide (Busby, 2014).

In Illinois we surveyed a total of 16 sites. Three sites were seeded with diverse specialty mixes that are separate from IDOT specification manual contract seed mixes. Six sites contained only the officially unspecified, but often seeded, low-diversity Class 5C pollinator mix, which has been in use since at least 2011. Seven sites contained standardized seed mixes from the IDOT *Standard Specifications for Road and Bridge Construction*, Section 250: Seeding (IDOT, 2022). One of these sites contained the Class 5C pollinator mix and Class 4 native grass mix. Two of these sites contained a mix of Class 4A low-profile native grass and Class 5A large flower native forb mixture. One site contained only the Class 4A low-profile native grass mix. Two sites in northern Illinois contained the Class 3 northern Illinois slope mixture. One site contained only the Class 4 native grass mix. The year of planting of surveyed sites ranged from 2007 to 2021.

In Indiana, we selected a total of 30 sites of interest from a contract list provided by INDOT. Contracts on this list were completed from 2016, when contract digitization became standardized at INDOT (INDOT employees, pers. comm.), to 2023. This master list contained over 1,000 contracts statewide, 700 of which involved no native seeding. We set additional parameters for these mixes to narrow options for the 300 remaining sites containing native mixes. We considered only mixes with overall seed costs between $1,000 and $5,000, because these amounts aligned with seed costs and general areal extents for sites selected in Illinois. We also selected sites established between 2016 and 2022 to temporally align Indiana sites with those in Illinois, prevent early establishment characteristics from biasing surveys, and avoid disturbing nascent sites. We also selected sites for geographic coverage across INDOT's six districts, selecting a roughly even number of sites in each district, with one site in each district containing the sole INDOT specified native floodplain mix. INDOT staff requested we add non-native turfgrass mixes to our surveys, so we attempted to find one site per district which contained a native mix and one of INDOT's turfgrass mixes, Mix R or Mix U. We omitted 12 sites of interest because we were unable to locate sufficient records, including adequate maps of the planting area and details on seed mix composition or because the planted sites were not oriented along the nearest roadway in a way that accommodated our survey methodology.

In Indiana, we were able to survey 18 sites, and none were omitted in the field. Eleven sites contained specialty native species mixes seeded by district managers. One of these sites contained the Mix R turfgrass mix as well. Two sites contained Mix R and the floodplain mix. One site contained Mix U and the floodplain mix. One site contained Mix U alone. Three sites contained only the INDOT native floodplain mix. Two of our floodplain mix–only sites each contained four plots arranged around the four corners of a bridge over a stream. We were able to survey three of the four plots in one of these sites, and two of the four plots in the other.

For each site, planting maps from contract records were georeferenced and superimposed onto satellite imagery using ArcGIS Pro (ESRI). We created reference polygons by tracing map data of the largest planted areas for each site and mix if a site contained multiple mixes. We recorded location information, distance of planting polygons from road pavement edge, and depth of planting to inform field surveys. These polygons were used later to ground truth our survey quadrat locations and for surrounding land cover analysis.

Vegetation Survey Methods

Site surveys were conducted from May 23 to August 7, 2024. Each week of survey work was organized to survey a cluster of four to six geographically proximate sites at most roughly 100 km (62 mi) apart from each other. Surveys began at the southernmost sites in Illinois, alternating state each week and working northward to follow phenological shifts in species.

At each site, we established a 50 m (164 ft) baseline parallel to the road in the widest portion of the largest and most accessible polygon(s) of each site. The baseline was located inside the planting, within 1 m (3.28 ft) of the edge of the planting area based on map boundaries and visible vegetation. We recorded a GPS point at the 0 m point of the baseline using a Garmin GPS, which we used to georeference quadrat locations. Transect-based quadrat surveys were conducted at a perpendicular direction from the 50 m (164 ft) baseline, away from the road, to investigate vegetation changes with increasing distance from the road edge. The position of each transect line along the baseline was randomized using a random number generator.

We conducted between two and four transect surveys based on site conditions and crew safety concerns with nearby traffic. Dangerous conditions close to busy highways usually received only two transect surveys and were usually the most species-poor sites. At 29 sites we surveyed three transects, four sites received two transects, and one received four transects.

We surveyed vegetation along each transect using between one and five 0.25 m^2 (2.69 ft^2) quadrats. Narrower sites received fewer quadrats. All quadrats on each transect were between 0 and 40 m (131 ft) from the baseline. Within each site, quadrat distances from the baseline were identical among transects. However, quadrat distances from the baseline were not standardized among sites to accommodate differently shaped planting areas and land features like ditches and to capture cover across multiple seed mix areas if different mixes were sown at different distances from the road. For each quadrat survey, we identified each species and estimated its cover to the nearest 5%, with species closer to 1% than 5% receiving a 1%. We also recorded percent cover of bare ground, dead plant litter, and/or standing water.

When conditions safely allowed for extra time at a site, we spent 5 minutes looking for and recording additional species within the planted site area not captured within our quadrats. This additional survey was to provide a more accurate overview of all species at a site, and a more accurate assessment of species that persisted from seed. We performed this for 20 sites and found species not covered by a quadrat within site borders in 12 of these sites.

Additional Data Collection

GPS-Referenced Distance from Road

For all quadrats, we used the georeferenced GPS point of the site in ArcGIS Pro along with the recorded distances along the 50 m (164 ft) baseline to determine the actual distance of each quadrat from the edge of the pavement to the nearest 0.1 m (0.33 ft). Because these distances may have differed due to road curvature by as much as 0.2 m (0.66 ft) from other quadrats assumed to be the same distance from the road, we averaged all quadrats at the same idealized distance from the road by this true distance. These mean distances from the road were used for all analyses.

Surrounding Land Cover and Principal Component Analysis

We assessed surrounding land cover for each surveyed site. In ArcGIS Pro we removed polygons that were not surveyed, and we used the Merge tool to combine planted polygons for any site with multiple seed mixes in a surveyed area to create a single polygon for use in the analysis. We buffered surveyed polygons to 100 m (328 ft) using a geodesic method and excluded the input polygon. We used the National Land Cover 2021 Dataset for Illinois and Indiana (30 m [98 ft] grid cells) for this analysis (U.S. Geological Survey 2014). Using the clip raster tool, we determined percentages of land cover within the buffers and combined land cover classes into eight land cover types (agriculture, developed, forest, shrubland, grassland, wetland, water, and barren ground).

Because land cover components are often correlated, we conducted a principal component analysis (PCA) to reduce the dimensionality of these data. Land cover percentages were arcsine square root transformed to improve normality before being scaled. Eigenvalues and eigenvectors were obtained from RStudio packages prcomp and FactoMineR (Lê et al., 2008; RStudio team, 2020).

On-site Environmental Variables and Principal Component Analysis

We measured slope angle and aspect of each quadrat area with a field compass to the nearest 5° of angle and aspect. As a proxy for soil compaction, we used a pounds-per-square-inch (PSI) probe (SpotOn® Digital Soil Compaction Meter) inserted at a rate of 5 cm (2 in.) per second to a depth of 30 cm (12 in.) at each site. The highest PSI shown during insertion was recorded to the nearest 5 PSI. When rocks prevented probe insertion, we attempted up to four more probes in different sections of the quadrat before listing the PSI as missing for that quadrat due to gravel.

Using a 2 cm (0.8 in.) diameter soil core, we collected a 10 cm (3.9 in.) deep core at each quadrat, aggregated cores into bags by distance from road at each site, and placed them immediately into a cooler. Soil samples were analyzed for organic matter, estimated nitrogen release, cation exchange capacity, pH, soluble salts, phosphorous, potassium, magnesium, calcium, and nitrate by Waypoint Analytical (Champaign, Illinois). At two sites we were unable to collect any soil cores for the five total quadrats at the nearest distance to the 50 m (164 ft) baseline, and at one site we were unable to get any soil cores for the six quadrats total at the two nearest distances to the baseline due to gravel and highly compacted soils. These quadrats were omitted from models that included soil components. For 64 of 298 quadrats that had soil data, collected soil cores were too small to be analyzed for soluble salt data. For 22 of these 64 quadrats, soil tests could not yield a nitrate value.

Because we expected soluble salt and nitrate concentrations to be important predictors of roadside plant community composition, we sought to interpolate data from complete soil cores to fill gaps in these data. As these different sites had differing problem cases, several solutions were implemented to impute missing data. For soluble salts we were able to fill in data for one site with values from a different site that was less than 100 m (328 ft) north along the same highway. We fit a linear regression (multiple $R^2 = 0.07$, df = 2, $p = 0.74$) to the mean distance from road values for this complete site's soil data to fill in soluble salt data for the other site. For four sites that lacked salt data for some but not all distances from road, we imputed missing values from linear regressions of the salt values vs. distance from road for sites with complete data. For three sites where we had a soluble salt value for the furthest or nearest quadrats from the road, we regressed the soluble salt data at the maximum recorded distance from the road for all sites with complete data against the minimum recorded distance from the road for all complete sites. We used this linear regression (multiple $R^2 = 0.17$, df = 22, $p = 0.048$) to predict the soluble salt values for the missing records. This regression showed a decreasing salt value with increasing distance from the road, which is consistent with previous studies (Schilling et al., 2018). One site had only middle-distance values, and so the linear formula for calculating near and far data was used from this middle distance, using the middle as a far and near proxy. These sites had a range of predicted values from 0.17 to 0.25 ppm from these methods. For the seven other sites missing all salt values, we plotted distance from the road against soluble salt values for all sites with complete data and used the mean of all values within ± 2.5 m (8.2 ft) of the missing distance. We chose the mean range so that for some of the missing values at the low and high distance from road ends of our dataset, we would not include the absolute lowest or highest values in the data. The range of these predicted values was between 0.18 and 0.21 ppm.

We similarly imputed missing nitrate values. However, we made an additional change in this methodology because nitrate values below 1 ppm were reported as "1." Any sites with 1 values at either the nearest or furthest distances from the road were omitted from regressions to prevent bias. Three sites had nitrate data from only the furthest quadrat from the road, and the linear regression used (multiple $R^2 = 0.83$, df = 12, $p < 0.001$) yielded nitrate values between 1.2 and 4.6 ppm for the missing far distances. This regression was used to calculate far distance values for one site, which yielded a maximum nitrate value of 21.1 ppm. There was only one site that lacked all nitrate data. For this site we took the median of all complete site nitrate values within ± 2.5 m (8.2 ft) of the missing distances.

Transformations were required to bring most soil variables to a normal or near-normal distribution based on Shapiro-Wilk test values of $p \geq 0.05$. Organic matter, estimated nitrogen release, and nitrate were log-transformed. Soluble salts and calcium were square-root transformed. Phosphorus and potassium were log+1 transformed. No transformation improved normality for cation exchange capacity ($W = 0.98$, $p = 0.05$), pH ($W = 0.89$, $p < 0.001$), or magnesium ($W = 0.97$, $p = 0.02$). Because soil chemical variables are often correlated, we conducted a PCA to reduce the dimensionality of these data. Eigenvalues and eigenvectors were obtained from RStudio packages prcomp and FactoMineR (Lê et al., 2008; RStudio team, 2020).

Model Selection

We used linear mixed-effects models to determine the best predictors of cover and richness of native seeded species, of all native species (those native to Illinois and Indiana according to the USDA Plants database [USDA-NRCS, 2024]), and of non-native species. We omitted slope and aspect from all models because more than two-thirds of all quadrats were measured on flat ground, and many of our most diverse sites were deliberately seeded on only flat areas. Variables of interest included age of planting in years, distance of quadrat from road edge, soil PSI within quadrat, latitude and longitude, the first three principal component axes for surrounding land cover, and the first four principal component axes for soil chemistry. Richness models also included number of species seeded in the mix for each quadrat. All non-PCA variables were scaled using the scale function in R (RStudio, 2024).

For all analyses, we removed 11 quadrats from our total of 309 because we were unable to collect any soil data from these quadrats or other quadrats at the site at the same distance from the road. These areas had highly compacted, gravel-rich soils. All four of the sites with omitted quadrats had other usable quadrats where we were able to collect soil cores. For the analysis of native seeded cover, we removed 16 quadrats in Indiana that were seeded with only Mix R or Mix U non-native turfgrasses, because there were no native species seeded at these sites. This removed one site entirely from the analysis. Non-native and all native cover models used all 298 quadrats that contained soil data.

We created linear mixed-effects models using the lmer package (RStudio, 2024) with site as a random effect and all other variables as fixed effects. We used the factorial dredge package (RStudio, 2024) to identify which variables led to predictive results with a greater than 50% weight across all factorial model runs. We also recorded the variables and conditions of the highest weighted model including log-likelihood, weight, and degrees of freedom. These variables were checked for correlation with the cor package (RStudio, 2024). All cover dredges contained 4,096 model runs, and all richness dredges contained 8,192 model runs.

Observations of Seeded Species

To determine which species were more or less likely to persist in these sites, we created an incidence table for any seeded native species that we found at sites where they were seeded. We also included incidences where a species in one or more mixes was found at a site that did not specify it, as it may have been seeded as part of a different project or naturally recruited at the site. If a seed mix called for an undisclosed mix of species in a particular genus, it was assumed that any native species of that genus found in our survey was seeded at that site. At total of 150 native species and 10 non-native grasses and clovers (*Trifolium* spp.) were specified across all seed mixes at sites.

RESULTS

Land Cover PCA

Reduction of land cover types at the 100 m (328 ft) scale resulted in three retained principal components (PCs) via scree plot, which amounted to 64% of the total variation (Table 7). The first axis described a gradient from natural land cover types, including forest, wetland, and water, to developed land. The second axis described a gradient from agricultural land and open water to grassland and shrubland. The third axis described a gradient from developed land to undeveloped land cover types, including agricultural land, grassland, and barren land.

Table 7. Loadings for surrounding land cover principal components, with the four largest loadings underlined and marked with an asterisk

Variable	PC1	PC2	PC3
Agriculture	−0.004	−0.562*	0.560*
Barren Land	0.112	0.186	0.362*
Developed	0.543*	0.042	−0.489*
Forest	−0.556*	0.139	−0.184
Grassland	−0.143	0.601*	0.427*
Shrubland	−0.226	0.202*	−0.173
Water	−0.399*	−0.472*	−0.178
Wetland	−0.391*	0.063	−0.195

Soil Chemistry PCA

Reduction of soil chemistry variables resulted in four retained PCs via scree plot, which amounted to 81% of the total variation (Table 8). The first axis represented a gradient from soils with high pH to soils with high estimated nitrogen release, organic matter, and potassium. The second axis had high positive loadings for calcium, cation exchange capacity, pH, and soluble salts. The third axis separated soils with high phosphorus and nitrate from those with high magnesium. The fourth axis represented a gradient from soils with high potassium, soluble salts, pH, and magnesium from those with high calcium and cation exchange capacity. Estimated nitrogen release and organic matter always loaded very closely with each other, as did calcium and cation exchange capacity.

Table 8. Loadings for soil chemistry principal components, with the largest loadings underlined and marked with an asterisk

Variable	PC1	PC2	PC3	PC4
Calcium	0.019	0.582*	−0.031	0.332*
Cation Exchange Capacity	0.085	0.574*	0.033	0.309*
Estimated Nitrogen Release	0.508*	−0.023	0.089	0.249
Magnesium	0.343	0.087	0.355*	−0.427*
Nitrate	0.114	0.081	−0.702*	−0.210
Organic Matter	0.512*	−0.025	0.087	0.233
pH	−0.240*	0.391*	0.020	−0.404*
Phosphorus	0.202	−0.107	−0.594*	0.110
Potassium	0.461*	−0.060	0.021	−0.337*
Soluble Salts	0.176	0.386*	−0.105	−0.403*

Cover and Richness Models

All model dredges run showed between one and eight variables with a greater than 50% weight in factorial dredging (Table 9). The highest weighted models for each cover and richness variable included between one and eight variables, with weights ranging from 0.006 to 0.028. Correlations between predictor variables were all under R^2 of 0.5.

Table 9. Percentage weights for variables included in linear mixed-effects models, with overall directional forcing shown in parentheses. Underlined values with asterisks were included in the highest weighted model.

Included variables	Native seeded cover IL, IN	Native seeded cover IL only	All native cover IL, IN	All native cover IL only	Non-native, non-seeded cover IL, IN	Non-native, non-seeded cover IL only	Native needed richness IL, IN	Native seeded richness IL only	All native richness IL, IN	All native richness IL only	Non-native, non-seeded richness IL, IN	Non-native, non-seeded richness IL only
Land Cover PC1	(+)30.2	(+)35.7	(+)58.2	(-)29.8	(+)45.5	(+)36.5	(+)75.1*	(+)33.4	(+)66.3*	(-)31.8	(+)51.8*	(-)29.7
Land Cover PC2	(-)25.9	(+)71.4*	(-)26.3	(+)29.4	(-)29.9	(-)36.1	(-)33.7	(+)31.4	(-)28.7	(-)28.3	(-)26.3	(-)95.6*
Land Cover PC3	(+)42.7	(+)33.6	(-)25.9	(+)43.9*	(+)27.0	(-)49.4*	(+)41.8	(+)27.6	(+)25.8	(+)65.3*	(+)26.4	(-)62.0*
Age of planting (yr)	(+)28.8	(-)26.6	(-)38.3	(-)67.5	(+)31.2	(+)75.0	(-)26.2	(-)25.7	(-)37.6	(-)37.0	(+)26.2	(+)91.6*
Latitude	(+)26.1	(+)36.5	(+)27.1	(+)33.9	(-)26.4	(+)40.7*	(-)27.9	(-)25.3	(-)26.0	(-)29.4	(-)26.3	(+)83.5*
Longitude	(+)29.8	(-)26.1	(-)28.5	(+)45.5*	(-)34.3	(-)38.0*	(+)33.5	(+)30.0	(+)28.6	(+)80.7*	(-)27.9	(+)59.8*
Soil compaction (PSI)	(-)26.1	(+)27.5	(+)26.1	(-)51.4*	(+)28.5	(+)69.0*	(-)33.4	(+)25.7	(-)47.1	(-)60.3*	(-)25.9	(+)39.1
Distance from road (m)	(+)>99.9*	(+)96.7*	(+)95.7*	(+)34.2	(-)49.6	(-)52.6	(+)>99.9*	(+)99.7*	(+)98.8*	(+)49.4	(-)82.1*	(-)74.1*
Soil PC1	(+)26.6	(-)27.6	(-)29.3	(-)49.6	(+)35.7	(+)90.0*	(+)33.6	(-)28.0	(+)27.1	(-)29.6	(+)47.8	(+)99.3*
Soil PC2	(-)33.8	(-)94.3*	(-)40.4	(-)91.7*	(+)63.5*	(+)55.0*	(+)30.4	(-)36.8	(-)28.9	(-)58.1*	(+)34.8	(+)45.4
Soil PC3	(+)73.4*	(+)26.0	(+)63.0*	(+)28.1	(-)35.6	(+)33.4	(+)32.9	(-)69.3*	(+)45.4	(-)30.5	(-)31.1	(+)71.6*
Soil PC4	(+)25.8	(+)25.1	(+)35.2	(-)36.5	(+)33.4	(+)65.7*	(-)27.7	(-)37.8	(+)33.1	(-)48.4	(-)26.8	(-)32.9
No. of species in mix							(+)>99.9*	(+)>99.9*	(+)99.5*	(+)>99.9*	(-)26.8	(+)36.2
Highest weighted model												
df	5	6	5	7	4	10	6	6	6	8	5	11
Log-likelihood	−474.1	−260.0	−30.9	−3.7	−24.6	−266.6	−54.9	−27.9	−635.7	−316.0	−65.4	−9.7
weight	0.022	0.028	0.011	0.009	0.006	0.011	0.016	0.019	0.012	0.013	0.010	0.020

All Sites Native Seeded Cover and Richness

We logit transformed native seeded cover to improve normalization of model residuals. Two variables each had a combined weight above 50% in all models for native seeded cover—distance from road and soil PC3—and the highest weighted model included only these two variables (Table 9, Figure 9). Greater native seeded cover across sites and quadrats was associated with increased distance from road, higher Mg, and lower nitrate and P.

We logit transformed native seeded richness to normalize residuals. Three predictor variables had summed weights above 50% in models for native species richness: distance from road, number of species in the planting mix, and land cover PC1 (Table 9, Figure 10). The highest weighted model included only these three variables. Greater native richness was associated with greater distance from road, higher seed mix diversity, and greater surrounding development.

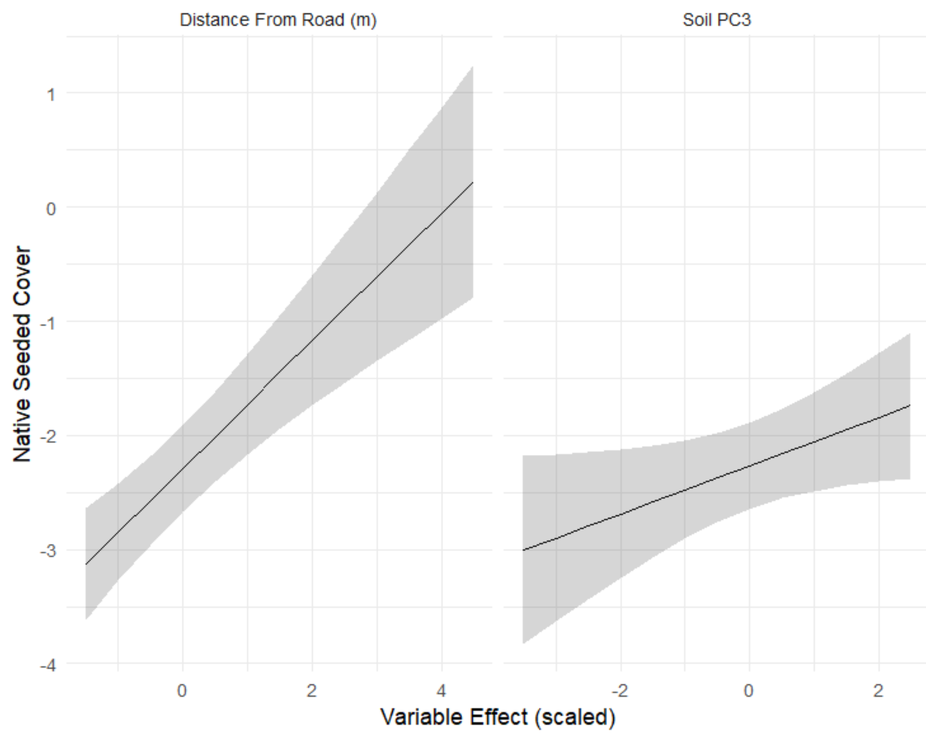

Figure 9. Graph. Effects plots for highly weighted (> 50%) variables for predicting native seeded cover.

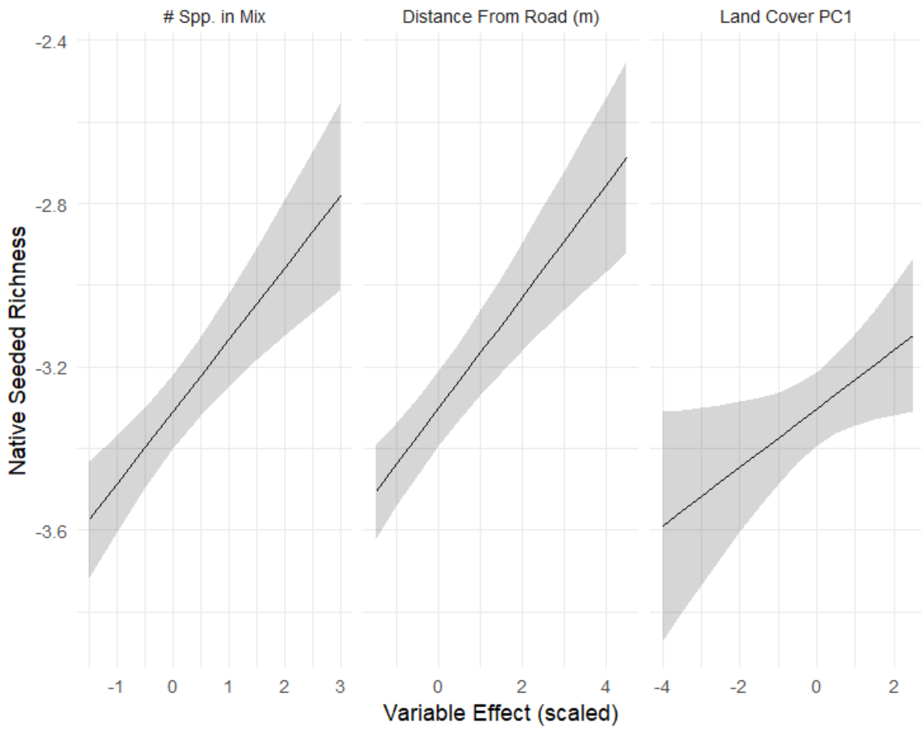

Figure 10. Graph. Effects plots for highly weighted (> 50%) variables for predicting native seeded richness.

All Sites All Native Cover and Richness

For cover by all native species in quadrats at sites across both states, three variables had weights above 50%. These were distance from road, land cover PC1, and soil PC3 (Table 9, Figure 11). The highest weighted model included only distance from road and soil PC3 with a weight of 0.011. Greater total native cover was associated with greater distance from road, higher Mg, lower nitrate and P, and potentially greater surrounding development.

For total native species richness of quadrats, three variables had weights above 50%. These were distance from road, number of species in the planting mix, and land cover PC1 (Table 9, Figure 12). The highest weighted model included only these three variables with a weight of 0.012. Thus, all native richness was higher with greater distance from road, higher mix diversity, and proximity to development.

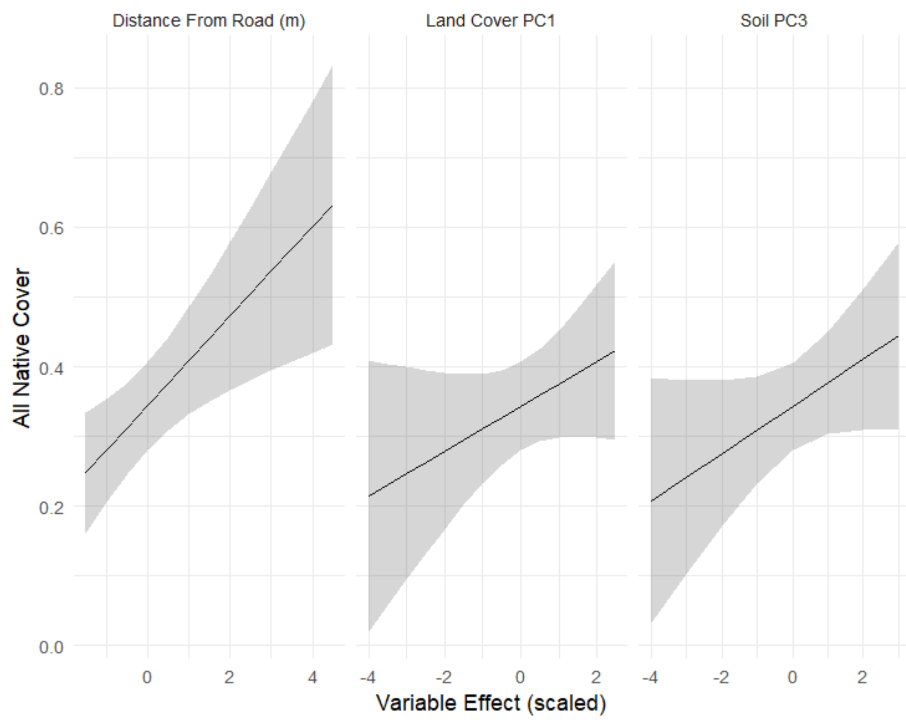

Figure 11. Graph. Effects plots for highly weighted (> 50%) variables for predicting native species cover.

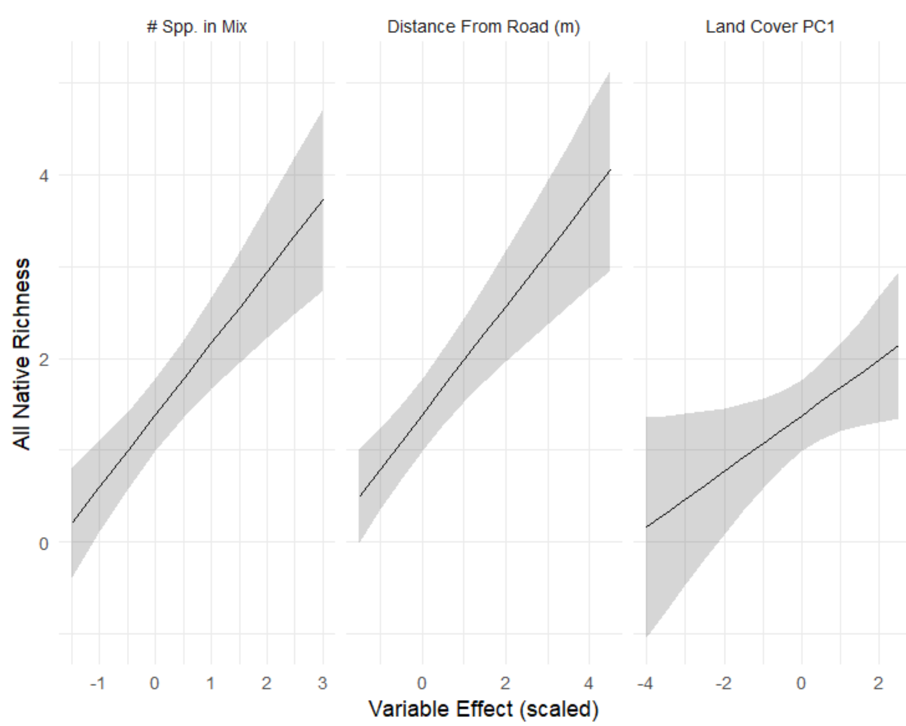

Figure 12. Graph. Effects plots for highly weighted (> 50%) variables for predicting native species richness.

All Sites Non-native, Non-seeded Cover and Richness

For non-native, non-seeded cover in quadrats, one variable, soil PC2, had a weight above 50%. The highest weighted model included only soil PC2 with a weight of 0.006 (Table 9, Figure 13). This suggests non-native cover increased with higher Ca, cation exchange capacity, pH, and soluble salts.

For richness of non-native species, two variables had weights above 50%. These were increasing land cover PC1 and decreasing distance from road (Table 9, Figure 14). The highest weighted model included only these two variables with a weight of 0.01. Thus, greater richness of non-native, non-seeded species was associated with decreased distance from road and greater surrounding development.

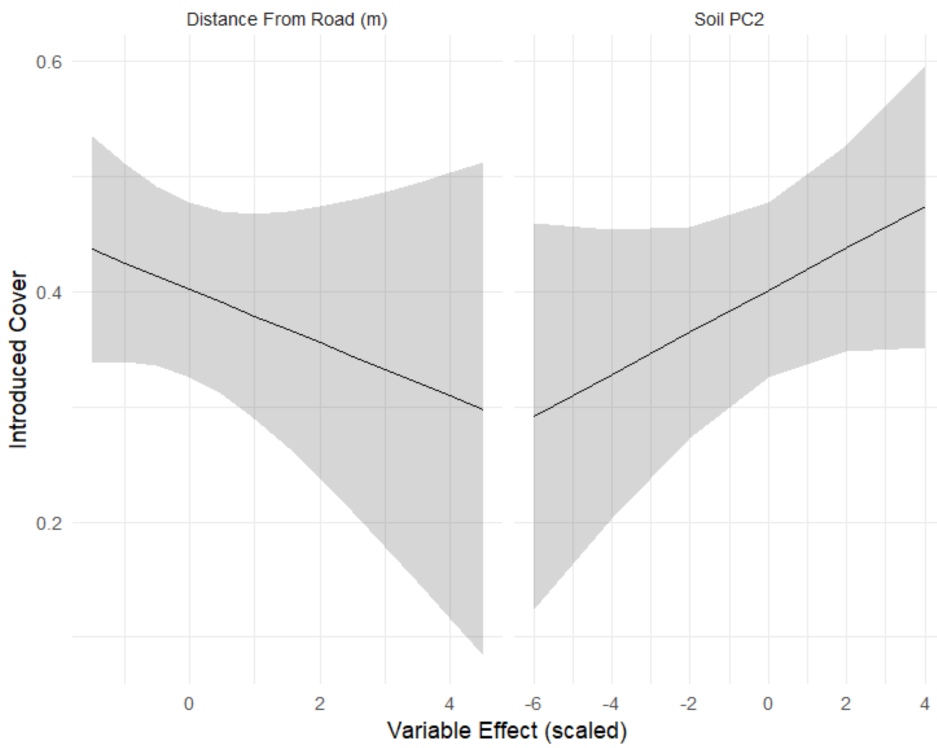

Figure 13. Graph. Effects plots for highly weighted (> 50%) variables for predicting cover of non-native, non-seeded species.

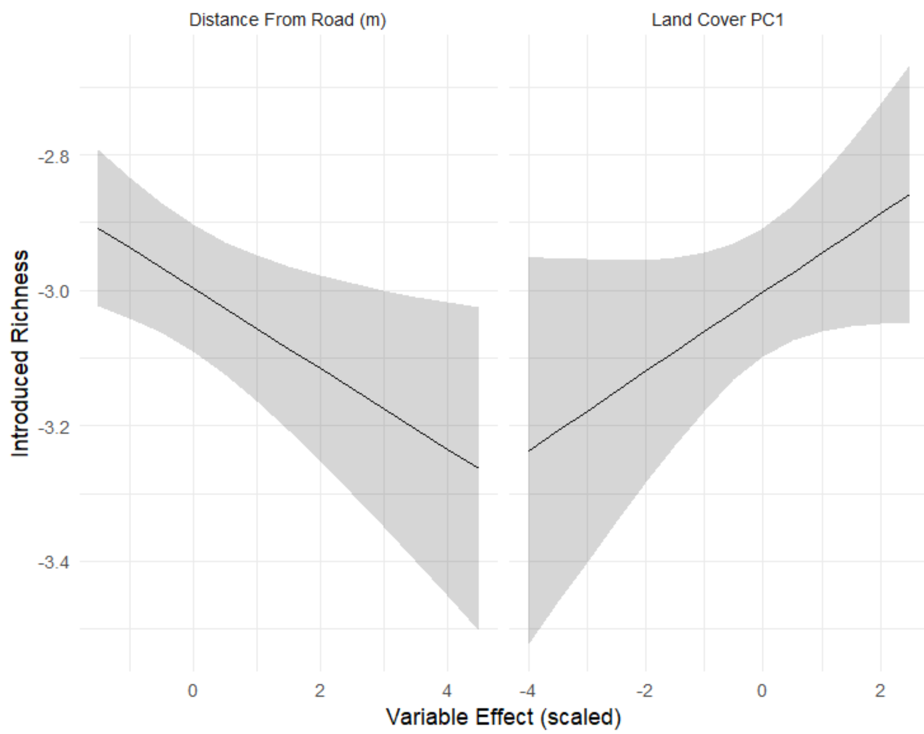

Figure 14. Graph. Effects plots for highly weighted (> 50%) variables for predicting richness of non-native, non-seeded species.

Illinois-Only Native Seeded Cover and Richness

For logit-transformed native seeded species cover of only Illinois site quadrats, three variables had a weight above 50%. These were distance from road, soil PC2, and land cover PC2. The highest weighted model included only these three variables with a weight of 0.028 (Table 9, Figure 15). Thus, Illinois seeded native cover was higher with greater distance from road, lower Ca, cation exchange capacity, pH, and soluble salts, and more surrounding grassland and less surrounding agriculture and water.

For logit-transformed native seeded species richness of only Illinois site quadrats, three variables had a weight above 50%: distance from road (with > 99% weight), number of species in the mix (with > 99% weight), and soil PC3. The highest weighted model included these three variables with a weight of 0.016 (Table 9, Figure 16) and indicated that native seeded species richness was greater with greater distance from road, more species seeded, and lower Mg and higher nitrate and P.

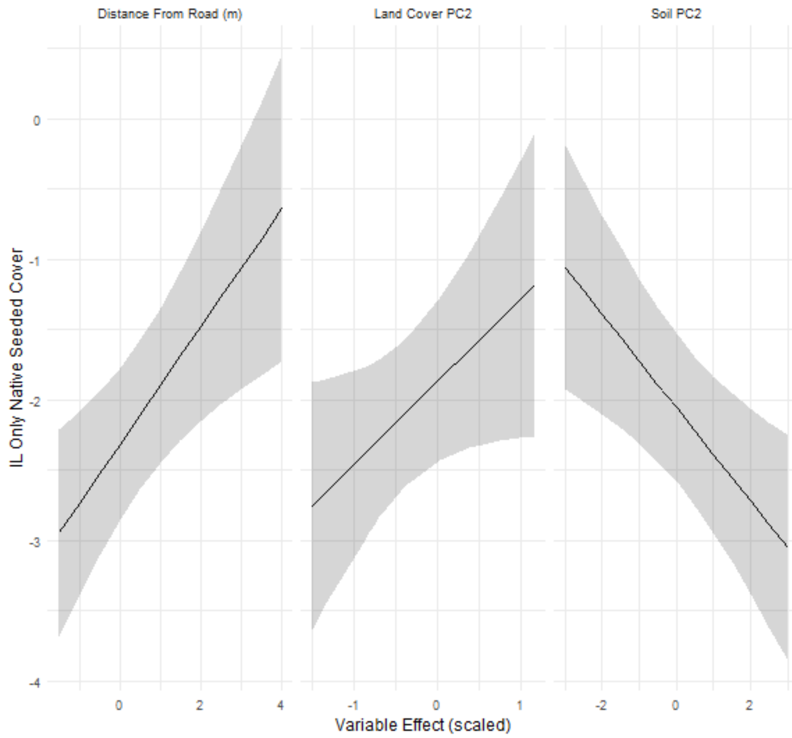

Figure 15. Graph. Effects plots for highly weighted (> 50%) variables for predicting Illinois-only native seeded cover.

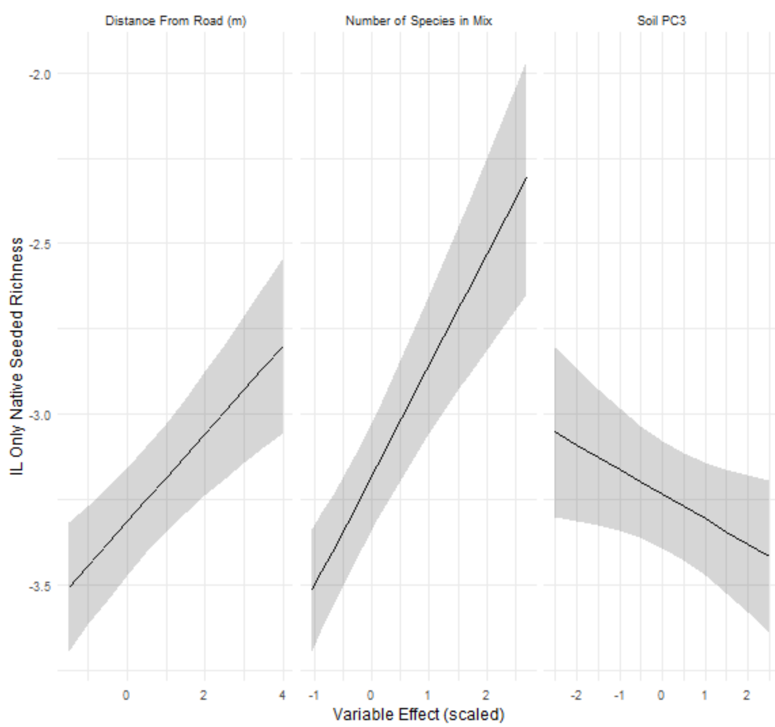

Figure 16. Graph. Effects plots for highly weighted (> 50%) variables for predicting Illinois-only native seeded richness.

Illinois-Only All Native Cover and Richness

For all native species cover of only Illinois site quadrats, three variables had a weight above 50%. These were soil PC2, age of planting, and soil compaction. The highest weighted model included two of these variables, soil compaction and soil PC2, as well as increasing land cover PC3 and increasing longitude. This model had a weight of 0.009 (Table 9, Figure 17). The model indicated that native cover in Illinois quadrats was greater with less compacted soil; more recent planting; lower soil Ca, cation exchange capacity, pH, and soluble salts; potentially greater surrounding agriculture, grassland, and barren land; and higher longitude (more eastern).

For all native species richness of only Illinois site quadrats, five variables had a weight above 50%: number of species in mix (with > 99% weight), longitude, land cover PC3, soil compaction, and soil PC2. The highest weighted model includes only these five variables with a weight of 0.013 (Table 9, Figure 18). Thus, native species richness was higher with more species seeded; more eastern sites; greater surrounding agriculture, grassland, and barren land; lower soil compaction; and lower soil Ca, cation exchange capacity, pH, and soluble salts.

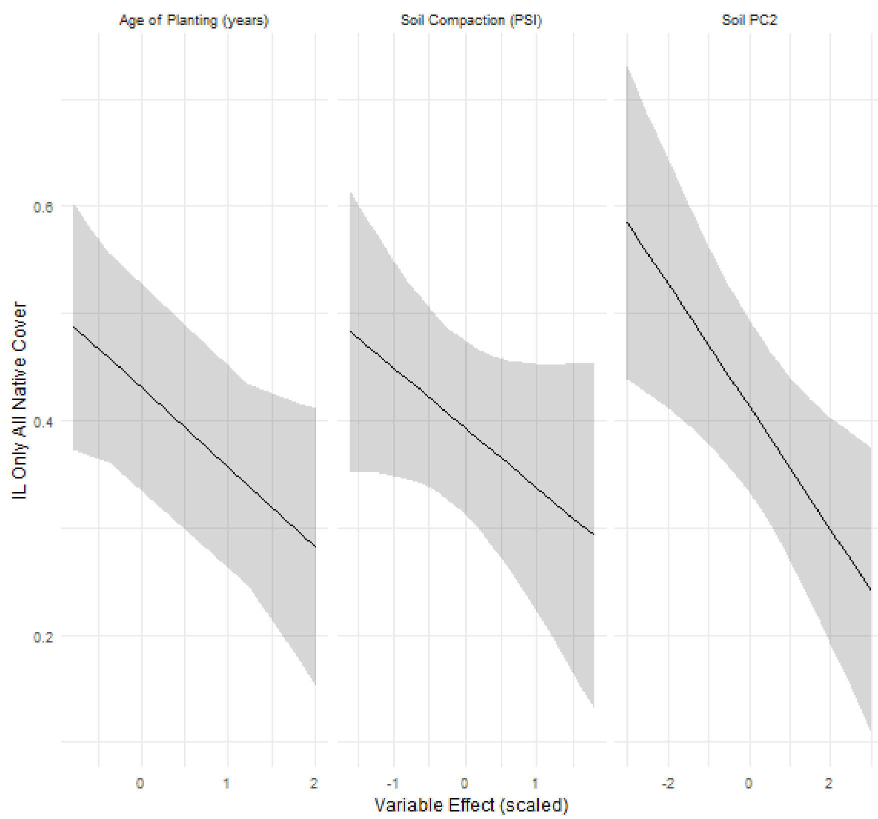

Figure 17. Graph. Effects plots for highly weighted (> 50%) variables for predicting Illinois-only all native cover.

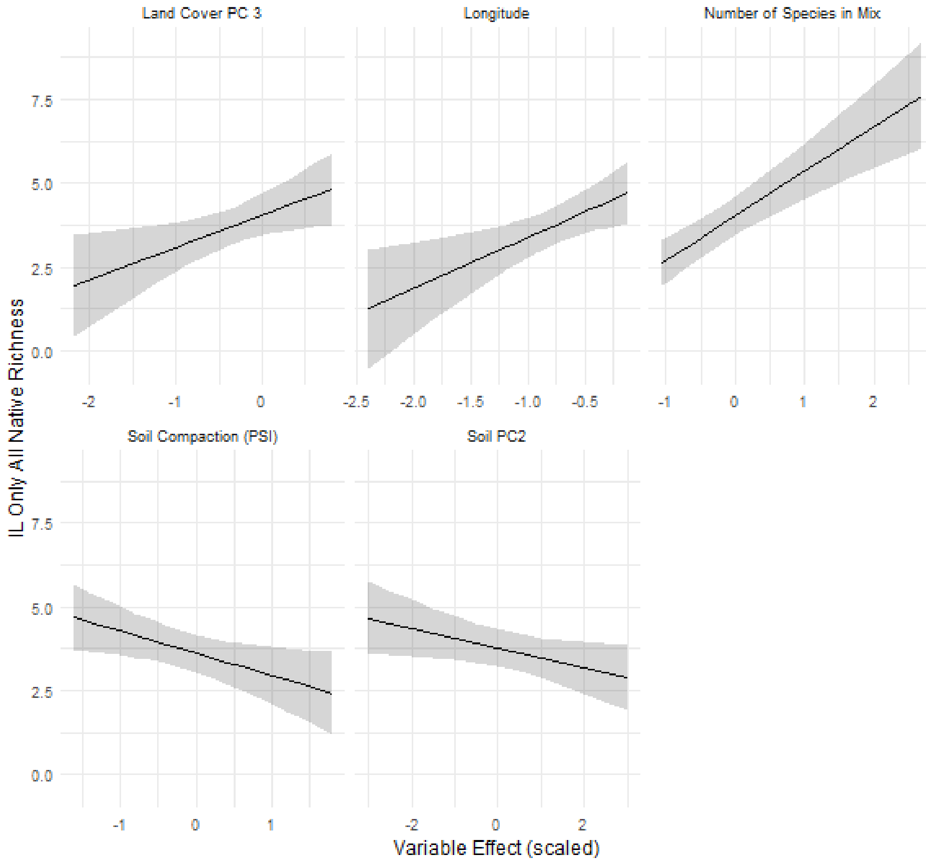

Figure 18. Graph. Effects plots for highly weighted (> 50%) variables for predicting Illinois-only all native richness.

Illinois-Only Non-native, Non-seeded Cover and Richness

For non-native, non-seeded species cover of only Illinois site quadrats, six variables had a weight above 50%. These were soil PC1, PC2, and PC4, age of planting, soil compaction, and distance from road. The highest weighted model included seven variables: soil compaction; soil PC1, PC2, and PC4; land cover PC3; latitude; and longitude. This model had a weight of 0.011 (Table 9, Figure 19). This model indicated that non-native, non-seeded cover in Illinois increased with older plantings; higher soil compaction; lower distance from road; greater estimated N release, organic matter, P, Ca, and cation exchange capacity; and potentially greater proximity to development, higher latitude (further north), and lower longitude (further east).

For non-native, non-seeded species richness of only Illinois site quadrats, eight variables had a weight above 50%, the most of any model. These were soil PC1, soil PC3, land cover PC2, land cover PC3, age of planting, distance from road, latitude, and longitude. The highest weighted model included all eight of these variables with a weight of 0.02 (Table 9, Figure 20). Thus, non-native, non-seeded richness was greater with older plantings; higher latitude (further north); higher longitude (further west); less distance from road; higher estimated N release, organic matter, Mg; decreased P and nitrate; and proximity to agriculture, water, and development.

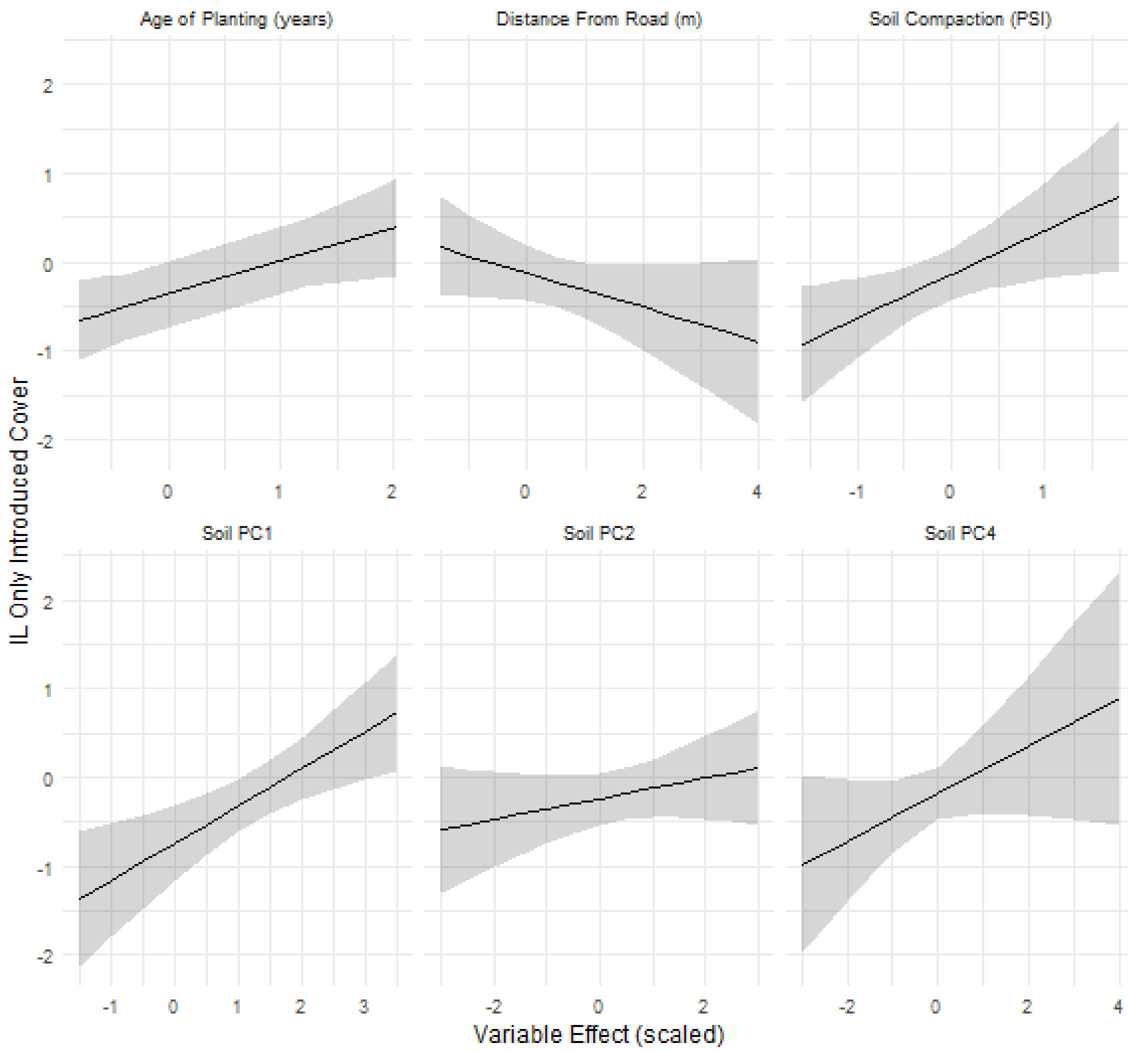

Figure 19. Graph. Effects plots for highly weighted (> 50%) variables for predicting Illinois-only non-native, non-seeded cover.

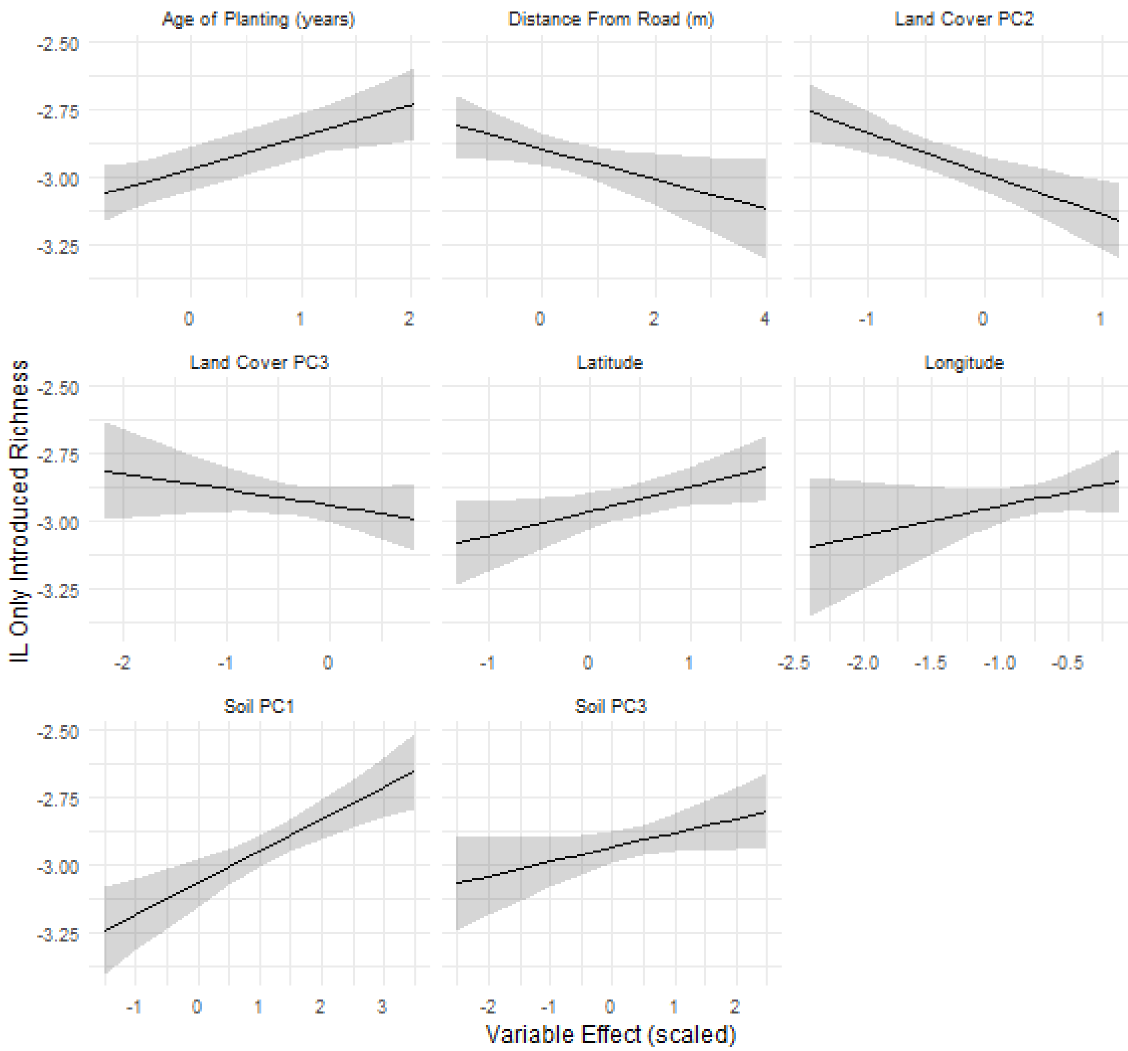

Figure 20. Graph. Effects plots for highly weighted (> 50%) variables for predicting Illinois-only non-native, non-seeded richness.

Seeded Site Observations

We observed 28 species at between 50%–100% of the sites where they were seeded (Table 10). Five species were present in 100% of seeded sites; however, three of them were only seeded at one site. Five species were found a total of 10 or more times each across all 34 sites: *Asclepias syriaca*, *Monarda fistulosa*, *Rudbeckia hirta*, *Heliopsis helianthoides*, and *Panicum virgatum*. These five species along with *Elymus virginicus* were also the most observed species at sites where they were seeded. Of all 150 native species seeded at one or more sites, 86 were not found during site surveys. Twenty-two of these 86 were only seeded at one site, and 20 species were seeded at five or more sites. One species, *Chamaecrista fasciculata*, was seeded at 12 sites but never observed. Forty species were observed in sites that did not list them in their seed mixes, and 14 of these species were never observed at the sites in which they were seeded. We believe many of these species were seeded at different times in these sites, but we could not find records of those seeding projects.

Table 10. Occurrences of seeded species (non-native species underlined and marked with an asterisk) in field survey sites

Scientific name	Common name	Sites seeded	Percentage of seeded sites observed	Percentage of all sites observed
*Festuca arundinacea**	Tall Fescue	5	80%	68%
Rudbeckia hirta	Black-eyed Susan	23	57%	41%
Monarda fistulosa	Wild Bergamot	21	62%	41%
Asclepias syriaca	Common Milkweed	18	67%	41%
*Festuca rubra**	Creeping Red Fescue	5	60%	38%
Heliopsis helianthoides	False Sunflower	17	53%	32%
Panicum virgatum	Switchgrass	11	73%	29%
Elymus virginicus	Virginia Wildrye	19	47%	26%
Ratibida pinnata	Gray-headed Coneflower	16	38%	26%
Asclepias verticillata	Whorled Milkweed	7	43%	24%
Echinacea purpurea	Broad-leaved Purple Coneflower	19	32%	21%
Bouteloua curtipendula	Side-oats Grama	14	50%	21%
Desmanthus illinoensis	Illinois Bundleflower	10	50%	21%
*Trifolium hybridum**	Alsike Clover	2	0%	21%
Andropogon gerardii	Big Bluestem	12	42%	18%
Carex vulpinoidea	Brown Fox Sedge	12	33%	18%
Schizachyrium scoparium	Little Bluestem	22	23%	15%
Asclepias incarnata	Swamp Milkweed	17	29%	15%
Symphyotrichum novae-angliae	New England Aster	17	29%	15%
Silphium laciniatum	Compass Plant	8	38%	15%
Zizia aurea	Golden Alexanders	7	71%	15%
Rudbeckia lacinata	Wild Goldenglow	7	43%	15%
Juncus effusus	Common Rush	4	50%	15%
Carex brevior	Plains Oval Sedge	2	50%	15%
*Lolium perenne**	Perennial Ryegrass	12	8%	12%
Verbena hastata	Blue Vervain	8	25%	12%
Gaillardia pulchella	Blanketflower	7	57%	12%
Penstemon digitalis	Foxglove Beardtongue	7	57%	12%
Hordeum jubatum	Foxtail Barley	6	0%	12%
Echinacea pallida	Pale Purple Coneflower	5	80%	12%
Eupatorium perfoliatum	Common Boneset	5	40%	12%
Symphyotrichum lanceolatum	White Panicle Aster	1	100%	12%
Elymus canadensis	Canada Wildrye	22	14%	9%
*Lolium multiflorum**	Annual Rye	22	14%	9%
Sorghastrum nutans	Indiangrass	10	30%	9%
Eryngium yuccifolium	Rattlesnake Master	7	43%	9%
Pycnanthemum virginianum	Virginia Mountain Mint	7	43%	9%
Physostegia virginiana	Obedient Plant	6	50%	9%
Symphyotrichum puniceum	Swamp Aster	6	50%	9%
Vernonia fasciculata	Smooth Ironweed	6	50%	9%
Leersia oryzoides	Rice Cut Grass	6	0%	9%
Carex cristatella	Crested Oval Sedge	5	60%	9%
Carex hystericina	Porcupine Sedge	3	100%	9%

Scientific name	Common name	Sites seeded	Percentage of seeded sites observed	Percentage of all sites observed
Helianthus grosseserratus	Sawtooth Sunflower	2	100%	9%
*Phleum pratense**	Timothy Grass	1	0%	9%
Juncus tenuis	Slender Rush	1	0%	9%
Oligoneuron rigidum	Stiff Goldenrod	10	10%	6%
Desmodium canadense	Showy Ticktrefoil	9	11%	6%
Asclepias tuberosa	Butterfly Milkweed	8	25%	6%
Siliphium terebinthinaceum	Prairie Dock	8	25%	6%
Rudbeckia subtomentosa	Sweet Black-eyed Susan	7	29%	6%
Senna hebecarpa	Wild Senna	6	33%	6%
Tradescantia ohiensis	Ohio Spiderwort	6	33%	6%
Sporobolus heterolepis	Prairie Dropseed	6	17%	6%
Coreopsis lanceolata	Lanceleaf Coreopsis	5	40%	6%
*Trifolium repens**	White Dutch Clover	5	20%	6%
Silphium integrifolium	Rosinweed	5	0%	6%
Rudbeckia triloba	Brown-eyed Susan	4	50%	6%
Solidago rugosa	Rough Goldenrod	4	50%	6%
Carex lupulina	Common Hop Sedge	4	25%	6%
Euthamia graminifolia	Grass-leaved Goldenrod	4	0%	6%
Silphium perfoliatum	Cup Plant	3	33%	6%
Verbena stricta	Hoary Vervain	3	33%	6%
Helianthus mollis	Downy Sunflower	2	0%	6%
Pycnanthemum tenuifolium	Slender Mountain Mint	1	100%	6%
Symphyotrichum ericoides	Heath Aster	1	0%	6%
*Avena sativa**	Spring Oats	27	4%	3%
Liatris pycnostachya	Prairie Blazingstar	13	8%	3%
Scirpus atrovirens	Dark-green Bulrush	9	11%	3%
Spartina pectinata	Prairie Cord Grass	9	11%	3%
Coreopsis tripteris	Tall Coreopsis	7	14%	3%
Lycopus americanus	Common Water Horehound	6	17%	3%
Symphyotrichum laeve	Smooth Blue Aster	6	17%	3%
Baptisia alba	Wild White Indigo	5	20%	3%
Parthenium integrifolium	Wild Quinine	5	20%	3%
Penthorum sedoides	Ditch Stonecrop	5	0%	3%
Carex frankii	Bristly Cattail Sedge	4	0%	3%
Verbesina alterniflora	Wingstem	4	0%	3%
Carex molesta	Field Oval Sedge	3	33%	3%
*Triticum aestivum 'Regreen'**	Regreen Cover Crop	3	0%	3%
Ageratina altissima	White Snakeroot	3	0%	3%
Boltonia asteroides	False Aster	2	50%	3%
Dalea purpurea	Purple Prairie Clover	2	50%	3%
Penstemon calycosus	Smooth Penstemon	2	50%	3%
Solidago caesia	Blue-Stemmed Goldenrod	2	50%	3%
Boehmeria cylindrica	False Nettle	2	0%	3%
Vernonia gigantea	Tall Ironweed	2	0%	3%
Carex bicknellii	Oval Prairie Sedge	1	100%	3%
Solidago gigantea	Late Goldenrod	1	0%	3%

Scientific name	Common name	Sites seeded	Percentage of seeded sites observed	Percentage of all sites observed
Chamaecrista fasciculata	Partridge Pea	12	0%	0%
Helenium autumnale	Sneezeweed	9	0%	0%
Asclepias sullivantii	Sullivant's Milkweed	8	0%	0%
Calamagrostis canadensis	Blue Joint Grass	8	0%	0%
Alisma subcordatum	Common water plantain	7	0%	0%
Glyceria striata	Fowl Manna Grass	7	0%	0%
Veronicastrum virginicum	Culver’s Root	7	0%	0%
Agrostis perennans	Upland Bentgrass	6	0%	0%
Lobelia siphilitica	Great Blue Lobelia	6	0%	0%
Sporobolus compositus	Rough Dropseed	6	0%	0%
Tridens flavus	Purpletop	6	0%	0%
Bidens cernua	Nodding Bur Marigold	5	0%	0%
Carex lurida	Bottlebrush Sedge	5	0%	0%
Mimulus ringens	Monkeyflower	5	0%	0%
Polygonum pennsylvanicum	Smartweed	5	0%	0%
Potentilla arguta	Prairie Cinquefoil	5	0%	0%
Angelica atropurpurea	Great Angelica	4	0%	0%
Carex comosa	Bristly Sedge	4	0%	0%
Carex crinita	Fringed Sedge	4	0%	0%
Doellingeria umbellata	Flat-top Aster	4	0%	0%
Elymus villosus	Silky Wildrye	4	0%	0%
Aquilegia canadensis	Wild Columbine	3	0%	0%
Campanulastrum americanum	Tall Bellflower	3	0%	0%
Carex squarrosa	Narrow-Leaved Cattail Sedge	3	0%	0%
Elymus riparius	Riverbank Wildrye	3	0%	0%
Eutrochium maculatum	Spotted Joe-Pye Weed	3	0%	0%
Heracleum lanatum	Cow Parsnip	3	0%	0%
Hibiscus moscheutos	Swamp Rose Mallow	3	0%	0%
Iris virginica shrevei	Blue Flag Iris	3	0%	0%
Sagittaria latifolia	Common Arrowhead	3	0%	0%
Scirpus cyperinus	Wool Grass	3	0%	0%
Scirpus validus	Soft-stem Bulrush	3	0%	0%
Symphyotrichum lateriflorum	Side-Flowering Aster	3	0%	0%
*Pucinellia distans**	Salty Alkaligrass	2	0%	0%
Anemone cylindrica	Thimbleweed	2	0%	0%
Buchloe dactyloides	Buffalograss	2	0%	0%
Carex cephalophora	Short-Headed Bracted Sedge	2	0%	0%
Carex gracillima	Graceful Wood Sedge	2	0%	0%
Carex scoparia	Lance-fruited Oval Sedge	2	0%	0%
Carex sparganioides	Burreed Sedge	2	0%	0%
Cephalanthus occidentalis	Buttonbush	2	0%	0%
Diarrhena americana	Beak Grass	2	0%	0%
Eleocharis palustris	Common Spikerush	2	0%	0%
Elymus hystrix	Bottlebrush Grass	2	0%	0%
Elymus trachycaulus	Slender Wheatgrass	2	0%	0%
Eutrochium purpureum	Sweet Joe-Pye Weed	2	0%	0%

Scientific name	Common name	Sites seeded	Percentage of seeded sites observed	Percentage of all sites observed
Lespedeza capitata	Round-headed Bushclover	2	0%	0%
Liatris spicata	Marsh Blazingstar	2	0%	0%
Lobelia cardinalis	Cardinal Flower	2	0%	0%
Solidago patula	Swamp Goldenrod	2	0%	0%
Sparganium eurycarpum	Common Bur Reed	2	0%	0%
Symphyotrichum cordifolium	Heart-leaved Blue Wood Aster	2	0%	0%
Symphyotrichum shortii	Short's Aster	2	0%	0%
Thalictrum dasycarpum	Purple Meadow Rue	2	0%	0%
Acorus calamus	Sweet Flag	1	0%	0%
Agrostis gigantea	Redtop	1	0%	0%
Carex stipata	Awl-Fruited Sedge	1	0%	0%
Carex tribuloides	Awl Fruited Oval Sedge	1	0%	0%
Carex typhinia	Common Cattail Sedge	1	0%	0%
Dalea candida	White Prairie Clover	1	0%	0%
Desmodium illinoense	Illinois Ticktrefoil	1	0%	0%
Helianthus occidentalis	Western Sunflower	1	0%	0%
Helianthus pauciflorus	Showy Sunflower	1	0%	0%
Koeleria macrantha	Prairie Junegrass	1	0%	0%
Liatris aspera	Rough Blazingstar	1	0%	0%
Lupinus perennis	Wild Lupine	1	0%	0%
Oligoneuron riddellii	Riddell's Goldenrod	1	0%	0%
Scirpus pendulus	Red Bulrush	1	0%	0%
Scirpus pungens	Chairmaker's Rush	1	0%	0%
Solidago flexicaulis	Zigzag Goldenrod	1	0%	0%
Solidago juncea	Early Goldenrod	1	0%	0%
Solidago nemoralis	Old-field Goldenrod	1	0%	0%
Spiraea alba	Meadowsweet	1	0%	0%

DISCUSSION

For all sites across Illinois and Indiana, we identified several variables that were correlated with the cover and richness of plant species in roadside plantings. Land cover PC1—which corresponded to a gradient from natural areas to urban, developed areas—was associated with native species cover and all three richness variables, but in an unexpected way. Cover of native species and richness of native, seeded, and non-native species all increased with increasing development within 100 m (328 ft) of planted sites. Proximity to development may have increased non-native, non-seeded species richness due to a greater diversity of introduced species near developed areas (Francis and Chadwick, 2015). Increases in native and seeded species cover and richness near developed areas are more difficult to explain but may have been due to increased maintenance of sites that were closer to developed areas, as maintenance is an important factor in native planting establishment (Kimball et al., 2014).

Distance from road was highly weighted for all models except non-native, non-seeded cover (although it approached our threshold of 50%). Native and native seeded cover and richness increased with distance from road, which is consistent with lower disturbance pressure and decreased soil contaminants including salts and automotive chemicals (Cale and Hobbs, 1991; Khan and Kathi, 2014; Sommer et al., 2018). Non-native, non-seeded species richness was greater closer to roads, which is also consistent with tolerance to disturbance and chemicals. It is important to note, however, that the sites we surveyed typically had high-diversity native mixes seeded at some distance from the road (generally > 4 m) and rarely had native mixes at the immediate road edge. Therefore, it is difficult to determine if these effects were due to initial planting decisions, environmental filtering of species assemblages, or a combination of both.

Soil PC3, which represented a gradient from soils rich in nitrate and P to those rich in Mg, was a highly weighted variable for native seeded and all native cover, such that high native cover and richness were found in soils with lower nitrate and P. This finding is consistent with previous literature reporting that native cover and richness are higher with lower nitrate and P due to increased competition with invasive plants (Brejda, 2000). However, it was somewhat surprising that high Mg correlated with greater native cover and richness considering the literature suggests Mg has a similar capacity to bolster non-native species (Franson et al., 2017). Soil PC2—which was associated with high Ca, cation exchange capacity, pH, and soluble salts—was associated with greater cover of non-native, non-seeded species. This is consistent with expectations, given that many non-native species can tolerate high salt concentrations, more basic soils, and more fertile soils (Brejda, 2000; Soti et al., 2020; Walker et al., 2021).

Native seed mix diversity was positively correlated with richness of seeded natives and all natives, but not non-natives. This suggests that seeding high-diversity native mixes led to a persistent increase in native species richness, even several years after planting. This result is consistent with Larson et al. (2011), who demonstrated that seed mix diversity impacts seeded and native richness but did not inhibit non-native species invasion.

A lack of high model weights associated with planting age across all sites was unexpected but suggests that factors other than years since planting were more important for the long-term persistence of native, seeded species. Differences in site ages between the two states may have complicated this analysis. Sites we surveyed in Illinois were either from 2007–2008 or from 2019–2021. All Indiana sites were planted 2016–2022, and many had high diversity. These differences may have masked any signal of age from the data. On the other hand, the lack of any high model weights associated with latitude and longitude suggest there was no geographic gradient for these variables across the states, and that plantings may have high cover and richness of native species (or non-native species) regardless of geographic location.

For Illinois-only sites, many of the trends of the combined dataset held true but with exceptions. Land cover PC1 was not highly weighted in any model, suggesting proximity to development was less of a predictor in Illinois. Age of planting was informative for native cover and non-native, non-seeded cover and richness. Younger plantings tended to have higher native cover, whereas older plantings tended to have increased cover and richness of non-native species. This may be a factor of diminishing maintenance of sites over time. Geographic patterns were also evident in Illinois. Specifically, diversity of non-native, non-seeded species was greater further north, and diversity of both native and non-native species was greater further east. Lower soil compaction was associated with increased native cover and richness and decreased non-native, non-seeded cover. It is possible that deep-rooted native species were able to reduce compaction over time, or that native assemblages just established more successfully in less compacted soils. Distance from the road was a predictor of seeded native cover and richness and non-native, non-seeded cover and richness, but not total native cover and richness. Soil variables suggested seeded native cover and total native cover in Illinois was best predicted by low soil PC2, which was associated with low Ca, cation exchange capacity, pH, and soluble salts, suggesting low tolerance of native species to salts and fertile soils. Cover and richness of non-native, non-seeded species was predicted by soil PC1, which was associated with high organic matter, estimated nitrogen release, and P. These fertile soils may allow non-natives to flourish. Seed mix diversity was a strong predictor of native seeded and all native richness.

A potentially important, but unknown, factor affecting vegetation in these sites was maintenance regime. Many sites had evidence of recent mowing or spot herbicide treatment of *Dipsacus* spp. However, with no records of how and when any of these sites were maintained, we could not include maintenance processes in our models. Based on previous studies, maintenance is certainly a key factor in success of a planting, and deferring maintenance for many years may cause an otherwise successful planting to fail due to invasion (Kimball et al., 2014). As such, a key recommendation for future work in this field would be to create and permanently retain maintenance records for sites, potentially via GIS database.

Our observations of seeded species (Table 10) yielded informative results and highlighted several species for wider incorporation in seed mixes due to high persistence. Although *Chamaecrista fasciculata* was often seeded and never observed, this should not be a reason not to use this species. It is a fast-growing annual legume that typically does not persist for many years but has important early cover and soil enrichment benefits in the establishment of a planting. *Carex bicknellii*, *Carex hystericina*, *Helianthus grossesserratus*, *Pycnanthemum tenuifolium*, and *Symphyotrichum lanceolatum* should be considered for use in more mixes, as they were present in 100% of seeded sites, even though they were seeded only once to thrice. The most reliable forbs, based on frequent observations and the large number of sites seeded, were *Monarda fistulosa, Rudbeckia hirta, Asclepias syriaca, Heliopsis helianthoides, Ratibida pinnata, Asclepias verticillata, Echinacea purpurea,* and *Desmanthus illinoensis*. These species were all observed at 32%–67% of seeded sites and are typical and disturbance-tolerant species for roadside seeding and prairie restorations. Based on the same criteria, the most reliable graminoids were *Panicum virgatum, Elymus virginicus, Bouteloua curtipendula, Andropogon gerardii, Carex vulpinoidea, Juncus effusus,* and *Carex brevior*. These graminoids were observed at 33%–73% of seeded sites. Wetland species were often unobserved due to having few surveyed sites in seeded wet areas and potentially a high degree of invasion of these sites by inundation-tolerant invasive species like *Phragmites australis, Phalaris arundinacea, Typha* spp., and *Rumex crispus*. Lastly, although never seeded, native species like *Oenothera biennis, Solidago canadensis, Ambrosia artemisiifolia, Apocynum cannabinum, Calystegia sepium, Cirsium discolor, Erigeron annuus, Eupatorium* spp., and *Symphyotrichum pilosum* were observed in many sites. Some of these species, particularly *Oenothera biennis, Eupatorium* spp., and *Symphyotrichum pilosum*, may be worth deliberate inclusion as early cover species. Some of the most diverse sites surveyed in Illinois District 3 specified the use of “Regreen” cover crop, a sterile wheat × wheatgrass hybrid. Unlike other non-native cover crops used in these plantings (*Avena sativa, Lolium perenne, Lolium multiflorum,* or *Triticum aestivum*) Regreen was never observed in any planting it was used in, suggesting its value as a strong early cover that does not persist in an assemblage.

The INDOT floodplain mix sites were generally very low in seeded species richness and cover, with a few observations *of Elymus canadensis, Desmanthus illinoiensis,* and *Rudbeckia hirta*. This mix may be poorly suited for wetland and ditch environments, given that most species in the mix are upland species and none are obligately wetland species (United States Army Corps of Engineers, 2020).

Overall, low soil fertility, surrounding development (or potentially maintenance regime), greater distance from road, and seed mix diversity appeared to be the most important predictors of native planting success and should be considered when incorporating native species. Many species that are common in native mixes were observed in these sites, even several years after initial planting, and should be considered for seeding in other areas, along with a few less common species with a high likelihood of persistence. We believe that maintenance regime is an important, but largely unrecorded, factor in native seeding success and should be more widely recorded by DOTs to facilitate future research.

CHAPTER 4: SUMMARY AND RECOMMENDATIONS

SUMMARY

Many maintenance benefits may be conferred by a switch to native species on roadways, including erosion control; fertilizer, pesticide, and sediment sequestration; inhibiting the establishment of introduced and woody species; insulating remnant prairies from invasive colonization; reducing driver visual fatigue; successful establishment without fertilizer or high fertility topsoil; and reducing the need for mowing. Ecological benefits of native species are numerous, including providing forage resources and habitat for many vertebrate and invertebrate species, connecting migration corridors, and potentially reducing deer-vehicle collisions by allowing deer more time to decide to cross a road.

Overall, our research shows that many native species can germinate and persist well in varied roadside conditions, but care needs to be taken to ensure success in the early stages of a planting. As a result of the degree of invasion in this region, long-term maintenance (mowing, prescribed burning) is required for the lifetime of a planting. However, maintenance can be reduced after the first several growing seasons with follow-up maintenance every three to five years.

RECOMMENDATIONS

Many native species can persist and even thrive near roadways and should be implemented in lieu of Eurasian turfgrasses whenever possible. Table 11 lists native species with proven records of success from our data. Rarely used species, especially species common to reference prairies but uncommon in seed mixes (e.g., *Dicanthelium* spp., Ericaceae, Violaceae, Caprifoliaceae, and Boraginaceae; Ladwig et al. 2020), should be tested experimentally for use along roadsides.

Seed mixes should be diverse with at least nine species and a diversity of functional groups (C3 and C4 grasses, forbs, legumes) to allow the assemblage to weather different environmental stressors (USDA NRCS, 2015; Meissen et al., 2020; Barak et al., 2022). Mixes should be seeded at a rate of 60–70 pure live seeds per ft^2. Annuals and biennials should not be more than 10% of the permanent seed mix; however, a native early cover assemblage should contain several annual forbs such as *Chamaecrista fasciculata, Rudbeckia hirta,* and *Oenothera biennis*. Planted seed mixes should be a diverse assemblage of native species at a roughly 1:1 ratio of graminoids:forbs and legumes. Higher rates of graminoids may be employed when early cover is needed, as high as 3:1 graminoids:forbs and legumes. Legumes should not be seeded at greater than 10% of a mix to avoid over-nitrifying soil. Early and late blooming forbs should be included in mixes for greater pollinator resource access and visual interest for motorists. Upland (FAC-UPL) species should be used in well-drained areas like inslopes, and wetland (OBL-FAC) species should be planted in wetter areas like ditches. More disturbance- and salt-tolerant natives should be seeded closer to the road edge, with less tolerant species beyond the 5 m (16 ft) safety strip. Coefficients of conservatism (CCs) can be useful for estimating disturbance tolerance, but high CC species may still establish near roadways.

From our results, soil fertility seems to be a significant determinant of native cover and richness. Therefore, soils should not be amended with fertilizer prior to seeding with a native assemblage.

Additionally, it may be beneficial to use a poorer soil for topsoil post-construction work to limit dominance by invasive plants (Brejda, 2000; Wilsey and Polley, 2006). Road salts are also a factor in native planting success, and where safe and feasible, road salt application should be reduced adjacent to native plantings, potentially by ameliorating salt with sand or gravel.

Seeding should take place in as large an area as possible to minimize edge effects. Lobes of cloverleaf interchanges are one of the best areas to minimize edge effects and to provide a large area for future seed harvest. Seeding of native mixes onto bare soil should be performed with a hydroseeding unit for best results (Bochet et al, 2010). However, a rangeland or native seed drill can also be a suitable method in large, low-slope areas. Straw mulch may be applied over top of a hydroseed slurry before it has fully dried. Ideally, straw mulch cut from existing plantings of native grassland should be employed (per MnDOT [2020], MoDOT [2023], ODOT [2023] specifications). If seeding into existing vegetation, the area should be mowed as low as possible, followed by seeding with a hydroseeder or rangeland or native grass drill seeder. For small areas, hand broadcasting and rolling with a cultipacking wheel may be sufficient. Seeding should take place in the fall following the end of construction. If a non-native cover crop is required, the Regreen cover crop should be used because it does not persist in an assemblage.

To establish plantings, we recommend mowing in early May, early June, and early July of the first year to 15–20 cm (6–8 in.) and mowing at least once from June–August of the second year (as per MnDOT [2020] specifications). Further maintenance every three to five years should be a full mow or ideally a prescribed burn. Prescribed burns in early spring (after insects break dormancy) are the ideal maintenance methods in most situations but require trained teams and public notice. If burning is infeasible, mowing and removal of cut material via raking is beneficial. Removed material can then be used as native prairie straw mulch for other seeding projects.

Lastly, for native plantings to maintain integrity and provide the benefits described throughout this report, planting maintenance and monitoring needs to be organized and saved to a searchable database for reference over the long term. ArcGIS programs may be the best tool for these data and can be a helpful resource for statewide messaging about the values and location of native plantings by the DOT. It may be worth consideration to assign a specific team to maintenance and monitoring of native roadside plantings, which could also include remnant and railroad prairies under DOT purview.

Table 11. Native species recommended for use in Midwestern DOT planting

Rank*	Common name	Scientific name	Plant type	Near roadway use	Cover crop potential	Salt tolerant
A	common milkweed	*Asclepias syriaca*	forb	Yes		
A	butterfly milkweed	*Asclepias tuberosa*	forb			
A	whorled milkweed	*Asclepias verticillata*	forb	Yes		
A	side-oats grama	*Bouteloua curtipendula*	graminoid	Yes	Yes	Yes
A	partridge pea	*Chamaecrista fasciculata*	legume	Yes	Yes	Yes
A	lanceleaf tickseed	*Coreopsis lanceolata*	forb	Yes	Yes	
A	pale purple coneflower	*Echinacea pallida*	forb	Yes		
A	purple coneflower	*Echinacea purpurea*	forb			
A	false sunflower	*Heliopsis helianthoides*	forb			
A	wild bergamot	*Monarda fistulosa*	forb	Yes		
A	evening primrose	*Oenothera biennis*	forb	Yes	Yes	
A	switchgrass	*Panicum virgatum*	graminoid	Yes		Yes
A	gray-headed coneflower	*Ratibida pinnata*	forb	Yes		
A	black-eyed susan	*Rudbeckia hirta*	forb	Yes	Yes	
A	New England Aster	*Symphyotrichum novae-angliae*	forb			
A	hoary vervain	*Verbena stricta*	forb	Yes		
B	yarrow	*Achillea millefolium*	forb	Yes	Yes	
B	big bluestem	*Andropogon gerardii*	graminoid			Yes
B	eastern white sage	*Artemisia ludoviciana*	forb			
B	swamp milkweed	*Asclepias incarnata*	forb			
B	plains oval sedge	*Carex brevior*	graminoid	Yes		
B	porcupine sedge	*Carex hystericina*	graminoid			
B	common hop sedge	*Carex lupulina*	graminoid			
B	field oval sedge	*Carex molesta*	graminoid			
B	brown fox sedge	*Carex vulpinoidea*	graminoid	Yes		
B	tall coreopsis	*Coreopsis tripteris*	forb			
B	poverty oatgrass	*Danthonia spicata*	graminoid			
B	Illinois bundleflower	*Desmanthus illinoensis*	legume	Yes	Yes	
B	showy ticktrefoil	*Desmodium canadense*	legume			
B	Canada wildrye	*Elymus canadensis*	graminoid	Yes	Yes	
B	Virginia wildrye	*Elymus virginicus*	graminoid	Yes	Yes	
B	rattlesnake master	*Eryngium yuccifolium*	forb			
B	tall boneset	*Eupatorium altissimum*	forb			
B	common boneset	*Eupatorium perfoliatum*	forb			
B	late boneset	*Eupatorium serotinum*	forb			
B	sawtooth sunflower	*Helianthus grosseserratus*	forb			
B	rigid goldenrod	*Oligoneuron rigidum*	forb			
B	foxglove beardtongue	*Penstemon digitalis*	forb			
B	obedient plant	*Physostegia virginiana*	forb			
B	slender mountainmint	*Pycnanthemum tenuifolium*	forb			

Rank*	Common name	Scientific name	Plant type	Near roadway use	Cover crop potential	Salt tolerant
B	Virginia mountainmint	*Pycnanthemum virginianum*	forb			
B	brown-eyed susan	*Rudbeckia triloba*	forb			
B	little bluestem	*Schizachyrium scoparium*	graminoid	Yes		
B	dark green bulrush	*Scirpus atrovirens*	graminoid			
B	wild senna	*Senna hebecarpa*	legume			
B	compassplant	*Silphium laciniatum*	forb			
B	indiangrass	*Sorghastrum nutans*	graminoid			
B	prairie cordgrass	*Spartina pectinata*	graminoid			Yes
B	smooth blue aster	*Symphyotrichum laeve*	forb			
B	swamp aster	*Symphyotrichum puniceum*	forb			
B	Ohio spiderwort	*Tradescantia ohiensis*	forb			
B	blue vervain	*Verbena hastata*	forb			
B	smooth ironweed	*Vernonia fasciculata*	forb			
B	golden alexander	*Zizia aurea*	forb			
C	broomsedge	*Andropogon virginicus*	graminoid	Yes		
C	wild white indigo	*Baptisia alba*	legume			
C	false aster	*Boltonia asteroides*	forb			
C	buffalograss	*Buchloe dactyloides*	graminoid			Yes
C	oval prairie sedge	*Carex bicknellii*	graminoid			
C	crested oval sedge	*Carex cristatella*	graminoid			
C	purple prairie clover	*Dalea purpurea*	legume			
C	blanketflower	*Gaillardia pulchella*	forb			
C	foxtail barley	*Hordeum jubatum*	graminoid			
C	prairie Junegrass	*Koeleria macrantha*	graminoid			Yes
C	prairie blazingstar	*Liatris pycnostachya*	forb			
C	water horehound	*Lycopus americanus*	forb			
C	wild quinine	*Parthenium integrifolium*	forb			
C	sweet black-eyed susan	*Rudbeckia subtomentosa*	forb			
C	prairie dock	*Siliphium terebinthinaceum*	forb			
C	cup plant	*Silphium perfoliatum*	forb			
C	rough goldenrod	*Solidago rugosa*	forb			
C	prairie dropseed	*Sporobolus heterolepis*	graminoid			
C	white panicle aster	*Symphyotrichum lanceolatum*	forb			

*Rank A, widely usable with proven track record. Rank B, less well-vetted in this report but still valuable for inclusion. Rank C, situationally useful and requires further assessment.

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