JOINT TRANSPORTATION RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

Feasibility of Utilizing Native Grasses and Forbs In Lieu of Exotic Cool Season Grasses on Roadside Rights-of-Way

Wesley Bollinger, Rabin Bhattarai, Jeffrey W. Matthews

SPR-4810 • Report Number: FHWA/IN/JTRP-2025/14 • DOI: 10.5703/1288284317878

RECOMMENDED CITATION

Bollinger, W., Bhattarai, R., & Matthews, J. W. (2025). *Feasibility of utilizing native grasses and forbs in lieu of exotic cool season grasses on roadside rights-of-way* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2025/14). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317878

AUTHORS

Wesley Bollinger
Graduate Research Assistant
Department of Natural Resources and Environmental Sciences
University of Illinois Urbana-Champaign

Rabin Bhattarai
Associate Professor
Department of Agricultural and Biological Engineering
University of Illinois Urbana-Champaign

Jeffrey W. Matthews
Associate Professor
Department of Natural Resources and Environmental Sciences
University of Illinois Urbana-Champaign
(217) 244-2168
jmatthew@illinois.edu
Corresponding Author

ACKNOWLEDGMENTS

We thank the Technical Review Panel for advice and input throughout the project. Andrew Kaul and David Zaya provided feedback on project conceptualization; David Zaya assisted with statistical analysis; Aaron Ivsin assisted with field work, GIS, and data entry; and Rohini Vembar and Matt Finzel assisted with field work.

JOINT TRANSPORTATION RESEARCH PROGRAM

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Published reports of the Joint Transportation Research Program are available at https://docs.lib.purdue.edu/jtrp/.

NOTICE

TECHNICAL REPORT DOCUMENTATION PAGE

<table>
<tr><td>1. Report No.
FHWA/IN/JTRP-2025/14</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Feasibility of utilizing native grasses and forbs in lieu of exotic cool season grasses on roadside rights-of-way</td><td colspan="2">5. Report Date
May 15, 2025</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Author(s)
Wesley Bollinger
Rabin Bhattarai, Ph.D. https://orcid.org/0000-0002-3433-299X
Jeffrey W. Matthews, Ph.D. https://orcid.org/0000-0002-5993-7610</td><td colspan="2">8. Performing Organization Report No.
FHWA/IN/JTRP-2025/14</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Joint Transportation Research Program
Hall for Discovery and Learning Research (DLR), Suite 204
207 S. Martin Jischke Drive
West Lafayette, IN 47907</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
SPR-4810</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Indiana Department of Transportation (SPR)
State Office Building
100 North Senate Avenue
Indianapolis, IN 46204</td><td colspan="2">13. Type of Report and Period Covered
Final Report</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code</td></tr>
<tr><td colspan="4">15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.</td></tr>
<tr><td colspan="4">16. Abstract
We assessed the status of 34 native species plantings along roadsides in Indiana and Illinois and evaluated soil conditions, distance from road, and surrounding landscape cover to determine which factors led to successful long-term establishment of plantings. Cover by seeded native species and native species overall increased with distance from road and decreased with increasing soil nitrate and phosphorous. Number of native species and seeded native species increased with distance from road and greater seed mix diversity. In contrast, richness of non-native, non-seeded species was greater at shorter distances from 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 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.</td></tr>
<tr><td colspan="2">17. Key Words
environmental quality, invasive plants, prairie, roadsides, seeding, soil quality, vascular plants</td><td colspan="2">18. Distribution Statement
No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
29</td><td>22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EXECUTIVE SUMMARY

Introduction

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 Indiana Department of Transportation (INDOT), we assessed the status of native species plantings along roadsides in Indiana and Illinois. We evaluated landscape and local factors to determine which factors led to successful long-term establishment of plantings and determined which species, when seeded, are most likely to persist in a roadside planting. 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 planting (INDOT Mix R or U). We estimated cover of plant species in 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 328 ft of each site. Data collected were used to determine which factors affected cover and richness of native seeded species; all native species; and non-native, non-seeded species.

Findings

Native seeded cover increased with greater distance from the road and lower soil nitrate and phosphorous. High overall native species cover was best predicted by greater distance from the road, lower nitrate and phosphorous, and proximity to developed land. Native seeded richness and 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 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 all 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.

Implementation

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 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 INDOT's standard specifications for seeding mixes, roadside planting, and roadside vegetation management.

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1. LITERATURE REVIEW

1.1 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 to persistent agriculture and development pressures (Wright & Wimberly, 2013). Illinois' Grand Prairie ecosystem, which covered approximately 21 million acres (8.7 million hectares; ~61% of land area) in 1820, now occupies around 0.01% of its original area. Iowa has seen a 99.9% decrease in its 28 million acres (11.3 million ha) of presettlement prairie habitat (Houseal & 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 500 mi (800 km) 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 & Matlack, 2009; Skultety & 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 2,070,000 mi (3,331,000 km). At a conservative estimate (assuming two lane roads at 12 ft [3.7 m] per lane [Federal Highway Administration {FHWA, 2024}]) this represents a paved road area of 6,025,000 acres (2,439,000 ha). For highway miles (centerline miles) alone, eight Midwestern Departments of Transportation (DOT) operate more than 101,000 centerline miles (162,000 km) of highways (Illinois DOT [IDOT], 2024; Iowa DOT [IaDOT], 2024; Indiana DOT [INDOT], 2021; Michigan DOT [MDOT], 2024; Minnesota DOT [MnDOT], 2024; Missouri DOT [MoDOT], 2024; Oregon DOT [ODOT], 2024; Wisconsin DOT [WisDOT], 2024). A conservative estimate of the unpaved right-of-way (ROW), consisting of interchanges, medians and roadside margins, excluding roads themselves is 1,100,000 acres (445,000 ha) given 50-ft (15-m) medians and 20-ft (6.1-m) shoulders. This estimate does not include the area of "cloverleaf" interchanges on highways, each lobe of which can be 10 or more acres (4 ha).

With the declared U.N. Decade on Ecosystem Restoration in full swing (Eisele & Hwang, 2019), the roadsides 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?

1.2 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 (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 non-native, invasive plants over native species (Brejda, 2000).

Roads and the vehicles that drive them carry invasive plant material, facilitating colonization of invasive plants along roadsides (von der Lippe & 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 including Bermudagrass (*Cynodon dactylon* [Tinsley et al., 2006; Schuster et al., 2018]). Planting native species 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 commonly utilized to maintain stands of 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 & Angold, 2000; Murray et al., 2009; Noordijk et al., 2011; Wojcik & Buchmann, 2012; Hopwood et al., 2015; Reppert & de Roode, 2018; Kaul & 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 store organic material 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 & 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 common (Cale & Hobbs, 1991; Schilling et al., 2018).

There are also roadway safety and economic benefits to utilizing 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 & 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 regrading work (Drake, 1980). For example, in Florida, the value of ROW ecosystem services (runoff prevention, organic matter accumulation, 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).

1.3 Best Practices for Seed Mix Design

Planting roadsides from seed 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 & Kathi, 2014; Sommer et al., 2018; Walker et al., 2021). Thus, selecting species for a roadside seed mix is a complex process based on many attributes. Considerations include, but are not limited to, cost, plant type (graminoid, legume, forb), plant 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 tend to be more expensive than commercially available, 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 much lower cost than the $10–100 per ounce for some native species. 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 & 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 & Matthews, 2022) dependent upon objectives.

Planting a variety of species with different functional traits will keep the planting diverse in species 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 (United States Department of Agriculture, Natural Resources Conservation Service [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 roadside plantings, low-cost, quick-establishing vegetative cover is a high priority. A minimum percentage cover of vegetation is a common criterion for stormwater permitting, and roadside managers generally consider 75% plant cover in the first year to be a successful seeding from bare ground (*personal communication*, IDOT and INDOT employees). A rapid cover mix should have a higher proportion of graminoid seeds relative to forb and legume seeds, as high as 3 parts graminoids to 1 part 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 vegetation height; on ROW areas like intersections 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 shoulders 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, more broadly, some families (e.g., *Dicanthelium* spp., Ericaceae, Violaceae, Caprifoliaceae, and Boraginaceae) may be worthy of consideration in an ROW mix pending experimental evidence of growth in those conditions.

Bloom phenology and public perception of attractiveness are non-structural 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 for 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 roadsides that 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 roadside 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: Obligate Wetland (OBL), Facultative Wetland (FACW), Facultative (FAC), Facultative Upland (FACU), and Upland (UPL). 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 the application of chloride-based deicers and anti-icing materials in winter. This is difficult to address due to limited evidence of salt tolerance among most Midwestern native plants and invasion by halophytes, aggressive salt-tolerant invasive plants, like giant reed (*Phragmites australis*), kochia (*Bassia scoparia*), and seaside goldenrod (*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 & 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 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 placed 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 scores are state specific and may be higher or lower across different parts of a species' range, though they rarely vary by more than 2 points across the range. Many forbs including milkweeds (*Asclepias* spp.), common evening-primrose (*Oenothera biennis*), yarrow (*Achillea millefolium*), smartweeds (*Polygonum* spp.), and black-eyed Susan (*Rudbeckia hirta*) have low CC values and are great candidates for early establishing roadside plants.

1.4 Best Practices for Seeding Methods and Management

Broadcast seeding, hydroseeding, and drill seeding are all options for establishing roadside vegetation. Although broadcast seeding 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 which is sprayed onto roadsides and generally covered with mulch unless seeded onto cut dried vegetation. This is the most effective seeding method for bare soil, 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, annual forbs, and legumes may be beneficial. Typical cover crops are oats (*Avena sativa*) for spring planting and perennial ryegrass (*Lolium perenne*) or wheat (*Triticum aestivum*) for fall planting, although they can persist in an assemblage (personal observations). Other cover crops to consider are native Canada wildrye (*Elymus canadensis*) and Virginia wildrye (*E. virginicus*), although these native, cool-season grasses may lead to fewer warm-season native grasses persisting (Herget, 2020; Kaul & Wilsey, 2022). Some fast-growing, annual forb and legume species like black-eyed Susan (*Rudbeckia hirta*), common evening-primrose (*Oenothera biennis*), and partridge pea (*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, safety, liability concerns, and a lack of trained employees (Harrington, 1994; *Personal correspondence*, IDOT staff). 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. The absence of fire is a primary reason for native species loss from prairie remnants (Leach & Givnish, 1996). Burning also increases the extent and depth of prairie plant roots, enriching soil and preventing erosion over the long term due to increased root biomass (Kitchen et al., 2009). A burn can be especially beneficial in early spring because it reduces pressure from undesirable species, clears dead plant material that inhibits 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 smooth brome (*Bromus inermis*), quackgrass (*Elymus repens*), and reed canarygrass (*Phalaris arundinacea*), in a Midwestern prairie restoration (Betz et al., 1996). Although most invasive species can be controlled by prescribed burns, some species like sericea lespedeza (*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, cutting followed by the removal of the cut plant material can be a functional alternative (Busby, 2014). Mowing without removal of cut material can also be beneficial but given the value of cut native prairie straw as establishment mulch for other plantings, collection of cut material should be attempted as often as possible. Although there are not many native prairie species that can withstand frequent mowing used for Eurasian turfgrasses, most native grasses and forbs are adapted to grazing and can thus tolerate annual mowing in a diverse assemblage. Few native tallgrass graminoids can form a typical turf, but shorter grama grasses (*Bouteloua* spp.), buffalograss *Buchloe dactyloides*, and sedges (*Carex* spp.) 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 colonization by native species (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).

2. SURVEY OF PREVIOUSLY PLANTED ROADSIDES

2.1 Introduction

Since the development of wheeled vehicles, roads have covered large swaths of the Earth's surface and have had tremendous impacts on the planet in the process. In the contiguous US alone, over 4,200,000 mi (6,800,000 km) 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 & 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 established in highway ROWs. Established native herbaceous plant communities inhibit growth of woody vegetation and invasive species more successfully than Eurasian cool-season turfgrasses (de Blois et al., 2004; Tinsley et al., 2006; Simmons et al., 2011; Schuster et al., 2018). Roadside native plantings can also insulate remnant habitats from colonization by invasive plants (Rowe, 2013). Native species can be planted without fertilizers, reducing both cost and risk of downstream eutrophication (Brejda, 2000). Furthermore, native plantings can remove and sequester agricultural chemicals including fertilizers and pesticides, reducing the amount that enters waterways (Hernandez-Santana et al., 2013; Zhou et al., 2014; Prosser et al., 2020; Tatariw et al., 2021). The deep roots of native prairie species reduce slope failure risk and the need for costly regrading work (Drake, 1980). These roots also allow native species to tolerate drought conditions better than Eurasian cool-season turfgrasses (Tinsley et al., 2006; Alvarez et al., 2007). Long-term savings arise due to reductions in maintenance and mowing (Turk et al., 2017). Unfortunately, despite these advantages, there are numerous challenges that inhibit the successful establishment of a roadside native plant community.

Roadsides are typically planted with seed mixes rather than plugs. However, successful establishment from seed is generally more difficult than establishment from plugs, especially for roadsides, which are often disturbed areas with poor soil and chemical contaminants (Khan & Kathi, 2014; Gallagher & Wagenius, 2016; Young et al., 2017; 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). Concentrations of pollutants decline or increase with distance from the road and depending on watershed characteristics (Cale & 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). Roadsides are also ideal areas for hardy, disturbance-tolerant invasive species to colonize from surrounding areas, inhibiting growth of native species (von der Lippe & 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.

INDOT is interested in increasing the usage of and improving successful installation of native species 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 ROW conditions and recommend improvements to INDOT 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: (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?

2.2 Methods

2.2.1 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 328 ft (100 m) of a nearby road, eleven 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 of these sites were seeded with diverse specialty mixes that are separate from IDOT specification manual contract seed mixes. Six other sites contained only the officially unspecified but often seeded low-diversity Class 5C, Pollinator Mix, which has been in use since at least 2011 (*personal communication,* IDOT employees). 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 (*personal communication*, INDOT employees), 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 equal 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 twelve 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.

2.2.2 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 60 mi (100 km) 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 164-ft (50-m) baseline parallel to 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 of the edge of the planting area based on map boundaries and visible vegetation. We recorded a GPS point at the 0-ft point of the baseline using a Garmin ETREX 22X GPS, which we used to georeference quadrat locations. Transect-based quadrat surveys were conducted in a perpendicular direction from the baseline, away from 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 2.7-ft^2 (0.25-m^2) quadrats. Narrower sites received fewer quadrats. All quadrats on each transect were between 0 and 131 ft (40 m) from the baseline. Within each site, the distances of quadrats from the baseline were identical among transects. However, quadrat distances from 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 the percent cover of bare ground, dead plant litter, and/or standing water.

When conditions safely allowed for extra time at a site, we spent five 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.

2.2.3 Additional Data Collection

2.2.3.1 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 164-ft (50-m) baseline to determine the actual distance of each quadrat from the edge of the pavement to the nearest 0.3 ft (0.1 m). As these distances may have differed due to road curvature by as much as 0.66 ft (0.2 m) from other quadrats assumed to be the same distance from road, we averaged all quadrats at the same idealized distance from road by this true distance. These mean distances from road were used for all analyses.

2.2.3.2 Surrounding Land Cover and Principal Components 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 328 ft (100 m) using a geodesic method and excluded the input polygon. We used the U.S. Geological Survey National Land Cover 2021 Dataset for Illinois and Indiana (98-ft [30-m] grid cells) for this analysis. Using the clip raster tool, 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., 2018; RStudio Team, 2020).

2.2.3.3 On-Site Environmental Variables and PCA. 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 2 in. (5 cm) per second to a depth of 12 in. (30 cm) 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 0.8-in. (2-cm) diameter soil core, we collected a 4-in. (10-cm) deep core at each quadrat, aggregated cores into bags by distance from road at each site and placed them immediately into a cooler at approximately 40°F. Soil samples were analyzed for organic matter, estimated nitrogen release, cation exchange capacity, pH, soluble salts (measured as conductivity), phosphorous, potassium, magnesium, calcium, and nitrate by Waypoint Analytical (Champaign, IL). At two sites we were unable to collect any soil cores for the five total quadrats at the nearest distance to the 164-ft (50-m) 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 which 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 integral parts of our models, we sought to interpolate data from complete soil cores to fill in 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 328 ft (100 m) 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 road for all sites with complete data against the minimum recorded distance from 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 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 road against soluble salt values for all sites with complete data and used the mean of all values within ± 8 ft (2.5 m) 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 which lacked all nitrate data. For this site we took the median of all complete site nitrate values within ± 8 ft (2.5 m) of the missing distances.

Transformations were required to bring most soil variables to a normal or near normal condition 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 principal component analysis (PCA) to reduce the dimensionality of these data. Eigenvalues and eigenvectors were obtained from RStudio packages prcomp and FactoMineR (Lê et al., 2018; RStudio Team, 2020).

2.2.3.4 Model Selection. We used linear mixed effects models to determine the best predictors of cover and richness of native seeded species, cover and richness of all species native to Illinois and Indiana according to the USDA Plants database (USDA-NRCS, 2024), as well as 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 (R Core Team, 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 (R Core Team, 2024) with site as a random effect and all other variables as fixed effects. We used the factorial dredge package (R Core Team, 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 (R Core Team, 2024). All cover dredges contained 4,096 model runs and all richness dredges contained 8,192 model runs.

2.2.3.5 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. A total of 150 native species and 10 non-native grasses and clovers (*Trifolium* spp.) were specified across all seed mixes.

2.3 Results

2.3.1 Land Cover PCA

Reduction of land cover types at the 328-ft (100-m) scale resulted in three retained principal components (PCs) via scree plot, which amounted to 64% of the total variation (Table 2.1). 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.

2.3.2 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 2.2). 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 2.1
Loadings for surrounding land cover principal components with the four largest loadings underlined.

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

TABLE 2.2
Loadings for soil chemistry principal components with the largest loadings underlined.

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

2.3.3 Cover and Richness Models

After running a dredge function in R where all permutations of model variables are tested for their predictive power, models of cover and richness for seeded native, all native, and all non-native non-seeded species showed between one and three variables with a greater than 50% weight in factorial dredging (Table 2.3). 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.

2.3.3.1 Native Seeded Species Cover and Richness. We performed a transformation for native seeded cover in R using the logit function 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 2.3, Figure 2.1). Greater native seeded cover across sites and quadrats was associated with increased distance from road, higher Mg, and lower nitrate and P.

Native seeded richness was logit transformed in R to normalize residuals. Three predictor variables had summed weights

TABLE 2.3
Percentage weights for variables included in linear mixed effects models, with overall directional forcing shown in parentheses. Values in bold indicate greater than 50% model weight, and underlined values were included in the highest weighted model.

	Cover			Richness		
Model Variables	**Native Seeded Species**	**All Native Species**	**Non-Native Non-Seeded Species**	**Native Seeded Species**	**All Native Species**	**Non-Native Non-Seeded Species**
Land Cover PC1	(+)30.2	**(+)58.2**	(+)45.5	**(+)75.1**	**(+)66.3**	**(+)51.8**
Land Cover PC2	(−)25.9	(−)26.3	(−)29.9	(−)33.7	(−)28.7	(−)26.3
Land Cover PC3	(+)42.7	(−)25.9	(+)27.0	(+)41.8	(+)25.8	(+)26.4
Age of planting (years)	(+)28.8	(−)38.3	(+)31.2	(−)26.2	(−)37.6	(+)26.2
Latitude	(+)26.1	(+)27.1	(−)26.4	(−)27.9	(−)26.0	(−)26.3
Longitude	(+)29.8	(−)28.5	(−)34.3	(+)33.5	(+)28.6	(−)27.9
Soil Compaction (PSI)	(−)26.1	(+)26.1	(+)28.5	(−)33.4	(−)47.1	(−)25.9
Distance from Road (m)	**(+)>99.9**	**(+)95.7**	(−)49.6	**(+)>99.9**	**(+)98.8**	**(−)82.1**
Soil PC1	(+)26.6	(−)29.3	(+)35.7	(+)33.6	(+)27.1	(+)47.8
Soil PC2	(−)33.8	(−)40.4	**(+)63.5**	(+)30.4	(−)28.9	(+)34.8
Soil PC3	**(+)73.4**	**(+)63.0**	(−)35.6	(+)32.9	(+)45.4	(−)31.1
Soil PC4	(+)25.8	(+)35.2	(+)33.4	(−)27.7	(+)33.1	(−)26.8
Number of Spp. In Mix				**(+)>99.9**	**(+)99.5**	(−)26.8
Most Weighted Models						
df	5	5	4	6	6	5
Log-Likelihood	−474.1	−30.9	−24.6	−54.9	−635.7	−65.4
Weight	0.022	0.011	0.006	0.016	0.012	0.010

above 50% in models for native species richness: distance from road, number of species in the planting mix, and land cover PC1 (Table 2.3, Figure 2.2). 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.

2.3.3.2 Overall Native Species Cover and Richness. For cover by all native species in quadrats at sites across both states, three variables (distance from road, land cover PC1, and soil PC3) had weights above 50% (Table 2.3, Figure 2.3). The highest weighted model included only distance from road and soil PC3 with a weight of 0.011. Greater total native cover was

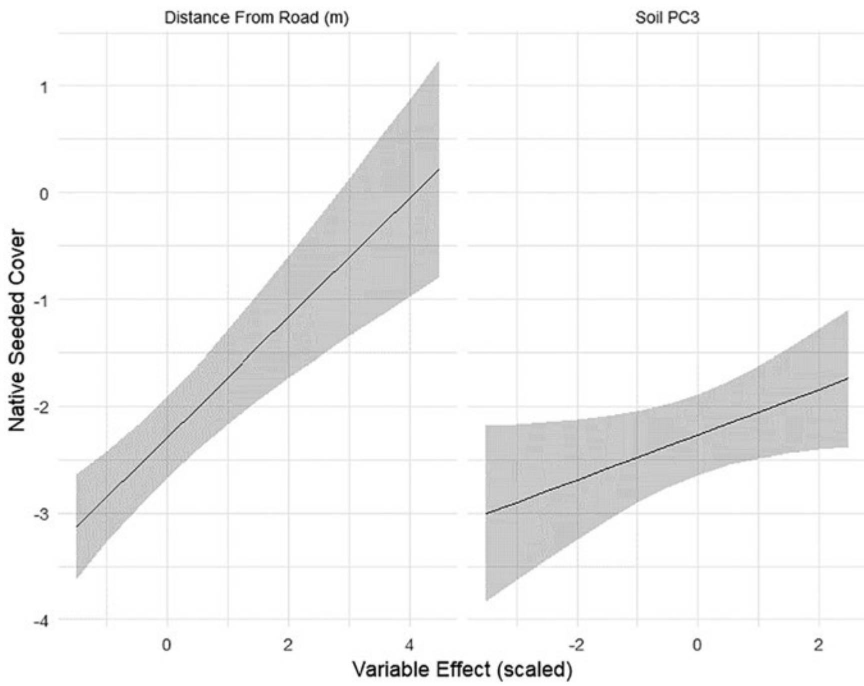

Figure 2.1 Effects plots for highly weighted (> 50%) variables (distance from road and soil PC3) for predicting native seeded cover.

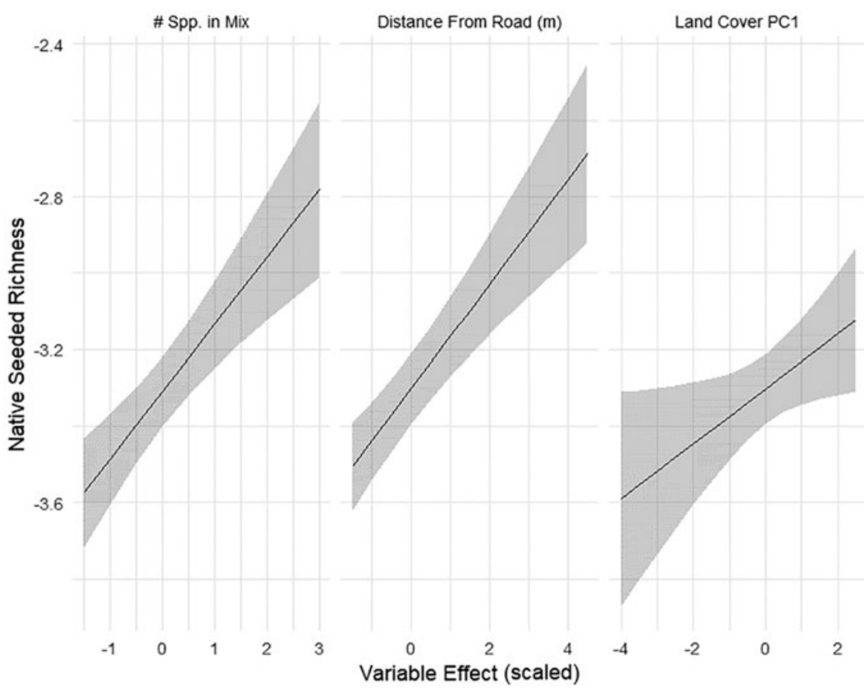

Figure 2.2 Effects plots for highly weighted (> 50%) variables (number of species planted, distance from road, and land cover PC1) for predicting native seeded richness.

associated with greater distance from road, higher magnesium, lower nitrate and phosphorous, and potentially higher 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 2.3, Figure 2.4). The highest weighted model included only these three variables with a weight of 0.012.

2.3.3.3 Introduced (Non-Native, Non-Seeded) Species Cover and Richness. For non-native, non-seeded cover in quadrats, one variable, soil PC2, had a weight above 50%.

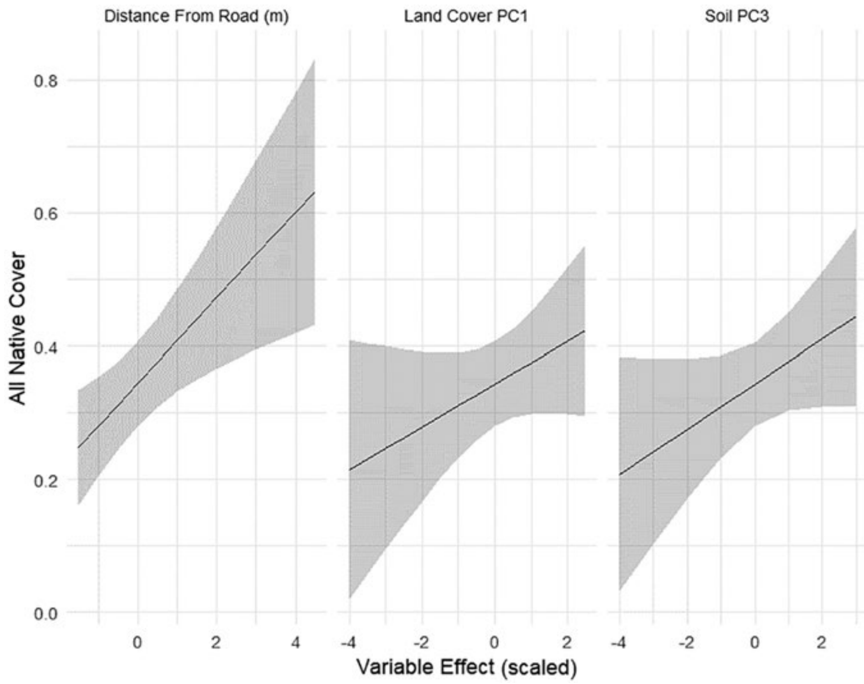

Figure 2.3 Effects plots for highly weighted (> 50%) variables (distance from road, land cover PC1, and soil PC3) for predicting native species cover.

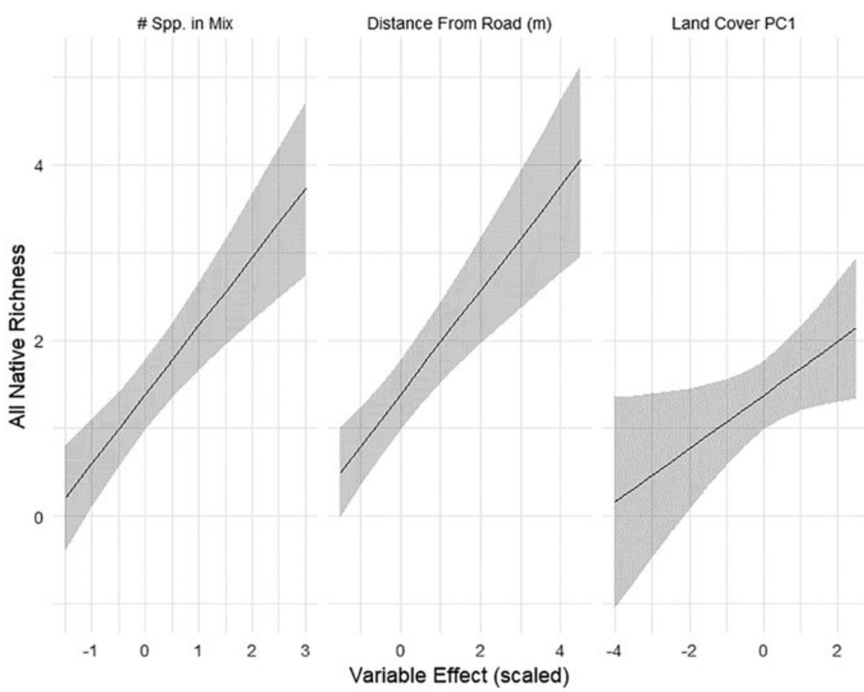

Figure 2.4 Effects plots for highly weighted (> 50%) variables (number of species planted, distance from road, and land cover PC1) for predicting native species richness.

The highest weighted model included only soil PC2 with a weight of 0.006 (Table 2.3, Figure 2.5). This suggests that non-native cover increased with higher calcium, 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 2.3, Figure 2.6). The highest weighted model included only these two variables with a weight of 0.01. Thus, greater invasive richness was associated with decreased distance from road and greater surrounding development.

2.3.4 Seeded Species Observations

We observed 28 species in over half of the sites where they were seeded (Table 2.4). Five species were present in 100% of seeded sites, however three of them were only seeded at

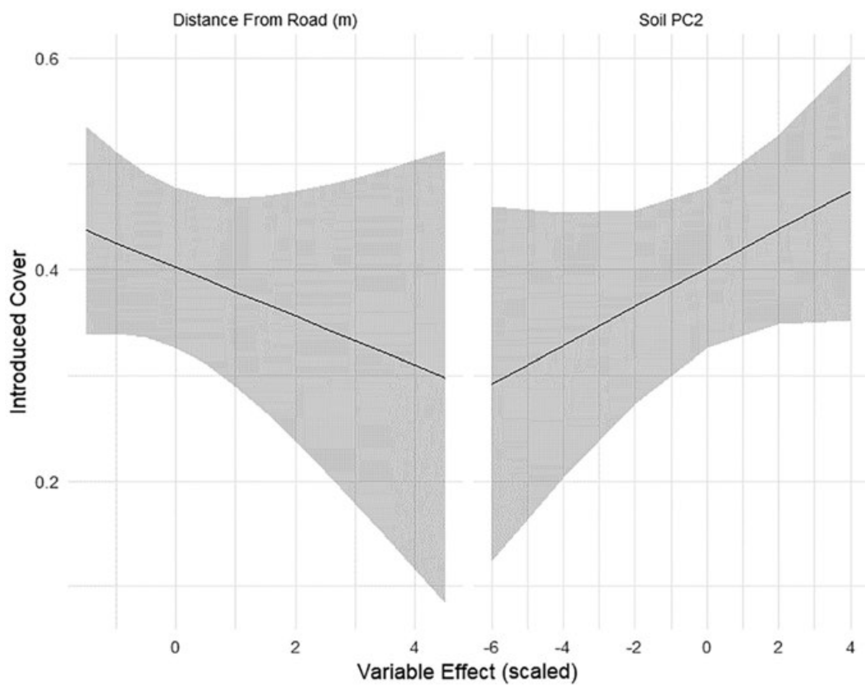

Figure 2.5 Effects plots for highly weighted (> 50%) variables (distance from road and soil PC2) for predicting cover of non-native, non-seeded species.

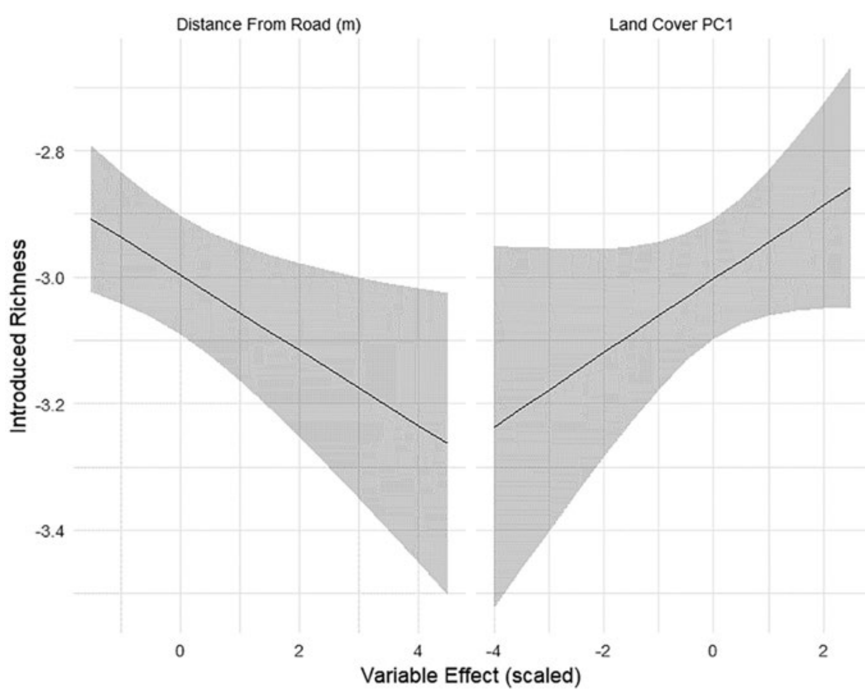

Figure 2.6 Effects plots for highly weighted (> 50%) variables (distance from road and land cover PC1) for predicting richness of non-native, non-seeded species.

TABLE 2.4
Occurrences of seeded species (non-native species underlined) 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%
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%

(*Continued*)

TABLE 2.4
(continued)

Scientific Name	Common Name	Sites Seeded	Percentage of Seeded Sites Observed	Percentage of All Sites Observed
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%
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%

(*Continued*)

TABLE 2.4
(continued)

Scientific Name	Common Name	Sites Seeded	Percentage of Seeded Sites Observed	Percentage of All Sites Observed
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%
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%

one site. Five species were found a total of 10 or more times each across all 34 sites: common milkweed (*Asclepias syriaca*), wild bergamot (*Monarda fistulosa*), black-eyed Susan (*Rudbeckia hirta*), false sunflower (*Heliopsis helianthoides*), and switchgrass (*Panicum virgatum*). These five species along with Virginia wildrye (*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, 20 species were seeded at 5 or more sites. One species, partridge pea (*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 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.

2.4 Discussion

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 328 ft (100 m) 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 & 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 approaches 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 & Hobbs, 1991; Khan & 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 > 13 ft [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 phosphorous to those rich in magnesium, 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 phosphorous. This finding is consistent with previous literature reporting that native cover and richness are higher with lower nitrate and phosphorous due to increased competition with invasive plants (Brejda, 2000). However, it was somewhat surprising that high magnesium correlated with greater native cover and richness considering that the literature suggests that magnesium has a similar capacity to bolster introduced species (Franson et al., 2017). Soil PC2, which was associated with high calcium, 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 introduced 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 leads 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 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 that 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.

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 teasel (*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 2.4) yielded informative results and highlighted several species for wider incorporation in seed mixes due to high persistence. Although partridge pea (*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. Oval prairie sedge (*Carex bicknellii*), porcupine sedge (*Carex hystericina*), sawtooth sunflower (*Helianthus grossesserratus*), slender mountain mint (*Pycnanthemum tenuifolium),* and white panicle aster (*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 wild bergamot (*Monarda fistulosa*), black-eyed Susan (*Rudbeckia hirta*), common milkweed (*Asclepias syriaca*), false sunflower (*Heliopsis helianthoides*), gray-headed coneflower (*Ratibida pinnata*), whorled milkweed (*Asclepias verticillata*), purple coneflower (*Echinacea purpurea*), and Illinois bundleflower (*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 switchgrass (*Panicum virgatum*), Virginia wildrye (*Elymus virginicus*), sideoats grama (*Bouteloua curtipendula*), big bluestem (*Andropogon gerardii*), brown fox sedge (*Carex vulpinoidea*), soft rush (*Juncus effusus*), and plains oval sedge *(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 giant reed (*Phragmites australis*), reed canarygrass (*Phalaris arundinacea*), cattail (*Typha* spp.), and curly dock (*Rumex crispus*). Lastly, although never seeded, native species like common evening-primrose (*Oenothera biennis*), Canada goldenrod (*Solidago canadensis*), common ragweed (*Ambrosia artemisiifolia*), Indian hemp (*Apocynum cannabinum*), hedge bindweed (*Calystegia sepium*), pasture thistle (*Cirsium discolor*), annual fleabane (*Erigeron annuus*), bonesets (*Eupatorium* spp.), and hairy aster (*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.

The INDOT Floodplain mix sites were generally very low in seeded species richness and cover, with a few observations of Canada wildrye (*Elymus canadensis*), Illinois bundleflower (*Desmanthus illinoiensis*), and black-eyed Susan (*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, soil fertility, surrounding development, distance from road, and seed mix diversity appear to be the largest covariates for 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.

3. SUMMARY AND RECOMMENDATIONS

The INDOT *Standard Specifications Handbook* (2022), Section 621: Seeding and Sodding specifies seed mix information and planting and maintenance requirements for Indiana. Four non-native roadside mixes list species of fescues, rye grasses, and clovers. Two non-native cover crop mixes are the spring oats (*Avena sativa*) and annual ryegrass (*Lolium multiflorum*) mix, and the fall rye (*Secale cereale*), pea (*Pisum sativum*), and crimson clover (*Trifolium incarnatum*) mix. In Section 621: Seeding and Sodding, the one native mix listed is for floodplain areas, generally below the 100-year floodline along streambanks and consists of 16 native species, including 7 graminoids, 5 forbs, and 4 legumes. This floodplain mix consists of no OBL species, one FACW species, two FAC species, nine FACU species, and four UPL species. This species assemblage more closely resembles an upland shortgrass prairie mixture than a floodplain mixture. For comparison, wetland mixtures listed by Iowa, Illinois, and Minnesota DOTs consist of primarily OBL to FACW species. While INDOT does seed other native species on a limited scale at the discretion of INDOT district land managers, there are no DOT-specified mixes beyond the floodplain mix (*personal communication*, INDOT employees). Section 622: Planting Trees, Shrubs and Vines has a specific section on crownvetch (*Securigera varia*) for use in erosion control. *Securigera varia* is invasive across the Midwest and should not be planted. This section also mentions "Seedlings for Wildlife Habitat" but does not mention which species are to be used in these plantings or specify that they are native to the region. No native species are listed in Section 622. Section 914: Soil Treatment Materials contains a list of 18 different seeded species and their required percentages of maximum weed seed content, purity, and actual germination. Only two are native to Indiana (Illinois bundleflower [*Desmanthus illinoensis*] and purple prairie clover [*Dalea purpurea*]). We recommend that INDOT examine additional species and a broader scope of native mixes. Given nearly identical habitat types and available native species to neighbor state Illinois, INDOT may wish to look to IDOT mixes to foster greater ecosystem services from their roadsides.

District-level native seeding does take place in Indiana, but it is not mandated at a state level and does not occur evenly across the state (*personal communication*, INDOT employees). There is a clear benefit of having multiple native species mixes mandated for use, but there is also value in allowing land managers with the interest and drive to perform custom seeding work outside the scope of specified mixes.

Based on our literature review and field survey, we provide in Table 3.1 recommendations for new seed mixes for slope, road edge, roadside, and wet ditch/wet slope plantings. Soil fertility seems to be a significant determinant of native cover and richness. Therefore, soils should not be amended with fertilizer after new construction prior to seeding with a native assemblage. We recommend planting only disturbance-tolerant natives near roads and less tolerant natives beyond 15 ft (4.6 m) from the pavement. Proximity to development may also impact native cover and richness as an artifact of increased maintenance and visibility of plantings.

Mixes should be seeded with either a native seed drill with multiple boxes for varied seed sizes, or ideally a hydroseeding unit, which appears to give the best results, and does not disturb soil (Bochet et al., 2010). Seeding should take place in the fall following the end of construction once plants have reached dormancy (generally mid-November or once soil temps reach

TABLE 3.1
Potential revisions for INDOT seed mixes.

Mix	Description	Scientific Name	Common Name	Oz/Acre
Slope Mix	Mostly floodplain mix species with additional well establishing species	*Agrostis perennans*	Upland Bentgrass	0.10
		Asclepias syriaca	Common Milkweed	43.6
		Bouteloua curtipendula	Side-oats Grama	43.6
		Chamaecrista fasciculata	Partridge Pea	64.5
		Desmanthus illinoensis	Illinois Bundleflower	41.5
		Desmodium canadense	Showy Tick Trefoil	31.7
		Echinacea purpurea	Purple Coneflower	29.0
		Elymus canadensis	Canada Wildrye	33.5
		Elymus virginicus	Virginia Wild Rye	49.8
		Heliopsis helianthoides	False Sunflower	28.1
		Hordeum jubatum	Foxtail Barley	10.9
		Monarda fistulosa	Wild Bergamot	2.5

(*Continued*)

TABLE 3.1
(continued)

Mix	Description	Scientific Name	Common Name	Oz/Acre
		Panicum virgatum	Switchgrass	12.4
		Ratibida pinnata	Yellow Coneflower	5.8
		Rudbeckia hirta	Black eyed Susan	1.9
		Schizachryium scoparium	Little Bluestem	11.6
		Sporobolus compositus	Rough Dropseed	5.4
		Symphyotrichum novae-angliae	New England Aster	2.2
		Tridens flavus	Purpletop	6.7
		Verbena stricta	Hoary Vervain	7.0
		Zizia aurea	Golden Alexander	15.8
Road Edge Mix	Low growing, salt and disturbance-tolerant species	*Bouteloua curtipendula*	Side-oats Grama	87.1
		Carex brevior	Plains Oval Sedge	12.0
		Carex vulpinoidea	Brown Fox Sedge	4.4
		Chamaecrista fasciculata	Partridge Pea	129.1
		Coreopsis lanceolata	Lanceleaf Coreopsis	31.1
		Echinacea pallida	Pale Purple Coneflower	90.8
		Elymus canadensis	Canada Wildrye	67.0
		Elymus virginicus	Virginia Wild Rye	99.6
		Hordeum jubatum	Foxtail Barley	21.8
		Rudbeckia hirta	Black eyed Susan	4.7
		Schizachryium scoparium	Little Bluestem	23.2
		Oenothera biennis	Evening Primrose	7.5
High Diversity Upland Mix	Diverse mix of more tolerant species seedable further from road edge	*Artemisia ludoviciana*	Eastern White Sage	0.8
		Bouteloua curtipendula	Side-oats Grama	108.9
		Chamaecrista fasciculata	Partridge Pea	80.7
		Desmanthus illinoensis	Illinois Bundleflower	51.9
		Desmodium canadense	Showy Tick Trefoil	39.6
		Echinacea pallida	Pale Purple Coneflower	36.3
		Echinacea purpurea	Purple Coneflower	29.0
		Elymus canadensis	Canada Wildrye	83.8
		Elymus virginicus	Virginia Wild Rye	124.5
		Heliopsis helianthoides	False Sunflower	35.1
		Monarda fistulosa	Wild Bergamot	3.1
		Oligoneuron rigidum	Rigid Goldenrod	5.3
		Panicum virgatum	Switchgrass	31.1
		Penstemon digitalis	Foxglove Beardtongue	2.1
		Ratibida pinnata	Yellow Coneflower	7.3
		Rudbeckia hirta	Black eyed Susan	2.4
		Schizachryium scoparium	Little Bluestem	29.0
		Symphyotrichum novae-angliae	New England Aster	2.7
		Zizia aurea	Golden Alexander	19.8
Wet Ditch, Wet Slope Mix	Wetland tolerant common species that can be seeded in a ditch or along a streambank	*Asclepias incarnata*	Swamp Milkweed	36.3
		Carex bicknellii	Oval Prairie Sedge	5.0
		Carex brevior	Plains Oval Sedge	6.0
		Carex cristatella	Crested Oval Sedge	1.8
		Carex hystericina	Porcupine sedge	5.8
		Carex molesta	Field Oval Sedge	7.0
		Carex vulpinoidea	Brown Fox Sedge	2.2
		Elymus virginicus	Virginia Wildrye	49.8
		Juncus effusus	Common Rush	0.1
		Juncus tenuis	Slender Rush	0.2
		Leersia oryzoides	Rice Cut Grass	5.8
		Lycopus americanus	Common Water Horehound	2.2
		Penstemon digitalis	Foxglove Beardtongue	3.3
		Physostegia virginiana	Obedient Plant	11.6
		Scirpus atrovirens	Dark-green Bulrush	0.4
		Spartina pectinata	Prairie Cord Grass	29.0
		Symphyotrichum novae-angliae	New England Aster	4.4
		Symphyotrichum puniceum	Swamp Aster	3.3

below 40°F). If seeding into bare soil, apply mulch (if possible, hay from native straw) to prevent overwintering erosion. Erosion should not be a concern if seeding into existing cut vegetation. Seeding can be conducted by mowing and killing existing vegetation with Glyphosate in late summer ahead of fall seeding. To establish plantings, we recommend mowing to a height of 6–8 in. in May, June, and July of the first year and mowing at least once from June–August of the second year. Further maintenance every three to five years can be a full mow or ideally a prescribed burn.

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About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at https://docs.lib.purdue.edu/jtrp/.

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Bollinger, W., Bhattarai, R., & Matthews, J. W. (2025). *Feasibility of utilizing native grasses and forbs in lieu of exotic cool season grasses on roadside rights-of-way* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2025/14). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317878