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HERBICIDE TOLERANCE OF NATIVE PERENNIAL GRASSES DURING VEGETATIVE ESTABLISHMENT IN DISTURBED URBAN SITES IN LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
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in

The School of Plant, Environmental and Soils Sciences

by
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B.S., Louisiana State University and Agricultural and Mechanical College, 1994
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ABSTRACT

The potential usage and benefits of native perennial grasses (NPG) in urban plantings may be severely hindered during establishment by high weed pressure. Two studies were conducted with the objectives of examining the tolerance of several NPG to commonly available herbicides during vegetative establishment; and comparison of establishment vigor of NPG in Louisiana when weed control is implemented. The first study was conducted in greenhouse conditions to evaluate tolerance of broomsedge (*Andropogon virginicus* L.); blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths)*;* Virginia wildrye (*Elymus virginicus* L.); switchgrass (*Panicum virgatum* L.); little bluestem (*Schizachyrium scoparium* (Michx.) Nash); and Indiangrass (*Sorghastrum nutans* (L.) Nash) established 6 weeks from plugs to applications of pendimethalin; sulfosulfuron; imazapic; triclopyr; or fenoxaprop. Overall, fenoxaprop was the most injurious to NPG and slowed tillering on affected species compared to controls. Plants treated with imazapic, triclopyr, or sulfosulfuron varied in tolerance among species as well as timing of application relative to temperature. Pendimethalin was consistently the least injurious to NPG. In the second study, the same NPG species were evaluated for establishment vigor in Baton Rouge, Louisiana and Fort Polk near Leesville, Louisiana over a 12-month period with pendimethalin applied at initial planting in October 2011 and again in March 2012. At the Baton Rouge site, little bluestem and broomsedge had the highest canopy coverages of 97.7% and 100% and corresponding biomasses 156.8 and 244.8 g at the conclusion of the 12-month establishment period along with the lowest weed encroachment of 1.7%. Little bluestem and broomsedge also achieved the highest canopy coverages and biomasses at the Fort Polk site, but overall NPG establishment was slower compared to NPG establishment in Baton Rouge. Environmental factors such as soil texture, fertility, and rainfall between the two locations affected NPG establishment. Results indicate herbicide applications at least during the first year of NPG vegetative establishment may be necessary to reduce weed competition in order to establish NPG in

disturbed urban sites. Species selection, herbicide selection and application, and site characteristics must be accounted for when establishing NPG in urban areas.

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Native Perennial Grasses: Interest and Benefits

Once established, native grasses generally require less maintenance and resource inputs such as irrigation water, and offer more resistance to disease and insect pests (Steiner 2010). These benefits have resulted in greater interest and application of native perennial grasses (NPG) as a landscape material (Knapp and Rice 1994) in retail or commercial areas, urban gardens and landscapes, public or utility right-of-ways, parks and recreational areas, golf courses, and public and corporate campuses (University of Illinois 2008). Horticultural interest in incorporating NPG in urban managed landscapes continues to increase (Thetford et al 2009; Smith and Whalley 2002) because NPG possess a wide array of characteristics that offer numerous benefits (England, Texas Master Naturalist Program n.d.; Tennessee Wildlife Resource Agency n.d.). A diverse range of urban landscaping needs and applications can potentially be addressed by the superior qualities of native plants.

Aesthetically, native perennial grasses provide a diverse palette of visual interest in the landscape. The multitude of leaf textures and colors can add uncommon contrast to more traditional or familiar plant material choices. Some warm season NPG have leaf shoots that exhibit seasonal color change as dormancy sets in. Since most NPG possess a clumping growth habit, visual space is created that can be used as negative space or filled with lower-growing contrasting ornamental plants. Because of the wide array of growth habits, different species of NPG can be chosen based on varying height levels alone. Inflorescences among NPG can be extremely diverse, with some species valued for their colorful flower shoots that rise above the foliage. Native perennial grasses can add the element of motion when mixed with woody plant selections. Upon dormancy, warm season NPG can be cut to a height of 15 to 30 cm need only have their shoots removed once in late winter, saving maintenance costs compared to frequent mowing required for traditional turfgrasses.

Urban horticulture applications of NPG extend beyond purely ornamental uses. Ecologically, NPG can help restore or increase biodiversity and contribute to small urban habitats for butterflies, bees and other insects that serve as important pollinators (Ries et al. 2001), (Burghardt 2009). Larger stands of NPG that produce seed can serve as a food source for urban songbirds.

Many species of native perennial grasses possess intriguing growth habits beyond the positive qualities found in the shoots or blooms. Because of their relatively deep and extensive root systems compared to turf-type grasses, NPG have been shown to increase soil organic matter, stabilization, and quality as well as reduce soil compaction over time (Stomberg and Kephart 1996). These deep and extensive root structures compared to more traditional landscape plant material or turfgrasses allow NPG to grow on marginal soils. Cherwin et al. (2009) found that low soil nutrient availability is one characteristic that favors native warm season C4 grass species. Deep roots also allow NPG to access soil moisture that is unavailable to shallower rooted plants such as turfgrass or flowering ornamental annuals. Because of this, NPG can be very drought tolerant once they are established.

Native perennial grasses can trap sediments and pesticides and so can improve water quality when planted as riparian strips (Steinke et al. 2009; Tennessee Valley Authority n.d.). Rankins et al. (2001) found that stands of big bluestem, switchgrass, eastern gama grass and tall fescue reduced total water volume runoff. In the same study, sediment losses were reduced by 66% and herbicide runoff was reduced by at least 59%. Not only can large buffers of NPG physically slow stormwater runoff entering streams and rivers, but they can aid water filtration into deeper layers of soil (Stomberg and Kephart 1996).

Because native grasses are adapted to local environmental conditions, it is posited that inputs such as irrigation, fertilization, or maintenance can theoretically be reduced or eliminated over the long-term (Cherwin et al. 2009). Grasses propagated from localized natural populations may also tolerate stresses common to the local area such as drought, occasional flooding, diseases and insect pests (Thetford et al. 2009). This stress tolerance aids in longevity, which is important to consider when evaluating landscape plants for reduced management inputs. Thetford et al. (2009), in their three-year trial, found four NPG species including switchgrass that exhibited the potential to be low-input long-term ornamental landscape plants. Indiangrass (‘Lometa’) was considered useful only as an annual or biennial grass. However, species that exhibit longevity further reduce inputs because established NPG create dense canopies that can lower weed pressure. Stromberg and Kephart (1996) observed that NPG, when managed early to establish successfully, can significantly crowd out annual weeds. Similarly, McGlone et al. (2011) found that established plants can better mitigate the effects of disturbance and increased invasive plant pressure.

In some applications, species of NPG are suitable alternatives to traditional vegetation selections such as non-native ornamental plants or turfgrasses that require high levels of inputs and management (Simmons et al. 2011). Skousen and Venable (2008) found that the seeding of fast-growing, non-native, shallow-rooted turfgrass such as common bermudagrass (*Cynodon dactylon*) and bahiagrass (*Paspalum notatum*) was common practice in the eastern United States along roadsides to prevent erosion after disturbance activity. Public highway departments long have tended to use the seeds of these non-native species because they offer practical benefits such as lower cost, large quantities are readily available, and because they have high germination and survivability rates (Skousen and Venable 2005). It should be noted that there is increased attention to the potential for non-native grasses to invade native prairies and other natural plant communities. One study suggests that exotic escapees from ornamental plantings may be to blame for the spread of invasive grasses such as pampas grass (*Cortaderia selloana*) in California (Thetford et al. 2009).

Kwit and Collins (2008) noted that traditional turf cover can require significant inputs such as irrigation, fertilizer and mowing. They studied vegetative cover on landfill waste caps and found that certain native grasses could establish and grow in place of commonly used turf cover, potentially reducing the amount of inputs required to maintain required groundcover. Further they suggested that landfill caps could be a potential management model for non-ornamental urban uses of NPG. Mintenko et al. (2002) evaluated native grasses for their suitability as low-input and low-maintenance turfgrass alternatives for the Northern Great Plains region of the United States; blue grama (*Bouteloua gracilis*) returned the best results.

There appears to be little comparative landscape trial data available to help managers make informed choices about which native species might be most appropriate to fulfill urban landscape functions. According to Thomas and Schrock (2004), little is known about the landscape use or value of 67 midwestern United States flowering native perennials identified as potential plant material in low-maintenance landscapes. Likewise, there are few studies evaluating the appropriateness of NPG for low-maintenance landscapes, especially in the sub-tropical south. Researchers in Texas surveyed residents to assess the public's perception about the use of native and non-native ornamental grasses in the landscape (Wolfe and Zajicek 1998)). They found that 90% of the respondents felt sample grasses had landscape value, and 96 % indicated that municipal governments should use them in landscaping projects. Thetford et al. (2009) promoted evaluations of horticultural uses for native grasses stating that emphasis should be given to those species that are identified as the best performers. Evaluations that focus on the strongest species or varieties will improve the chances of their acceptance and use by the ornamental horticulture industry (Thetford et al. 2009).

Without an available species list recommending specific NPG species for urban use in the subtropical south-central US, six NPG species that represented a diverse selection of grasses found in Louisiana or in neighboring states were selected for evaluation: blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths)*;* broomsedge (*Andropogon virginicus* L.*);* Indiangrass (*Sorghastrum nutans* (L.) Nash); little bluestem (*Schizachyrium scoparium* (Michx.) Nash)*;* switchgrass (*Panicum virgatum* L.)*;* and Virginia wildrye (*Elymus virginicus* L.). Four grasses, broomsedge, Indiangrass, little bluestem, switchgrass, were selected because of their occurrence in the Cajun Prairie remnants in southwestern coastal Louisiana (Allen et al. 2001). A fifth grass, Virginia wildrye, served as the study's only cool season NPG. The sixth grass, blue grama, typically is found in drier climates such as central and western Texas, but its low-growing nature shows promise as a turfgrass alternative in other parts of the United States (Simmons et al. 2011).

The USDA Plant Database (USDA, NRCS) provides numerous plant growth characteristics which are summarized below for the six NPG used in our study: blue grama is a warm, short, perennial bunchgrass typically 21 to 51 cm high that forms dense clumps in the south. The seedheads are attractive and look like eyebrows. It prefers drier soils and has no known pests. Broomsedge is a tall, dense, warm season perennial bunchgrass reaching 61 to 122 cm. It has red or rusty inflorescences that last well into winter. Broomsedge produces a large quantity of viable seed and prefers wetter soils than blue grama. It does not have any major pests. Indiangrass is a tall warm season perennial bunchgrass that can grow 91 to 213 cm in height. It has attractive golden yellow blooms and is used in erosion control and prairie restoration areas. Little bluestem is one of the most widely distributed native grasses. It is a warm season perennial bunchgrass that is recognized for its bluish-green leaf color contrasting with rusty inflorescences in autumn. Little bluestem is drought tolerant and adaptable to many soil types. It is used in erosion control and can tolerate some shade. The grass is usually 31 to 91 cm tall and has no major pests. Switchgrass is a tall warm season perennial bunchgrass that reaches 91 to 152 cm and produces an attractive large, open panicle. It is a very adaptable grass and is important in erosion control efforts. Virginia wildrye is a cool season perennial bunchgrass that is typically 61 to 91 cm tall and can tolerate some shade. It has lush foliage and an attractive seedhead.

1.2 Barriers to Establishment

Although the interest in and use of beneficial NPG in urban landscapes is growing, there have been limited species plant trials or landscaping establishment recommendations for the subtropical south-central US. While researchers in other geographic areas have pursued this somewhat further, there is an apparent lack of consumer information about and awareness of NPG for Louisiana and other Gulf Coast states. This could be preventing more widespread use of NPG.

Much of the scientific literature on NPG focuses mainly on prairie ecosystem plant surveys or restoration efforts, not on their use in urban or roadside plantings in our unique climate in the southeastern United States. Additionally, NPG have been investigated as alternative plant material for grazing livestock forage, hay production or oldfield conversion, but little else. This research may be helpful in identifying potential species for use and for recommended establishment and maintenance methods that might be adapted to urban landscapes in the southeast.

Literature on prairie restoration and NPG forage establishment literature stresses that early and consistent weed control is of primary importance for successful establishment. Typically forage pastures or prairies are planted through seed, but whether NPG establishment is attempted by seeding or planting live plugs or containerized plants, aggressive annual weeds quickly germinate and compete with NPG. Even when planted as live plugs, NPG typically are slow growing for one or two years as they are genetically predisposed to establish relatively large root systems prior to accelerating above ground biomass gain. Holmes and Rice (1996) noted that NPG primarily allocate the majority of their biomass to a well-developed, deep root system. Likewise, Abraham et al. (2009) found NPG germinate slower and preferentially establish root systems, leaving short or small foliage canopies that are more susceptible to shading by weeds. Left uncontrolled, these weeds outcompete young NPG, reducing survival the first year.

Weed pressure is a continuous challenge in numerous agricultural and landscape horticulture applications, especially in the subtropical United States given the extended growing season and moderate winter temperatures. In Louisiana, competing weeds in landscape applications include aggressive, invasive exotic perennial and annual grass species such as common bermudagrass (*Cynodon dactylon* L.), bahiagrass (*Paspsalum notatum*), and barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.). In particular, annual grassy weeds may need to be a primary focus for control since their management through herbicides will be more complicated.

Weed pressure can be further increased by the soil disturbance that typically occurs on a new planting site. In preliminary NPG trials at Louisiana State University that did not incorporate immediate or effective weed control, weed pressure quickly overtook the test plots which resulted in little, if any, NPG establishment. A “no till” approach may be helpful to NPG establishment projects, since exotic and fast growing weeds oftentimes favor disturbed areas.

Weed suppression is imperative to any successful NPG establishment, but when investigating NPG for urban horticultural uses, weed control must also be considered for aesthetic reasons. Ornamental landscaping projects generally strive to create orderly, structured greenspaces, and the public has become accustomed to maintenance priorities that keep these areas weed free. Using NPG in such urban landscapes will most likely be subject to similar expectations of quick, weed-free establishment, whereas prairie restoration or NPG forage projects are generally not constrained by such performance measures. Low weed pressure is an important visual component of public perception of landscaping in many urban areas. Varlamoff et al. (2001) conducted a survey of Georgia homeowners and found that 76% felt a weed-free lawn was “very important,” “important,” or “somewhat important.” An additional survey that gauged responses to various landscape designs, plant materials, structures and levels of care found that respondents felt that the “weedy” yard example was unattractive, messy and showed a lack of care (Nassauer 1993).

Thetford et al. (2009) found that the establishment of NPG can be especially challenging for disturbed urban areas due to high weed encroachment. Wilson et al. (2010) stated that initial weed competition is a significant roadblock to re-vegetation work, and that weeds prevent the establishment of NPG. Skousen and Venable (2008) concluded that reduction of competition from non-native species is critical to increasing roadside cover of native grass species, especially since native grasses tend to establish more slowly. Dickson et al. (2010) found that the presence of non-native plants impeded native C4 grass establishment mainly by causing death of the native grass seedlings. The invasive grass species smooth brome (*Bromus inermis*) was shown by Dillemuth et al. (2009) to negatively affect the growth and establishment of native prairie cordgrass (*Spartina pectinata*) within a tallgrass prairie ecosystem in North Dakota. A significant negative relationship was found between the growth of prairie cordgrass and the amount of smooth brome grass that had infested the same site.

Wilson et al. (2010) found that increasing perennial grass shoot cover further controls the suppression of weeds in the establishment area. Similarly, Corbin and D'Antonio (2004) found evidence that established native grasses can reduce exotic grass productivity. Abraham et al. (2009) noted that previous research indicated that established NPG can compete with exotic annual weeds, while seedlings of NPG may be negatively affected by annual weeds since they tend to germinate earlier and in greater numbers than NPG. Abraham et al. (2009) reported that the reduction of annual grass competition can help increase native grass establishment, as can planting NPG as live plugs rather than planting seeds. Stromberg et al. (2007) reported that establishment by vegetative grass plug has a greater chance of success and can be kept weed free with pre-emergent herbicides, and that plugs are a good choice when rapid establishment is desired.

Some research suggests that soil fertility may affect the amount of weed pressure NPG experience on a given site. Skousen and Venable (2008) concluded that applying varying low rates of 10-20-10 fertilizer did not increase native grass cover in roadside seed-grown plantings, suggesting fertilizer application does not hasten NPG establishment. Slow uptake of nitrogen (N) could be due to the slow shoot growth of NPG early in establishment. Parker and Schimel (2010) concluded that invasive non-native annual grasses may enrich soil N levels, in turn favoring the growth or germination of these same weedy grasses. It appears, then, that adding N to an NPG planting area could serve to increase annual weed growth, further hindering NPG establishment.

Some research indicates that using materials such as mulches might help certain species achieve greater establishment success. Busby et al. (2006) studied growth and establishment trials of switchgrass (*Panicum virgatum*) and indiangrass (*Sorghastrum nutans*) to determine if application of uncomposted municipal waste by-product material could be used to increase warm season NPG establishment at two different locations in the mid-south United States. Switchgrass performed extremely well in this study, but Indiangrass did not.

1.3 Weed Control with Herbicides

With weed pressure hindering NPG establishment, various forms of weed control were considered for the current study. Management options include mechanical removal, burning, adding mulches and applying herbicides. In rural areas where NPG re-establishment is desired for large-scale forage conversion, prairie ecosystem restoration, or wildlife habitat improvement, controlled burning is often used for weed control and to maintain the vigor and herbaceous nature of the prairie (Jackson et al. 2010). Controlled burns are much harder to implement due to local ordinances and safety and health considerations. In the absence of fire as a tool, use of hand weeding and mulches represents significant costs (Flory and Clay 2009). Varlamoff et al. (2001) conducted a survey of Georgia homeowners and found that 41% of respondents who do their own landscaping reported using herbicides. The use of herbicides during establishment may be the best choice in disturbed urban areas.

Guidelines for urban NPG establishment using herbicides are lacking, so again prairie restoration and forage research must be used as a basis of information. Compared to agronomic and landscape commodities, relatively few herbicide tolerance studies have been conducted on NPG, resulting in fewer herbicidal compounds being registered for NPG application outside of forage establishment. Studies that have examined herbicide use on NPGs have reported varied levels of NPG tolerance. For example, Wilson et al. (2010) concluded, imazapic resulted in significant injury to perennial grasses during the first year of establishment from seeds. However, they also found that established perennial grasses exhibit a greater degree of tolerance to imazapic. This suggests imazapic should be used to control grassy weeds only after the perennial grasses of interest have established. Many of the NPG evaluated by Wilson et al. (2001) tolerated the herbicides chlorosulfuron, clopyralid, 2,4-D and dicamba once they had reached the three to four leaf grass stage, and most of the NPGs proved extremely tolerant to several broadleaf herbicides. The further reported that increasing perennial grass shoot cover further controls the suppression of weeds in the establishment area. This could imply that non-grass specific herbicides can be safely used in the early stages of NPG establishment but then later halted as the NPG shoot canopy cover takes over the weed control function.

In another study, Almquist and Lym (2010) reported similar results with the broadleaf herbicide aminopyralid used to control Canada thistle in a restored tall grass prairie. They found aminopyralid caused very little, if any, injury to perennial grasses, and that decreasing weed encroachment led to more vigorous big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*) growth. Tjelmeland et al. (2008) observed that the herbicide tebuthiuron reduced canopy cover of exotic buffelgrass while increasing canopy cover of native grasses.

Flory and Clay (2009) studied various invasive weed removal techniques and observed the results on the remaining native plant communities. Their study found that the grass herbicide fluaziflop negatively affected the growth of or killed the native grasses. Flory and Clay (2009) further stated that the use of the pre-emergent herbicide pendimethalin may have negatively affected the overall coverage of native grasses because it prevented new germination of native grass seed, but it is not clear how pendimethalin would have affected solely the existing native grass plants.

Hickman and Derner (2007) observed changes in plant species and their relative composition in a remnant central Texas prairie after the cessation of 25 years of broadleaf herbicide use. Annual forbs increased in number dramatically, as might be expected, and C4 perennial grass cover only increased marginally. This suggests that the existing NPG were tolerant of repeated broadleaf herbicide applications. Stromberg et al. (2007) stated that establishment using vegetative grass plugs can be kept weed free with pre-emergent herbicides.

The two most appropriate options for weed control for this current study were the use of mulches to cover the soil surface between NPG plants or the application of herbicides over the NPG canopy. Spreading mulch is more appropriate for smaller landscaping beds, so it was determined that herbicides might offer the most practical way to tackle weed suppression. If early establishment is successful, within two years many NPG species could be large and dense enough to outcompete and suppress weeds. Smaller NPG or those with more open canopies likely would require weed management for longer periods. A concise, tested and repeatable protocol for the sub-tropical south-central United States that addresses grass species selection, establishment techniques and weed control through herbicides was not found. Therefore, this research study will investigate the use of herbicides to control weeds during vegetative establishment of NPG.

CHAPTER 2: HERBICIDE TOLERANCE OF NATIVE PERENNIAL GRASSES DURING VEGETATIVE ESTABLISHMENT IN DISTURBED URBAN SITES IN LOUISIANA

2.1 Introduction

Interest in incorporating native perennial grasses (NPG) in urban managed landscapes continues to increase (Thetford et al. 2009) because NPG offer a wide array of characteristics beneficial to a diverse range of urban applications. Native perennial grasses not only provide aesthetically pleasing landscapes, but have been shown to increase soil organic matter, stabilization, and quality as well as improve water quality when planted as riparian strips (Steinke et al. 2009). Native perennial grasses restore urban habitats for organisms including butterflies and other insects that serve as important pollinators (Ries et al. 2001; Burghardt 2009). In some applications, species of NPG are suitable alternatives to traditional vegetation selections such as turfgrasses or annual ornamental beds that require high levels of inputs and management (Simmons et al. 2011). Because NPG are adapted to local environmental conditions, it is postulated that inputs such as irrigation, fertilization, and maintenance can be reduced or eliminated over the long-term (Cherwin et al. 2009).

Although the use of NPG in various urban landscapes is becoming more accepted, establishment of NPG can be especially challenging for disturbed urban areas due to high weed encroachment (Thetford et al. 2009). Wilson et al. (2010) stated that initial weed competition is a significant roadblock to re-vegetation work, and that weeds prevent the establishment of perennial grasses. Exotic and fast growing weeds favor disturbed areas, and when left uncontrolled, will out-complete juvenile NPG. During the first year of establishment, NPG preferentially establish root systems, leaving short or small foliage canopies vulnerable to weed competition.

Weed pressure is a continuous challenge in numerous agricultural and landscape horticulture applications especially in the subtropical United States (US) given the extended growing season and moderate winter temperatures. In Louisiana, weed pressures in landscape applications include aggressive, invasive exotic perennial and annual weed species such as common bermudagrass (*Cynodon dactylon* L.), bahiagrass (*Paspsalum notatum*), and barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.).

In rural areas where NPG re-establishment may be desired for large-scale forage conversion, prairie ecosystem restoration, or wildlife habitat improvement, controlled burning is often prescribed as an effective method for weed control and existing vegetation removal (Jackson et al. 2010). However, in urban settings, controlled burns are not as easily implemented due to local ordinances and safety and health considerations. Use of hand weeding and mulches represent significant costs (Flory and Clay 2009) while patience with natural succession processes within the urban setting not only extends the duration of NPG establishment but negatively affects aesthetics, an important component in many urban areas (Varlamoff et al. 2001; Nassauer 1993). Therefore, the temporary use of herbicides during NPG establishment may be warranted for disturbed urban areas.

Compared to agronomic and landscape commodities, few herbicide tolerance studies have been conducted on NPG used in urban landscapes. This has led to fewer herbicidal compounds being registered for NPG application. Studies that have examined herbicide use on NPG have reported varied levels of NPG tolerance. For example, Wilson et al. (2010) concluded, imazapic resulted in significant injury to perennial grasses during the first year of establishment for seeds. However, established perennial grasses exhibit a greater degree of tolerance to imazapic, suggesting imazapic should be used to control grassy weeds only when the perennial grasses of interest have established. Many of the NPG evaluated in their study tolerated the herbicides chlorosulfuron, clopyralid, 2,4-D and dicamba after the three to four leaf stage and most of the NPG were extremely tolerant to several broadleaf herbicides. In another study, Almquist and Lym (2010) reported similar results with the broadleaf herbicide aminopyralid on Canada thistle in a restored tall grass prairie. They found aminopyralid caused very little, if any, injury to perennial grasses, and that decreasing weed encroachment led to more vigorous big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*) growth.

Before any proper growth comparison can be conducted between NPG to determine suitability to various urban conditions or applications, implementing an effective weed control strategy must be devised. Therefore, it is proposed that herbicide applications during the first year of NPG vegetative establishment may be necessary to reduce weed competition in order to assess and promote NPG growth and adoption in urban settings. The objectives of this study were to examine the tolerance of several NPG to commonly available herbicides when establishing NPG vegetatively; and to compare establishment vigor of NPG at two urban locations in Louisiana when weed control was implemented.

2.2 Materials and Methods

2.2.1 Greenhouse Herbicide Tolerance Experiments

Experiments to evaluate NPG tolerance to several commonly available herbicides were conducted under greenhouse conditions in August 2011 (experiment 1) and September 2011 (experiment 2) at the Louisiana State University (LSU) Agricultural Center Botanic Gardens at Burden in Baton Rouge, Louisiana (30.41062°N, -91.10340°E). The six NPG selected for herbicide tolerance included: blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths); broomsedge (*Andropogon virginicus* L.); Indiangrass (*Sorghastrum nutans* (L.) Nash); little bluestem (*Schizachyrium scoparium* (Michx.) Nash); switchgrass (*Panicum virgatum* L.); and Virginia wildrye (*Elymus virginicus* L.). All species are known to grow in the Louisiana coastal prairie region named the Cajun Prairie (Allen et al 2001), in other areas of Louisiana, or in adjacent states.

Plants were obtained as plugs in 70 cell trays from Nature Hills Nursery (Omaha, NE) in June and August 2011. Plugs were grown in 2.0 L containers filled with a 90:10 coarse sand:peat moss substrate (BWI Companies, Inc., Jackson, MS). This mix minimizes buffering capacity to allow maximum herbicide uptake by NPG roots. Post-plug planting maintenance included irrigation every two days at 2.5 cm with twice-weekly fertigation at 200 ppm N. The irrigation source was from a municipal water source treated with sulfuric acid to lower water pH from ~8.6 to 6.5. Irrigation pH was monitored weekly. Average temperatures were 31.3°C/ 21.2°C during the first experiment and 26.1°C/12.8°C during the second experiment.

Herbicide Application: After six weeks of establishment, NPG were removed from the greenhouse for herbicide applications. Plants were taken outside during herbicide applications to minimize herbicide volatilization and drift among NPG. All NPG were treated with pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzamine) 4.7 L/ha, sulfosulfuron (N-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-2-(ethylsulfonyl)imidazo[1,2-a]pyridine-3-sulfonamide) at 0.14 Kg/ha + 0.25 % non-ionic surfactant, imazapic (5-methyl-2-(4-methyl-5-oxo-4-propan-2-yl-1H-imidazol-2-yl)pyridine-3-carboxylic acid) at 0.59 L/ha + 0.25% non-ionic surfactant, triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester) at 3.5 L/ha, or fenoxaprop ((+)-ethyl 2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy] propanoate) at 2.9 L/ha with the exception of plants that served as untreated controls. The herbicide compounds and application rates selected for the experiments reflect high labeled application rates for turf and ornamental areas as well as right-of-ways for control of weed pressures commonly encountered during establishment in Louisiana (Dr. Ron Strahan, 2011, pers. comm., 24 May). Herbicides were applied at a spray volume of 280.6 L/ha using a flat fan 3-nozzle boom sprayer with water as the carrier and CO_2 as the propellant. Plants were returned to the greenhouse 4 h post-herbicide application with post-plant maintenance previously described resumed after 24 h. Other pesticides were not applied during this period.

Data Collection: Post-herbicide application, plant injury was rated every 2 weeks for 6 weeks using a 0 to 100% scale following guidelines outlined by the Southern Weed Science Society (Research Methods in Weed Science, Third Edition, 1986) to assess herbicide effects on color, stunting, or changes in plant vigor. Other measurements included plant height recorded every 2 weeks for 6 weeks after treatment (WAT) and tiller counts recorded at the initiation of the experiment and 6 WAT.

Statistical Design: Native perennial grass species were arranged in a split-plot design with four replications. The five herbicides plus untreated control served as the main plot fixed factors with six NPG species randomly arranged within each herbicide and control. Plant injury, height, and tiller number responses were analyzed following the generalized linear method in the statistical software SAS (SAS, 2012). Initial tiller numbers (0 WAT) were treated as covariates for analysis at 6 WAT. Data across experiments 1 and 2 were not pooled if interaction terms accounting for experiments were not significant at $p \geq 0.20$. Post-hoc means separations of plant injury, height and tiller number employed Fisher's protected Least Significant Difference (LSD) at $p \leq 0.05$.

2.2.2 Field Establishment Experiments

Site Characterization and Preparation: Experiments to evaluate NPG growth the first year after vegetative planting were initiated in October 2011 at the LSU Agricultural Center Botanic Gardens at Burden (hereafter Baton Rouge) in Baton Rouge, Louisiana and United States Fort Polk Military Installation (hereafter Fort Polk) (31.02939°N, -93.21010°E) near Leesville, Louisiana. The Baton Rouge site's soil is characterized as Oprairie silt loam, 5.3 pH, 24.3 ppm P and 105.9 ppm K. The Fort Polk site is Briley loamy fine sand, 5.6 pH, 20.7 ppm P, and 45.7 ppm K. Average temperatures for the one year study period were 25.7°C/ 14.6°C in Baton Rouge and 25.6°C/14.8°C at Fort Polk. Total rainfall was 156.1 cm and 149.1 cm in Baton Rouge and Fort Polk, respectively, with average relative humidity measuring 71.3% and 70.8%, respectively. While overall climactic data were similar between the two locations for the year-long field establishment study, the July 2012 through October 2012 period was considerably drier at Fort Polk which recorded 36.4 cm of rainfall compared to 61.7 cm measured in Baton Rouge.

Experimental areas measuring 8 m x 12.5 m were prepared for NPG establishment by eliminating existing vegetation with an herbicide mixture of glyphosate (N-(phosphonomethyl)glycine) at 14 L/ha and sulfosulfuron (N-[[(4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]-2-(ethylsulfonyl)imidazo[1,2-a]pyridine-3-sulfonamide) at 0.14 Kg/ha. Herbicides were applied using a

3-nozzle boom sprayer at spray volume of 280.6 L/ ha 4 weeks prior to planting. The area was scalped and raked rather than tilled to lessen any interfering vegetative debris.

The native grass plants selected for the field portion of the research included the NPGs listed in the herbicide tolerance experiments. Plugs were obtained from Nature Hills Nursery (Omaha, NE) and grown in 2.5 L containers filled with a 75:25 fine pine bark:coarse sand substrate (Phillips Bark Processing Company, Inc., Brookhaven, MS) under greenhouse conditions for 14 weeks prior to planting in the field. Post-plug planting maintenance included irrigation every two days at 2.5 cm with twice-weekly fertigation at 200 ppm N. The irrigation source was from a municipal water source treated with sulfuric acid to lower water pH from ~8.6 to 6.5. Irrigation pH was monitored weekly. Pesticides were not applied during this period.

NPG Planting and Post-Planting Maintenance: Native perennial grass plugs were planted on 13 and 20 October 2011 in Baton Rouge and Fort Polk, respectively. The planting procedure included the use of a mechanical auger to drill 10 cm diameter holes to a depth of 15 cm. Drilling minimized surface disruption to limit weed encroachment as well as to standardize planting hole size. A total of 16 plugs were planted within a 3.4 m^2 area 46 cm apart per species per experimental unit. Plugs of each NPG were replicated three times.

Plugs were irrigated for 6 weeks after planting at 2.5 cm per day with overhead irrigation using municipal water. No fertilization or supplemental irrigation was applied for the remainder of the 12-month establishment experiment. Two weeks after planting and again in March 2012, each experimental area was treated with a broadcast application of pendimethalin at 4.7 L/ha. Pendimethalin was applied using a 3-nozzle boom sprayer at spray volume of 280.6 L/ha and immediately incorporated with 2.5 cm of overhead irrigation. Pendimethalin was selected as the only herbicide applied based on the results of the greenhouse herbicide tolerance experiments.

Data Collection: Post-herbicide application, canopy coverage, quality color ratings, and weed coverage were rated and recorded quarterly from October 2011 to October 2012. Color quality ratings were based on a 1 to 9 scale with 1 indicating dead or dormant plants; 5 indicating a minimal acceptable rating; and 9 representing ideal plant quality/greeness. At the conclusion of the 12-month experiment, NPG shoots were excised at the plant-soil interface and plant height recorded. Shoots were dried for 72 hrs at 60°C and biomass determined gravimetrically.

Statistical Design: Native perennial grass plants were arranged in a randomized complete block design with three replications. Data collected concerning canopy coverage, quality color ratings, weed coverage, plant height and shoot biomass were analyzed following the generalized linear method in the statistical software SAS (SAS, 2012). Data were not pooled across locations if interaction terms accounting for experiments were not significant at $p \leq 0.20$. Post-hoc means separations of canopy coverage, quality color ratings, weed coverage, plant height and shoot biomass employed Fisher's LSD at $p \leq 0.05$.

2.3 Results

<u>2.3.1 Greenhouse Herbicide Tolerance Experiments</u>

Data concerning the tolerance of herbicides is presented by species. This method of data presentation was selected to allow the reader greater emphasis on understanding specific species' herbicidal tolerances since the dynamics of herbicide effects on mixed swards was not fully elucidated.

Blue Grama: During the first experiment examining blue grama tolerance to various herbicides, imazapic, fenoxaprop, sulfosulfuron, and triclopyr resulted in injury ratings >30% within 6 WAT (Table 1). Blue grama treated with imazapic exhibited the greatest injuries of 61%, 86%, and 81% at 2, 4, and 6 WAT, respectively; followed by fenoxaprop, sulfosulfuron, and triclopyr–treated blue grama with injuries of 55%, 45%, and 35%, respectively, 6 WAT. In the second experiment, imazapic-treated blue grama exhibited injury >30% within 2 WAT while fenoxaprop, sulfosulfuron, and triclopyr–treated blue grama injury never exceeded 30% during the six week experimental period. Pendimenthalin-treated blue grama consistently resulted in the least injury at 3 to 4% in each experiment.

Table 1. Herbicide injury of blue grama native perennial grass plugs at 2, 4 and 6 weeks after herbicide treatment in 2011.

		Percent injury[y]		
	Herbicide	Weeks after treatment (WAT)		
Grass species	active ingredient	2 WAT	4 WAT	6 WAT
		Experiment 1		
		---------------------------%------------------------		
Blue grama	Control	0.0[z] A	0.0 A	0.0 A
	Fenoxaprop	33.8 B	75.0 C	55.0 B
	Imazapic	61.3 C	86.3 C	81.3 C
	Pendimethalin	0.0 A	1.3 A	3.8 A
	Sulfosulfuron	18.8 B	40.0 B	45.0 B
	Triclopyr	18.8 B	35.0 B	35.0 B
		Experiment 2		
		---------------------------%------------------------		
Blue grama	Control	0.0[z] A	0.0 A	0.0 A
	Fenoxaprop	10.0 AB	0.0 A	10.0 AB
	Imazapic	45.0 C	37.5 C	35.0 B
	Pendimethalin	5.0 AB	0.0 A	2.5 AB
	Sulfosulfuron	17.5 B	30.0 BC	25.0 B
	Triclopyr	30.0 BC	17.5 B	5.0 AB

[z] Injury ratings means are separated using Fisher's Least Significant Difference (LSD) at $p \leq 0.05$. Means with different letters are significantly different within the species within each WAT measurement interval for each experiment.
[y] Percent injury ratings are based on 0 to 100% scale following guidelines outlined by the Southern Weed Science Society (Research Methods in Weed Science, Third Edition, 1986).

Changes in blue grama growth for imazapic were more evident in tiller measurements (Table 2) compared to plant height. For example, imazapic-treated blue grama had slower tillering production of 28 and 80 tillers to 36 and 103 tillers 0 to 6 WAT for experiments 1 and 2 compared to controls that increased tillers from 21 and 84 tillers to 90 and 228 tillers during the same time periods. Sulfosulfuron and triclopyr treatments resulted in less consistent tiller growth across experiments. Tiller numbers were equal to or above controls in the first experimental run and below controls in the second experimental run. Pendimethalin-treated blue grama resulted in increased tiller numbers up to 169 and 263 tillers 6 WAT in each experiment.

Table 2. Tillering of six native perennial grass species at 0 and 6 weeks after treatment with five herbicides in 2011.

Grass species	Herbicide active ingredient	Experiment 1 Tiller no. No. weeks after treatment (WAT) 0 WAT	6 WAT	Experiment 2 Tiller no. No. weeks after treatment (WAT) 0 WAT	6 WAT
Blue grama	Control	21	90[z] B	84	228[z] C
	Fenoxaprop	40	45 A	123	292 E
	Imazapic	28	36 A	80	103 A
	Pendimethalin	49	169 D	120	263 D
	Sulfosulfuron	50	107 C	130	132 B
	Triclopyr	40	81 B	82	126 B
Broomsedge	Control	13	33 A	13	32 A
	Fenoxaprop	15	34 A	13	31 A
	Imazapic	14	38 AB	16	27 A
	Pendimethalin	10	36 A	20	61 B
	Sulfosulfuron	22	53 BC	15	24 A
	Triclopyr	20	57 C	29	68 B
Indiangrass	Control	31	97 C	45	63 B
	Fenoxaprop	40	56 A	54	51 AB
	Imazapic	37	138 D	62	53 AB
	Pendimethalin	45	122 D	53	45 A
	Sulfosulfuron	52	166 E	63	39 A
	Triclopyr	39	78 B	53	38 A
Little bluestem	Control	23	46 AB	25	43 A
	Fenoxaprop	18	38 A	22	50 AB
	Imazapic	23	42 AB	30	53 AB
	Pendimethalin	18	47 AB	30	66 B
	Sulfosulfuron	21	48 AB	28	36 A
	Triclopyr	20	55 B	28	65 B
Switchgrass	Control	25	40 B	14	17 A
	Fenoxaprop	20	13 A	15	14 A
	Imazapic	14	9 A	18	16 A
	Pendimethalin	18	22 A	22	19 A
	Sulfosulfuron	16	24 AB	18	9 A
	Triclopyr	9	8 A	20	14 A
Virginia wildrye	Control	18	46 C	62	114 C
	Fenoxaprop	16	20 B	42	131 D
	Imazapic	22	3 A	52	48 A
	Pendimethalin	24	45 C	49	105 C
	Sulfosulfuron	24	28 B	59	80 B
	Triclopyr	24	24 B	44	40 A

[z] Tiller number means are separated using Fisher's LSD at $p \leq 0.05$. Means with different letters are significantly different within each species at 6 WAT.

The herbicides evaluated did not statistically affect blue grama height throughout the experimental periods compared to controls (Table 3); however, imazapic, fenoxaprop, and sulfosulfuron application resulted in reduced plant heights from initial heights of 23.1, 25.4 and 25.3 cm to 17.1, 21 and 19.3 cm 6 WAT. Controls and pendimethalin-treated blue grama increased from 20 and 27.3 cm to 26.3 and 34.3 cm, respectively.

Broomsedge: In the first experimental run, fenoxiprop and pendimethalin-treated broomsedge plants exhibited injury >30% 6 WAT (Table 4). Broomsedge exhibited one of the highest injury ratings recorded for pendimethalin across all species tested. However, no deleterious effects were observed related to plant height or tillering for broomsedge-treated plants in either experimental run. Imazapic, sulfosulfuron and triclopyr-treated broomsedge resulted in injury ratings of <30% 6 WAT for both experimental runs. However, in experiment 2 fenoxiprop-treated plants exhibited the highest injury 25% 6 WAT, a slight recovery from 43% injury 2 WAT. Imazapic and sulfosulfuron demonstrated 15% and 18% injury respectively 6 WAT, and no injury was observed on triclopyr-treated plants.

Tiller number increased for all broomsedge plants 6 WAT. Tillering of control plants was consistent between experimental runs with increases of 13 to 33 tillers and 13 to 32 tillers. Tiller increased the highest 6 WAT in the first experimental run for triclopyr-treated plants from 20 to 57, and increased 22 to 53 for sulfosulfuron-treated plants. Tiller count increases for broomsedge plants treated with the remaining three herbicides did not result in differences from control plants. In the second experimental run, the results were similar to the first with the exception of pendimethalin and triclopyr-treated broomsedge increasing tillering the highest from 20 to 61 and 29 to 68, following injury ratings. Otherwise, fenoxaprop, imazapic and sulfosulfuron-treated plants did not produce statistically different tiller increases from controls.

Table 3. Shoot height of six native perennial grasses measured at 0, 3 and 6 weeks after herbicide treatment in 2011.

		Shoot height (cm)		
	Herbicide	No. of weeks after treatment (WAT)		
Grass species	active ingredient	Week 0	Week 3	Week 6
		----------------------------cm------------------------		
Blue grama	Control	20.0[z] A	26.9 AB	26.3 AB
	Fenoxaprop	25.4 A	21.3 A	21.0 AB
	Imazapic	23.1 A	19.6 A	17.1 A
	Pendimethalin	27.4 A	34.4 B	28.9 B
	Sulfosulfuron	25.3 A	23.8 A	19.3 AB
	Triclopyr	24.6 A	26.0 A	24.5 AB
Broomsedge	Control	18.5 A	21.5 A	31.3 B
	Fenoxaprop	21.3 A	20.8 A	18.6 A
	Imazapic	24.0 AB	26.5 AB	51.0 C
	Pendimethalin	24.9 AB	31.1 B	49.5 C
	Sulfosulfuron	22.3 AB	27.8 AB	44.8 C
	Triclopyr	29.8 B	28.8 AB	44.1 C
Indiangrass	Control	30.8 A	40.5 A	35.9 A
	Fenoxaprop	32.8 A	39.4 A	34.5 A
	Imazapic	32.8 A	40.9 A	34.5 A
	Pendimethalin	32.5 A	41.0 A	31.4 A
	Sulfosulfuron	32.3 A	39.0 A	30.8 A
	Triclopyr	32.1 A	39.9 A	33.8 A
Little bluestem	Control	45.3 A	46.5 AB	49.8 AB
	Fenoxaprop	47.0 A	45.0 A	43.1 AB
	Imazapic	42.4 A	47.5 AB	40.0 A
	Pendimethalin	50.5 A	51.8 AB	49.5 AB
	Sulfosulfuron	48.3 A	49.4 AB	44.6 AB
	Triclopyr	46.8 A	54.3 B	50.1 B
Switchgrass	Control	33.4 AB	42.9 BC	39.5 B
	Fenoxaprop	38.4 B	43.4 C	39.3 B
	Imazapic	28.6 A	25.4 A	26.0 A
	Pendimethalin	36.5 AB	46.3 C	43.9 B
	Sulfosulfuron	30.3 A	35.1 B	31.3 AB
	Triclopyr	34.6 AB	36.6 BC	36.3 B
Virginia wildrye	Control	24.4 A	19.8 B	24.1 B
	Fenoxaprop	24.6 A	19.8 B	20.5 B
	Imazapic	24.3 A	10.8 A	7.3 A
	Pendimethalin	25.0 A	24.9 B	24.6 B
	Sulfosulfuron	23.3 A	22.3 B	17.3 AB
	Triclopyr	25.9 A	22.3 B	17.1 AB

[z] Shoot height means from experiments 1 and 2 were combined and are separated using Fisher's LSD at $p \leq 0.05$. Means with different letters are significantly different within each species within each WAT measurement interval.

Table 4. Herbicide injury of broomsedge native perennial grass plugs at 2, 4 and 6 weeks after herbicide treatment in 2011.

Grass species	Herbicide active ingredient	Percent injury[y] Weeks after treatment (WAT) 2 WAT	4 WAT	6 WAT
		Experiment 1		
		----------------------------%------------------------		
Broomsedge	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	41.3 B	57.5 B	50.0 C
	Imazapic	3.8 A	5.0 A	25.0 B
	Pendimethalin	1.3 A	15.0 A	32.5 BC
	Sulfosulfuron	3.8 A	2.5 A	7.5 AB
	Triclopyr	6.3 A	0.0 A	2.5 AB
		Experiment 2		
		----------------------------%------------------------		
Broomsedge	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	42.5 C	32.5 B	25.0 B
	Imazapic	20.0 B	17.5 B	15.0 AB
	Pendimethalin	0.0 A	0.0 A	0.0 A
	Sulfosulfuron	15.0 AB	25.0 B	17.5 AB
	Triclopyr	0.0 A	0.0 A	0.0 A

[z] Injury ratings means are separated using Fisher's Least Significant Difference (LSD) at $p \leq 0.05$. Means with different letters are significantly different within the species within each WAT measurement interval for each experiment.
[y] Percent injury ratings are based on 0 to 100% scale following guidelines outlined by the Southern Weed Science Society (Research Methods in Weed Science, Third Edition, 1986).

Height increased for all herbicide-treated broomsedge plants except broomsedge treated with fenoxaprop. Fenoxaprop resulted in a decreased broomsedge height from 21.25 cm to 18.625 cm 6 WAT compared to control plants that increased from 18.5 cm to 31.25 cm. Interestingly, imazapic, pendimethalin, sulfosulfuron and triclopyr all increased height far more than control plants 6 WAT, measuring 51 cm, 49.5 cm, 44.75 cm, 44.125 cm, respectively, even though some of these treatments resulted in visual herbicide injury.

Indiangrass: Fenoxaprop was the only herbicide that resulted in a deleterious effect on Indiangrass in each experimental run at 43% and 55% injury (Table 5). The remaining herbicides did not result in injury above 14% during the first six week experiment. However, in the second experimental run, fenoxaprop and sulfosulfuron-treated Indiangrass exhibited injury of 55% and 50% respectively, while imazapic, pendimethalin and triclopyr-treated plants demonstrated <30% injury 6 WAT.

Table 5. Herbicide injury of Indiangrass native perennial grass plugs at 2, 4 and 6 weeks after herbicide treatment in 2011.

Grass species	Herbicide active ingredient	Percent injury[y] Weeks after treatment (WAT) 2 WAT	4 WAT	6 WAT
			Experiment 1	
		-----------------------------	%	-------------------------
Indiangrass	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	17.5 B	61.3 C	42.5 B
	Imazapic	6.3 AB	17.5 B	2.5 A
	Pendimethalin	5.0 AB	0.0 A	3.8 A
	Sulfosulfuron	5.0 AB	3.8 AB	13.8 A
	Triclopyr	6.3 AB	0.0 A	2.5 A
			Experiment 2	
		-----------------------------	%	-------------------------
Indiangrass	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	12.5 AB	45.0 B	55.0 B
	Imazapic	27.6 B	37.2 B	16.8 A
	Pendimethalin	0.0 A	0.0 A	2.5 A
	Sulfosulfuron	32.5 B	42.5 B	50.0 B
	Triclopyr	6.3 A	2.5 A	7.5 A

[z] Injury ratings means are separated using Fisher's Least Significant Difference (LSD) at p≤0.05. Means with different letters are significantly different within the species within each WAT measurement interval for each experiment.

[y] Percent injury ratings are based on 0 to 100% scale following guidelines outlined by the Southern Weed Science Society (Research Methods in Weed Science, Third Edition, 1986).

Tiller growth of control plants increased from 31 to 97 and 45 to 63 in each of the experiments, while fenoxiprop-treated plants exhibited the slowest rate of tillering. This slower tillering rate coincided with observed injury ratings. Tiller count increased greatly 6WAT for imazapic (37-138), pendimethalin (45-122) and sulfosulfuron (52-166), and increased moderately for triclopyr (39-78). These tiller results generally followed the same trend observed in injury ratings. However, in the second experimental run at 6 WAT tillering decreased for Indiangrass treated with any of the five herbicides tested. Pendimethalin, sulfosulfuron and triclopyr experienced the largest reduction in tiller count from 53 to 45, 63 to 39, and 53 to 38, respectively. Fenoxaprop and imazapic-treated plants exhibited less of a decline in tillering from 54 to 51 and 62 to 53, irrespective of the higher injury ratings associated with fenoxaprop-treated Indiangrass.

Height measurements for the control plants increased from 30.75 cm to 35.875 cm 6 WAT. There was no significant difference in height across any of the five herbicides (fenoxaprop, imazapic, pendimethalin, sulfosulfuron and triclopyr), although slight height reductions occurred on the pendimethalin and sulfosulfuron-treated plants from 32.5 cm to 31.375 cm and 32.25 cm to 30.75 cm, respectively. Injury ratings do not appear to be good indicators of height changes in Indiangrass. Interestingly, all plants experienced a height increase from 0 WAT to 3 WAT, followed by declines in plant height 3 to 6 WAT.

Little Bluestem: In the first experimental run, little bluestem treated with fenoxaprop experienced the highest injury at 55% 6 WAT compared to imazapic, pendimethalin, sulfosulfuron and triclopyr-treated little bluestem that exhibited < 30 injury 6 WAT (Table 6). However, in the second experimental run, fenoxaprop, imazapic and sulfosulfuron-treated little bluestem resulted in higher injury ratings 6 WAT at 43%, 33%, and 27% injury, respectively. Pendimethalin and triclopyr treatment results were consistent across experimental runs with no significant injury.

Little bluestem control plants increased tillering in both experimental runs from 23 to 46 tillers and 25 to 43 tillers, respectively. All herbicide-treated little bluestem plants increased tillers during each experiment. However, in the first experimental run, fenoxaprop-treated bluestem produced the lowest tillers from 18 to 38, which followed a similar pattern to injury ratings. Imazapic, pendimethalin and sulfosulfuron tillering had similar tillering growth as controls, whereas triclopyr-treated plants exhibited the highest increase in tillers from 20 to 55. In the second experimental run, plants treated with sulfosulfuron increased tiller count similar to controls, while little bluestem treated with fenoxaprop, imazapic, pendimethalin and triclopyr exhibited higher tillering compared to controls.

Table 6. Herbicide injury of little bluestem native perennial grass plugs at 2, 4 and 6 weeks after herbicide treatment in 2011.

Grass species	Herbicide active ingredient	Percent injury[y] Weeks after treatment (WAT) 2 WAT	4 WAT	6 WAT
		Experiment 1		
		----------------------------%------------------------		
Little bluestem	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	17.5 B	70.0 B	55.0 B
	Imazapic	5.0 AB	15.0 A	10.0 A
	Pendimethalin	5.0 AB	0.0 A	0.0 A
	Sulfosulfuron	0.0 A	0.0 A	0.0 A
	Triclopyr	11.3 AB	0.0 A	8.8 A
		Experiment 2		
		----------------------------%------------------------		
Little bluestem	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	40.0 B	30.0 B	42.5 B
	Imazapic	27.5 B	30.0 B	32.5 B
	Pendimethalin	0.0 A	0.0 A	0.0 A
	Sulfosulfuron	22.5 B	17.5 B	27.5 B
	Triclopyr	7.5 AB	0.0 A	10.0 AB

[z] Injury ratings means are separated using Fisher's Least Significant Difference (LSD) at p≤0.05. Means with different letters are significantly different within the species within each WAT measurement interval for each experiment.
[y] Percent injury ratings are based on 0 to 100% scale following guidelines outlined by the Southern Weed Science Society (Research Methods in Weed Science, Third Edition, 1986).

The height of the control plants increased from 45.25 cm to 49.75 cm over the course of the 6 week experiments. The greatest height reduction was observed in plants treated with imazapic from 42.4 cm at 0 WAT to 40 cm at 6 WAT. Changes in height were not significantly different for plants treated with fenoxaprop, pendimethalin and sulfosulfuron compared to controls.

Switchgrass

Switchgrass exhibited >30% injury 6 WAT when treated with fenoxaprop, imazapic, pendimethalin, sulfosulfuron, triclopyr during the first experimental run, with fenoxaprop and triclopyr-treated plants showing the highest injury ratings of 70% and 81% respectively (Table 7).

Conversely in the second experimental run, switchgrass treated with the same five herbicides demonstrated no significantly different injury.

Table 7. Herbicide injury of switchgrass native perennial grass plugs at 2, 4 and 6 weeks after herbicide treatment in 2011.

		Percent injury[y]		
	Herbicide	Weeks after treatment (WAT)		
Grass species	active ingredient	2 WAT	4 WAT	6 WAT
		Experiment 1		
		----------------------------%------------------------		
Switchgrass	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	30.0 B	70.0 C	70.0 C
	Imazapic	41.3 B	50.0 B	51.3 BC
	Pendimethalin	10.0 A	12.5 A	37.5 B
	Sulfosulfuron	35.0 B	55.0 BC	40.0 B
	Triclopyr	65.0 C	62.5 BC	81.3 C
		Experiment 2		
		----------------------------%------------------------		
Switchgrass	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	6.3 A	12.5 AB	0.0 A
	Imazapic	8.7 A	18.8 B	0.0 A
	Pendimethalin	0.0 A	2.5 AB	0.0 A
	Sulfosulfuron	11.3 A	20.0 B	21.3 A
	Triclopyr	0.0 A	0.0 A	0.0 A

[z] Injury ratings means are separated using Fisher's Least Significant Difference (LSD) at $p \leq 0.05$. Means with different letters are significantly different within the species within each WAT measurement interval for each experiment.
[y] Percent injury ratings are based on 0 to 100% scale following guidelines outlined by the Southern Weed Science Society (Research Methods in Weed Science, Third Edition, 1986).

Tiller count of the control plants in the first experimental run increased from 25 to 40 tillers 6 WAT. All five tested herbicides resulted in statistically lower tiller counts than the control in combination with the higher injury ratings for the first experimental run. Pendimethalin and sulfosulfuron led to a slight increase in tiller number from 18 to 22 tiller and 16 to 24 tillers, respectively, 6 WAT. Fenoxaprop, imazapic and triclopyr all reduced tillering 6 WAT. In the second experimental run, control tiller count increased from 14 to 17 tillers 6 WAT with all herbicide-treated switchgrass having similar tiller numbers 6 WAT as controls

Switchgrass control plants increased in height from 33.4 cm to 39.5 cm 6 WAT. All other herbicides with the exception of imazapic resulted in increased height. Imazapic-treated plant height reduced from 28.6 cm to 26 cm 6 WAT.

Virginia Wildrye: Virginia wildrye sustained significant injury 6 WAT from four of the five herbicides tested in the first experimental run (Table 8). Imazapic resulted in 98% injury, while fenoxaprop, sulfosulfuron and triclopyr-treated plants exhibited 73%, 58% and 70% injury 6 WAT, respectively. Similar injury ratings >30% occurred for imazapic and triclopyr-treated Virginia wildrye in the second experimental run. Pendimethalin-treated plants were the only plants to exhibit <30% injury 6 WAT in each of the experiments. Interestingly, during the second experimental run, fenoxaprop-treated plants exhibited only 10% injury 6 WAT.

Table 8. Herbicide injury of Virginia wildrye native perennial grass plugs at 2, 4 and 6 weeks after herbicide treatment in 2011.

		Percent injury[y]		
	Herbicide	Weeks after treatment (WAT)		
Grass species	active ingredient	2 WAT	4 WAT	6 WAT
		Experiment 1		
		----------------------------%------------------------		
Virginia wildrye	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	37.5 B	87.5 C	72.5 B
	Imazapic	61.3 C	100.0 C	97.5 C
	Pendimethalin	1.3 A	12.5 A	20.0 A
	Sulfosulfuron	21.3 B	57.5 B	57.5 B
	Triclopyr	27.5 B	45.0 B	70.0 B
		Experiment 2		
		----------------------------%------------------------		
Virginia wildrye	Control	0.0 A	0.0 A	0.0 A
	Fenoxaprop	15.0 AB	2.5 A	10.0 AB
	Imazapic	22.5 BC	42.5 BC	45.0 BC
	Pendimethalin	5.0 AB	0.0 A	5.0 A
	Sulfosulfuron	17.5 B	30.0 B	30.0 B
	Triclopyr	37.5 C	50.0 C	57.5 C

[z] Injury ratings means are separated using Fisher’s Least Significant Difference (LSD) at $p \leq 0.05$. Means with different letters are significantly different within the species within each WAT measurement interval for each experiment.
[y] Percent injury ratings are based on 0 to 100% scale following guidelines outlined by the Southern Weed Science Society (Research Methods in Weed Science, Third Edition, 1986).

Tiller count for the control plants increased in each experimental run from 18 to 46 tillers and 62 to 114 tillers, respectively. Given the high injury of most herbicides on Virginia wildrye, only pendimethalin-treated plants increased tiller count 6 WAT similar to controls during the first experimental run. Fenoxaprop, sulfosulfuron and triclopyr-treated Virginia wildrye increased tiller count at a slower rate while imazapic greatly reduced tillering from 22 to 3 6 WAT. In the second experimental run, the effects of imazapic were muted with tillering remaining static at 52 and 48 tillers, and triclopyr-treated plants exhibited similar tiller reductions from 44 to 40, matching injury ratings. Virginia wildrye treated with pendimethalin increased tillers from 49 to 105 similar to controls while fenoxaprop increased tiller count 6 WAT above control plant rates with 42 to 131 tillers. Sulfosulfuron-treated plants increased tiller count at a slower rate than the control.

Over the six week experiment period, the height of controls remained static at 24.4 cm and 24.1 cm at 0 and 6 WAT. Fenoxaprop, pendimethalin, sulfosulfuron and triclopyr-treated plants heights were all similar to controls. However, following visual injury ratings, imazapic led to the greatest height reduction of 10.8 cm to 7.3 cm.

2.3.2 Field Establishment Experiments

Based on the results of the greenhouse herbicide tolerance study, pendimethalin was the only herbicide applied to the field experiments. Pendimethalin was applied twice during the 12-month establishment period to control weed encroachment.

Baton Rouge Location: Final establishment measurements recorded as canopy coverage differed for the Baton Rouge and Fort Polk locations. In Baton Rouge, little bluestem, Virginia wildrye, and broomsedge attained canopy coverages of 96.7%, 100% and 100% and high visual ratings of 8 within the 12 month observation period (Tables 9 and 10). During the same period blue grama, switchgrass, and Indiangrass were slower to establish with canopy coverages between 46.7% and 70% and visual ratings of 6.7 to 7.7. The only cool-season NPG, Virginia wildrye predictably exhibited the greatest decline in coverage from 100% to 53.3% during warmer weather from July to October along with the greatest decline in visual rating from 7 to 1.3. The remaining warm-season NPG species exhibited static or slight declines the months immediately post planting from October 2011 to April 2012 compared to Virginia wildrye that increased canopy coverage from 46.7% to 80% during the same period. Declines in visual ratings from July to October for the warm-season NPG appear to be a function of dormancy.

Table 9. Vegetative establishment measured as percent canopy coverage of six native perennial grasses from October 2011 to October 2012 at two locations in Louisiana.

	Percent canopy coverage			
	Baton Rouge			
Grass species	Oct. 2011	Apr. 2012	Jul. 2012	Oct. 2012
	--------------------	--------------------	% --------------------	--------------------
Blue grama	40.0[z] BC	43.3 BC	56.7 C	46.7 C
Broomsedge	33.3 CD	33.3 CD	83.3 B	96.7 A
Indiangrass	43.3 B	26.7 D	46.7 C	70.0 B
Little bluestem	60.0 A	50.0 B	90.0 AB	100.0 A
Switchgrass	30.0 D	30.0 D	56.7 C	50.0 C
Virginia wildrye	46.7 B	80.0 A	100.0 A	53.3 C
	Fort Polk			
Grass species	Oct. 2011	Apr. 2012	Jul. 2012	Oct. 2012
	--------------------	--------------------	% --------------------	--------------------
Blue grama	40.0[z] B	36.7 BC	40.0 A	40.0 BC
Broomsedge	30.0 C	43.3 AB	46.7 A	46.7 AB
Indiangrass	40.0 B	30.0 C	23.3 B	10.0 E
Little bluestem	50.0 A	50.0 A	46.7 A	53.3 A
Switchgrass	30.0 C	33.3 C	23.3 B	26.7 D
Virginia wildrye	46.7 A	50.0 A	40.0 A	33.3 DC

[z] Canopy coverage means are separated using Fisher's LSD at $p \leq 0.05$. Means with different letters are significantly different among species within each measurement time period at each location.

Table 10. Grass shoot color rating of six native perennial grasses from October 2011 to October 2012 at two locations in Louisiana.

	Color rating			
	Baton Rouge			
Grass species	Oct. 2011	Apr. 2012	Jul. 2012	Oct. 2012
Blue grama	8.0[z,y] A	6.7 B	6.3 C	2.0 AB
Broomsedge	7.7 A	7.7 A	8.0 A	3.0 A
Indiangrass	7.0 B	5.3 B	7.0 B	3.0 A
Little bluestem	8.0 A	8.0 A	8.0 A	3.3 A
Switchgrass	8.0 A	8.0 A	7.7 A	2.0 AB
Virginia Wildrye	7.7 A	8.0 A	7.0 B	1.3 B

(Table 10 continued on page 31)

(Table 10 continued)

Grass species	Fort Polk Oct. 2011	Apr. 2012	Jul. 2012	Oct. 2012
Blue grama	8.0^{z,y} A	4.0 C	5.3 AB	1.0 B
Broomsedge	8.0 A	7.3 AB	4.0 BC	2.7 A
Indiangrass	7.0 B	2.7 D	2.3 D	1.0 B
Little bluestem	8.0 A	7.7 AB	6.7 A	1.0 B
Switchgrass	8.0 A	7.0 B	5.7 A	1.0 B
Virginia Wildrye	8.0 A	8.0 A	3.3 CD	1.0 B

[z] Color rating means are separated using Fisher's LSD at $p \leq 0.05$. Means with different letters are significantly different among species within each measurement time period at each location.
[y] Color rating based on a 1-9 scale, with 9 being the highest/greenest.

During the 12-month establishment period at Baton Rouge, weeds accounted for <11.7% of the establishment area from October 2011 to July 2012 (Table 11). Weed encroachment increased to as high as 50% in October 2012, the final month of observation. However, NPG that attained higher canopy coverages typically resulted in the lowest weed encroachment. For example, broomsedge and little bluestem with >97.7% canopy coverage resulted in <2% weed encroachment compared to 23.3% weed encroachment for switchgrass and Indiangrass at 50% and 70% canopy coverages, respectively. In the case of Virginia wildrye, decreases in canopy coverage from 100% to 53.3% did not result in substantially higher weed encroachment observed at 3.3% in October 2012 most likely due to dying or dead plant debris shading the soil.

At the conclusion of the 12-month establishment period, NPG that had the greatest canopy coverages such as little bluestem and broomsedge resulted in the highest biomass accumulation of 156.8 and 244.8g (Table 12), respectively, and corresponding heights of 18.6 and 18.6 cm (Table 13). Native perennial grasses that did not have high canopy coverages exhibited lower biomass accumulation and shorter heights. Switchgrass, Indiangrass, and blue grama had heights of 15.3, 13.4, and 13.3 cm and biomasses of 25.4, 37.5, and 53.8 cm, respectively. In the case of Virginia wildrye, biomass in October 2012 was 49.2g with an average height of 14.4 cm. Heights for NPGs generally declined over the 12-month establishment period from initial plant heights at planting in October 2011. The only exception was broomsedge which increased from 15.3 to 18.3 cm.

Table 11. Weed coverage on plots of six native perennial grasses from October 2011 to October 2012 at two locations in Louisiana.

	Percent weed coverage			
	Baton Rouge			
Grass species	Oct. 2011	Apr. 2012	Jul. 2012	Oct. 2012
	----------------------	----------------------%	----------------------	----------------------
Blue grama	0.0[z] A	10.0 A	6.7 B	50.0 A
Broomsedge	0.0 A	5.0 B	3.3 BC	1.7 C
Indiangrass	0.0 A	6.7 B	11.7 A	23.3 B
Little bluestem	0.0 A	5.0 B	1.7 C	1.7 C
Switchgrass	0.0 A	10.0 A	6.7 B	23.3 B
Virginia wildrye	0.0 A	5.0 B	1.7 C	3.3 C
	Fort Polk			
Grass species	Oct. 2011	Apr. 2012	Jul. 2012	Oct. 2012
	----------------------	----------------------%	----------------------	----------------------
Blue grama	0.0[z] A	40.0 A	3.3 AB	11.7 AB
Broomsedge	0.0 A	36.7 A	0.0 B	10.0 B
Indiangrass	0.0 A	25.0 A	6.7 A	28.3 A
Little bluestem	0.0 A	56.7 A	1.7 B	5.0 B
Switchgrass	0.0 A	55.0 A	6.7 A	11.7 AB
Virginia wildrye	0.0 A	36.7 A	3.3 AB	13.3 AB

[z] Weed coverage means are separated using Fisher's LSD at $p \leq 0.05$. Means with different letters are significantly different among species within each measurement time period at each location.

Table 12. Grass shoot biomass dry weight excised at soil surface of six native perennial grasses from October 2011 to October 2012 at two locations in Louisiana.

	Grass shoot biomass dry weight (g)		
		Baton Rouge	Fort Polk
Grass species	Initial Oct. 2011	Final Oct. 2012	Final Oct. 2012
	----------------------	----------------------g	----------------------
Blue grama	21.3[z] B	53.8 C	74.0 C
Broomsedge	14.7 CB	244.8 A	191.2 A
Indiangrass	36.3 A	37.5 C	32.1 D
Little bluestem	43.8 A	156.8 B	129.4 B
Switchgrass	9.6 C	25.4 C	46.7 D
Virginia wildrye	19.6 CB	49.2 C	107.0 BC

[z] Shoot biomass dry weight means are separated using Fisher's LSD at $p \leq 0.05$. Means with different letters are significantly different among species within the initial measurement time period and within each location's final measurement time period.

Table 13. Grass shoot height of six native perennial grasses from October 2011 to October 2012 at two locations in Louisiana.

	Grass shoot height (cm)		
		Baton Rouge	Fort Polk
Grass species	Initial Oct. 2011	Final Oct. 2012	Final Oct. 2012
	------------------------------cm--------------------------------		
Blue grama	14.7[z] D	13.3 B	10.3 C
Broomsedge	15.3 D	18.3 A	11.5 BC
Indiangrass	19.3 C	13.4 B	5.8 D
Little bluestem	23.3 B	18.6 A	14.4 A
Switchgrass	45.7 A	15.3 AB	13.5 AB
Virginia wildrye	19.0 C	14.4 B	10.2 C

[z] Shoot height means are separated using Fisher's LSD at $p \leq 0.05$. Means with different letters are significantly different among species within the initial measurement time period and within each location's final measurement time period.

Fort Polk Location: The top performing NPG were similar to the Burden location with little bluestem, broomsedge, and Virginia wildrye attaining the highest canopy coverages of 53.3%, 46.7%, and 50% along with blue grama at 40% canopy coverage. These species also had the highest visual ratings between 7.3 and 8 in April 2012. Indiangrass and switchgrass canopy coverages were the lowest at 10% and 26.7% at the end of the 12-month establishment period.

Although there appear to be some similarities in performance between locations, the majority of the NPG species did not reach substantially higher canopy coverages compared to planting coverages in October 2011. Blue grama was static in canopy coverage at 40% in October 2011 and 2012 while broomsedge and little bluestem exhibited increases in canopy coverages of 16.7% and 3.3%, respectively, during the 12 months. Switchgrass and Indiangrass exhibited declines in canopy coverages from 30% and 40% to 26.7% and 10%, respectively. Even though patterns of slight declines or static canopy coverage were observed for NPG at Burden from October to April, the declines or static growth for NPG at Fort Polk during the same period appeared to continue into summer and late autumn. This failure of NPG to establish is also noted with visual quality ratings. From October 2011 to July 2012 all NPG species declined from 7 and 8 ratings to between 2.3 and 6.7 ratings. Declines in visual ratings in October 2012 are a function of warm-season NPG dormancy.

One factor that could have contributed to the declines in NPG establishment at Fort Polk was the development of winter annual weeds in late winter. All NPG species had between 25% and 56.7% weed encroachment in April 2012 with weed encroachment reduced to 0 to 6.7% in July 2012. However, dead or dying weed debris may have negatively impacted NPG to the point of affecting growth during the warmer months. Additional factors negatively affecting NPG establishment could have been the considerably drier mid-summer to autumn period at Fort Polk and poor soil fertility associated with its sandy textured soils most likely slowed NPG establishment (Volder et al 2010). As a result, the trend of higher canopy coverage to lower weed encroachment was not as obvious at Fort Polk compared to Baton Rouge.

The slower establishment of NPG at Fort Polk did result in slightly lower biomass accumulated compared to NPG in Baton Rouge. Again little bluestem and broomsedge had the greatest biomasses at 129.4 and 191.2 g with heights 14.4 ad 11.5 cm followed by Virginia wildrye and blue grama at 107 and 74 g and heights of 10.2 and 10.3 cm, respectively. Switchgrass had positive increases in biomass from 9.6 g in October 2011 to 46.7 g in October 2012, whereas Indiangrass declines in canopy coverage were noted with reduced biomass from 36.6 to 32.1 g and declines in height of 19.3 to 5.8 cm. All NPG with the exception of Indiangrass had increases in biomass over the 12-month period with greater accumulation occurring for taller canopies with higher canopy coverage. Interestingly, all NPG at Fort Polk had lower heights per species after the 12-month establishment period compared to initial heights at planting in October 2011 as well as NPG heights at Burden after 12 months of establishment.

2.4 Discussion

The potential use and benefits of NPG in urban plantings may be severely hindered during the establishment period from high weed pressure. Previously published scientific work has repeatedly reported difficulty in establishing native plants in disturbed soils due to high weed pressure (Thetford et al. 2009; Wilson et al. 2010). Uncontrolled weed pressure not only limits NPG establishment, but also makes comparisons among NPG species vigor difficult (Thetford et al. 2009). Aggressive weed encroachment can also negatively affect the aesthetic value NPG offer in the urban landscape. With weed control a primary concern, the initial study in this series of experiments focused on herbicide tolerance of NPG established vegetatively from plugs under greenhouse conditions. The herbicide tolerance study's two experiments occurred at different times of the year, with experiment 1 subject to warmer temperatures compared to experiment 2. Herbicide injury levels of greater than 30% were considered unacceptable for establishment success and aesthetic reasons. At the completion of the herbicide tolerance experiments, the second study evaluated establishment vigor in the field when weed pressure was controlled through application of an herbicide. One cool season and five warm season NPG were evaluated in both the herbicide tolerance and field establishment studies.

Blue grama is a fine-bladed grass that is being used as a native turfgrass alternative to more traditional exotic turf species. Blue grama was least tolerant of imazapic, a gramaticide applied primarily to control weedy grasses. Imazapic resulted in 81.3% and 35 % injury ratings for experiments 1 and 2, respectively, with more injury occurring during the warmer temperatures of experiment 1. Although height measurements were taken for all species and treatments, it appeared tiller number data were more indicative of injury ratings than height. For some grass species such as blue grama, however, tillering was not as strong or consistent an indicator of injury level. Tiller counts for blue grama increased for all herbicide treatments. Pendimethalin, the study's only herbicide with solely preemergence activity, caused the least amount of injury for blue grama. Other herbicides in the tolerance study may have some preemergence activity, but were chosen for evaluation based on their post-emergence use.

Broomsedge was a tolerant grass species overall, exhibiting tiller count increases for all herbicides. Fenoxaprop, the second gramaticide of the study, was the most injurious to broomsedge at

50% during experiment 1, but resulted in less than 30% injury for experiment 2. Broomsedge tolerated most herbicides well including imazapic, but experienced higher injury ratings during warmer temperatures, even from pendimethalin. The broadleaf herbicide triclopyr, used to control woody species and vines, caused the least amount of injury to broomsedge plants. Tiller count was not a good indicator or injury for broomsedge.

Fenoxaprop caused the most injury for Indiangrass in both experiments with ratings of 42.5% and 55%, respectively. Indiangrass experienced more injury during the cooler temperatures of experiment 2, but was still very tolerant of imazapic, pendimethalin and triclopyr. Tiller counts increased for all herbicides in experiment 1, but all decreased for experiment 2. Changes in tillering were a good indicator of injury for this species, with Indiangrass ultimately being tolerant overall. Little bluestem grass demonstrated good general herbicide tolerance, with pendimethalin being the least injurious. Sulfosulfuron, a selective herbicide used to control sedges, was also well tolerated by little bluestem. Fenoxaprop-treated plants resulted in the highest injury ratings for little bluestem, at 55% and 42.5%, respectively, for experiments 1 and 2. All test plants increased tiller count, with tillering being a better indicator of injury in experiment 1.

Switchgrass was injured by all herbicides in warmer temperatures, but experienced very little injury in cooler temperatures. Fenoxaprop caused the most injury at 70% in experiment 1, with tiller counts decreasing for most herbicides tested in that same experiment. Switchgrass tolerated pendimethalin the best in experiment 2, but did experience some injury with this herbicide in experiment 1. Percent injury could be related fairly well to tillering. Virginia wildrye was the only cool season grass included in this series of experiments, and it showed the greatest herbicide tolerance to pendimethalin. Imazapic and triclopyr were most deletarious, with fenoxaprop and sulfosulfuron also causing injury >30%. Tiller count often increased and provided good direction for injury ratings, with damage more likely during warmer temperatures.

Virginia wildrye was the least tolerant grass species across all herbicides, while broomsedge, Indiangrass and little bluestem exhibited the most tolerance. Higher injury ratings in general were observed during the warmer temperatures of experiment 1 with fenoxaprop and imazapic causing the most damage between the two experimental runs. This is similar to the findings of Wilson et al. (2010) who observed that targeted chemical removal of grassy weed species in NPG swards is expectedly more injurious to NPG than are herbicides targeting broadleaf species. They also reported that imazapic was highly injurious when applied to NPG during the first year of establishment for seeded swards, but that tolerance to imazapic increased after NPG were established (Wilson et al. 2010). Herbicide application timing, rate and frequency should be considered along with plant age in determining the best herbicide management scheme. Gramaticides like fenoxaprop and imazapic need to be carefully monitored to prevent unintended effects on non-target grass species. Cessation or implementation of herbicide regimes can also alter species composition in mixed NPG swards, such as what Hickman and Derner (2007) found when they observed the effects of stopping 25 years of broadleaf herbicide applications on a Texas prairie.

Occasional differences in injury ratings between experiment 1 and 2 for the same herbicide or within the same species could be caused by temperature differences during the two runs since other factors such as growth media and post-planting maintenance were the same across both greenhouse experiments. In experiment 1 the average temperatures were 31.3°C/ 21.2°C compared to 26.1°C/12.8°C during experiment 2. Temperature affects herbicide uptake, translocation, and metabolism and thus affects plant tolerance, growth and recovery (Kudsk and Kristensen 1992).

Results for sulfosulfuron and triclopyr showed more variation among species and temperatures within each experimental run. Pendimethalin ranked as the least injurious herbicide for almost all NPG species although switchgrass and broomsedge, when treated with pendimenthalin, uniquely exhibited injury exceeding 30% during experiment 1 only. All NPG treated with pendimethalin otherwise exhibited injury <10% and tiller count increase similar to controls. The frequently disturbed soils of urban landscapes can produce high weed pressures, and preemergence herbicides such as pendimethalin are expected to prevent weed germination and encroachment during vegetative establishment of plants in these areas. Stromberg et al. (2007) found that NPG have a much greater potential for successful vegetative establishment if kept weed free using preemergence herbicides. Flory and Clay (2009) stated that removal of weed species led to greater native plant establishment and vigor in their study evaluating various invasive weed removal techniques. Interestingly, Flory and Clay (2009) further observed that pendimethalin may negatively affect the eventual rate of increase in coverage of native grasses by preventing germination of native grass seed that has been deposited by previously-established NPG.

With the two greenhouse experiments demonstrating that all six NPG had the greatest tolerance to pendimethalin, only this herbicide was applied to control weeds in the field study that was designed to evaluate NPG establishment vigor. This field establishment study occurred in two different locations in southern Louisiana. Each site, Baton Rouge and Fort Polk, had different soil types and some short-term variability in climactic factors. Pendimethalin was applied twice during the year-long establishment period but it did not seem to restrict or otherwise interfere with NPG growth.

Establishment vigor was measured primarily through canopy coverage percentages, and little bluestem and broomsedge consistently achieved the highest canopy coverage during the 12-month establishment observation period at both sites. Indiangrass performed moderately well in Baton Rouge but exhibited poor results in Fort Polk, possibly due to its sandier soils. Virginia wildrye established well in Baton Rouge with 100% coverage, but with the onset of warm temperatures, experienced expected reductions in canopy coverage earlier in the summer than the warm season NPG species. Virginia wildrye was the only cool-season grass evaluated in the study, which explains its highest observed canopy coverage in April 2012 at both locations during moderate temperatures in South Louisiana. The remaining species of switchgrass and blue grama achieved lower canopy coverages of 40% to 46.7% and 26.7% to 50%, respectively, between the two locations within the 12-month observation period. Shoot biomass weights generally followed canopy coverage results. Establishment success appears to vary widely among individual NPG species, and other research observing notable variances was completed by Bugg et al. (1997).

The difference in soil texture and periodic variations in temperature and rainfall between the two locations is evident in plant vigor and possibly herbicide efficacy. Factors such as increasing soil temperatures and the presence of sandier soils have been reported to negatively affect pendimethalin persistence (Zimdahl et al, 1984), which is an important component in preemergence efficacy. The higher weed encroachment observed in April 2012 at Fort Polk compared to Baton Rouge likely hindered NPG growth the following months and could have been related to shortened persistence of pendimethalin in the sandier soils of that site. In addition, some of the late cool season or early warm season weeds could have already germinated at the time of the 2012 pendimethalin application, although their small relative size was not reflected in weed coverage observations at that time. The <10% weed encroachment observed for all species in July 2012 at Fort Polk in conjunction with the declining canopy coverage of Virginia wildrye over late summer and early autumn, suggest factors other than less effective weed control contributed to poorer overall NPG establishment. Given the similar latitude of the two locations, the considerably drier mid-summer to autumn period at Fort Polk and poor soil fertility associated with its sandy textured soils most likely slowed NPG establishment (Volder et al 2010).

By summer 2012 the pendimethalin applied in March 2012 would have degraded, and an inverse relationship between canopy coverage and weed encroachment appeared to be developing more clearly in the Baton Rouge field experiment. Species with the highest canopy coverage at both locations returned the lowest weed coverage results, but canopy coverage was greater overall in Baton Rouge due primarily to soil and climactic differences. Broomsedge and little bluestem both with >96.7% canopy coverage resulted in <2% weed encroachment compared to 23.3% weed encroachment for switchgrass and Indiangrass with canopy coverages of 50% and 70%, respectively. These results indicate that dense canopy shade may be able to reduce weed pressure during the first year of vegetative establishment for some NPG species. Greatly reduced weed pressure improves aesthetics during NPG establishment, but perhaps most importantly demonstrates progress towards the reduction of maintenance inputs to control weed pressure for those NPG species that establish more quickly. Pendimethalin applications at planting and again during the early part of 2012 helped control weed pressure as the five warm season NPG broke dormancy, but by the summer dense canopy coverage appeared to overcome any continued weed pressure. For NPG species that did not establish as quickly, inputs such as herbicide applications may need to be carried into the second year after planting, or the species may need to be initially planted more densely and in greater number.

Based on this work, NPG warm season species little bluestem, broomsedge, and possibly Indiangrass can be established vegetatively within a year on finer textured disturbed urban soils using an effective weed control strategy. Cool season NPG Virginia wildrye could also be established vegetatively within one year while employing a weed control program. As field trials here were focused on comparing NPG establishment, only a single herbicide regimen was employed. Based on the positive weed control results of somewhat limited pendimethalin use, more frequent applications should be considered since NPG vigor did not appear to be negatively affected. Other preemergence herbicides could therefore show promise for successful weed control, and the two tolerance experiments demonstrated that several NPG could withstand other classes of herbicides. Therefore, in practice post-emergence herbicides could be applied in conjunction with a preemergence herbicide regimen to accelerate the establishment of NPG in urban sites while maintaining acceptable aesthetics. Native perennial grass species selection must consider soil and climactic characteristics, and herbicide selection must additionally account for the effects of application rate, seasonal timing and frequency on each particular species at different growth stages. For these reasons, establishment of an NPG species monoculture landscape may be easier in urban areas than the establishment of a mixed NPG species sward.

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