NATIVE PLANT ESTABLISHMENT AND COMPETITION WITH AN INVASIVE SPECIES ON GEORGIA ROADSIDES

BY

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(Under the Direction of Patrick McCullough)

ABSTRACT

Invasive species are a costly problem on roadsides in Georgia that require chemical and cultural control. Currently, agronomists manage invasive weeds with mowing and herbicide applications on grassy roadsides but alternative strategies are needed to enhance the potential for long-term control. Restoration through the establishment of sustainable native plant communities may be an effective alternative for invasive weed control on Georgia roadsides. Species selection, seeding timing, seeding rate, and location could influence the establishment of native species under roadside conditions and warrant further investigation. In field experiments, the native species blackeyed Susan (*Rudbeckia hirta* L.), indiangrass (*Sorghastrum nutans* (L.) Nash), lanceleaf coreopsis (*Coreopsis lanceolata* L.), swamp milkweed (*Asclepias incarnata* L.) and wild bergamot (*Monarda fistulosa* L.) had high potential for successful establishment on Georgia roadsides. Seeding of native species in the spring generally had faster initial establishment than fall seeding. Greenhouse studies indicated that Johnsongrass (*Sorghum halepense* (L.) Pers.), a problematic roadside weed, had a higher competitive growth than indiangrass during establishment. Mowing 60 days after seeding reduced Johnsongrass and indiangrass biomass 88% and 4% at 30 days after mowing, respectively. Results suggest that sequential mowing following regrowth may reduce the competitiveness of Johnsongrass with indiangrass.

INDEX WORDS: Blackeyed Susan (*Rudbeckia hirta* L.), Competition, Indiangrass (*Sorghastrum nutans* (L.) Nash), Johnsongrass (*Sorghum halepense* (L.) Pers.), Lanceleaf coreopsis (*Coreopsis lanceolata* L.), Mowing, Native species, Restoration, Swamp milkweed (*Asclepias incarnata* L.), Wild bergamot (*Monarda fistulosa* L.)

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DEDICATION

This thesis is dedicated to my mother, Susan Ward, and my father, Robert Johnston, for their unwavering support and encouragement.

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Christopher R. Johnston

The University of Georgia

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Invasive Species and Weeds on Roadsides

Natural ecosystems in the U.S. have been subjected to the competitive establishment of over 5,000 introduced plant species, many of which are weedy and/or invasive (Morse et al. 1995). A loss in valuable ecosystem function is frequently observed in such areas where invasive species dominate (Campbell 1994; Kurdila 1995; Whisenant 1990). In 2000, the estimated annual nonindigenous weed control costs in the U.S. were approximately $9 billion (Pimentel et al. 2000). Roadsides are a particular area of concern for the establishment of invasive species and may serve as entry points to vulnerable ecosystems (Mortensen et al. 2009; Pauchard & Alaback 2004). Due to the large number of highways and transportation routes in Georgia, successful management of invasive weeds can be a long-term challenge for agronomists.

Multiple factors contribute to the establishment of invasive species on roadsides. Roadside disturbances reduce species diversity, and contribute to the establishment of invasive weeds (Knops et al. 1999; Levine 2000). Roadside soils are enriched with nitrogen that originates from vehicle emissions which could enhance weed establishment and competitiveness (Haan 2011; Davis et al. 2000; Rickey & Anderson 2004; Jodoin et al. 2008). Georgia's diverse geographic regions include elevations that range from sea level to 1,200+ m, with pine and hardwood species that vary with soil type and moisture (Hodler and Schretter 1986). This geographic heterogeneity may increase the frequency of potentially problematic exotic species that could spread throughout the state.

Chemical control is the primary means by which the Georgia Department of Transportation manages weeds and vegetation on roadsides. Herbicide programs are utilized 9 to 10 months per year and vary by region. Many postemergence herbicides are selected for control of a targeted weed species. Effective control of weeds, such as Johnsongrass (*Sorghum halepense* (L.) Pers.) or broomsedge (*Andropogon virginicus* L.), often requires multiple herbicide applications per year (Georgia Department of Transportation 2013).

Roadsides can serve as habitats for invasive plants and exacerbate the further spread into other areas (Mortensen et al. 2009). Additionally, roadsides are major conduits in spreading invasive species due to disturbances associated with maintenance (Christen and Matlack 2008). Mortensen et al. (2009) noted that invasion of a widely distributed invasive grass in the mid-Atlantic had a higher rate of spread when introduced to roadsides compared to wetland or forest habitats. This was noted even when major disturbances were not present on the roadsides evaluated. Exotic shrub species in Eastern U.S. deciduous ecosystems have shown to decline in density with increasing distance from the nearest road (Flory & Clay 2006). Therefore, focusing inputs on detecting and controlling weeds directly on roadsides may reduce the potential for encroachment into adjacent lands. Roadsides that are in close proximity to other disturbed lands may have higher potential to be invaded by exotic species. Jodoin et al. (2008) noted common reed (*Phragmites australis*) was more likely to invade roadsides near agricultural landscapes compared to roadsides near woodlands. Invasive species have been shown to have higher growth rates than native plants, and overgrowth may cause safety issues on roadsides due to decreased visibility and limited shoulder space (Baruch & Goldstein 1999; James & Drenovsky 2007).

Invasive species can be toxic to livestock in pastures and forages. For example, leafy spurge (*Euphorbia esula* L.) contains a toxin with irritating properties that can cause deadly scours in cattle (Messersmith and Lym 1983; Selleck et al. 1962). Drought-stressed or heavily fertilized Johnsongrass has been reported to be toxic to grazing livestock (Elmore et al. 2009; Everest et al. 2005). Invasive plants can also serve as hosts/vectors of diseases that affect other plant and animal species. Maize crops in the U.S. have been threatened from a mosaic virus that is transmittable from infected Johnsongrass (Shepherd 1965). Aphid populations that serve as vectors of barley and cereal yellow dwarf viruses (*Luteovirus* spp.) in native perennial bunchgrasses have increased reproduction on exotic annual plant species (Malmstrom et al. 2005; Gray and Gildow 2003). This may result in an increase in the transmission of these viral pathogens to native perennial bunchgrasses. Risk of human exposure to ehrlichiosis (caused by *Ehrlichia* spp.) has been demonstrated to be elevated in the presence of the invasive plant *Lonicera maackii* (Rupr.) Maxim. (Allan et al. 2010; Dawson et al. 1991). Therefore, invasive weed control is critical for the sustainability of public and private lands in numerous aspects.

Ecological Restoration

Ecological restoration is a process in which disturbed ecosystems are returned to a more environmentally sustainable nature (SER 2004). The health of an ecosystem is often marked by its ability to maintain the functions of producing and cycling energy during disturbances (Schulze and Mooney 1994). Species diversity is particularly critical in maintaining ecosystem integrity (Schulze & Mooney 1994; Rapport et al. 1998; Knops et al. 1999). Disturbed areas are known to have increased potential for invasive weed establishment (Hobbs and Huenneke 1992). Restoration may be a valuable strategy in preventing further spread of invasive species that establish in disturbed areas (Hobbs 2000, MacDougall & Turkington 2005; Forman & Alexander 1998). A potential strategy of ecological restoration is the establishment of functional and sustainable native plant communities that are competitive with invasive weeds.

Numerous factors are involved in the success of ecological restoration. On a regional level, pools of desirable species in close proximity are important to colonize restored areas. Temperature, habitat suitability, and interspecific competition are more influential for successful establishment at the local level (Palmer et al. 1997). When restoring habitats, the degree and size of the disturbance have been noted to be important aspects in choosing genetic sources of plants. Hybrids and plant species of mixed genotypes may be necessary to restore large, heavily disturbed areas, whereas locally sourced plants may be sufficient in areas with less intense disturbances (Lesica and Allendorf 1999). Determination of optimum densities and proportions of installed native species may improve the efficiency of restoration efforts by maximizing interspecific competition with invasive species and minimizing intraspecific competition (Mangla et al. 2011).

The reintroduction of native plant species to areas being restored can be carried out numerous ways. Frequently, existing vegetation is removed by chemical or cultural means to prepare areas for restoration with native plants (Price and Weltzin 2003; Masters et al. 2001; Stanley et al. 2008). Transplanting of wetland soil has been used to successfully reestablish native species in drained areas after reflooding (Brown and Bedford 1997). Hydroseeding, a plant establishment practice where a slurry containing fertilizer and a seed mixture is sprayed onto the ground, is an effective means of anchoring native seed to steep slopes (González-Alday et al. 2009; Brindle 2003).

Herbicides have been effectively used in restoration with native plants. Wilson and Gerry (1995) noted that using glyphosate in plots after seeding increased native seedling cover 20-fold. Glyphosate is often used in treating areas prior to seeding native species (Price and Weltzin 2003; Masters et al. 2001; Stanley et al. 2008). Glyphosate is an environmentally benign herbicide, and is the dominant broad-spectrum weed control option worldwide (Duke and Powles 2008). Imazapyr and clopyralid have been used successfully in Savanna restoration to reduce the overstory of invasive woody plants (Freeman & Jose 2009; Ansley and Castellano 2006).

There are a multitude of secondary benefits associated with ecological restoration. Restoration of native shrubs in a coastal sage scrub habitat was demonstrated by Cione et al. (2002) to reduce fire frequency, consequently limiting invasibility by exotic annuals. Abundance of several nonnative species was reported by Price and Weltzin (2003) to be decreased by about one-third when treated with herbicides, mowed, burned and/or seeded with native species. The application of organic soil amendments in addition to native plant seed on steep, disturbed terrain has been shown to provide quick and effective erosion control while establishing persistent native species communities in the long-term (Brindle 2003).

Johnsongrass

Johnsongrass is a troublesome warm-season perennial found throughout Georgia. It causes significant yield loss in row crops and reduces stands of roadside grasses from competitive growth and allelopathic properties (Warwick and Black 1983, Holm et al. 1977).

The invasive potential of Johnsongrass in Georgia stems from its aggressive rhizomatous growth and prolific seedhead production (Warwick and Black 1983).

Johnsongrass was introduced and/or naturalized on all continents except for Antarctica (Groves 1991, Tutin et al. 1980, Holm et al. 1977, McWhorter 1989). Johnsongrass is believed to be native to the Mediterranean on both the European and African continents and was once cultivated for forage and hay in the U.S. (Howard 2004, Newman 1993; Strausbaugh 1977). Johnsongrass belongs to the *Poaceae* family, *Panicoideae* subfamily, *Andropogoneae* tribe, and is a member of the *Sorghum* genus along with cultivated sorghum (*S. bicolor*) (United States Department of Agriculture 2005). The species can be a diploid (2n=20) or tetraploid (2n=40) (Stewart, Jr. 2009).

Johnsongrass has cauline leaves with a ribbed smooth surface and membranous ligules with no auricles. A prominent white midvein is especially conspicuous in mature leaves. Leaves are generally 20-60 cm long and 1.0-3.3 cm wide, which is conducive to shading and inhibiting photosynthesis of other species (Warwick and Black 1983; Holm et al. 1977). Seedheads are open with large and erect pyramidal panicles at maturity.

Similar to many agronomic crops, Johnsongrass is a short-day plant and seed production can be prolific (Ghersa et al. 1985). Sexual reproduction of Johnsongrass generally involves self-pollination, however wind-facilitated cross-fertilization is possible in dense populations (Newman 1993; Warwick & Black 1983; Wheeler & Hill 1957). Newman (1993) reported that flower production generally starts around 2 months after active growth begins, and occurs throughout the rest of the growing season. Bennett (1973) noted up to 1.1 kg of seed per season could be produced by a single plant in Mississippi, and average production in the southern U.S. in habitable sites has been estimated to be 855 L ha^{-1} (Howard 2004).

Established Johnsongrass populations typically spread vegetatively through rhizomes (Holm et al. 1977). This growth habit lends to the difficulty for control. Approximately 90% of rhizome growth occurs after flower formation. However, rhizome growth occurs before or after flower emergence with primary initiation occurring at the 5-7 leaf stage (Horowitz 1972a; Warwick & Black 1983). Secondary and tertiary rhizomes generally form the following springs after primary development and become the primary rhizomes for the season (Howard 2004; Hull 1970). In the spring, new rhizomes become the primary providers of energy for vegetative growth (Newman 1993). Rhizomes are typically present closer to the surface when clay content is high, whereas well-cultivated and less heavy soils have potential to facilitate the growth of much deeper rhizome systems (Holm 1977; Monaghan 1979). Compacted soil generally results in the formation of smaller rhizomes that are close to the surface (Cates and Spillman 1907).

Huang and Hsiao (1987) reported that Johnsongrass seed exposed to a 16 hour day length had stimulated germination at 35°C, but inhibited germination at 22°C, suggesting light inhibits germination at lower temperatures. No significant difference was observed between light and dark treatments at 28°C. Germination has been modeled as a function of temperature and depth of seed below the soil surface (Prostko et al. 1998). Greenhouse studies by Benvenuti et al. (2001) showed that Johnsongrass seed buried 8 cm or more below the soil surface exhibited under 5% emergence. A similar experiment illustrated that the majority of seedlings germinate from ≤7 cm below the soil surface (Holm et al. 1977). McWhorter (1972) reported a lower germination rate in clay soil than in a fine sandy loam.

Germination is affected by both mechanical and chemical dormancy. Generally, a scarification event and oxygen are required for fully dormant seeds to germinate (Howard 2004; Huang & Hsiao 1987). The presence of tannin compounds in the seedcoat reduces the permeability for moisture and is the primary cause of mechanical dormancy (Bennett 1973; Taylorson & McWhorter 1969).

In addition to plant competition, Johnsongrass harbors crop pests and has allelopathic properties (Warwick and Black 1983). Germination and seedling growth of numerous plant species may be inhibited from decaying leaves and rhizomes, extracts of plant tissues, and root and rhizome exudates of Johnsongrass (Vasilakoglou 2005, Abdul-Wahab & Rice 1967, Lolas & Coble 1982). Dhurrin, prunasin and taxiphyllin, all cyanogenic glycosides, as well as p-hydroxybenzadelhyde have been identified as allelopathic agents present in Johnsongrass (Nicollier et al. 1983, Abdul-Wahab and Rice 1967).

Johnsongrass may host a number of crop pests and diseases (Howard 2004). Johnsongrass has been identified as a source for maize dwarf mosaic virus (*Potyvirus* sp.) and maize chlorotic dwarf virus (*Waikavirus* sp.). It also hosts leafhoppers (*Graminella nigrifons* (Forbes)) and numerous aphid species can readily transmit these diseases to corn (*Zea mays* (L.)) crops (Knoke et al. 1983). A study by McKern et al. (1990) on viral protein coats suggest that several strains of maize dwarf mosaic virus are closely related to Johnsongrass mosaic virus (Yang & Mirkov 1997). Bacteria antigenically related to the pathogen responsible for causing phony peach disease has been isolated from Johnsongrass (Weaver et al. 1980).

Johnsongrass Control

Mechanical Johnsongrass control is typically reliant on weakening rhizome systems and controlling seed production (Hauser and Arle 1958). Mowing is an effective and practical method of destroying Johnsongrass shoots in many areas, and reduces carbohydrates in rhizomes (Horowitz 1972b). Plowing and disking are effective control methods in row crop situations.

McWhorter and Hartwig (1965) noted disking in soybeans controlled Johnsongrass rhizomes >90%. In the clay soils of the southeastern U.S., repeated summer diskings may effectively control Johnsongrass, especially in drier years (Hauser and Arle 1958). Frequent (monthly and bi-weekly) mowing of Johnsongrass has been reported to result in both a significant decrease in regrowth as well as a reduction in rhizome length (Hauser and Arle 1958; Horowitz 1972b).

Herbicides are frequently used for Johnsongrass control. Greenhouse experiments have shown that foliar and foliar plus soil treatments of nicosulfuron at 40 g ai ha^{-1} can prevent Johnsongrass regrowth from rhizomes (Camacho et al. 1991). A similar study noted nicosulfuron applications at the ≤4-leaf growth stage controlled seedling and rhizome Johnsongrass ≥90% (Rosales-Robles et al. 1999). Both sulfosulfuron, and a combination product containing metsulfuron (sold under the name Pastora®) have been labeled for Johnsongrass control (Anonymous 2011; Anonymous 2012). Rosales-Robles et al. (1999) reported that clethodim at 35 g ha^{-1} has been noted to give excellent seedling Johnsongrass control up to the 8-leaf growth stage, but the rate must be doubled to give ≥90% control of rhizome Johnsongrass at younger growth stages. Glyphosate applications have been shown to prevent regrowth in rhizome Johsnongrass (Camacho and Moshier 1991). The addition of ammonium sulfate to glyphosate at 0.42 kg ha^{-1} provided similar fall control and spring regrowth control to glyphosate alone at 0.84 kg ha^{-1} (Salisbury et al. 1991). Despite extensive research on chemical control options for Johnsongrass, Bussan and Dyer (1999) noted that herbicides are generally not an effective long-term control strategy. Implementation of an integrated weed control program may be necessary for effective long-term Johnsongrass control.

Indiangrass

Indiangrass (*Sorghastrum nutans* (L.) Nash) is a perennial, warm-season bunchgrass native to North America. It is a principle component of tallgrass prairies in the central and eastern U.S. (Owsley 2011; Barnett & Vanderlip 1969). Indiangrass has rhizomatous growth, and is used for erosion control, forage, and hay production (Owsley 2011; USDA-Natural Resources Conservation Service 2012). Indiangrass's native range extends from Quebec south to Florida, and as far west as Arizona. It belongs to the *Poaceae* family, *Panicoideae* subfamily, and *Andropogoneae* tribe (United States Department of Agriculture 2003). Numerous cultivars of the species have been identified as tetraploid (2n=40) (Riley & Vogel 1982).

Indiangrass has narrow leaves with a pubescent sheath and stem. A well-substantiated identifying characteristic is the "rifle-sight" shaped ligule (Owsley 2011). The inflorescence is a single panicle that matures from a golden to brown color. Spikelets include a perfect, terminal floret along with a sterile floret generally in the form of a sterile lemma. A normal spikelet produces only one caryopsis as its fruit (Barnett & Vanderlip 1969). Seeds are awned and brown in color.

Germination and seedling emergence of indiangrass have been inconsistent in previous research. Blake (1935) noted that time of year and pregermination seed treatment cause a large amount of variability in seedling emergence. Robocker et al. (1953) noted consistent emergence in the first three years after a seed harvest. Seedling vigor has been shown to be higher with larger sized seeds, and may be due to increased amounts of food reserves for embryos compared to smaller seeds (Kneebone & Cremer 1955).

Indiangrass may also be allelopathic. Gorz et al. (1979) found indiangrass may contain dhurrin, a cyanogenic glycoside also produced by Johnsongrass. Like members of several other genera from the tribe *Andropogoneae*, indiangrass has been known to exhibit silicon deposition in its roots (Sangster 1978). Indiangrass has been established successfully on roadsides in the southeast for erosion control and may have potential in Georgia (McCreery et al. 1975).

Objective

The establishment of native species on Georgia roadsides may reduce vegetation management costs as well as provide an alternative method of invasive weed control. However, research on effective methods of establishing native plant species in Georgia is limited. The objectives of this research were to evaluate: (1) species selection, seeding timing and rate, and location on native plant establishment on Georgia roadsides, and (2) the ability of indiangrass to compete with Johnsongrass during establishment from seed.

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CHAPTER 2

NATIVE PLANT ESTABLISHMENT ON GEORGIA ROADSIDES[1]

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[1]C. R. Johnston, P. E. McCullough, and D. G. Shilling. Submitted to *Agronomy Journal*, 10/20/14.

Abstract

Invasive weeds are a costly problem on Georgia roadsides due to limited management options and a lack of competition from roadside grasses. The introduction of species native to Georgia roadsides could reduce maintenance costs and suppress invasive weeds. However, limited research has been conducted on the potential of using native plant species on Georgia roadsides. Field experiments were conducted in Georgia to evaluate establishment of 29 species (12 grasses and 17 forbs) established in the fall and/or spring at two seeding rates. Blackeyed Susan (*Rudbeckia hirta* L.), swamp milkweed (*Asclepias incarnata* L.) and indiangrass (*Sorghastrum nutans* (L.) Nash) were the quickest to establish of all species, while blackeyed Susan, lanceleaf coreopsis (*Coreopsis lanceolata* L.) and wild bergamot (*Monarda fistulosa* L.) provided the greatest ground cover over the 12 month experiment. At 4 of the 5 sites, an additional 1 to 4 more of the species evaluated established ≥20% ground cover in the spring compared to fall seeding. Species seeded in the spring also established faster during the first 4 months after seeding. Overall, blackeyed Susan, indiangrass, lanceleaf coreopsis, swamp milkweed and wild bergamot have the best potential, of the species tested, to establish under roadside conditions in Georgia, while all other species tested have limited to no potential.

Introduction

Effective weed control on roadsides requires costly chemical and cultural management practices to maintain. Herbicides used for roadside vegetation control in Georgia are expensive and frequently require multiple applications for effective control (McCullough 2014). In addition, some herbicides used for roadside weed management can persist in the environment, causing public concern (Watson et al. 1989; Di Carlo and Fuentes 2000; Whitemore et al. 2008).

Mowing roadsides in conventional vegetation management programs may suppress weeds, but research determining its efficacy is limited. Dorsey (2009) estimated that mowing alone costs the Georgia Department of Transportation approximately $20 million per year, but the impact of this practice on weeds is not clearly understood.

Roadside restoration with native plant species may enhance the ability for agronomists to manage weeds by promoting natural competition to reduce the need for chemical and cultural weed control. For example, using native plants in Iowa has reduced average county herbicide use on roadsides 70-90% since the 1980s (Quarles et al. 2003). Corbin & D'Antonio (2004) noted that native grasses have potential to reduce aboveground productivity of annual grasses in California such as great brome (*Bromus diandrus* Roth), slender wild oat (*Avena barbata* Link.) and rat's-tail fescue (*Vulpia myuros* (L.) C. Gmelin). This research also noted that newly emerged dicot weeds produced less biomass when in polyculture with native species. Tall grass prairie restoration during a 7-year Minnesota study reduced weed biomass compared to unrestored sites by 94% (Blumenthal et al. 2003). Establishing native species has been shown to reduce maintenance costs and establish populations in areas where invasive species dominate (Quarles 2003; Seabloom et al. 2003).

Proper establishment practices such as optimum planting timing and proper species selection are critical for roadside restoration (Mangla 2011). The Georgia Department of Transportation has interests in the establishment of native species on roadsides to enhance competition with weeds, reduce maintenance, and restore areas after construction. However, there is limited information available regarding the potential for native plant species in Georgia to establish under roadside conditions. The objective of this research was to evaluate the effects of species selection, timing of seeding, seeding rate and location on native plant establishment throughout Georgia.

Materials and Methods

Field experiments were conducted in Commerce, Griffin, Macon, Newnan, and Tifton, GA. Site description, soil type, soil pH, GPS coordinates, plot size and seeding dates are presented in Table 2.1. A total of 29 native species were seeded at two timings (spring and fall). In September 2012, all sites were treated with glyphosate (Roundup Pro® 4L, Monsanto Company, Creve Coeur, Missouri) at 4 kg ae ha^{-1} in order to kill existing vegetation. A sequential treatment was made after 3 weeks. Glyphosate was also applied once in March prior to spring seedings. Glyphosate was applied using a CO_2-pressured backpack sprayer calibrated to deliver 235 L ha^{-1} with a three 8004 flat-fan nozzles (Tee Jet, Spraying Systems Co., Roswell, GA). On the day of seeding, sites were sliced at 1 cm depth with a mechanical slicer (Graden GS04 Verticutter, Graden USA Inc., Richmond, VA). Debris was blown off and plots were seeded by hand. All seed was mixed with milorganite as a carrier at ~18 g m^{-2}.

All 29 species were seeded in Commerce and Newnan in Fall 2012 and Spring 2013. The experimental design was a split-block with four replications. Seeding time was the whole plot and species were subplots. The seeding rate was 11 kg ha^{-1} as specified by the Georgia Department of Transportation's planting guidelines (GDOT 2011).

The Griffin site was seeded with all 29 species in both Fall 2012 and Spring 2013, with two seeding rates per species. The experimental design was a split-block design with four replications. The whole plot was seeding time, while the subplots were a factorial combination of species and seeding rate. Seeding rates were 11 kg ha^{-1} and 100 seeds m^{-2}. Griffin was the only site to receive irrigation, which was done as needed throughout the first month after seeding with a water reel.

At Macon and Tifton, the 17 cool-season species were seeded in Fall 2012 and the 12 warm-season species were seeded in Spring 2013 (Table 2.2). Experimental design for the Macon and Tifton sites were a randomized complete block with four replications. Due to space limitations at these sites, fall and spring seedings were separate experiments. The seeding rate was 11 kg ha^{-1}.

Visual percent cover and plant counts were recorded at 4, 8, and 12 months after seeding (MAS). Data were subjected to analysis of variance at the 0.05 probability level in SAS (SAS® Institute v. 9.4, Cary, NC) using the General Linear Mixed Procedure. Means were separated using pairwise t-tests. For the Commerce and Newnan data, species by seeding timing interactions were tested. For the Griffin data, species by seeding timing, species by rate, seeding timing by rate, and species by seeding timing by rate interactions were tested.

Results

Commerce Site. In the fall seeding in Commerce, plant emergence and establishment was slow compared to the spring seeding (Table 2.3). By 4 MAS, wild bergamot had the best establishment of all species with 7% cover, but no other forbs were observed at this time. Wild bergamot reached 23% cover by 12 MAS. Mountain mint had slow establishment in the fall and was not observed until 12 MAS when it reached 14% cover. The only species notably present at 8 MAS were blackeyed Susan and lanceleaf coreopsis, but cover was ≤14% for these species. Indiangrass and purpletop both had 20% cover at 12 MAS, but indiangrass had ~50% fewer plants m^{-2} than purpletop. Deertongue had 5% cover by 12 MAS, but was not observed at 4 and

8 MAS, which was similar to indiangrass and purpletop. The two species with the greatest establishment at 12 MAS were blackeyed Susan with 42 plants m^{-2} and lanceleaf coreopsis with 32 plants m^{-2}. Final plant counts for wild bergamot and mountain mint were 18 plants m^{-2} and 13 plants m^{-2}, respectively. Final plant counts for deertongue, indiangrass and purple top were 5 plants m^{-2}, 4 plants m^{-2} and 7 plants m^{-2}, respectively.

The species with the fastest establishment from the spring planting was black-eyed Susan, which had 71% cover at 4 MAS. Mountain mint showed very fast establishment as well, with 51% cover at 4 MAS. It maintained >50% cover throughout the experiment and had the greatest establishment of any species by 12 MAS. Wild bergamot had the second highest cover of any species at 4 MAS at 64%, and was comparable in establishment to blackeyed Susan and mountain mint at 12 MAS with 49% cover. Lanceleaf coreopsis had 18% cover at 4 MAS in spring and rose to 29% cover by 12 MAS. The only other forb present at 12 MAS was tall coreopsis with 8% cover. Partridge pea and swamp milkweed had 16% and 23% cover at 4 MAS, respectively, but neither were observed at 12 MAS.

At 4 MAS in spring, indiangrass, little bluestem, and switchgrass had >10% cover and were the only three grasses present throughout the experiment (Table 2.3). Indiangrass had the best establishment of the grasses at 4 MAS with 30% cover. Indiangrass decreased to 14% cover by 12 MAS, and was the only grass that persisted. All other species were unable to establish >2% cover at 4 or 12 MAS. At 12 MAS, the species with the best establishment were blackeyed Susan, mountain mint, and wild bergamot with 56, 78 and 67 plants m^{-2}, respectively. Lanceleaf coreopsis, tall coreopsis, and indiangrass had 32, 4, and 12 plants m^{-2} at 12 MAS, respectively.

Griffin Site. The species that established and maintained cover from the fall seeding were mountain mint, lanceleaf coreopsis, black-eyed Susan and wild bergamot, but no species were identified until 12 MAS (Table 2.4). All species that established by 12 MAS had higher percent cover at the 11 kg ha^{-1} seeding rate than at the 100 seeds m^{-2} rate. Lanceleaf coreopsis had the best final establishment of all species at the 11 kg ha^{-1} at 84% cover, but only 39% cover was reached at the 100 seeds m^{-2} rate. Blackeyed Susan and wild bergamot had 35 and 59% cover at the 11 kg ha^{-1} rate, respectively, and cover was approximately one half for each species at the 100 seeds m^{-2} rate. Mountain mint was the only species to not establish by 12 MAS at the 100 seeds m^{-2} rate, and at the 11 kg ha^{-1} rate had the poorest establishment of all species observed at 11% cover. Final plant counts at the 11 kg ha^{-1} rate were 17 plants m^{-2} for blackeyed Susan, 47 plants m^{-2} for lanceleaf coreopsis, 8 plants m^{-2} for mountain mint, and 43 plants m^{-2} for wild bergamot. At the 100 seeds m^{-2} rate, final counts for blackeyed Susan, lanceleaf coreopsis and wild bergamot were 6, 20 and 23 plants m^{-2}, respectively. The 11 kg ha^{-1} seeding rate for blackeyed Susan and wild bergamot used 38 and 4 times as much seed as the 100 seeds m^{-2} rate for each species, respectively. However, cover at the 11 kg ha^{-1} rate was only approximately twice as high for both species as the cover observed from the 100 seeds m^{-2} rate.

Seed planted in spring had poor establishment due to intensive weed pressure (Table 2.4). Wild bergamot was the only species observed, and had 29% cover and 23 plants m^{-2} at 12 MAS at the 11 kg ha^{-1} rate. No species established at the 100 seeds m^{-2} rate.

Macon Site. Lanceleaf coreopsis had the greatest establishment of any species planted in the fall with 65% cover at 12 MAS (Table 2.5). However, cover was ≤21% in the first 8 MAS. Blackeyed Susan cover increased 6 to 42% from 4 to 8 MAS, but decreased to 51% at 12 MAS.

Mountain mint was not observed until 12 MAS where it had 49% cover. Wild bergamot also had slow establishment in the fall but reached 54% cover at 12 MAS. Tall coreopsis was the only other forb with >10% cover at any date. Tall coreopsis was not observed at 4 or 8 MAS, but had 12% cover at 12 MAS. Sneezeweed and white snakeroot had 6 and 7% cover, respectively, at 12 MAS, but neither were observed in the first 8 MAS.

The only grasses that established after fall plantings were Virginia wild rye and river oats (Table 2.5). Virginia wild rye had 5% cover at 8 MAS, but was absent at 12 MAS. River oats was not observed until 12 MAS and had 7% cover. Blackeyed Susan, lanceleaf coreopsis, mountain mint and wild bergamot all had the highest plant counts of any forb at 12 MAS, with 25, 32, 33 and 24 plants m^{-2}, respectively. Poor final establishment (<5 plants m^{-2}) was observed with tall coreopsis, sneezeweed, white snakeroot, and river oats.

In the spring experiment, no forbs were observed at 12 MAS. At 4 MAS, butterfly weed and swamp milkweed had a similar cover averaging 32%. Partridge pea was the only other forb observed in the study with only 6% cover at 4 MAS. Indiangrass had the fastest establishment with 54% cover at 4 MAS, but declined to 34% by 12 MAS. Switchgrass was not observed at 4 MAS, but had the best final establishment of any grass with 39% cover. Deertongue and little bluestem had similar establishment by 12 MAS with 16 and 19% cover, respectively. However, deertongue had faster initial establishment with 20% cover at 4 MAS compared to only 11% cover for little bluestem. Switchgrass had the highest final plant count at 27 plants m^{-2}. Deertongue, indiangrass and little bluestem all had similar final plant counts averaging 6 plants m^{-2}. All other species had no establishment.

Newnan Site. In the fall seeding, the only forbs to establish by 4 MAS were blackeyed Susan and wild bergamot, averaging 14% cover (Table 2.3). Cover of these species increased over time and reached 78 and 70 plants m^{-2} at 8 MAS. Lanceleaf coreopsis and mountain mint had 14 and 8% cover, respectively. Mountain mint was slow to establish in the fall compared to the spring. The only grass that established in the fall seeding was Virginia wild rye at 4 MAS at only 2% cover. Final counts for lanceleaf coreopsis and mountain mint were similar, averaging 18 plants m^{-2}. The Newnan site was mowed in September 2013 and thus data for 12 MAS is not available for the fall seeding.

From establishment in spring, mountain mint had the best ground cover of any forb species at 4 MAS and reached 53% cover at 12 MAS (Table 2.3). Blackeyed Susan and wild bergamot followed a similar trend in reduction of cover by the end of the study, decreasing from 50 to 38% and 24 to 19% cover from 4 to 12 MAS, respectively. Lanceleaf coreopsis improved in establishment with time, increasing from 18 to 29% cover from 4 to 12 MAS. Tall coreopsis had ~10% cover at 4 MAS and 12 MAS. Swamp milkweed and sneezeweed averaged 29% cover at 4 MAS but were not observed at 12 MAS. Similarly, partridge pea reached 14% cover at 4 MAS, but was not observed at 12 MAS. Deertongue and switchgrass were the only grasses observed in the study to establish from spring seedings. Deertongue had 14% cover and switchgrass had 9% cover at 4 MAS, however neither were observed by 12 MAS. Mountain mint had the highest final plant count at 88 plants m^{-2}. Blackeyed Susan, lanceleaf coreopsis and wild bergamot had 32, 20 and 17 plants m^{-2} at 12 MAS, respectively. Tall coreopsis had the lowest final count at 4 plants m^{-2}.

Tifton Site. In the fall study, lanceleaf coreopsis and blackeyed Susan cover increased over time and reached 94% and 56% cover at 12 MAS, respectively (Table 2.5). Wild bergamot was not observed until 8 MAS and reached a final 29% cover at 12 MAS. Mountain mint was not observed at 4 or 8 MAS, but reached 10% cover at 12 MAS. No grasses were established at any time in the fall study. All other species did not establish >1% cover. Lanceleaf coreopsis had the highest final count of any species at 63 plants m^{-2}. Blackeyed Susan and wild bergamot had comparable final counts of 22 and 18 plants m^{-2}. Mountain mint had only 5 plants m^{-2} at 12 MAS.

Although establishment did occur within the first 4 MAS in the spring experiment, no species were observed at 12 MAS. This could have been caused by heavy weed pressure (Table 2.5). Butterfly weed had the best establishment of any forb at 4 MAS with 29% cover, while partridge pea had a comparable ground cover of 20%. The only other forb observed at 4 MAS was swamp milkweed which established 6% cover. Indiangrass had the quickest establishment at 4 MAS of the grasses at 60% cover, while switchgrass had the second highest cover at 41%. Purpletop was the only other grass species with >10% cover at 4 MAS with 16%. Little bluestem established but only had 5% cover. All other species did not establish >1% cover.

Discussion

Blackeyed Susan, swamp milkweed and indiangrass had the quickest establishment across the majority of sites. Blackeyed Susan had the best establishment of these species in the first 4 MAS. Blackeyed Susan and indiangrass have been noted in past research to have a good potential for roadside establishment. Christiansen (1994) noted that these species may establish when existing vegetation was not removed prior to seeding. Swamp milkweed was the only other forb species with >20% cover in a majority of the sites (Commerce, Newnan and Macon). This may be a result of higher soil moisture content at these sites, as the species is known to inhabit wet roadsides in the Midwest (Willson and Price 1976). Indiangrass was the quickest grass to establish at Commerce, Macon and Tifton. Past research has noted successful establishment of indiangrass on Georgia roadsides without the need for supplemental fertilization (McCreery et al. 1975). Blackeyed Susan, lanceleaf coreopsis and wild bergamot are the most promising species observed to persist at least 12 MAS based on the performance observed across all sites. Cull (1976) reported effective establishment of blackeyed Susan and wild bergamot on roadsides by using a similar planting methodology. No grass species had >0% cover at a majority of the sites at 12 MAS.

Differences in establishment were observed due to timing of seeding. More of the 29 species tested established by 4 MAS in the spring seedings of Commerce and Newnan than in the fall seedings. At both Commerce and Newnan, more grass species were observed in the spring seeding at 4 MAS than in the fall seeding. McCreery et al. (1975) noted higher cover and stand thickness of indiangrass when planted in the spring, which is consistent with results in Commerce. Contrary to initial establishment at 4 MAS, more grass species persisted to 12 MAS in Commerce when seeded in the fall compared to the spring. Heavy spring/summer weed pressure could have caused poor grass persistence in spring seedings. Heavy spring weed pressure was noted at Griffin and Tifton sites. Large crabgrass (*Digitaria sanguinalis* (L.) Scop.) and southern crabgrass (*Digitaria ciliaris* (Retz.) Koel.) were grasses that were observed to be particularly problematic in the plots seeded in the spring across all sites. The most problematic broadleaf weeds were dog fennel (*Eupatorium capillifolium* (Lam.) Small) and mare's tail (*Conyza canadensis* (L.) Cronq.). Overall, spring seeding was more effective for initial establishment, however further research is needed to evaluate the possible benefits from herbicide use. Appropriate herbicide use could improve native plant establishment by enhancing interspecific competition with weeds.

The vast difference in size of seed of native species warrants further investigation in order to make recommendations for proper seeding rates. Appropriate seeding rates are species-specific. Seeding lanceleaf coreopsis at 100 seeds m^{-2} is the equivalent of a 29.97 kg ha^{-1} seeding rate, while a rate of 100 seeds m^{-2} for seeding blackeyed Susan is equivalent to only 3.15 kg ha^{-1}. Within each species that established, the differences in cover between both seeding rates suggest there may be a point in which increasing the seeding rate causes too much intraspecific competition. Previous research on grass and forb seeding rates suggests that while forb stand density is highly correlated with increasing seeding rate, grass stand density may decrease with increasing seeding rates (Eiswerth et al. 2009; Launchbaugh and Owensby 1970). Determining an optimal seeding rate for native grass and forb species may be critical for roadside establishment in Georgia and warrants further investigation.

The poor establishment of native species at the Griffin site may be related to irrigation. Griffin was the only site to receive irrigation, and past research has noted significantly increased weed cover and dominance over natives when irrigation is applied to areas being renovated (Banerjee et al. 2006). Benayas et al. (2002) noted decreased seedling survival of a native leguminous shrub in mid-summer under irrigated conditions, which is consistent with the poor establishment of shrub species seeded in Griffin during the spring.

Conclusions

The species with most potential to quickly establish on Georgia roadsides are blackeyed Susan, indiangrass, and swamp milkweed. Blackeyed Susan, lanceleaf coreopsis and wild bergamot had the best performance and most consistent results across the five sites. Determining which species is most appropriate may depend on the speed of ground cover establishment needed. Forb species tended to have more consistent establishment than grasses. The speed of establishment as well as the number of species observed were generally higher when seeded in the spring. Further research is warranted on successful practices in establishing native plant communities on roadsides. In particular, the effect of irrigation practices, seeding rate, mowing, and pre-seeding herbicide treatments for weed control should be investigated to determine the magnitude of their effect of restoring areas with native plants. Consideration of site-specific factors such as soil organic matter and pH may also provide important insight in the success of native species establishment on Georgia roadsides.

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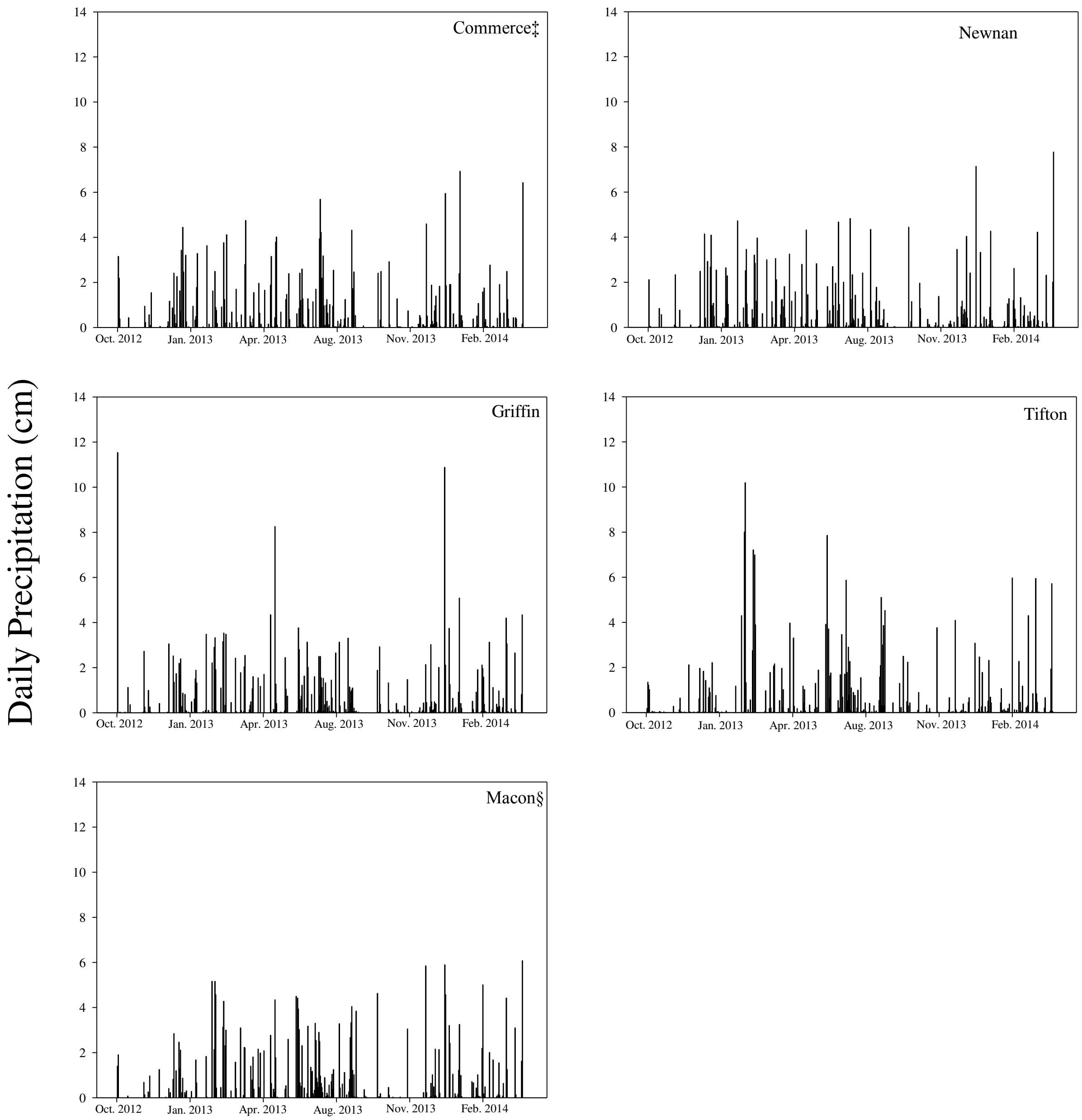

Figure 2.1. Daily precipitation at five locations used for field studies throughout Georgia, 2012-2014.

†Data obtained from Georgia Automated Environmental Monitoring Network.

‡Commerce, GA data obtained from Danielsville, GA weather station.

§Macon, GA data obtained from Byron, GA weather station.

[¶]Newnan, GA data obtained from Roopville, GA weather station.

Table 2.1. Site location and experimental factors information for five field studies evaluating native species establishment, 2012-2014 throughout Georgia.

Site	GPS Coordinates	Soil Type	pH	Plot Size (m^2)	Seeding Date	Description
Commerce	34.26°N, 83.46°W	Sandy Loam	5.3	2.16	Fall Timing - October 5, 2012 Spring Timing - April 2, 2013	Plots on exit of I-85
Griffin	33.25°N, 84.30°W	Sandy Clay Loam	5.3	3.24	Fall Timing - October 9, 2012 Spring Timing - April 12, 2013	Plots at Dempsey Research Farm at UGA Griffin
Macon	32.91°N, 83.70°W	Sandy Clay Loam	5.1	3.15	Fall Study - October 1, 2012 Spring Study - March 29, 2013	Plots on exit of I-75
Newnan	33.33°N, 84.77°W	Sandy Loam	7.3	3.15	Fall Timing - October 5, 2012 Spring Timing - April 9, 2013	Plots on side of I-85
Tifton	31.48°N, 83.52°W	Sandy Clay Loam	6.8	2.7	Fall Study - October 11, 2012 Spring Study - March 28, 2013	Plots on exit of I-75

Table 2.2. Species seeded in five locations throughout Georgia in field studies, 2012-2014.

Species	Common Name	Family	Seed viability (%)	Type/Season
Ageratina altissima†	White Snakeroot	Asteraceae	100	Forb/Cool-Season
Asclepias incarnata‡	Swamp Milkweed	Apocynaceae	90	Forb/Warm-Season
Asclepias tuberosa‡	Butterfly Weed	Apocynaceae	86	Forb/Warm-Season
Aster pilosus‡	Frost Aster	Asteraceae	92	Forb/Cool-Season
Chamaecrista fasciculate‡	Partridge Pea	Fabaceae	84	Forb/Warm-Season
Chasmanthium latifolium§	River Oats	Poaceae	100	Grass/Cool-Season
Coreopsis lanceolata‡¶	Lanceleaf Coreopsis	Asteraceae	80	Forb/Cool-Season
Coreopsis tripteris#	Tall Coreopsis	Asteraceae	94	Forb/Cool-Season
Elymus canadensis‡	Canada Wild Rye	Poaceae	91	Grass/Cool-Season
Elymus virginicus‡	Virginia Wild Rye	Poaceae	94	Grass/Cool-Season
Eupatorium fistulosum‡§	Joe Pye Weed	Asteraceae	90	Forb/Cool-Season
Eupatorium perfoliatum§	Boneset	Asteraceae	100	Forb/Cool-Season
Helenium autumnale§	Sneezeweed	Asteraceae	77	Forb/Cool-Season
Helianthus angustifolius††	Swamp Sunflower	Asteraceae	100	Forb/Warm-Season
Hystrix patula§	Bottlebrush Grass	Poaceae	98	Grass/Cool-Season
Leersia oryzoides§	Rice Cut Grass	Poaceae	100	Grass/Warm-Season
Lysimachia ciliata§	Fringed Loosestrife	Myrsinaceae	100	Forb/Cool-Season
Monarda fistulosa‡	Wild Bergamot	Lamiaceae	87	Forb/Cool-Season
Panicum clandestinum†	Deertongue	Poaceae	96	Grass/Warm-Season
Panicum virgatum‡	Switchgrass	Poaceae	97	Grass/Warm-Season
Pycnanthemum tenuifolium§	Mountain Mint	Lamiaceae	100	Forb/Cool-Season
Rudbeckia hirta‡	Black-eyed Susan	Asteraceae	94	Forb/Cool-Season
Schizachyrium scoparium‡	Little Bluestem	Poaceae	78	Grass/Warm-Season
Scirpus cyperinus§	Woolgrass	Cyperaceae	100	Sedge/Cool-Season
Solidago nemoralis†	Goldenrod	Asteraceae	100	Forb/Cool-Season
Sorghastrum nutans‡	Indiangrass	Poaceae	79	Grass/Warm-Season
Tridens flavus¶	Purple Top	Poaceae	98	Grass/Warm-Season
Tripsacum dactyloides¶	Eastern Gamagrass	Poaceae	100	Grass/Warm-Season
Vernonia novaboracensis‡	Ironweed	Asteraceae	90	Forb/Warm-Season

†Seed obtained from Roundstone Native Seed, LLC. 9764 Raider Hollow Rd., Upton, KY 42784.

‡Seed obtained from Prairie Nursery, Inc., PO BOX 306, Westfield, WI 53964.

§Seed obtained from Prairie Moon Nursery, 32115 Prairie Lane, Winona, MN 55987

¶Seed obtained from Native American Seed Farm, 3791 U.S. 377, Junction, TX 76849

#Seed obtained from Ohio Prairie Nursery, PO BOX 174, Hiram, OH 44234

††Seed obtained from Easy Wildflowers, PO BOX 522, Willow Springs, MO 65793

Table 2.3. Cover and plant counts for 29 species seeded at Commerce and Newnan, GA, 2012-2014.

		Commerce (MAS[†])						Newnan (MAS)					
		Cover			Plant count			Cover			Plant count		
Seeding Time	Species	4	8	12	4	8	12	4	8	12	4	8	12
			%			$\#/m^2$			%			$\#/m^2$	
Fall	Blackeyed Susan	0	14	63	0	18	42	16	36	.	17	78	.
	Bottlebrush Grass	0	1	0	0	<1	0	0	0	.	0	0	.
	Butterfly Weed	0	0	1	0	0	<1	0	0	.	0	0	.
	Deertongue	0	0	5	0	0	5	0	0	.	0	0	.
	Eastern Gamagrass	1	0	0	<1	0	0	0	0	.	0	0	.
	Indiangrass	0	0	20	0	0	4	0	0	.	0	0	.
	Lanceleaf Coreopsis	0	12	31	0	5	32	0	14	.	0	20	.
	Little Bluestem	0	0	0	0	0	0	0	0	.	0	0	.
	Mountain Mint	0	0	14	0	0	13	0	8	.	0	17	.
	Partridge Pea	0	0	10	0	0	1	0	2	.	0	1	.
	Purple Top	0	0	20	0	0	7	0	0	.	0	0	.
	Rice Cut Grass	4	0	0	1	0	0	0	0	.	0	0	.
	River Oats	0	0	0	0	0	0	0	0	.	0	0	.
	Sneezeweed	0	0	0	0	0	0	0	0	.	0	0	.
	Swamp Milkweed	0	0	8	0	0	2	0	0	.	0	0	.
	Switchgrass	0	0	0	0	0	0	0	0	.	0	0	.
	Tall Coreopsis	0	0	9	0	0	7	0	0	.	0	0	.
	Virginia Wild Rye	0	0	0	0	0	0	2	0	.	1	0	.
	Wild Bergamot	7	0	23	18	0	18	12	34	.	14	70	.
Spring	Blackeyed Susan	71	.	50	87	.	56	50	.	38	60	.	32
	Bottlebrush	0	.	0	0	.	0	0	.	0	0	.	0

Grass												
Butterfly Weed	0	.	0	0	.	0	0	.	0	0	.	0
Deertongue	0	.	0	0	.	0	14	.	0	6	.	0
Eastern Gamagrass	0	.	0	0	.	0	0	.	0	0	.	0
Indiangrass	30	.	14	19	.	12	0	.	0	0	.	0
Lanceleaf Coreopsis	18	.	29	11	.	32	18	.	29	10	.	20
Little Bluestem	11	.	0	1	.	0	0	.	0	0	.	0
Mountain Mint	51	.	53	75	.	78	60	.	53	131	.	88
Partridge Pea	16	.	0	2	.	0	14	.	0	1	.	0
Purple Top	0	.	0	0	.	0	0	.	0	0	.	0
Rice Cut Grass	0	.	0	0	.	0	0	.	0	0	.	0
River Oats	0	.	0	0	.	0	0	.	0	0	.	0
Sneezeweed	2	.	0	1	.	0	28	.	0	29	.	0
Swamp Milkweed	23	.	0	5	.	0	29	.	0	17	.	0
Switchgrass	11	.	0	5	.	0	9	.	0	5	.	0
Tall Coreopsis	0	.	8	0	.	4	10	.	11	5	.	4
Virginia Wild Rye	0	.	0	0	.	0	0	.	0	0	.	0
Wild Bergamot	64	.	49	87	.	67	24	.	19	52	.	17
Seeding Timing	***	n/a	NS	***	n/a	***	***	n/a	n/a	***	n/a	n/a
Species	***	***	***	***	***	***	***	***	***	***	***	***
Seeding Timing* Species	***	n/a	**	***	n/a	***	***	n/a	n/a	***	n/a	n/a

† MAS = months after seeding.

‡ Species that did not establish on any date included boneset, Canada wild rye, fringed loosestrife, frost aster, goldenrod, ironweed, Joe Pye weed, swamp sunflower, white snakeroot, and woolgrass.

[§]* = significant at 0.05 probability level; ** = significant at 0.01 probability level; *** = significant at 0.001 probability level; NS = not significant; n/a = analysis not applicable.

Table 2.4. Cover and plant counts for 29 species seeded at Griffin, GA, 2012-2014.

Rate	Seeding Time	Species	Cover (MAS[†]) 4	8	12	Plant count 4	8	12
			——	%	——	——	#/m^2	——
11 kg ha^{-1}	Fall	Blackeyed Susan	0	0	35	0	0	17
		Lanceleaf Coreopsis	0	0	84	0	0	47
		Mountain Mint	0	0	11	0	0	8
		Wild Bergamot	0	0	59	0	0	43
	Spring	Blackeyed Susan	0	.	0	0	.	0
		Lanceleaf Coreopsis	0	.	0	0	.	0
		Mountain Mint	0	.	0	0	.	0
		Wild Bergamot	0	.	29	0	.	23
1076 seed m^{-2}	Fall	Blackeyed Susan	0	0	18	0	0	6
		Lanceleaf Coreopsis	0	0	39	0	0	20
		Mountain Mint	0	0	0	0	0	0
		Wild Bergamot	0	0	28	0	0	17
	Spring	Blackeyed Susan	0	.	0	0	.	0
		Lanceleaf Coreopsis	0	.	0	0	.	0
		Mountain Mint	0	.	0	0	.	0
		Wild Bergamot	0	.	0	0	.	0
		Rate	n/a	n/a	***	n/a	n/a	***
		Seeding Timing	n/a	n/a	***	n/a	n/a	**
		Species	n/a	n/a	***	n/a	n/a	***
		Seeding Timing*Species	n/a	n/a	***	n/a	n/a	***
		Seeding Timing*Rate	n/a	n/a	*	n/a	n/a	NS
		Species*Rate	n/a	n/a	***	n/a	n/a	***
		Seeding Timing*Species* Rate	n/a	n/a	***	n/a	n/a	NS

[†]MAS = months after seeding.

[‡]Species that did not establish on any date included boneset, bottlebrush grass, butterfly weed, Canada wild rye, deertongue, Eastern gamagrass, fringed loosestrife, frost aster, goldenrod, indiangrass, ironweed, Joe Pye weed, little bluestem, partridge pea, purple top, rice cut grass, river oats, sneezeweed, swamp milkweed, swamp sunflower, switchgrass, tall coreopsis, Virginia wild rye, white snakeroot, and woolgrass.

[§]* = significant at 0.05 probability level; ** = significant at 0.01 probability level; *** = significant at 0.001 probability level; NS = not significant; n/a = analysis not applicable.

Table 2.5. Cover and plant counts for 29 species seeded at Macon and Tifton, GA, 2012-2014.

		Macon (MAS†)						Tifton (MAS)					
		Cover			Plants/m²			Cover			Plants/m²		
Study	Species	4	8	12	4	8	12	4	8	12	4	8	12
			%			#/m²			%			#/m²	
Fall	Blackeyed Susan	6	42	51	2	8	25	31	45	56	47	34	22
	Lanceleaf Coreopsis	4	21	65	1	11	32	5	35	94	6	21	63
	Mountain Mint	0	0	49	0	0	33	0	0	10	0	0	5
	River Oats	0	0	7	0	0	4	0	0	0	0	0	0
	Sneezeweed	0	0	7	0	0	1	0	0	1	0	0	0
	Tall Coreopsis	0	0	12	0	0	3	0	0	0	0	0	0
	Virginia Wild Rye	0	5	0	0	2	0	0	0	0	0	0	0
	White Snakeroot	0	0	6	0	0	1	0	0	0	0	0	0
	Wild Bergamot	0	6	54	0	12	24	0	4	29	0	7	18
	Species	**	***	***	*	***	***	***	***	***	***	***	***
Spring	Butterfly Weed	36	.	0	18	.	0	29	.	0	12	.	0
	Deertongue	20	.	16	13	.	6	1	.	0	0	.	0
	Indiangrass	54	.	34	39	.	8	60	.	0	44	.	0
	Little Bluestem	11	.	19	6	.	3	5	.	0	1	.	0
	Partridge Pea	6	.	0	1	.	0	20	.	0	2	.	0
	Purple Top	0	.	0	0	.	0	16	.	0	8	.	0
	Swamp Milkweed	28	.	0	5	.	0	6	.	0	1	.	0
	Switchgrass	0	.	39	0	.	27	41	.	0	10	.	0
	Species	***	n/a	***	***	n/a	***	***	n/a	n/a	***	n/a	n/a

†MAS = months after seeding.

‡Species that did not establish on any date in the fall experiments included boneset, bottlebrush grass, Canada wild rye, fringed loosestrife, frost aster, goldenrod, Joe Pye weed, and woolgrass. Species that did not establish on any date in the spring experiments included Eastern gamagrass, ironweed, rice cut grass and swamp sunflower.

§* = significant at 0.05 probability level; ** = significant at 0.01 probability level; *** = significant at 0.001 probability level; NS = not significant; n/a = analysis not applicable.

CHAPTER 3

COMPETITION OF INDIANGRASS WITH JOHNSONGRASS DURING ESTABLISHMENT[2]

[2]C. R. Johnston, D. G. Shilling, and P. E. McCullough. To be submitted to *Weed Technology*.

Abstract

Johnsongrass (*Sorghum halepense* (L.) Pers.) is a difficult weed to control in Georgia due to heavy seed production and aggressive rhizomatous growth. One potential method for managing Johnsongrass more effectively is by restoring Georgia roadsides with a native and/or desirable species such as indiangrass. However, alternative species must be able to outcompete undesirable species such as Johnsongrass. Understanding interspecific competition between native and invasive species has received limited investigation. Therefore, greenhouse experiments were conducted to evaluate competition of Johnsongrass with indiangrass during establishment at five proportions (100:0, 25:75, 50:50, 75:25, or 0:100 of Johnsongrass to indiangrass). Biomass per plant and rate of culm length growth of Johnsongrass increased 2 to 3 times as proportion decreased relative to indiangrass at 60 DAS. Similar trends were observed with biomass per plant at 30 and 90 DAS. Indiangrass had similar biomass production and culm length growth rates in all mixtures. However, indiangrass had 82 to 244% higher biomass per plant and 70 to 139% longer culm lengths in monoculture compared to mixtures with Johnsongrass at 60 DAS. Relative crowding coefficients were ≥1.55 for Johnsongrass at all dates in all mixtures, and equivalent yield ratios for Johnsongrass ranged from 0.26-0.17 across all dates. Indiangrass was more affected by interspecific competition before and after mowing, while Johnsongrass was more affected by intraspecific competition. Johnsongrass maintained competitive dominance over indiangrass throughout the experiment. Mowing at 60 DAS reduced the biomass per plant of indiangrass and Johnsongrass 4% and 88% across all proportions by 30 days after mowing (90 DAS), respectively. This disproportionate effect of mowing on the biomass of the two species suggests that sequential mowing programs after regrowth could reduce the competitive advantage of Johnsongrass over indiangrass.

Introduction

Johnsongrass (*Sorghum halepense* (L.) Pers.) is a troublesome perennial weed in the southeastern United States. Effective control is often challenging due to its competitive nature with desirable species. Johnsongrass has heavy seed production and aggressive rhizomatous growth that contribute to its invasive potential in various cropping systems (Warwick and Black 1983). The large leaf size (~20-60 cm long and 1.0-3.3 cm wide) of Johnsongrass is capable of shading other nearby plant species, thus limiting their photosynthetic capacity (Warwick and Black 1983; Holm et al. 1977). In addition to its competitive growth habit, Johnsongrass produces several allelopathic compounds that may further contribute to its ability to cause yield loss in row crops and reductions in stands of desirable species (Nicollier et al. 1983; Abdul-Wahab and Rice 1967; Warwick and Black 1983; Holm et al. 1977).

Johnsongrass is problematic on roadsides since conventional control methods are costly and labor intensive. Many selective herbicides for Johnsongrass control in roadside vegetation are effective but have major limitations. For example, sulfosulfuron has been noted to cause substantial injury to tall fescue and may cause unacceptable injury in roadside applications (Lycan and Hart 2004). Spring MSMA applications have been shown to provide 95% control of rhizome Johnsongrass, however current buffer restrictions in proximity to water bodies limit MSMA use on roadsides (Millhollon 1970; U.S. Environmental Protection Agency 2013). Glyphosate is a nonselective herbicide that may control Johnsongrass, but off-target injury to desirable plants limits applications (Camacho and Moshier 1991). Johnsongrass has significant potential for regrowth after herbicide injury from viable rhizomes that are not controlled from applications.

Cultural control of Johnsongrass can be effective in row crops, but are often impractical on roadsides. McWhorter & Hartwig (1965) reported disking can provide >90% destruction of existing rhizomes from dehydration. In the clay soils of the southern U.S., repeated diskings in summer may provide effective control (Hauser and Arle 1958). Mowing can be used to reduce vigor of Johnsongrass in turfgrass or forage species (Horowitz 1972; Ross 1979). Mowing may prevent the formation of an extensive, aggressive rhizome system by interrupting vegetative growth. Frequent clipping has been reported to reduce rhizome length and vegetative regrowth in Johnsongrass but agronomists are often limited with mowing frequencies on roadsides due to cost (Hauser and Arle 1958; Horowitz 1972; Summerlin Jr. et al. 2000).

The introduction of competitive species may reduce Johnsongrass populations. Indiangrass (*Sorghastrum nutans* (L.) Nash) is a native warm-season perennial grass species that has strains adapted to Georgia. In a preliminary experiment, indiangrass had a relatively faster growth rate compared to other native warm-season grasses such as switchgrass (*Panicum virgatum* L.), purpletop (*Tridens flavus* (L.) A. S. Hitchc.), and Eastern gamagrass (*Tripsacum dactyloides* (L.) L.) (personal observation). Previous research has shown Indiangrass is a well-adapted species for roadside erosion control in Georgia (McCreery et al. 1975). Indiangrass may successfully establish in abandoned pastures dominated by invasive species (Price and Weltzin 2003). The establishment of Indiangrass on roadsides could limit Johnsongrass spread and reduce its population to manageable levels through interspecific competition. The objective of this research was to evaluate the competition of seedling Indiangrass with Johnsongrass in different proportions and determine if mowing shifts competitive behavior of either species.

Materials and Methods

Greenhouse studies were conducted in Griffin, GA (33.26°N, 84.28°W) from May-August 2013 and June-September 2014 using a replacement series experimental design with four replications (de Wit 1960). Both species were seeded in a potting mix (Fafard® 3B Mix, Sun Gro Horticulture, Agawam, MA) in 79.0 cm^2 surface area x 8.9 cm depth plastic containers. Seeding took place on May 31 in 2013 and June 13 in 2014. Seedlings were thinned to a population density of 4 plants per 79 cm^2 pot at 5 different proportions of Johnsongrass to indiangrass per pot (100:0, 75:25, 50:50, 25:75 and 0:100). Preliminary studies were conducted similar to a method used by Willard and Shilling (1990) to determine a plant density high enough to allow interspecific competition and a soil fertility level high enough to eliminate competition for nutrients. This density was assessed to be 4 plants per 79 cm^2 for each species. One 1,290 cm^2 tray was used for each proportion that contained 18 pots (79 cm^2) per tray. Plants were fertilized at the rate of 67 kg ha^{-1} of nitrogen (LESCO® MacroN 28-7-14 Sprayable Fertilizer, LESCO Inc., Cleveland, OH) at 10 days after seeding (DAS). The greenhouse used was set to a daytime temperature of 30°C and a nighttime temperature of 20°C.

Plants were allowed to grow from seed for 60 days. At 30 and 60 DAS, total shoot biomass was harvested. After the 60 DAS harvest, all plants were mowed to a height of 15 cm. At 90 DAS (representing 30 days after mowing), final shoot biomass was harvested. Only the containers in the center of each 18-pot tray were used for the biomass harvests to eliminate the border effect. Shoots were dried in an oven at 54°C for ~72 hours and weighed. Competitive ability of each species was determined using relative crowding coefficients (RCC), equivalent yield ratios (EYR), relative yield (RY) and relative yield totals (RYT), based on dry weight data. Relative yield was calculated as the percentage of biomass a species produced at each mixture divided by the biomass it produced in monoculture. Relative yield totals were calculated as the sum of relative yields of both species in a particular mixture. Using the equation described by Harper (1977), a relative crowding coefficient was calculated for biomass per plant at each proportion. Culm length for each treatment was measured every 10 days prior to mowing at 60 DAS. Total shoot biomass and shoot biomass per plant were also analyzed.

Experimental design was a randomized complete block with four replications. Biomass, culm length, and relative yield data were subjected to analysis of variance at the 0.05 probability level in SAS (SAS® Institute v. 9.4, Cary, NC) using the General Linear Model Procedure. Means were separated using Fisher's Protected LSD Test at $\alpha = 0.05$. Slope coefficients for average culm length as a function of DAS were subjected to a homogeneity of slopes test, and means were separated using pairwise F-tests. Experiment by treatment interactions were not detected, and thus data were pooled over years.

Results

Biomass per plant. Biomass per plant of Johnsongrass decreased with increasing proportion in mixture across all dates (Figure 3.1). Johnsongrass produced 1.51 to 3.89 g $plant^{-1}$ and 3.65 to 9.31 g $plant^{-1}$ at 30 and 60 DAS, respectively. At 90 DAS, Johnsongrass biomass per plant was only 0.43 to 1.26 g $plant^{-1}$. At all harvests, Johnsongrass produced the most biomass per plant at the 25% proportion. The least biomass per plant produced by Johnsongrass was in monoculture at all harvest dates. For indiangrass, only 0.05 to 0.09 g $plant^{-1}$ was produced at 30 DAS. At 60 DAS and 90 DAS, 0.31 g $plant^{-1}$ was produced by indiangrass in monoculture and was a significantly higher than any of the mixtures. Indiangrass had similar biomass across all mixtures at 60 DAS and 90 DAS. At 90 DAS, biomass of indiangrass decreased per plant with increasing proportion in mixture from 25 to 75%. However, three times as much biomass per plant was produced in monoculture compared to the 75% proportion. The trend was similar at 60 DAS at all proportions.

Culm length. The culm length of Johnsongrass increased from 5 to 86.5 cm plant^{-1}, 6 to 93.8 cm plant^{-1}, 3.9 to 111.1 cm plant^{-1}, and 5.5 to 123.1 cm plant^{-1} at the 100%, 75%, 50% and 25% proportion, respectively, from 10 to 60 DAS (Table 3.1). The culm length of indiangrass increased from 0.9 to 11.7 cm plant^{-1}, 1.1 to 6.9 cm plant^{-1}, 1.3 to 6.3 cm plant^{-1}, and 1.1 to 4.9 cm plant^{-1} at the 100%, 75%, 50% and 25% proportion, respectively, from 10 to 60 DAS. Across all dates, Johnsongrass had a greater culm length than indiangrass in all mixtures and in monoculture. At 50 and 60 DAS, the culm length of Johnsongrass increased with decreasing proportion. From 30 through 60 DAS, Johnsongrass in the 25% proportion had the longest culm length (51.8 to 123.1 cm plant^{-1}), and at 50 and 60 DAS Johnsongrass in monoculture had the shortest culm length (72.3 and 86.5 cm plant^{-1}, respectively). Conversely, the average culm length of indiangrass was greatest in monoculture for 30 to 60 DAS compared to other proportions. Furthermore, there was no apparent trend in culm length as a function of increasing or decreasing proportion for indiangrass until 60 DAS, where average culm length increased at every increase in proportion. The slope coefficient for the regression equation for average culm length of Johnsongrass over time increased with decreasing proportion (1.71 to 2.48). However, the slope coefficient of the regression equation of indiangrass increased with increasing proportion (0.06 to 0.22).

Relative Yield, Relative Yield Total (RYT), and Equivalent Yield Ratio (EYR). Johnsongrass had a higher relative yield than indiangrass until its proportion in mixture decreased to ≤25% at all harvests (Figure 3.1). The RYT values at 30 DAS in the 50:50 and 25:75 mixtures were significantly greater than 1.0. At 60 DAS, decreases in the relative yield of Johnsongrass as its proportion decreased were attributable to increased relative yield of indiangrass. The RYT at 60 DAS was ~1.0 across all mixtures. At 90 DAS, the relative yield curve for Johnsongrass was not inversely correlated with indiangrass. From the 75:25 to 50:50 Johnsongrass:indiangrass mixture, relative yield of both species increased. The trend at 90 DAS from the 50:50 to 25:75 mixture was similar to that of the same mixture at 30 DAS, where the relative yield of Johnsongrass decreased, but indiangrass was consistent. Regardless, the RYT at 90 DAS was ~1.0 across all mixtures.

The equivalent yield ratio (EYR) is described by Griffin et al. (1989) as the intersection point between the relative yield curves of two species, and can be interpreted as the proportion in mixture one species must have to equal the relative yield of the other species. The EYR of Johnsongrass decreased with time, and thus the competitiveness towards indiangrass increased with time (Figure 3.1). At 30 DAS the EYR of Johnsongrass was 0.26, which indicates that Johnsongrass could produce the same relative yield as indiangrass when it was only ~26% of the mixture. At 60 DAS the EYR of Johnsongrass decreased to 0.2, and at 90 DAS the EYR of Johnsongrass was at its lowest at 0.17.

Relative Crowding Coefficient (RCC). In a replacement series study where two species are in mixture, each species has an RCC value in each given mixture. As the RCC of a species increases in polyculture, competition towards the other species increases (Harper 1977, de Wit 1960, Griffin et al. 1989). An RCC of <1.0 indicates that a plant is at a competitive disadvantage whereas an RCC of >1.0 indicates an advantage (Griffin et al. 1989). The two species are assumed to be competing for the same resource if the product of the RCC for each species is ~1.00 (Griffin et al. 1989; Bhaskar and Vyas 1988). The RCC of Johnsongrass at the 75:25, 50:50 and 25:75 Johnsongrass:indiangrass mixtures was 1.61, 1.55 and 2.29, 2.23, 5.43, and 7.19, and 1.91, 5.05 and 10.09 at 30 DAS, 60 DAS and 90 DAS, respectively (Table 3.2). The RCC of indiangrass at the 75:25, 50:50 and 25:75 Johnsongrass:indiangrass mixtures were 0.62, 0.65 and 0.44, 0.45, 0.18 and 0.14, and 0.52, 0.2 and 0.1 at 30 DAS, 60 DAS and 90 DAS, respectively. The highest RCC for Johnsongrass was 10.09 at the 25:75 mixture at 90 DAS, whereas the highest RCC for indiangrass was 0.65 at 30 DAS at the 50:50 mixture. The product of the RCC for each species ranged 0.98 to 1.01 across all mixtures and all harvests, indicating that the two species were competing for the same resource. Thus, comparing shoot biomass is applicable when determining competition for these species.

Discussion

At 60 DAS, indiangrass was susceptible to the competition of Johnsongrass regardless of proportion. Compared to monoculture, the biomass of indiangrass significantly decreased once Johnsongrass reached 25% of the mixture at both 60 DAS and 90 DAS. The trends associated with culm length of indiangrass at 50 and 60 DAS as a response to proportion were similar to the trends with biomass. The slope coefficient for culm length of indiangrass over time increased as Johnsongrass was phased out of mixture. These trends suggest that the vast majority of interspecific competition was to the detriment of indiangrass. The taller stature of Johnsongrass prior to mowing likely shaded indiangrass and reduced its photosynthetic capacity. At 90 DAS, indiangrass was subjected to intraspecific competition, but only when in mixture with Johnsongrass. This was evident by the reductions in biomass of indiangrass as it increased from

25 to 75% of the mixture. However, the increased biomass at the 100% proportion suggests indiangrass was likely released from intraspecific competition when Johnsongrass was no longer present in the mixture. The presence of Johnsongrass may have reduced rooting space and/or incoming sunlight enough to force indiangrass to compete with itself by 90 DAS.

Culm length, biomass per plant production, and RCCs were generally greater with Johnsongrass when it was at a lower proportion in mixtures. The slope coefficient associated with average culm length with time was highest with Johnsongrass when it was at 25% of the mixture. In conclusion, intraspecific competition was likely the primary factor affecting biomass production for Johnsongrass. The reductions in Johnsongrass biomass per plant and average culm length, with increasing proportion in mixture, may be due to limited root space and self-shading associated with higher density.

RYTs at 30 DAS were significantly greater than 1.0 at the 50:50 and 25:75 (Johnsongrass:indiangrass) mixtures. According to Harper (1977), this suggests that the species were not effectively competing at those proportions at 30 DAS. This is likely due to each species not having reached the size where resources requirements (space, water, light, etc.) became large enough to promote any level of interspecific competition that reduced biomass production. Contrarily, the product of each species' RCC values at 30 DAS were ~1.00, suggesting competitive interference was occurring (Griffin et al. 1989). According to the RCC data, the effect of proportion increased with time, which suggests an increase in overall demands for resources that promoted greater interspecific competition over time.

The effect of mowing reduced the biomass of Johnsongrass significantly more than indiangrass in the short-term. Johnsongrass had an 88% reduction in biomass per plant from 60 DAS to after mowing at 90 DAS across all proportions. However, the average reduction in biomass per plant of indiangrass was only 4% over this period. This is likely due to the greater height and above-ground biomass overall of Johnsongrass, as it had a much higher percentage of its above-ground biomass above the 15 cm mowing height. Regardless, the EYR of Johnsongrass continued to decrease with time to 0.17 at 90 DAS. This suggests its competitive ability did not decrease by 90 DAS regardless of the disproportionate effects from mowing.

Since more biomass was removed from Johnsongrass than indiangrass as a result of mowing, Johnsongrass likely experienced a greater reduction in photosynthetic rate. Furthermore, since Johnsongrass was significantly taller prior to mowing and likely shaded indiangrass, an increase in sunlight reaching indiangrass resulting from the mowing may have enhanced its rate of photosynthesis. Further research is warranted to determine if this disproportionate effect of mowing on photosynthetic tissues of Johnsongrass can be exploited to enhance the competitive ability of native grasses of shorter stature over time.

The interruption in photosynthesis of Johnsongrass with mowing may be a beneficial strategy in ecologically restoring areas with native species. Selecting native species with different growth habits than Johnsongrass may help reduce competition when a cultural practice such as mowing is involved. Additional research is necessary to determine if the behavior of this native and invasive grass mixture is similar when Johnsongrass emerges from rhizomes instead of seed.

The use of native species in addition to vegetation management practices such as mowing has long term implications on ecological restoration and biodiversity. Vegetation management practices can augment interactions between plant species, and can be utilized to shift species composition to become more ecologically favorable. Collins et al. (1998) noted that mowing and the reintroduction of grazing to disturbed grasslands enhanced biodiversity in Kansas.

Researchers in Oregon noted that four years of mowing at 15 cm in late spring converted a site dominated by an exotic perennial grass (*Arrhenatherum elatius* (L.) Beauv. ex J. & C. Presl.) into a native prairie grass-dominated site (Wilson & Clark 2001; Mahmoud et al. 1975). The amount of time required for these aforementioned cultural management practices to become effective warrants further research into the long-term interactions of native and invasive species in the southeastern United States.

Conclusions

Throughout both years of the 90 day study, Johnsongrass was a superior competitor in terms of RCCs and EYRs. The general trend associated with RCCs and EYRs did not change as a result of mowing. At 30 DAS, RYTs were >1.0 in two of the proportions used, suggesting competition at that time was minimal. This was likely due to the fact that resource demands were not yet high enough to force the species to compete as a result of young plant size/age at 30 DAS. Overall, Johnsongrass was more heavily affected by intraspecific competition, which was suggested by the decreasing culm length and biomass per plant as a function of increasing proportion in mixture. Indiangrass was more affected by interspecific competition, and biomass per plant of indiangrass was significantly lower in all mixtures compared to that in monoculture at 60 DAS and 30 DAM. Further research is warranted to determine if the competitive ability of these species does eventually shift as a result of mowing over longer periods of time, as well as if the detrimental effects of mowing on perennial grasses can be exploited to restore native grasses in Georgia.

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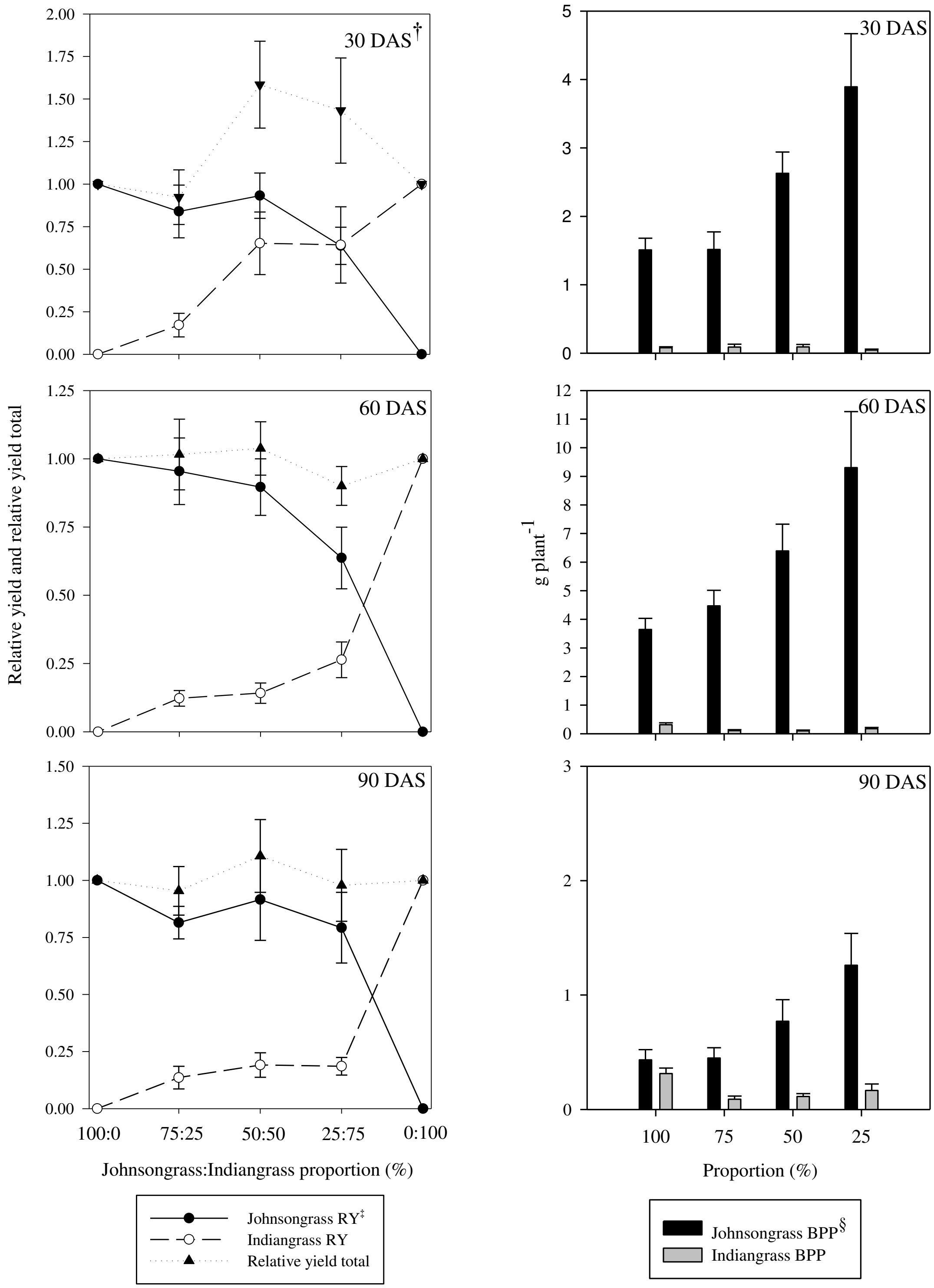

Figure 3.1. Relative yield and relative yield totals, and biomass per plant of Johnsongrass and indiangrass in greenhouse replacement series experiments, 2013-2014, Griffin, GA.

[†]DAS = days after seeding.

[‡]RY = relative yield.

[§]BPP = biomass per plant.

Table 3.1. Average culm length of Johnsongrass and indiangrass in greenhouse replacement series experiments at Griffin, GA, 2013-2014.

		Average Culm Length (DAS[†])						Regression		
Proportion	Species	10	20	30	40	50	60	Equation[‡]	r^2	SE[§]
		cm plant^{-1}								
100	Johnsongrass	5	16.4	42.4	65.3	72.3	86.5	$y = -11.82 + 1.71x^{C}$	0.86	11.93
0	Indiangrass	--	--	--	--	--	--	--	--	--
75	Johnsongrass	6	12.8	39.4	64.5	85	93.8	$y = -17.81 + 1.94x^{BC}$	0.86	13.55
25	Indiangrass	1.1	4.5	6.4	6.7	5.5	4.9	$y = 2.60 + 0.06x^{b}$	0.08	3.81
50	Johnsongrass	3.9	18.2	50.8	72.6	96.4	111.2	$y = -20.51 + 2.27x^{AB}$	0.85	16.82
50	Indiangrass	1.3	3	5.7	5.6	6.4	6.3	$y = 1.22 + 0.10x^{b}$	0.37	2.25
25	Johnsongrass	5.5	17.4	51.8	76.1	103.1	123.1	$y = -24.13 + 2.48x^{A}$	0.78	22.92
75	Indiangrass	1.1	3.1	5.1	7.6	5.9	6.9	$y = 0.93 + 0.12x^{b}$	0.25	3.46
0	Johnsongrass	--	--	--	--	--	--	--	--	--
100	Indiangrass	0.9	2.7	7.6	9.6	9.5	11.7	$y = -0.62 + 0.22x^{a}$	0.71	2.44
	LSD $(0.05)_{JG}$[¶]	1.4	NS[#]	8.5	NS	14.4	22.5			
	LSD $(0.05)_{IG}$[††]	NS	NS	NS	NS	2.2	2.9			

[†]DAS = days after seeding.

[‡]Linear regression analysis using equation: $y = a + bx$ where y is average culm length, a and b are constants, and x is time in days since seeding. Slope means were separated using pairwise F-tests at $\alpha = 0.05$. Slopes within each species followed by the same letter do not differ significantly.

[§]SE = standard errors of the estimate.

[¶]LSD $(0.05)_{JG}$ = least significant difference of proportion effects on average culm length of Johnsongrass. Means were separated using Fisher's LSD Test at $\alpha = 0.05$.

[#]NS = not significant.

[††]LSD $(0.05)_{IG}$ = least significant difference of proportion effects on average culm length of indiangrass. Means were separated using Fisher's LSD Test at $\alpha = 0.05$.

Table 3.2. Relative crowding coefficients of Johnsongrass and indiangrass in mixtures in greenhouse replacement series experiments at Griffin, GA, 2013-2014.

	Relative Crowding Coefficients (DAS†)								
	30			60			90		
	JG:IG Ratio‡			JG:IG Ratio			JG:IG Ratio		
	75:25	50:50	25:75	75:25	50:50	25:75	75:25	50:50	25:75
RCC J§	1.61	1.55	2.29	2.23	5.43	7.19	1.91	5.05	10.09
RCC I¶	0.62	0.65	0.44	0.45	0.18	0.14	0.52	0.20	0.10
RCC J x RCC I	1.00	1.01	1.01	1.00	0.98	1.01	0.99	1.01	1.01

†DAS = days after seeding.

‡JG:IG Ratio = Johnsongrass:indiangrass ratio

§RCC J = relative crowding coefficient of Johnsongrass.

¶RCC I = relative crowding coefficient of indiangrass.

CHAPTER 4

OVERALL CONCLUSIONS

Invasive species are a costly problem on Georgia roadsides. Chemical, mechanical and cultural management practices currently incorporated by roadside agronomists have several limitations for controlling invasive weeds. Herbicides used on roadsides are often expensive and repeated use has contributed to the development of herbicide resistance in weed populations. Mowing is a costly management practice with limited practicality for suppressing invasive weeds in many situations. One management alternative for the Georgia Department of Transportation is the establishment of native species on roadsides. These species could reduce inputs and costs associated with roadside vegetation management by promoting competition with invasive weeds.

Species selection, location, timing of seeding, and seeding rate may influence native plant establishment under roadside conditions. From a two-year field experiment, blackeyed Susan, indiangrass, and swamp milkweed displayed quick establishment across the majority of locations evaluated. Blackeyed Susan, lanceleaf coreopsis, and wild bergamot persisted through 12 months after seeding at all sites. Native forbs established more successfully than grasses. While the speed of establishment was better on average when seeded in the spring, heavy weed pressure limited spring establishment at two of the sites. The effect of seeding rate on establishment was species-specific. Further research is needed to evaluate factors that could enhance native species establishment such as irrigation, seeding rate, soil amendments and herbicide use.

The nature of competition between native and invasive species is an important aspect of native plant restoration, especially on roadsides where invasive species are persistent.

Johnsongrass is an invasive species on Georgia roadsides and was more competitive than a native grass, indiangrass, in a 90-day experiment. However, mowing reduced shoot biomass of Johnsongrass more than indiangrass at 30 days after mowing. Johnsongrass was more affected by intraspecific competition, while indiangrass was more susceptible to interspecific competition from Johnsongrass. Differential responses to mowing across both species may be due to growth habits of these species. Further research is warranted to determine the influence of mowing on long-term (>90 days) competition of indiangrass with Johnsongrass.