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Native Plant Establishment on Georgia Roadsides

Christopher R. Johnston, Patrick E. McCullough,* and Donn G. Shilling

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 could reduce maintenance costs and suppress invasive weeds on roadsides, however, limited research has been conducted with these species in this environment. 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 mo experiment. At four of the five sites, up to four additional species of those evaluated established ≥20% ground cover in the spring seeding compared to fall. Species seeded in the spring also established faster during the first 4 mo 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.

Effective weed control on roadsides requires costly chemical and cultural management practices to maintain. Herbicides used for roadside vegetation control 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; Whitmore et al., 2008). Mowing roadsides in conventional vegetation management programs may suppress weeds. Dorsey (2009) estimated that mowing in Georgia costs the Georgia Department of Transportation approximately US$20 million per year; however the impact of this practice on weed populations has received limited investigation.

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 to 90% since the 1980s (Quarles, 2003). Corbin and 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-yr 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 et al., 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 1. A total of 29 species native to Georgia (Table 2) were seeded at two timings (spring and fall). In September 2012, all sites were treated with glyphosate [*N*-(phosphonomethyl) glycine; Roundup Pro 4L, Monsanto Company, Creve Coeur, MO] at 4 kg a.e. ha^{-1} to kill existing vegetation. A sequential application was made after 3 wk. Glyphosate was also applied once in March before spring seedings. Glyphosate was applied

Dep. of Crop and Soil Sciences, University of Georgia, Griffin, GA 30223.
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*Corresponding author (pmccull@uga.edu).

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Abbreviations: MAS, month after seeding.

Table 1. Site location and experimental factors information for five field studies evaluating native species establishment, 2012 to 2014 throughout Georgia.

Site	GPS Coordinates	Soil type	pH	Plot size	Seeding date	Description
				m^2		
Commerce	34.26°N, 83.46°W	sandy loam	5.3	2.16	Fall timing–5 Oct. 2012 Spring timing–2 Apr. 2013	Plots on exit of I-85
Griffin	33.25°N, 84.30°W	sandy clay loam	5.3	3.24	Fall timing–9 Oct. 2012 Spring timing–12 Apr. 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–1 Oct. 2012 Spring study–29 Mar. 2013	Plots on exit of I-75
Newnan	33.33°N, 84.77°W	sandy loam	7.3	3.15	Fall timing–5 Oct. 2012 Spring timing–9 Apr. 2013	Plots on side of I-85
Tifton	31.48°N, 83.52°W	sandy clay loam	6.8	2.7	Fall study–11 Oct. 2012 Spring study–28 Mar. 2013	Plots on exit of I-75

Table 2. Species seeded in field studies at five Georgia locations, 2012 to 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 fasciculata‡	Partridge pea	Fabaceae	84	Forb/warm-season
Chasmanthium latifolium§	River oat	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¶	Purpletop	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.

using a CO_2–pressured backpack sprayer calibrated to deliver 235 L ha^{-1} with three flat-fan nozzles (8004 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). The mechanical slicer was directed by hand to make one pass across all plots. Debris was removed with a backpack blower before plots being broadcast seeded by hand. All seed was mixed with milorganite as a carrier at ~18 g m^{-2}. Seed was raked into soil by hand at each plot after broadcasting.

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

Table 3. Cover and plant counts for 29 species seeded at Commerce and Newnan, GA, 2012 to 2014.

Seeding time	Species†	Commerce, MAS‡						Newnan, MAS					
		Cover			Plant count			Cover			Plant count		
		4	8	12	4	8	12	4	8	12	4	8	12
		%			no. m^{-2}			%			no. 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 oat	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 grass	0	.	0	0	.	0	0	.	0	0	.	0
	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 oat	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	***	na§	ns	***	na	***	***	na	na	***	na	na
	Species	***	***	***	***	***	***	***	***	***	***	***	***
	Seeding timing × species	***	na	**	***	na	***	***	na	na	***	na	na

** Significant at 0.01 probability level.

*** Significant at 0.001 probability level.

† 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.

‡ MAS = months after seeding.

§ na = analysis not applicable; ns = not significant.

specified by the Georgia Department of Transportation planting guidelines (Georgia Department of Transportation, 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). The experimental design for the Macon and Tifton sites was 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}.

Table 4. Cover and plant counts for 29 species seeded at Griffin, GA, 2012 to 2014.

Rate	Seeding time	Species†	Cover, MAS‡			Plant count		
			4	8	12	4	8	12
			%			no. 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
100 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	na§	na	***	na	na	***
		Seeding timing	na	na	***	na	na	**
		Species	na	na	***	na	na	***
		Seeding timing × species	na	na	***	na	na	***
		Seeding timing × rate	na	na	*	na	na	ns
		Species × rate	na	na	***	na	na	***
		Seeding timing × species × rate	na	na	***	na	na	ns

* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

*** Significant at 0.001 probability level.

† 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.

‡ MAS = months after seeding.

§ na = analysis not applicable; ns = not significant.

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. At Commerce, Griffin, and Newnan sites the effect of block and the interaction of block and seeding timing were considered random effects. At Commerce and Newnan, seeding timing, species, and their interaction were considered fixed effects while seeding timing, species, rate and all interactions were considered fixed effects at Griffin. At Macon and Tifton, the effect of block was considered a random effect while species was a fixed effect.

Precipitation in the fall of 2012 was very low across all sites, however precipitation was relatively regular in the spring of 2013. Precipitation was most frequent across all sites in the summer of 2013. Temperatures in the spring and summer of 2013 were unusually low compared to previous years.

RESULTS

Commerce Site

In the fall seeding in Commerce, plant emergence and establishment was slow compared to the spring seeding (Table 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 [*Tridens flavus* (L.) A.S. Hitchc.] both had 20% cover at 12 MAS, but indiangrass had approximately 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 and 13 plants m^{-2}, respectively. Final plant counts for deertongue, indiangrass and purple top were 5, 4, 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

Table 5. Cover and plant counts for 29 species seeded at Macon and Tifton, GA, 2012 to 2014.

Study	Species†	Macon, MAS‡						Tifton, MAS					
		Cover			Plants m^{-2}			Cover			Plants m^{-2}		
		4	8	12	4	8	12	4	8	12	4	8	12
		%			no. m^{-2}			%			no. m^{-2}		
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 oat	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	***	na§	***	***	na	***	***	na	na	***	na	na

* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

*** Significant at 0.001 probability level.

† 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.

‡ MAS = months after seeding.

§ na = analysis not applicable.

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 (*Chamaecrista fasciculata* Michx.) 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 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 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 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 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 oat (Table 5). Virginia wild rye had 5% cover at 8 MAS, but was absent at 12 MAS. River oat 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 oat.

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}. No other species established.

Newnan Site

In the fall seeding, the only forbs to establish by 4 MAS were blackeyed Susan and wild bergamot, averaging 14% cover (Table 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 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 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 some species established 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 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. Christiansen (1995) noted that blackeyed Susan and indiangrass can establish on roadsides when existing vegetation was not removed before 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 indicative of higher soil moisture content at these sites, as the species is known to inhabit wet roadsides in the Midwest (Willson and Price, 1977). 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 (1978) 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. Several of the grasses established more successfully at the sites with more acidic soils; both little bluestem and indiangrass had a higher average percent cover at Commerce than at Newnan, and deertongue, indiangrass, and little bluestem all had a higher average percent cover at Macon than at Tifton.

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 [*D. 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. Further research is needed to evaluate the possible benefits from herbicide use. Appropriate postemergence herbicide use could improve native plant establishment by enhancing interspecific competition with weeds, particularly when seeded in the spring.

The vast difference in size of seed of native species warrants further investigation to make recommendations for proper seeding rates. Appropriate seeding rates should be species specific. For instance, seeding lanceleaf coreopsis at 100 seeds m^{-2} is the equivalent of a 2.8 kg ha^{-1} seeding rate, while a rate of 100 seeds m^{-2} for seeding blackeyed Susan is equivalent to only 0.29 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 (Launchbaugh and Owensby, 1970; Eisworth et al., 2009). 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 the 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 grass and forb 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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