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Growth, Reproductive Potential, and Control Strategies for Deeproot Sedge (*Cyperus entrerianus*)

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Greenhouse, growth chamber, and field studies were conducted at Stoneville, MS, in 2000 to 2008, to determine the growth rate, reproductive and overwintering potential, and control of deeproot sedge. In growth chamber studies, deeproot sedge growth rate (ht) and plant dry wt were greatest at 25/35 C (night/day temperatures), when compared with regimes of 5/15, 15/25, and 20/30 C. Based on the average number of scales (fruiting sites per spikelet), spikelets per inflorescence, and culms per plant, deeproot sedge reproductive potential was 2.6-, 6.2-, and 17.4-fold greater than Surinam, green, and knob sedges, respectively. A single deeproot sedge plant produced an average of 85,500 achenes annually. Mowing at 15-cm ht weekly prevented achene production but did not kill deeproot sedge plants. The average number of inflorescences produced on mowed plants was 1.2 to 4 times greater in 2- and 1-yr-old deeproot sedge plants, respectively, when compared with unmowed plants. Mature deeproot sedge achenes were produced between monthly mowings. In a 3-yr field study, glyphosate, glufosinate, hexazinone, and MSMA provided more than 85% control of deeproot sedge, and above the soil, live deeproot sedge plant dry wt was reduced by 50, 64, 68, 72, 86, and 93% by dicamba, halosulfuron-methyl, MSMA, hexazinone, glufosinate, and glyphosate, respectively. All (100%) deeproot sedge plants 1 yr old or older overwintered at Stoneville, MS, at 33°N latitude.

Nomenclature: 2,4-D; dicamba; glufosinate; glyphosate; halosulfuron-methyl; hexazinone; imazapic; MSMA; picloram; triclopyr; deeproot sedge, *Cyperus entrerianus* Boeck. CYPEN; green sedge, *Cyperus virens* Michx. CYPVI; knob sedge, *Cyperus pseudovegetus* Steud. CYPPV; Surinam sedge, *Cyperus surinamensis* Rottb. CYPSU.
Key words: Weed biology, reproductive potential, weed control.

De 2000 a 2008 se realizaron estudios de invernadero, de cámara de crecimiento y de campo en Stoneville, MS, para determinar la tasa de crecimiento, el potencial reproductivo y de supervivencia durante el invierno y el control de la maleza *Cyperus entrerianus.* En los estudios de cámara de crecimiento, la tasa de crecimiento (altura) de *C. entrerianus* y el peso seco de la planta fueron mayores para las temperaturas de 25/35 C (noche/día) cuando se compararon a regímenes de 5/15, 15/25 y 20/30 C. Basado en el número promedio de escamas (sitios de fructificación por fruto), espiguillas inflorescencia^{-1} y culmos planta^{-1}, el potencial reproductivo de *C. entrerianus* fue 2.6, 6.2 y 17.4 veces mayor que *C. surinamensis, C. virens* y *C. pseudovegetus,* respectivamente. Una sola planta de *C. entrerianus* produjo un promedio de 85,500 aquenios anualmente. La poda semanal a 15-cm de altura previno la producción de aquenios, pero no mató a las plantas de *C. entrerianus.* El número promedio de inflorescencias producidas en plantas podadas fue 1.2 a 4 veces mayor en plantas de *C. entrerianus* de dos y un año, respectivamente, cuando se compararon con plantas sin podar. Se produjeron aquenios maduros entre podas mensuales. En un estudio de campo de 3 años, glifosato, glufosinato, hexazinone y MSMA proporcionaron más del 85% de control de *C. entrerianus* y el peso seco de la parte aérea de la planta se redujo en 50, 64, 68, 72, 86 y 93% con la aplicación de dicamba, halosulfuron-methyl, MSMA, hexazinone, glufosinato y glifosato, respectivamente. El 100% de las plantas de *C. entrerianus* de un año de edad o mayores, sobrevivieron al invierno en Stoneville, MS, a 33 grados de latitud norte.

Deeproot sedge is a native of temperate regions of South America (Carter 1990; Rosen et al. 2006). It is an erect, clumping perennial with rounded-triquetrous culms, dark purple to almost blackish bases, and rhizomes deeply set in the soil; the clumps frequently produce 20 to 100 culms and inflorescences per year (Bryson and DeFelice 2009; Carter and Bryson 1996). Like a number of other nonnative invasive sedges (Bryson and Carter 2010; Bryson et al. 2003, 2008; Carter et al. 1996; Majure and Bryson 2008), the range of deeproot sedge seems to be expanding at an alarming rate in the past 2 decades (Rosen et al. 2006). In addition to its native range in South America, deeproot sedge is found in the Caribbean Islands, Mexico, and the southeastern United States (Barros 1960; Carter 1990; Kükenthal 1936; Rosen et al. 2006; Tucker 1994; Tucker et al. 2002). Rosen et al. (2006) speculate that deeproot sedge was introduced by separate events into Texas and Florida before 1941. Although deeproot sedge was present in the United States, it was not recognized until 1990 (Carter 1990). Since its introduction, deeproot sedge has spread rapidly in the coastal plain of the southern United States (Carter 1990). Currently, this nonnative, invasive sedge is found in more than 70 counties in Alabama, Florida, Georgia, Louisiana, Mississippi, and Texas (Bryson and Carter 2008; Carter et al. 2009; Rosen et al 2006). Flooding, construction equipment, mowing, and soil-moving activities, especially along highways, disperse the small achenes of deeproot sedge causing new infestations among various disturbed habitats (Carter 1990; Carter and Bryson 1996; Rosen et al. 2006). From these disturbed areas, deeproot sedge has also spread into pastureland, conservation

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set asides, abandoned row crops, and forested and natural areas (Carter 1990; Carter and Bryson 1996; Carter et al. 2009; Rosen et al. 2006). Deeproot sedge has displaced native vegetation, even in undisturbed habitats, often creating large monocultures (Rosen et al. 2006). Without widespread control, deeproot sedge will likely continue to spread rapidly, infesting agricultural, forested, riparian, and urban areas. Although deeproot sedge has not been reported as a weed of rice (*Oryza sativa* L.) or other row crops in the United States yet, it infests rice production in Paraguay (Carter 1990).

In the southern United States, deeproot sedge reproduces sexually from copious achene production and asexually from deep-set rhizomes (Bryson and Carter 2008; Carter and Bryson 1996). Vegetative reproduction of deeproot sedge is from short, woody rhizomes. Preliminary estimates were that deeproot sedge might produce several million achenes per hectare annually (Bryson and Carter 2004), and preliminary achene germination studies indicated moderate to high viability (55 to 95%)(Carter and Bryson 1996). In most of the southeastern United States, deeproot sedge flowers and fruits from June until frost in November or December (Bryson and Carter 1994; Carter 1990; Carter and Jones 1991), but in tropical areas of southern Florida, Louisiana, and Texas, achene production may be year-round (C. T. Bryson, personal observation [in southern Louisiana in 2009]). Also, preliminary research suggests that deeproot sedge populations could spread northward into Arkansas, North Carolina, South Carolina, Tennessee, and Virginia (Rosen et al. 2006). Additional research is needed to determine basic biological and ecological traits and to develop more-effective methods of prevention and control.

The objective of this research was (1) to determine growth rate and reproduction and overwintering potential of deeproot sedge, (2) to compare sexual reproductive potential of deeproot sedge to closely related species of *Cyperus*, and (3) to evaluate control of deeproot sedge by mowing and herbicides.

Materials and Methods

All greenhouse, growth chambers, and field studies were conducted at Stoneville, MS (33°N latitude). Plant material was collected from natural populations described below, and measurements were performed in laboratories at Stoneville, MS.

Deeproot Sedge Growth. Deeproot sedge achenes were collected from Jackson County, MS, in the fall of 1993 and were increased in preliminary greenhouse and field evaluations at Stoneville, MS. Deeproot sedge achenes were planted in 15-cm-diam, plastic pots filled with a 1 : 1 mixture of potting media (Jiffy Mix, Jiffy Products of America Inc., Batavia, IL) and soil (Bosket sandy loam, fine-loamy, mixed thermic Molic Hapludalfs) in a greenhouse set to 30/22 C (± 3 C) day/night temperature. Natural light was supplemented with sodium vapor lamps to provide at least a 14-h photoperiod. Deeproot sedge seedlings were thinned to 1 plant pot^{-1} using forceps and were transferred into growth chambers immediately after emergence in 2002 and 2003. Twelve deeproot sedge plants (replications) were grown in each growth chamber for 20 wk, and the experiment was repeated. The experiment was conducted as a split-split plot with environments (growth chamber) as a subplot, time of sampling as a sub-subplot, and individual pots (single plants) as plots. Growth chambers were maintained at 5/15, 15/25, 20/30, and 25/25 C night/day temperatures, with a 14-h photoperiod and 70% relative humidity. Pots (plots) were placed in plastic trays and were watered from below as needed until harvested. Data on plant ht and number of leaves, culms initiation, and dry wt by plant parts were recorded weekly. Plants were harvested 20 wk after emergence (WAE), oven-dried, and dry wt data were recorded for leaves, culms, inflorescences, bracts, and roots. Data were subjected to ANOVA, and means were separated at the 5% level of significance using Fisher's Protected LSD using SAS software (Version 9.1., SAS Institute Inc., Cary, NC). The experiment was repeated, and data were combined because there were no significant interactions between runs. Regression analysis was performed for plant growth (ht and leaf number) and plotted, and box plots were constructed with Sigma Plot (Version 10.0, Systat Software Inc., San Jose, CA) for various plant parts.

Comparative Reproductive Potential. Mature inflorescences were collected in September and October from 1993 to 2004, from naturally occurring populations of deeproot, green, knob, and Surinam sedges (Table 1) to compare reproductive potential. These species are widespread, weedy sedges of the southeastern United States and belong to *Cyperus* section *Luzulae* (Denton 1978). Spikelet length and culm ht of each species were determined with a digital caliper (Mitutoyo [Tokyo, Japan] Digital Plastic Caliper, available from Forestry Supplier, Inc., Jackson, MS) and a meter ruler. Number of scales per spikelet, spikelets per inflorescence, and culms per plant, as well as culm ht, were collected for each species to determine the potential number of achenes produced per plant. Normally, except for the terminal scale of the spikelet, each scale is associated with one achene. Therefore, to estimate achene production, 20 spikelets were randomly selected from each inflorescence, and the numbers of scales were counted. Total numbers of spikelets per inflorescence were counted from two inflorescences per plant, and the number of culms bearing inflorescences was counted per plant. Data for unequal number of samples per species were subjected to the *t* test within parameters (plant part) compared by species, using Microsoft Office Excel software (Microsoft Excel 2003, Microsoft Corporation, Redmond, WA 98052), and by box plots for parameters, constructed with Sigma Plot.

Deeproot Sedge Control with Mowing and Tillage. Deeproot sedge plants were established in 15-cm-diam, plastic pots, as described above. Plants were transplanted into the field, 2 m apart, in May 2000 to 2002, on a Dundee silt loam soil (fine-silty, mixed thermic Aeric Ochraqualf) with pH 6.7 and 1% organic matter, a CEC of 15 cmol C kg^{-1}, and soil textural fractions of 26% sand, 56% silt, and 18% clay. Deeproot sedge plants at 1 and 2 yr old were mowed at 15 cm above the soil surface and at intervals of once per week, once per month, or not at all. The number of culms and inflorescences from 10

Table 1. Locations of deeproot sedge, green sedge, knob sedge, and Surinam sedge seed and plant collections (1993 to 2004) for a comparison of morphological characteristics to predict reproductive potential (2002 to 2004); for deeproot sedge growth-chamber experiments (2002 to 2003); for deeproot sedge control evaluation by mowing, tillage, and herbicides; and for overwintering trials (2000 to 2006) at Stoneville, MS.

Species	Location	GPS[a] coordinates
Deeproot sedge	Jackson County, MS	30°20′41.64″N, 88°30′46.50″W
	Jones County, MS	31°41′48.24″N, 89°06′52.77″W
	Washington County, MS	33°26′23.81″N, 90°53′09.91″W
Green sedge	Bolivar County, MS	33°35′32.68″N, 90°46′03.27″W
	Rankin County, MS	32°20′04.90″N, 90°05′59.04″W
	Washington County, MS	33°09′37.82″N, 90°56′23.45″W
Knob sedge	Leflore County, MS	33°25′04.51″N, 90°14′24.44″W
	Rankin County, MS	32°19′33.07″N, 90°07′12.28″W
	Washington County, MS	33°27′57.52″N, 90°54′11.79″W
Surinam sedge	Bolivar County, MS	33°33′49.02″N, 91°07′28.30″W
	Harrison County, MS	30°21′56.43″N, 89°05′30.52″W
	Lee County, MS	34°10′08.55″N, 88°43′10.50″W

[a] Abbreviation: GPS, global positioning system.

individual deeproot sedge plants were recorded weekly for each treatment from June 1 until November 1, 2002 to 2003. The experiment was established as a randomized complete block with 4 replications. The experiment was duplicated. Because there was no experiment (time) by treatment interactions, experiments were combined. Data were subjected to ANOVA, and means were separated at the 5% level of significance by Fisher's Protected LSD test using SAS software, and regression analysis was performed and plotted with Sigma Plot software.

Portions (four random blocks, 4 m by 10 m) of the deeproot sedge–infested areas were disked in 2005 and 2006, once in May, and once each month from April until October, and were then compared with undisked areas. Mortality and seedling emergence were recorded as observations.

Control with Herbicides. Herbicide efficacy studies were conducted from 2004 to 2006 in a containment area on a U.S. Department of Agriculture–leased research farm, 4.0 km northeast of Stoneville, MS. Deeproot sedge plants were established in the greenhouse in pots and established in the field in 2002 to 2004. Deeproot sedge achenes were planted in 15-cm-diam, plastic pots as described above. Plants were transplanted into the field 2 m apart in May of 2002 to 2004 on a Dundee silt loam as described above. The herbicide 2,4-D was applied at 1.0 kg ai ha^{-1}, along with 2,4-D + picloram at 0.8 + 0.4 kg ai ha^{-1}, dicamba at 1.1 kg ai ha^{-1}, glufosinate at 0.4 kg ai ha^{-1}, glyphosate at 2.2 kg ai ha^{-1} (= 1.6 kg ae ha^{-1}), halosulfuron-methyl at 0.07 kg ai ha^{-1}, hexazinone at 0.6 kg ai ha^{-1}, imazapic at 0.1 kg ai ha^{-1}, MSMA at 2.2 kg ai ha^{-1}, picloram at 0.6 kg ai ha^{-1}, and triclopyr at 1.1 kg ai ha^{-1}, during the first week of July 2004 and 2006, with a tractor-mounted sprayer with TeeJet 8002 standard flat-spray nozzles (TeeJet standard spray nozzles, Spraying Systems Co., Wheaton, IL), in 140 L ha^{-1} of spray solution of water and an nonionic surfactant (Induce is a nonionic, low-foam wetter/spreader adjuvant that contains 90% nonionic surfactant [alkylaryl and alcohol ethoxylate surfactants], fatty acids, and 10% water, Helena Chemical Company, Memphis, TN) at 0.25% v/v at 193 kPa. Visual estimates of control (0%, no control; 100%, dead) were recorded 6 wk after treatment (WAT). Live (green), aboveground portions of deeproot sedge plants were harvested, dried, and weighed at 6 WAT, and root systems were removed from the soil with a shovel, tapped lightly to remove excessive soil, transported in plastic bags, and washed over a screen before drying. The experiment was established as a randomized complete block with four replications and 10 plants per plot. Data were subjected to ANOVA, and means were separated at the 5% level of significance by Fisher's Protected LSD test using SAS software. Data from 2004 and 2006 were combined because there was no time by treatment interaction.

Overwintering Potential. Field observations of deeproot sedge plants were made monthly at Stoneville, MS, during winter and spring months in the untreated plots in the previous two experiments from 2003 to 2006. Plant mortality, culm production, and growth data were recorded for each plant. Data are presented as general observations.

Results and Discussion

Deeproot Sedge Growth. In growth chamber studies, deeproot sedge growth rate (Figure 1) and dry wt (Figure 2) was greatest for the highest temperature regime 25/35 C (night/day) when compared with the lower temperature regimes of 5/15, 15/25, and 20/30 C (night/day). Plant ht was sixfold greater for the 15/25 and 20/30 C night/day temperature regimes and 12-fold greater for the 25/35 C night/day temperature regime when compared with the 5/15 C night/day temperature regime (Figure 1). The average number of leaves per deeproot sedge plant was eightfold greater for the 25/35 C night/day temperature regime when compared with the lowest temperature regime (5/15 C night/day regime) and about eightfold greater than it was for the 15/25 and 20/30 C night/day temperature regimes (Figure 2). Deeproot sedge leaf and root dry wt for the 25/35 C night/day temperature regime was four- and fivefold greater than for the 5/15, 15/25, and 20/30 C night/day temperature regimes (Figure 3). These data indicate deeproot sedge growth is greater at the higher, rather than the lower, temperatures.

In growth chambers, only the deeproot sedge plants in 25/35 C (night/day) temperature regime produced inflorescences (Figure 4). At 20 WAE, the average deeproot sedge root and leaf dry wt comprised more than 95% of the total plant dry wt biomass.

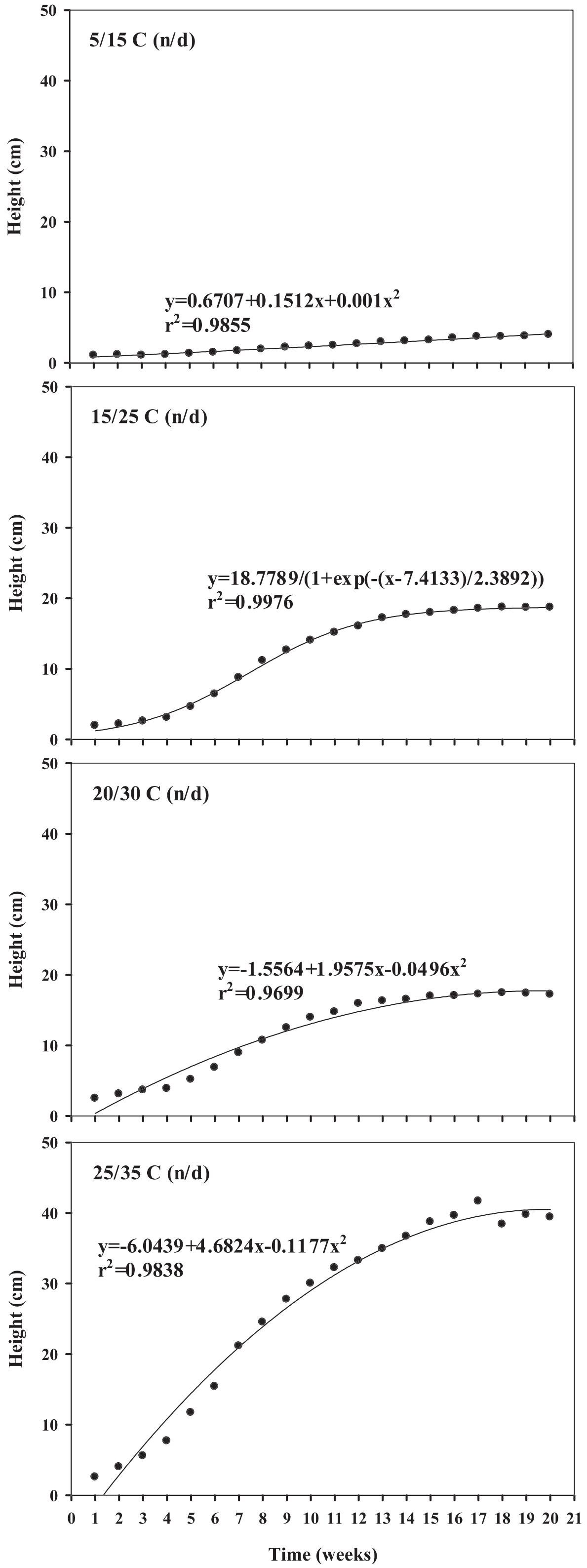

Figure 1. Average plant ht of deeproot sedge under four temperature regimes (5/15, 15/25, 20/30, and 25/35 C night/day temperatures] in growth chamber conditions at Stoneville, MS.

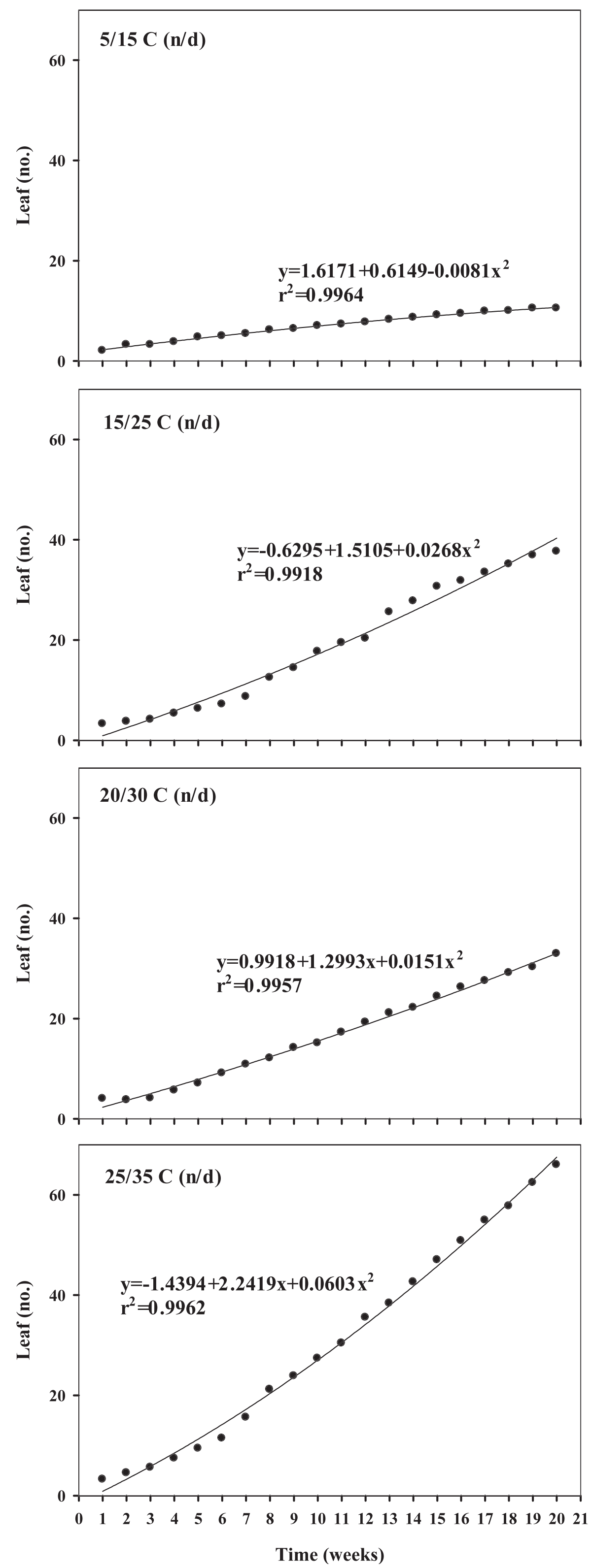

Figure 2. Average number of leaves of deeproot sedge under four temperature regimes (5/15, 15/25, 20/30, and 25/35 C night/day temperatures) in growth chamber conditions at Stoneville, MS.

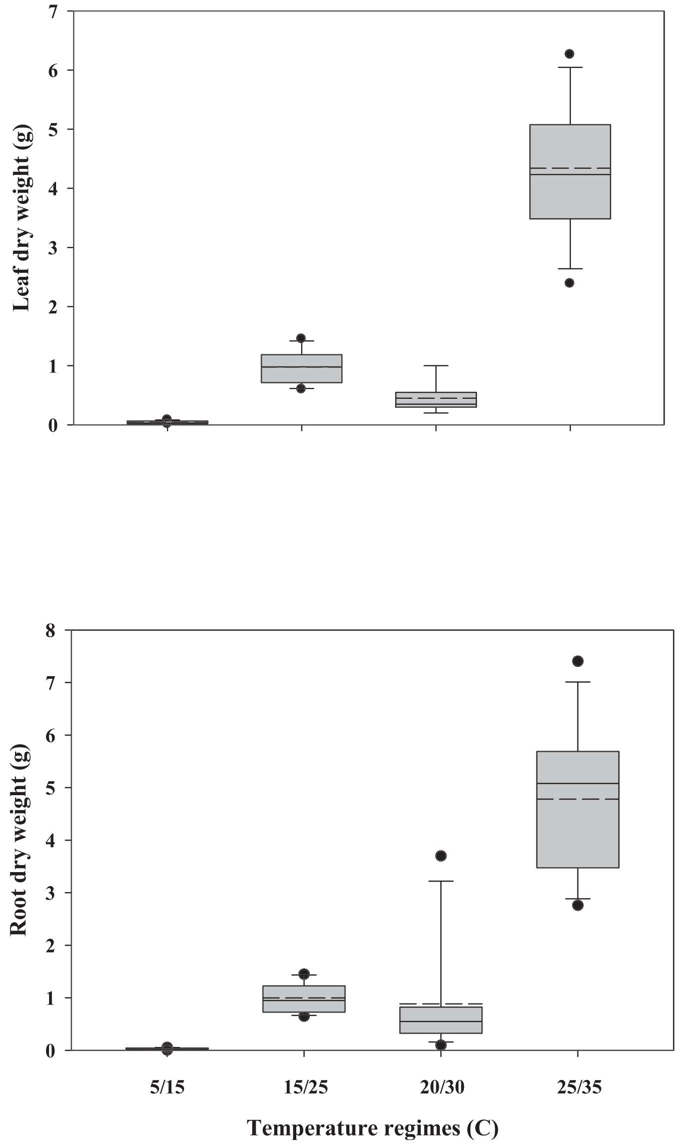

Figure 3. Box plots of plant dry wt of deeproot sedge, under four temperature regimes (5/15, 15/25, 20/30, and 25/35 C night/day temperatures) in growth chamber conditions at Stoneville, MS. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentile, and solid dots indicate outliers. The number of independent observations was 24.

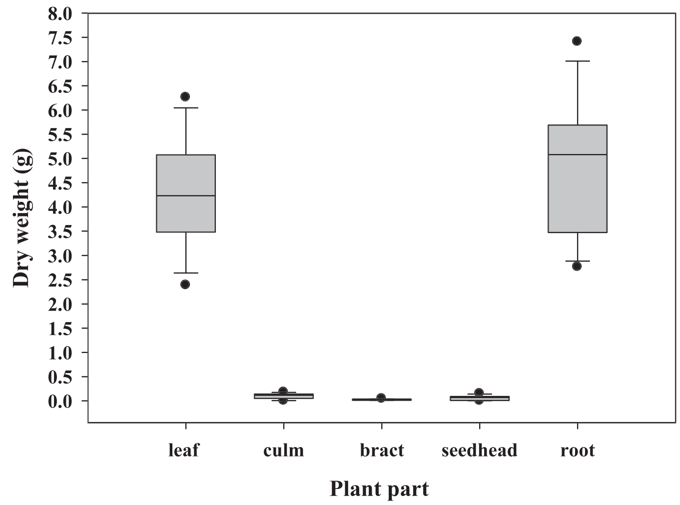

Figure 4. Box plots of average leaf, culm, bract, seed head (inflorescence), and root plant dry wt of deeproot sedge, under four temperature regimes (5/15, 15/25, 20/30, and 25/35 C night/day temperatures) in growth-chamber conditions at Stoneville, MS. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentile, and solid dots indicate outliers. The number of independent observations was 24.

Comparative Reproductive Potential. The average spikelet length of deeproot sedge (5 mm) was shorter than it was for the green sedge (15 mm) and the Surinam sedge (8 mm) and was only slightly longer than it was for the knob sedge (4 mm) (Figure 5). Among the four sedges, the average numbers of scales per spike (fruiting sites) were greatest in Surinam sedge (24 scales spike^{-1}) and 1.3-, 1.4-, and 2-fold greater than it was for deeproot, green, and knob sedges, respectively (Figure 6). However, the average numbers of spikelets per inflorescence for deeproot sedge were 1.3, 1.5, and 2.2 times greater than it was for the average number of spikelets per inflorescence for green, knob, and Surinam sedges, respectively (Figure 7). Likewise, the average numbers of culms per plant of deeproot sedge were 2.2, 4.4, and 7.3 times greater than the number of culms per plant in Surinam, green, and knob sedges, respectively (Figure 8). Using the average number of scales per spike, spikelets per inflorescence, and culms per plant, the potential average number of achenes produced per plant would be 4,900, 13,800, 24,000, and 85,500 for knob, green, Surinam, and deeproot sedges, respectively. Thus, deeproot sedge reproductive potential (number of achenes per plant) was 3.6-, 6.2-, and 17.4-fold greater than that of Surinam, green, and knob sedges, respectively. At the density of 1 plant m^{-2}, deeproot sedge could produce about 4.3 billion achenes ha^{-1} annually. In addition, because deeproot sedge average culm ht was 1.2, 1.3, and 2.5-fold taller than green, knob, and Surinam sedges, respectively (Figure 9), the deeproot sedge achenes may possibly be dispersed at a greater distance than achenes from other sedges because of its taller culms. Wind dispersal of deeproot sedge achenes could be farther from the mother plant than for the other sedges based on culm ht alone. Additional research is needed to determine the role of natural (environmental processes and wildlife) and anthropogenic dispersal of achene from mother plants.

Deeproot Sedge Control with Mowing and Tillage. Deeproot sedge plants were not killed from mowing, and plants mowed weekly failed to produce mature inflorescences; however, 1- and 2-yr-old plants that were mowed once per month produced more culms and inflorescences than plants that were not mowed (Figure 10). By November 1, the cumulative average number of culms per 1-yr-old deeproot sedge plants was about fourfold greater when mowed monthly

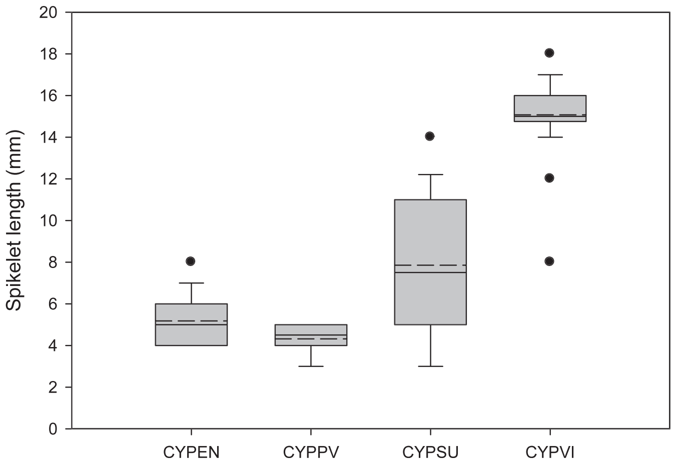

Figure 5. Box plots of spikelet length (mm) for deeproot sedge (CYPEN), knob sedge (CYPPV), Surinam sedge (CYPSU), and green sedge (CYPVI) accessions collected in Mississippi. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentile, and solid dots indicate outliers. The number of independent observations was 47, 22, 28, and 42 for deeproot sedge, knob sedge, Surinam sedge, and green sedge, respectively.

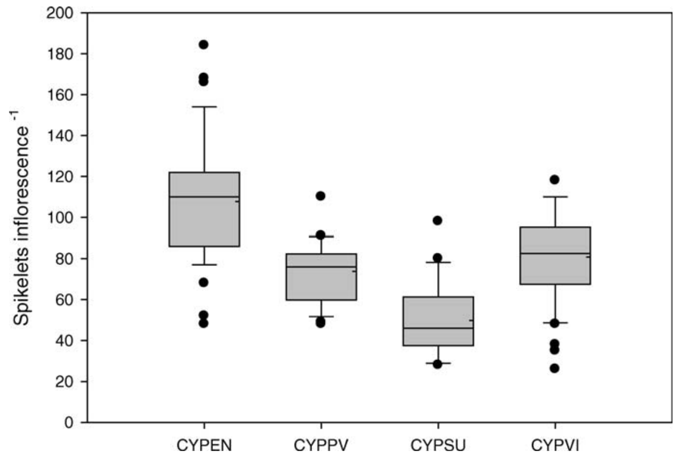

Figure 7. Box plots of spikelets per inflorescence for deeproot sedge (CYPEN), knob sedge (CYPPV), Surinam sedge (CYPSU), and green sedge (CYPVI) accessions collected in Mississippi. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentile, and solid dots indicate outliers. The number of independent observations was 47, 22, 28, and 42 for deeproot sedge, knob sedge, Surinam sedge, and green sedge, respectively.

compared with plants that were not mowed (Figure 10A). The average, cumulative number of deeproot sedge culms per plant in 2-yr-old plants was 1.2-fold greater for plants mowed monthly compared with unmowed plants (Figure 10B). Mature achenes were observed on inflorescences of deeproot sedge plants that were mowed once per month; however, some inflorescences did not produce mature achenes. Thus, monthly mowing reduced the total number of achenes produced but did not eliminate sexual reproduction of deeproot sedge. Interruptions in weekly and monthly mowing schedules throughout the growing season are likely to result in deeproot sedge achene production and increased reproductive potential.

A single disking failed to kill established (1 yr old and older) deeproot sedge plants. Disking monthly from April until October killed all established deeproot plants; however, seedlings emerged from previously infested sites after rainfall in excess of 3 cm, if the soil surface remained damp for more than 24 h.

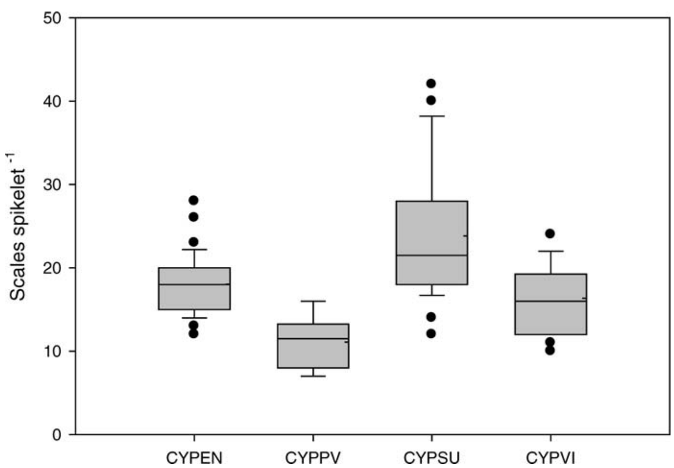

Figure 6. Box plots of scales/spikelet for deeproot sedge (CYPEN), knob sedge (CYPPV), Surinam sedge (CYPSU), and green sedge (CYPVI) accessions collected in Mississippi. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentile, and solid dots indicate outliers. The number of independent observations was 47, 22, 28, and 42 for deeproot sedge, knob sedge, Surinam sedge, and green sedge, respectively.

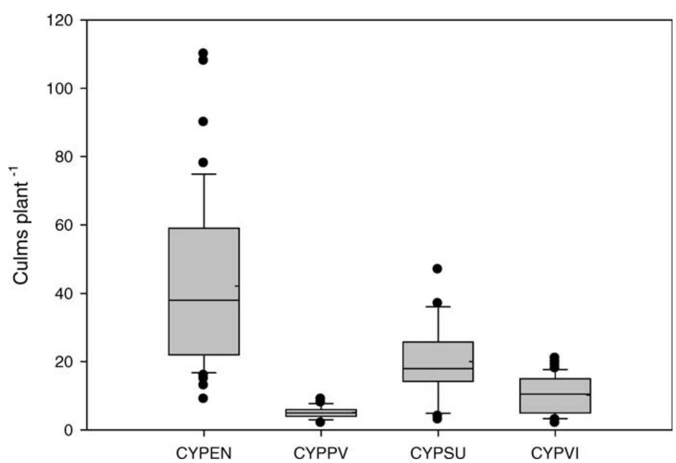

Figure 8. Box plots of culms per plant for deeproot sedge (CYPEN), knob sedge (CYPPV), Surinam sedge (CYPSU), and green sedge (CYPVI) accessions collected in Mississippi. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentile, and solid dots indicate outliers. The number of independent observations was 47, 22, 28, and 42 for deeproot sedge, knob sedge, Surinam sedge, and green sedge, respectively.

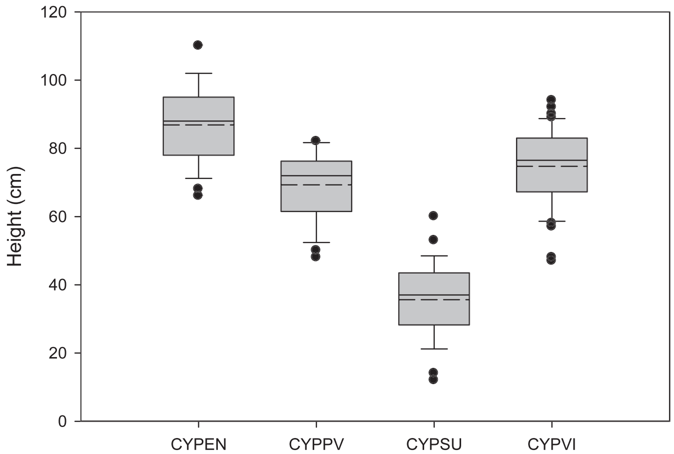

Figure 9. Box plots of culm ht (cm) for deeproot sedge (CYPEN), knob sedge (CYPPV), Surinam sedge (CYPSU), and green sedge (CYPVI) accessions collected in Mississippi. The boundary of box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentile, and solid dots indicate outliers. The number of independent observations was 47, 22, 28, and 42 for deeproot sedge, knob sedge, Surinam sedge, and green sedge, respectively.

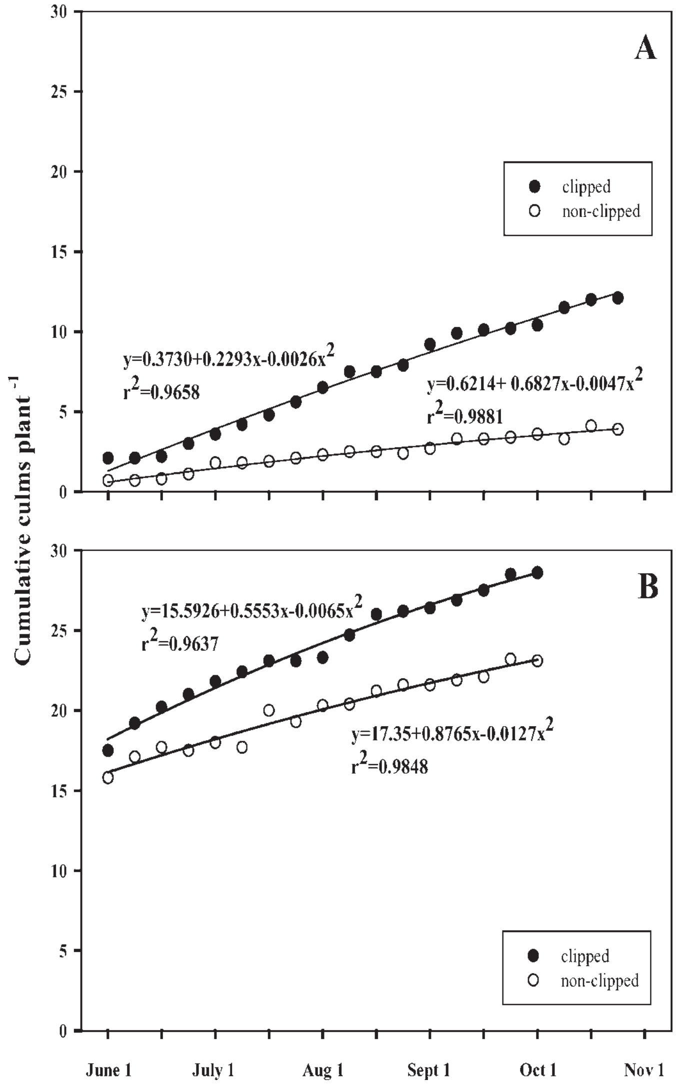

Figure 10. The average cumulative number of culms produced by (A) 1-yr old, and (B) 2-yr-old deeproot sedge plants when plants were clipped (mowed) monthly vs. unclipped (not mowed) at Stoneville, MS.

Deeproot Sedge Control with Herbicides. From a 3-yr field study (2004 to 2006), the most effective herbicides for deeproot sedge control were glyphosate, glufosinate, halosulfuron-methyl, and MSMA, with each providing greater than 85% control 6 WAT (Table 2). Dry plant wt of live plant material 6 WAT was reduced by 66, 80, 85, and 93% following treatments of MSMA, halosulfuron-methyl, glufosinate, and glyphosate, respectively, when compared with the untreated deeproot sedge plants. The 2,4-D + picloram and the dicamba provided more than 70% control of deeproot sedge at 6 WAT, whereas 2,4-D, imazapic, picloram, and triclopyr provided 60% or less deeproot sedge control at 6 WAT. Deeproot sedge average dry wt of aboveground live material was reduced by 29% by imazapic, 29% by picloram, 29% by triclopyr, 40% by 2,4-D, 40% by2,4-D + picloram, 50% by dicamba, 64% by halosulfuron-methyl, 68% by MSMA, 72% by hexazinone, 86% by glufosinate, and 93% by glyphosate when compared with untreated plants. Even though MSMA provided adequate deeproot sedge control and reduction of live plant dry wt (85% and 68%, respectively), it should not be considered as a viable option for use because it is no longer available and was not as effective as glyphosate, glufosinate, and halosulfuron-methyl.

Overwintering Potential. By the end of the first and second growing seasons (2002 to 2005), the average plant dry wt of deeproot sedge was 1.2 and 2.8 kg, respectively. As seen during the monthly general field observations, 100% of the mowed deeproot sedge plants, as well as all untreated, established 1- and 2-yr-old deeproot sedge plants survived winters for the duration of the trial (2003 to 2006). In fact, deeproot sedge foliage remained green well into the winter each year for all trials. Even during the coldest temperatures recorded in January and February (night temperatures to less than −8 C), some deeproot sedge foliage within the clumps remained green in all field trials; however, culm production ceased each year following the first hard freeze (temperatures less than 0 C). Thus, deeproot sedge possesses the potential to expand its range and survive north of 33°N latitude. A single deeproot sedge population was detected as far north as 34°N latitude in Tunica County, MS (Rosen et al. 2006). The Tunica County, MS, deeproot sedge population was near newly constructed casinos, hotels, and other businesses and an expansion of highways U.S. 61 and the future I-69, so it is likely that deeproot sedge was introduced into Tunica County, MS, by contaminated construction equipment.

The phenology of deeproot sedge differs from other species of the *Cyperus* section *Luzulae* group and from annual sedges, such as brown flatsedge (*Cyperus fuscus* L.)(Bryson and Carter 2008, 2010; Rosen et al. 2006). Deeproot sedge remains green longer during the year, produces greater plant biomass, and generates more achenes than do other members of the *Luzulae* group. Unlike brown flatsedge, deeproot sedge continues to

Table 2. Effect of various herbicide treatments on the aboveground, 2-yr-old deeproot sedge plants 6 wk after treatment in a field containment area at Stoneville, MS (2004 to 2006).

Herbicide	Deeproot sedge		
	Rate	Dry wt	Control
	kg ai ha^{-1}	g	%
2,4-D	1.0	1.7	60
2,4-D + picloram	0.8 + 0.4	1.7	70
Dicamba	1.1	1.4	78
Glufosinate	0.4	0.4	94
Glyphosate	2.2	0.2	98
Halosulfuron-methyl	0.07	1.0	88
Hexazinone	0.6	0.8	92
Imazapic	0.1	2.0	40
MSMA	2.2	0.9	85
Picloram	0.6	2.0	40
Triclopyr	1.1	2.0	40
None	—	2.8	0
LSD ($P = 0.05$)[a]		0.4	8

[a] Fisher's Protected LSD at the 0.05 probability level.

produce large numbers of leaves after culm and inflorescence production is initiated (Bryson and Carter 2010).

Because deeproot sedge continues to spread at an alarming rate, additional research is needed to determine more-effective methods to prevent dispersal, to evaluate its potential ecological range in the United States, and to develop more-effective methods of control once this sedge becomes established.

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