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Review

Ecotype Variability and Edaphic Characteristics for Cogongrass (*Imperata cylindrica*) Populations in Mississippi

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Cogongrass is a highly invasive, perennial grass that is found on all continents, except Antarctica. It continues to spread at an alarming rate in the southeastern United States. Cogongrass has been reported from a wide array of habitats; however, soils from areas where cogongrass grows have never been characterized. Live cogongrass plants, herbarium specimens, and soil samples were collected from 53 cogongrass populations from across the 10 physiographic regions and land use areas in Mississippi. Cogongrass leaf and inflorescence morphology varied among sites, and plants were found in soils varying widely in texture (ranging from 28 to 86% sand, 3 to 48% silt, and 6 to 43% clay), organic matter content (ranging from 0.9 to 5.0%), pH (ranging from 4.4 to 8.0), and nutrient status: 6 to 190 kg ha^{-1} (15 to 470 lb A^{-1}) of phosphorus (P), 46 to 734 kg ha^{-1} of potassium (K), 150 to 7,620 kg ha^{-1} of calcium (Ca), 26 to 1,090 kg ha^{-1} of magnesium (Mg), 1 to 190 kg ha^{-1} of zinc (Zn), 145 to 800 kg ha^{-1} of estimated sulfur (S) based on organic matter, and 57 to 300 kg ha^{-1} of sodium (Na). These soil parameters were highly variable among cogongrass populations, even within physiographic regions or land use areas, and encompassed much of the soil physiochemical diversity within the state. Soil characteristics were significantly correlated with leaf length (Ca, K, Mg, P, Zn, and percentage of sand and silt), leaf width (Ca, P, Mg, and percentage of sand and silt), the leaf length-to-width ratio (K and P), inflorescence length (Na, P, and pH), inflorescence width (S, organic matter, and pH), and the inflorescence length-to-width ratio (S and organic matter). These data indicate that cogongrass is able to establish, emerge, grow, and reproduce on a wide array of soils in Mississippi. This ability provides cogongrass an advantage over other plant species that are more limited in the soil types that support their growth.

Nomenclature: Cogongrass, *Imperata cylindrica* (L.) Beauv. IMPCY.

Key words: Morphology, ecotypic variability, edaphic characteristics, invasive weeds, soil characteristics.

Cogongrass is an aggressive, rhizomatous, perennial grass and is among the most troublesome weeds worldwide. It ranks as the world's seventh worst agricultural weed (Falvey 1981; Holm et al. 1977). Because it grows in subtropical, tropical, and some temperate regions of the world, cogongrass continues to spread and cause problems on all continents, except Antarctica (Akobundu and Agyakwa 1998; Bryson and Carter 1993; Holm et al. 1977; Hubbard et al. 1944). Since its introduction into the United States in the early 1900s, cogongrass has continued to spread and is now established in Alabama, Florida, Georgia, Louisiana, Mississippi, Oregon, South Carolina, Texas, and Virginia (Bryson and Carter 1993; Byrd and Bryson 1999; Dickens 1974; Dickens and Buchanan 1971; Faircloth et al. 2005).

Cogongrass is a member of the subfamily *Panicoideae*, supertribe *Andropogoneae* (Gabel 1982), and subtribe *Saccharine* (Clayton 1972). Gabel (1982) recognized nine species in the genus *Imperata* and stated that cogongrass is the most variable species in the genus worldwide. Hubbard et al. (1944) recognized five varieties of cogongrass

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Interpretive Summary

Cogongrass is one of the most difficult to control, nonnative, invasive weeds in the southeastern United States. It occurs in a wide array of habitats from open roadsides, meadows, pastures, and rights-of-way to shaded forests. Leaf size (length and width) and inflorescence size (length and width) were variable among cogongrass populations in Mississippi. Soil characteristics are reported to be very diverse for sites where cogongrass has established, spread, and reproduced; however, no literature, to our knowledge, has measured the soil diversity and compared these soils with phenotypic diversity in cogongrass observed in field situations. Soil characteristics from cogongrass population sites were highly variable and covered about 90% of the soil variability found across Mississippi. Cogongrass was found to grow on a wider spectrum of soil texture and pH conditions than many agricultural crops. Cogongrass spread into diverse and uninfested areas throughout Mississippi and into other states is highly likely, based on its adaptability and growth on a wide range of soils and environments. Land resource managers and invasive plant managers in Mississippi and other states should survey for cogongrass in a wide array of soil characteristics.

worldwide: *I. cylindrica* var. *africana* (Andersson) C. E. Hubb., *I. cylindrica* var. *condensata* (Steud.) Hack. Ex Stuck., *I. cylindrica* var. *europaea* (Andersson) Asch. & Graebn., *I. cylindrica* var. *latifolia* (Hook f.) C. E. Hubb., and *I. cylindrica* var. *major* (Nees) C. E. Hubb. Cogongrass var. *major* was the most widely distributed variety worldwide and the variety introduced into the United States (Hubbard et al. 1944).

Cogongrass leaves and culms arise from subsoil, scaly rhizomes and reach lengths of 1.2 to 3 m (Brown 1944; Gabel 2003; Holm et al. 1977). Cogongrass leaf blades are up to 150 cm long and range from 1.0 to 28.0 mm wide; and inflorescences range from 5.7 to 52.0 cm long (Gabel 2003). Two similar *Imperata* species are reported in the United States, Brazilian satintail (*Imperata brasiliensis* Trin.) and satintail (*Imperata brevifolia* Vasey)(Gabel 2003). Culm length and leaf length and width for Brazilian satintail and satintail fall within the range of the culm and leaf measurements provided for cogongrass (Gabel 2003); thus, these morphological traits are useless for distinguishing the three species. Cogongrass possesses two stamens per flower and differs from Brazilian satintail and satintail, which have only one stamen per flower (Gabel, 1982, 2003); however, Hall (1998) speculated that hybridization could occur between cogongrass and Brazilian satintail.

Cogongrass is extremely invasive from seed and from rhizomes (Dozier et al. 1998) and is very competitive with native and with desirable nonnative species and crops for light, water, nutrients, and space (Eussen and Wirjahardja 1973). Cogongrass thrives in open areas along roadways and, infrequently, in cultivated areas, forests, parks, pastures, pine plantations, mining spoils, and other natural and recreational areas (Coile and Shilling 1993; Dozier et al. 1998; Willard et al. 1990) and is difficult to control with herbicides or other methods (Bryson et al. 2007; Dickens and Buchanan 1975; Faircloth et al. 2005; Johnson et al. 1999; Miller 1999; Udensi et al. 1999; Yager and Smith 2009). Chemical and cultural control of cogongrass is very difficult because of vigorous rhizome expansion in soil and the extensive rhizome biomass in relation to the aboveground biomass (Tominaga, 1993; Tominaga et al. 1989). The most effective herbicides for cogongrass management include glyphosate and imazapyr (Dozier et al. 1998; Udensi et al. 1999). Cogongrass control requires multiple applications over multiple years (Johnson et al. 1999; Miller 1999). However, imazapyr and other soil-sterilant herbicides often interfere with the reestablishment of much or all the desirable native vegetation, a critical component of the rehabilitation process (Byrd and Bryson 1999; Johnson et al. 1999; Yager and Smith 2009).

Because cogongrass extracts soil moisture from shallow soil depths, it is particularly competitive with other perennial grasses (Dozier et al. 1998) and competes with other plant species by producing allelopathic chemicals in its rhizomes (Casini et al. 1998; Eussen 1979; Inderjit and Dakshini 1991; Koger and Bryson 2004; Koger et al. 2004). Cogongrass, a pyogenic species, relies on soil to insulate subterranean rhizomes from fire (Lippincott 2000). Fire eliminates dense cogongrass thatch, which promotes very intense and hot fires that destroy most other aboveground vegetation, and it creates huge monoculture expanses, maintains vegetative dominance, and alters natural ecosystems (Eussen and Wirjahardja 1973; Garrity et al. 1996; Lippincott 2000; Soerjani and Soemarwoto 1969). Ultimately, fire promotes cogongrass survival and propagule establishment (Eussen and Wirjahardja 1973).

Cogongrass is highly adaptable to a wide range of environmental and edaphic conditions and frequently forms dense, monotypic stands over large areas (Chikoye et al. 1999; Garrity et al. 1996) and is genetically diverse (Capochichi et al. 2008; Vergara et al. 2008); however, literature is not available that describes the soil characteristics over a wide area, nor does it describe the potential cogongrass morphological variability that result from soil characteristics. The primary objectives of this research were to determine the range of soil characteristics where cogongrass is observed in Mississippi and to determine whether cogongrass morphological variability is related to soil characteristics.

Materials and Methods

Live and pressed specimens of cogongrass populations and soil samples were collected in 53 Mississippi counties and from the 10 physiographic or land resource use areas identified by Lowe (1921) and Morris (1989)(Figure 1). These land use areas are unique in topography, hydrology,

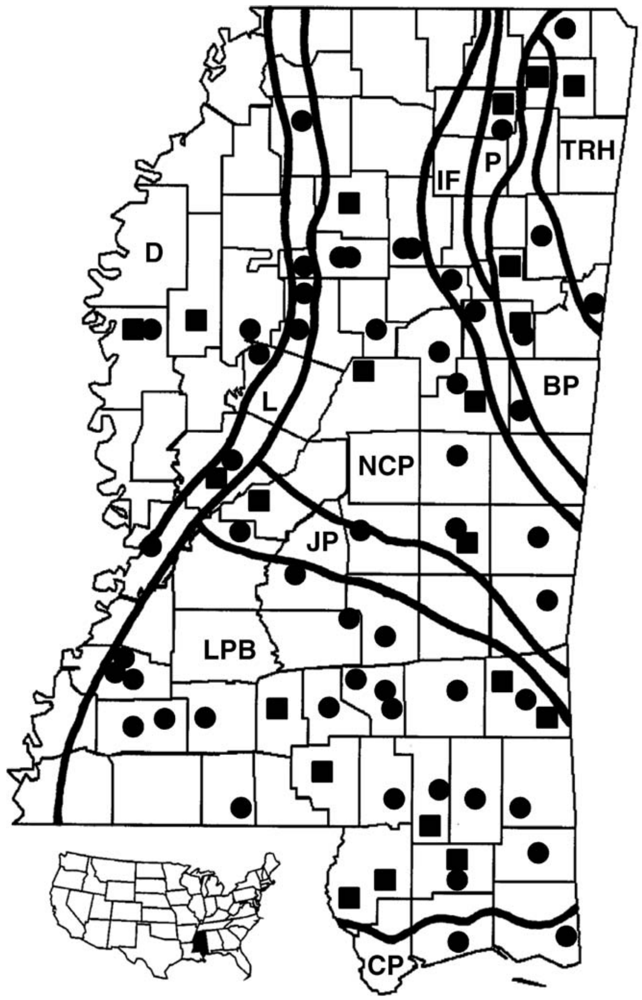

Figure 1. Locations of cogongrass (*Imperata cylindrica*) collections by physiographic or land resource use areas in Mississippi adapted from Lowe (1921) and Morris (1989). Abbreviations: BP, Black Prairie; CP, Coastal Pine Meadows; D, Delta; IF, Interior Flatwoods; JP; Jackson Prairie; L, Loess Bluffs; LPB, Longleaf Pine Belt; NCP, North Central Plateau; P, Pontotoc Ridge; and TRH, Tennessee River Hills. Circles show where cogongrass soil and specimens were collected; squares show where only specimens were collected.

and soils. For instance, the Delta region comprises a relatively level topography and alluvial soils with origin upstream in the Mississippi River drainage, whereas the Loess Bluff region comprises deeply dissected topography with soils of loess origin (Lowe 1921). The Black Prairie and Jackson Prairie regions are areas with undulating topography and dark brown or blackish soils that generally have a higher pH than the hilly topography and the acidic soils of the Longleaf Pine Belt, North Central Plateau, Pontotoc Ridge, and Tennessee River Hills regions (Lowe 1921).

Sexual and asexual reproduction was noted from each of the cogongrass population sites. Samples were collected only from Mississippi for this study because it is currently unlawful to transport live propagules of a federal noxious weed across state lines. For morphological analysis, specimens were collected randomly from sites within cogongrass populations and pressed in newsprint using the procedures described in Carter et al. (2007)(Figure 1). Herbarium vouchers for each collection were deposited in the herbarium of the Southern Weed Science Research Unit (Stoneville, MS), and duplicates will be distributed to other herbaria. Cogongrass samples were collected as near to the anthesis stage as possible (April and May). Phenology of cogongrass and distance between points prevented uniformity of all collections, even within populations. From the 53 sites where soil was sampled, two stamens per flower were recorded for each of the accessions, with the exception of 12 populations that were not collected at prime anthesis; however, at least one remnant floret possessed two stamens in 8 of those 12 accessions. For one accession from Winston County in the North Central Plateau region, the predominant ($>$ 98%) stamen number per floret was two, but several florets possessed a single stamen. This population may or may not be a hybrid between cogongrass and Brazilian satintail, similar to hypothesized hybridization suggested by Hall (1998) for some populations of cogongrass and Brazilian satintail in Florida. Leaf and inflorescence length and width were measured with a digital caliper[1] from dried cogongrass specimens collected at sites identified in Figure 1. The length and width were measured on the longest cogongrass leaf blade from each dried specimen. The number of specimens per accession varied depending on the number of specimens that were located within a population and were at anthesis. A total of 378 leaf samples from 77 cogongrass population sites and 486 inflorescence samples from 64 cogongrass population sites were measured. Soil samples were not taken from a number of these cogongrass population sites because soil sampling was initiated after the specimens were collected, and many cogongrass populations were being controlled with herbicides and could not be detected. Therefore, morphological and soils data were correlated for only sites where both were sampled.

Live cogongrass rhizomes were placed in 30-cm-diam, plastic pots filled with a 1 :1 mixture of potting media[2] and soil (Bosket sandy loam, fine-loamy, mixed thermic Mollic Hapludalfs). Cogongrass plants were maintained in a greenhouse set to a 30/22 C (86/72 F) ($\pm$ 3 C) day/night temperature. Natural light was supplemented with light from sodium vapor lamps during winter months to provide at least a 14-h photoperiod. Plants were watered as needed and were grown in greenhouse until leaf length and width measurements were taken in May 2009, the same time of the year that cogongrass usually flowers in the wild. Like the dried specimens, length and width were measured for the longest cogongrass leaf blade from each greenhouse-grown accession.

Three to five soil samples were collected at cogongrass sites in Mississippi, where live and pressed specimens were also collected. Each sample was from the top 6 cm from within the cogongrass population. The samples were mixed, sifted with a 2.0-mm-mesh screen, and sent to a soil testing laboratory.[3] The percentage of organic matter, pH, Ca, K, Mg, Na, P, and Zn and an estimate of organic S based on the organic matter were obtained for 53 samples; soil texture was obtained from 44 of the 53 locations. Although N levels were determined, the data are not presented here because they were so variable, and it was impossible to determine whether N had been added to the sites where soils were sampled. Lancaster soil testing methodology (Cox 2001) was used for Ca, K, Mg, Na, P, and Zn and for an estimate of organic S, and analysis was obtained. Soil pH was measured in water at 1 : 2 soil–water. Cation exchange capacity was estimated from the total number of exchangeable cations, and organic matter was determined by the loss of mass after ignition (Nelson and Sommers 1996). Particle size analysis was performed by the hydrometer methods, with corrections for temperature as needed (Ashworth et al. 2001; Scott 2000).

Statistics. Soil physiochemical properties and mean values for plant morphological parameters were transformed to the natural log and subjected to correlation analysis in SAS.[4] Box plots for selected plant and soil parameters were constructed with Sigma Plot,[5] and differences among plant parameters between field and greenhouse conditions were evaluated in Excel,[6] using a two-tailed, pairwise *t* test (significant at $P \leq 0.05$).

Results and Discussion

Cogongrass morphology. Cogongrass leaf length-to-width ratio compared with inflorescence length-to-width ratio by physiographic or land resource use areas in Mississippi are presented in Figure 2. There were no obvious outlier groupings of leaf and inflorescence parameters by physiographic or land resource use areas in Mississippi; however, cogongrass accessions aggregated more from the Loess Bluffs and the Jackson Prairie than from the Black Prairie and the Longleaf Pine Belt regions. These groupings may be due to the limited number of observations, to genetic variability, or to environmental and edaphic factors; however, each of these accessions was nested in the overall morphological diversity within the populations sampled.

Leaf and inflorescence lengths, widths, and length-to-width ratios were variable among the field-collected cogongrass populations (Figures 3 and 4). From field collected cogongrass specimens, the longest cogongrass leaves at a site were, on average, 27.0 cm (10.5 in) long, with 90% of leaf lengths falling between 12.2 and 47.2 cm (Figure 3). Cogongrass leaf width averaged 5.0 mm, and the average, largest cogongrass length-to-width ratio was

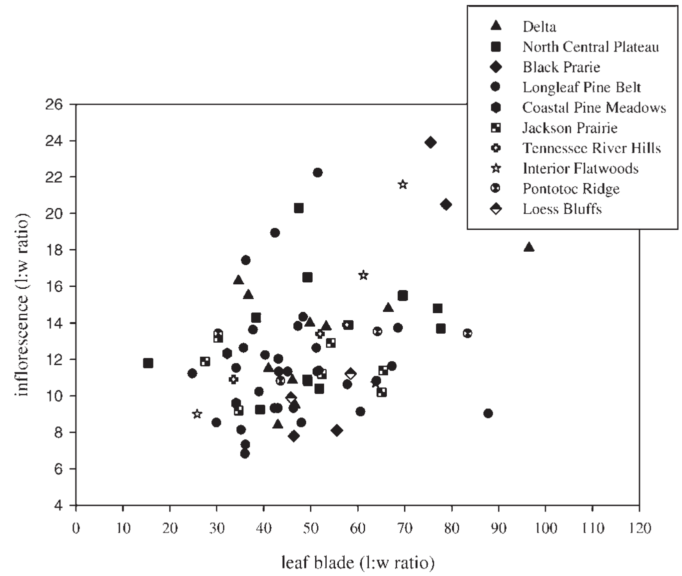

Figure 2. Morphological comparison of inflorescence length-to-width ratio to leaf blade length-to-width ratio in field-collected cogongrass (*Imperata cylindrica*) populations from 10 physiographic or land resource use areas in Mississippi, adapted from Lowe (1921) and Morris (1989).

5.3 (Figure 3). Average cogongrass inflorescence length was 98.6 mm, with an average width of 8.3 mm and an average length-to-width ratio of 12.4 (Figure 4). Leaf and inflorescence parameters, even those recorded outside the 90% range, were well within the range Gabel (1982, 2003) provided for cogongrass.

In comparing the 44 live cogongrass samples grown in the greenhouse with the wild populations, the leaf length, leaf width, and length-to-width ratios were greater for

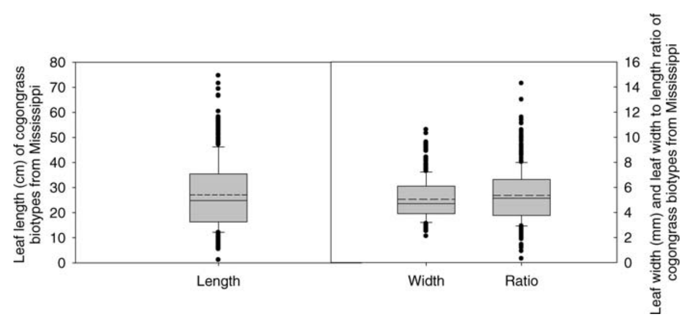

Figure 3. Box plot of leaf length (in millimeters), width (in millimeters), and the leaf length-to-width ratio for cogongrass (*Imperata cylindrica*) biotypes in Mississippi. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed 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 percentiles, and solid dots indicate outliers. The number of independent observations is 378.

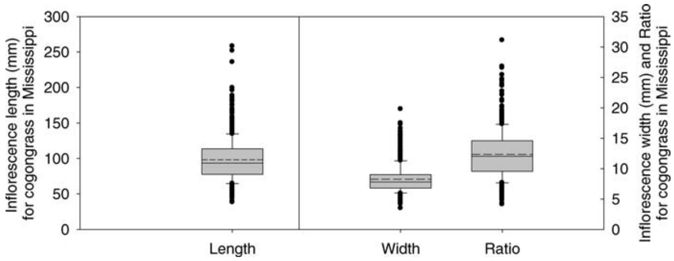

Figure 4. Box plot of inflorescence length (in millimeters), width (in millimeters), and the length-to-width ratio for cogongrass (*Imperata cylindrica*) biotypes in Mississippi. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed 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 percentiles, and solid dots indicate outliers. The number of independent observations is 486.

plants grown in the greenhouse under the same temperature regime and soil mixture (Table 1). This would be expected because cogongrass samples were provided a constant environment, watered daily, and the soil mixture contained added nutrients from the potting media. Although each accession possessed larger leaves than the field-collected specimens did, there were no distinguishable shifts in leaf length and width when compared with the other cogongrass accessions.

Soil Characteristics for Cogongrass Populations. Soils from cogongrass sites for various physiographic or land resource use areas in Mississippi were extremely diverse (Figures 5 and 6). Active growth, spread, and inflorescence production occurred at each of these cogongrass population and soil sample sites. Cogongrass was collected from almost the entire soil-texture range (sand, silt, and clay) as expected for Mississippi (Figure 5). Averaged over all cogongrass population sites, the sand, silt, and clay content

Table 1. Two-tailed *t* test for differences in cogongrass leaf length, leaf width, and leaf length-to-width ratio between field-collected and greenhouse-grown conditions within the same soil type.

Parameter	Leaf length	Leaf width	Ratio
	cm	mm	
Field	27.7[a] (12.9)[b]	5.1 (1.4)	5.3 (1.7)
Greenhouse	66.3 (14.1)	9.0 (1.4)	7.4 (1.7)
P value[c]	< 0.0001	< 0.0001	< 0.0001

[a] Values are the means of 44 paired observations.

[b] Parenthetic values are the standard deviations from the means.

[c] P value was generated using a two-tailed, paired *t* test.

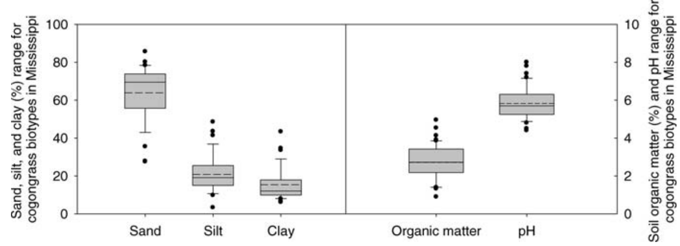

Figure 5. Box plots for sand, silt, clay, organic matter content, and soil pH where cogongrass (*Imperata cylindrica*) is known to occur in Mississippi. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates 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 percentiles, and solid dots indicate outliers. The number of independent observations is 44 for the percentage of sand, silt, and clay, and 53 for percentage of organic matter and pH.

averaged 64, 21, and 15%, respectively. The percentage of sand was highest (> 60%) in soils from cogongrass population sites sampled in the Coastal Pine Meadows and Longleaf Pine Belt regions and lowest (< 47%) from cogongrass population sites in the Black Prairie, Delta, and Jackson Prairie regions. Most (90%) soils ranged from 34 to 79% sand. The percentage of silt in soils from cogongrass population sites was highly variable throughout Mississippi. Of the cogongrass population sites samples, 90% ranged from 10 to 42% silt. The lowest silt content was from the cogongrass population site sampled in Clarke County (3%) in the Longleaf Pine Belt. From cogongrass population sites, percentage of clay was highest in soils from the Black Prairie, Delta, and Jackson Prairie regions (> 23%) and was lowest (< 12%) in soils from various

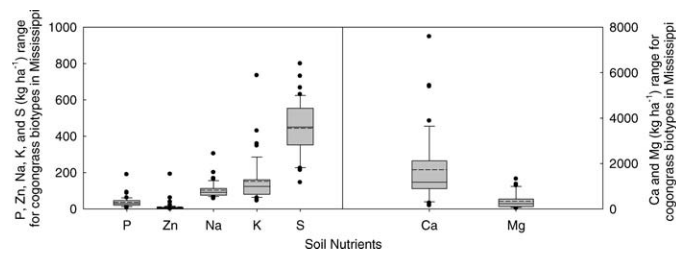

Figure 6. Box plots for soil nutrient levels (in grams per cubic meter) where cogongrass (*Imperata cylindrica*) is known to occur in Mississippi. The boundary of the box closest to zero indicates the 25th percentile, a solid line within the box marks the median, a dashed line within the box delineates 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 percentiles, and solid dots indicate outliers. The number of independent observations is 53.

Table 2. Correlation of soil physiochemical properties with edaphic characteristics of cogongrass biotypes collected from within Mississippi.

Soil	Inflorescence length	Inflorescence width	Inflorescences ratio[a]	Leaf length	Leaf width	Leaf ratio[a]
Sand	−0.1055	−0.0323	−0.0888	−0.1503	−0.18664*	−0.0588
Silt	0.2353***[a]	.1511*	0.1313*	0.2106*	0.3141***	0.0401
Clay	0.0352	0.1704**	−0.1061	0.1035	0.0603	0.0945
Organic matter	0.0604	0.2435***	−0.1406*	−0.0494	0.0399	−0.0998
pH	−0.2651****	−0.2651****	−0.0219	0.0343	0.0759	−0.0120
P	0.2538****	0.0605	0.2317***	0.3602****	0.2747**	0.2742**
K	0.20618**	0.1782**	0.0779	0.2687**	0.1996*	0.2094*
Ca	−0.05154	0.0119	−0.0679	0.1588	0.1259	0.1168
Mg	0.0074	0.0621	−0.0458	0.1434	0.1580	0.0701
Zn	0.0206	−1205	0.1258	0.2039*	0.2769**	0.0578
S	0.0601	0.2432***	−0.1407*	−0.0483	0.0416	−0.0997
Na	0.2418***	0.0978	0.1845**	−0.0129	−0.0758	0.0431

[a] Length-to-width ratio.

* Slope is significant at $P \leq 0.05$.

** Slope is significant at $P = 0.01$.

*** Slope is significant at $P = 0.001$.

**** Slope is significant at $P = 0.0001$.

sites in the Coastal Pine Meadows, Longleaf Pine Belt, and North Central Plateau regions. Most (90%) of the clay content in the soils ranged from 8 to 34%. These ranges are typical for the regions of Mississippi and represent soils derived from different parent materials (Vanderford 1962; 1975). Some of these areas are alluvial deposits, especially in the Delta region, whereas others have developed in wind-blown loess areas, such as the Loess Bluff region.

Like textural data, soil pH from cogongrass collection sites was highly variable and ranged from 4.4 (extremely acidic) for soils from George and Green counties in the Longleaf Pine Belt region to 8.0 in marl soils above and adjacent to chalk outcrops in Oktibbeha County in the Black Prairie region (Figure 5). Most of the cogongrass population sites (90%) were from soils with a pH that ranged from 4.5 to 7.4. For most agronomic crops, soils with a pH below 5.5 would require the addition of lime for optimum production (Vanderford 1962; 1975). Excellent cogongrass growth and inflorescence production were observed from areas with low to high pH from which plant and soil samples were collected; in fact, length and diameter of cogongrass inflorescences were negatively correlated with soil pH (Table 2).

The highest percentage of organic matter for the cogongrass populations was recorded from George and Jackson counties (> 4.3%) in the Longleaf Pine Belt and Coastal Pine Meadows regions, and the lowest was from a highly disturbed roadside soil in Grenada County (0.9%) in the North Central Plateau region. From all cogongrass population sites, 90% of the organic matter ranged from 1.4 to 4.0% with a mean of 2.7% (Figure 5). In Mississippi, organic matter content in soils varies based on native vegetation or on the crop being grown, such as a meadow or pasture (Vanderford 1962; 1975). Organic matter is higher in soils under native vegetation, meadows, and pastures than in soils that are highly tilled or disturbed, oxidizing the organic matter (Vanderford 1962; 1975). Inflorescence diameter was positively correlated with soil organic content, but leaf dimensions showed no differences among cogongrass populations from areas with low or high organic matter content (Table 2).

The highest soil level of P (190 kg ha^{-1}) was from a cogongrass population site on a catfish pond levee in Washington County in the Delta region and was lowest (6 kg ha^{-1}) at sites from Grenada and Newton in the Central and Jackson Prairie regions. Levels of P ranged from 14 to 60 kg ha^{-1} from 90% of the cogongrass population sites sampled (Figure 6). The highest soil level of extractable K (734 kg ha^{-1}) was from cogongrass population sites in Oktibbeha County in the Black Prairie region, and the lowest K levels (46 kg ha^{-1}) were from Simpson County in the Longleaf Pine Belt region. Levels of extractable Ca from cogongrass population sites ranged from > 7,620 kg ha^{-1} in the Black Prairie, Jackson Prairie, and Loess Bluff regions to < 169 kg ha^{-1} from Winston County in the North Central Plateau region and Jefferson Davis and Jones counties in the Longleaf Pine Belt region. Levels of extractable Mg from cogongrass population soils were highest (1,090 kg ha^{-1}) from Grenada County in the North Central Plateau region and lowest (26 kg ha^{-1})

from Oktibbeha County in the Interior Flatwoods region. Soil levels of Zn were highest (190 kg ha^{-1}) from cogongrass population sites in Lauderdale County in the Longleaf Pine Belt region and lowest ($<$ 1.2 kg ha^{-1}) in Clarke, Greene, and Wayne counties also in the Longleaf Pine Belt region. From cogongrass population sites, soil levels of S based on estimates of organic matter were highly variable throughout Mississippi. The highest S content soils from cogongrass population sites included a number of counties in the Coastal Pine Meadows, Jackson Prairie, Longleaf Pine Belt, and Pontotoc Ridge regions ($>$ 500 kg ha^{-1}), and the lowest S content level (146 kg ha^{-1}) was from Grenada County in the North Central Plateau region. Soil content of extractable Na from cogongrass population sites was the most variable from one region to another and within regions. The highest Na levels from cogongrass population sites were from the Coastal Pine Meadows, Longleaf Pine Belt, and North Central Plateau regions, and the lowest Na levels were scattered among regions. Throughout Mississippi, Na levels ranged from 68 to 150 kg ha^{-1} for 90% of the cogongrass populations.

From personal observations in Mississippi, the only areas and soils that cogongrass does not seem to thrive in are those that are persistently saturated with water. These areas are flooded or maintain maximum saturation for much of the growing season. However, in many areas of Mississippi, cogongrass was observed growing adjacent to waterways, on stream and river banks, levees, and sandbars and on the margins of wetlands in a wide array of soils.

The diversity of soils from cogongrass population sites is representative of the diverse soil characteristics for Mississippi soils. For instance, pH of Mississippi soils range from 4.0 to 8.4 with pH of most ($<$ 90%) soils ranging between 4.5 and 7.8 (Vanderford 1962; 1975). The wide range of pH (4.4 to 8.0) for soils from cogongrass population sites (Figure 5) is a wider range than optimum soil pH for agricultural crop production in Mississippi. Most agronomic crops produce optimum growth between pH 6.0 and 7.0. Although crops will continue to grow, adverse soil reactions (i.e., low and high pH) can affect the availability of other nutrients. For soybean [*Glycine max* (L.) Merr], pH of $<$ 6.0 reduces nodule development and symbiotic nitrogen fixation.

Cogongrass Morphology vs. Soil characteristics. Cogongrass leaf blade length, width, and length-to-width ratio for field-collected specimens were less than those grown in the greenhouse in the same soil mixture (Table 1). Longer and wider leaves could be expected for greenhouse plants because cogongrass plants were provided additional fertility from the soil mixture, uniform daily water, and some shading from greenhouse glass. Morphology (leaf and inflorescence parameters) among individual cogongrass accessions did not differ significantly among accessions between the native soils and greenhouse soil mixture.

Based on field-sampled cogongrass plants and soils, there were positive correlations between leaf length and Ca, K, Mg, P, Zn, and the percentage of sand and silt (Table 2). Positive correlations were detected between field-collected cogongrass leaf width and Ca, P, Mg, and the percentage of sand and silt. For cogongrass leaf length-to-width ratio, only K and P were positively correlated. Positive correlations were detected between inflorescence length and Na, P, and pH; between inflorescence width and S, based on organic content, organic matter, and pH; and between the inflorescence length-to-width ratio for S and organic matter. Cogongrass morphology (leaf length, width, leaf length-to-width ratio, and inflorescence length) was most consistently correlated with soil P.

These data demonstrate that leaf and inflorescence morphology of cogongrass in nature are variable and that some soil characteristics correlate with cogongrass phenotypic expression; however, these correlations are generally weak in nature (i.e., no $r^2 > 0.13$). These data also demonstrate that cogongrass grows, spreads, and flowers over a wide range of soil textures, pH, organic matter, and soil nutrients. Its ability to grow in a diverse range of soils, as presented here, in addition to its rapid growth and competitiveness, allelopathy, and survival after fire, are all traits that make cogongrass one of the world's most troublesome weeds (Coile and Shilling 1993; Dozier et al. 1998; Eussen and Wirjahardja 1973; Garrity et al. 1996; Bryson and Koger 2004; Bryson et al. 2004; Lippincott 2000; Soerjani and Soemarwoto 1969; Willard et al. 1990). The spread of cogongrass into areas previously not infested throughout Mississippi is highly likely based on its adaptability and growth in a wide range of soils and environments presented here. In fact, Holly and Ervin (2007) evaluated cogongrass establishment and growth from seed in soils from three recently invaded areas of Mississippi (Delta, Pontotoc Ridge, and Black Prairie regions); they found excellent growth in all the soils tested, but reproduction was not evaluated. Brewer and Cralle (2003) determined cogongrass invasion was reduced in a longleaf pine (*Pinus palustris* Mill.) savanna with the addition of P. Additional research is needed to determine whether fertile seed are produced from cogongrass plants growing in various soils and to evaluate the genetic variability within these and additional cogongrass populations and determine how they differ from Brazilian satintail and satintail throughout the United States.

The observed breadth of soil conditions under which cogongrass was observed is very similar to observations for other native or exotic grasses that are already widespread in Mississippi, e.g., broomsedge (*Andropogon virginicus* L.) and johnsongrass [*Sorghum halepense* (L.) Pers.](personal observation). Other researchers have found strong similarities in soil conditions under which common native and nonnative plant species occur. For example, Porazinska et al. (2003) found that not only were soil characteristics similar among areas occupied by native and nonnative plants but also that these similarities extended to the soil microbial assemblage, composition, and soil processes, such as nitrogen mineralization. In experiments using serpentine soils, Harrison et al. (2001) also found few to no statistically significant relationships between soil parameters and performance of two invasive species, wild oat (*Avena fatua* L.) and soft brome (*Bromus hordeaceus* L.). Additionally, but not surprisingly, the general pattern reported here of positive correlation between plant growth parameters and soil fertility is a common occurrence in both observational (Gelbard and Harrison 2003) and experimental (Huenneke et al. 1990) studies of invasive grasses. Thus, although cogongrass would be expected to spread most rapidly in fertile soils, there is little evidence to suggest soil characteristics alone could limit its spread within Mississippi or, most likely, within adjacent states as well.

Sources of Materials

[1] Mitutoyo Digital Plastic Caliper, Forestry Supplier, Inc., 205 West Rankin Street, Jackson, MS 39201.

[2] Jiffy mix, Jiffy Products of America Inc., Batavia, IL 60510.

[3] Plant and Soil Sciences, Soil Testing and Plant Analysis Laboratory, Mississippi State University Extension Service, Mississippi State University and U.S. Department of Agriculture Cooperative Extension Service, Box 9610, Mississippi State, MS 39762.

[4] Statistical Analysis Systems (SAS) software, Version 9.1, SAS Institute Inc., Box 8000, SAS Circle, Cary, NC 27513.

[5] Sigma Plot 10.0, Systat Software Inc., San Jose, CA 95110.

[6] Microsoft Excel 2003, Microsoft Corporation, Redmond, WA 98052.

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