28 COGON GRASS

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PEST STATUS OF WEED

Cogon grass, *Imperata cylindrica* (L.) Beauv., has been ranked as one of the ten worst weeds of the world (Holm *et al.*, 1977) (Fig. 1). In tropical and subtropical regions around the globe, this aggressive, rhizomatous perennial is generally considered a pernicious pest plant due to its ability to successfully disperse, colonize, spread, and subsequently compete with and displace desirable vegetation and disrupt ecosystems over a wide range of environmental conditions (Holm *et al.*, 1977; Brook, 1989; Bryson and Carter, 1993; Dozier *et al.*, 1998). These characteristics and consequences of cogon grass infestations are similarly evident even within the native or endemic range in the Eastern Hemisphere, as it has long been considered one of Southeast Asia's most noxious weeds (Brook, 1989).

Figure 1. Cogon grass, *Imperata cylindrica,* (a) a partial plant showing stems, leaves, roots and elongating rhizomes; (b) a stem with leaves; (c) plume-like inflorescence of many paired flowers. (Modified from Coile and Shilling, 1993.)

Nature of Damage

Economic damage. In areas other than closed-canopy forests or plantations, where cogon grass survives poorly due to shading, and heavily cultivated lands, where it is kept in check mechanically, infestations are treated by relatively costly, laborious, and repetitive control measures. Currently the most effective management strategies in the United States have involved integrating mechanical (e.g., discing, mowing), cultural (e.g., burning), chemical (e.g., herbicide applications of glyphosate and imazapyr), and revegetation methods (Shilling and Gaffney, 1995; Dozier *et al.*, 1998). However, a single herbicide application can cost as much as $400/ha. Impacts on non-target species from herbicide application are often severe, creating disturbances that allow for the re-invasion by cogon grass or secondary invasion by other weedy species (Gaffney and Shilling, 1996). For both economical and environmental reasons, the currently recommended control strategies often are unacceptable, necessitating consideration of some form of classical biological control (Shilling and Gaffney, 1995; Dozier *et al.*, 1998). There are only a few localized benefits of cogon grass. These include use for thatch, forage, erosion control, paper making, and bedding material for livestock. There also are minor traditional uses for human foods and medicines (Holm *et al.*, 1977; Watson and Dallwitz, 1992). Silica bodies in the leaves, razor-like leaf margins, relatively low yields, and very low nutritive and energy values make cogon grass a poor forage (Coile and Shilling, 1993; Colvin *et al.*, 1993).

Outside of the United States, cogon grass has been reported as a problem in more than 35 annual and perennial crops, including rubber, coconut, oil palm, coffee, date, tea, citrus, forests, field crops (rice), and row crops (corn) (Holm *et al.*, 1977; Brook, 1989; Waterhouse, 1999). Problems with cogon grass often have arisen on lands cleared of natural forest, which are then quickly colonized by cogon grass before cultivation, during plantation establishment and growth, or soon after the abandonment of land used for short-duration shifting agriculture (Brook, 1989). Left unchecked, colonized areas become densely infested with cogon grass, are difficult to convert to other vegetation, and are fire-prone climax communities (Seth, 1970). Cogon grass infestations damage crops through competition, causing suppressed growth, reduced yields, and delayed harvests. In addition to being highly competitive, the rhizomes of cogon grass may physically injure other plants and appear to be allelopathic in certain situations (Brook, 1989; Bryson and Carter, 1993).

Since the introduction of cogon grass into Alabama around 1912, and Mississippi and Florida in the early 1920s, infestations in the southeastern United States have created pest problems in lawns, pastures, golf courses, roadways, railways and other right-of-ways, mine reclamation areas, plantations, forests (Fig. 2), and recreational and natural areas (Bryson and Carter, 1993; Dozier *et al.,* 1998; Willard *et al.,* 1990).

Figure 2. A severe infestation of *Imperata cylindrica* in a longleaf pine upland in central Florida.

Ecological damage. Cogon grass' tendency to form dense, persistent and expanding stands allows it to displace other vegetation. Its abundant biomass prevents recruitment of other plants and changes the properties of the litter and upper soil layers (Lippincott, 1997). In Florida sandhill communities, cogon grass stands can destroy the habitat of rare species such as gopher tortoises (*Gopherus polyphemus* [Holbrook]) and indigo snakes (*Drymarchon corais couperi* [Daudin]) (Shilling *et al.*, 1995; Lippincott, 1997). Cogon grass also is flammable and increases fine-fuel loads. Resultant fires tend to be hotter and taller, and potentially more frequent, even in communities adapted to frequent fire (e.g., longleaf pine [*Pinus palustris* Mill.] and wiregrass [*Aristida beyrichiana* Trin. and Rupr.] cover type). Extensive rhizome reserves of cogon grass enable it to quickly regrow. Also, fires induce flowering and seeding, reduce competition from other plants, and create openings for seedling establishment (Bryson and Carter, 1993; Dozier *et al.,* 1998; Shilling *et al.,* 1995).

Extent of losses. More than 500 million ha of cogon grass have been estimated to occur worldwide (Holm *et al*., 1977). In Asia, where an estimated 200 million ha are dominated by cogon grass, infested areas are increasing at a rate of 150,000 ha annually (Soerjani, 1970). At least 100,000 ha. are estimated to be infested in Alabama, Florida, and Mississippi (Dickens, 1974; Schmitz and Brown, 1994).

Geographical Distribution

Cogon grass has been reported as a weed in 73 countries and on all six continents. It is widely distributed in Africa, Australia, southern Asia, and the Pacific Islands, and less extensively distributed, or a less serious problem, in southern Europe, the Mediterranean, the Middle East, Argentina, Chile, Colombia, the Caribbean, and the southeastern United States (Fig. 3). It has been found at latitiudes from 45°N (Japan) to 45°S (New Zealand), and from sea level to over 2,000 m elevation (Holm *et al.,* 1977).

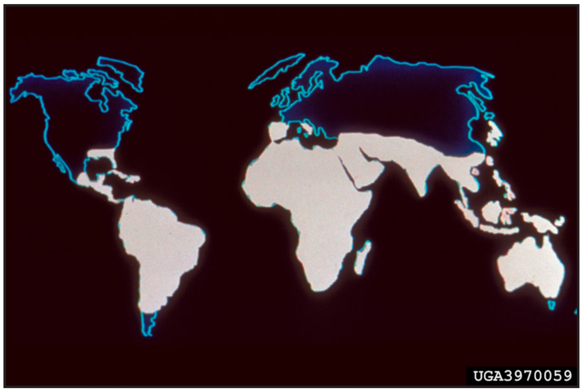

Figure 3. The general distribution of *Imperata cylindrica* throughout the world, depicted by areas of white. (Based on information from Holm *et al.*, 1997.)

In the United States, cogon grass occurs in Florida, Georgia, Alabama, Mississippi, Louisiana, South Carolina, and Texas (Fig. 4). It is distributed throughout Florida (Langeland and Burks, 1998) and is widely distributed in Mississippi (Patterson and McWhorter, 1983; C. Bryson, pers. comm.), and southern Alabama (Dickens, 1974). It is established at some locations in Louisiana, South Carolina (Allen *et al*., 1991; Bryson and Carter, 1993), southern Georgia (Byrd and Bryson, 1999; Coile, pers. comm.), and in Tyler County, Texas (USGS, 1999).

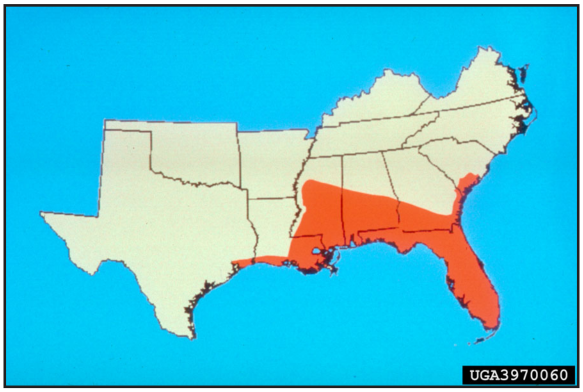

Figure 4. The general distribution of *Imperata cylindrica* in the United States, depicted by area in red.

A red-tipped ornamental cultivar, *Imperata cylindrica* 'Rubra,' is extensively promoted as Red Baron, or Japanese Blood Grass, in many other states (Hall, 1998; C. Bryson, pers. comm.). This red-colored ornamental cultivar can revert to the green form, which is the invasive variety (Greenlee, 1992; Dozier *et al*., 1998; Hall, 1998; C. Bryson, pers. comm.). Plants propagated by tissue culture, rather than division, seem particularly prone to revert to the aggressively spreading green form (Greenlee, 1992).

Imperata cylindrica 'Rubra' is very cold tolerant (Shilling *et al*., 1997), and has persisted in Michigan for several years in an ornamental garden (C. Bryson, pers. comm.). Should this cold-tolerant cultivar be introduced into the southeast and hybridize with *I. cylindrica* var. *major*, hybrids might exhibit both invasiveness and cold tolerance, allowing for significant range extension to the north and west (Shilling *et al*., 1997).

BACKGROUND INFORMATION ON PEST PLANT

Taxonomy

The descriptions of the genus (*Imperata* Cirillo. Pl. Rar. Neap. 2:26 1792) and species (*Imperata cylindrica* [L.] Beauv., Ess. Nouv. Agrost. 7. 1812) occurred in 1792 and 1812, respectively. Gabel (1982) identified 29 synonyms for *I. cylindrica*.

The genus *Imperata*, family Poaceae, subfamily Panicoideae, supertribe Andropogonodae, tribe Andropogoneae (Gabel, 1982; Watson and Dallwitz, 1992), subtribe Saccharinae (Clayton, 1972; Campbell, 1985), includes nine species worldwide (Gabel, 1982). Hubbard *et al*. (1944) recognized five varieties of *I. cylindrica* worldwide: *major, africana, europaea, latifolia*, and *condensata*, with the most widely distributed variety, *major,* occurring in the United States.

The global cultural impact and importance of *I. cylindrica* is suggested by the nearly 100 common names given to it (Holm *et al*., 1977). Some of the most widely recognized of these are blady grass, alang-alang, lalang, cogon grass, and speargrass.

Biology

Cogon grass is an erect, perennial grass, with linear to lanceolate, mostly basal leaf blades up to 1.5 m tall and to 2 cm wide (Gabel, 1982; Lippincott, 1997; Langeland and Burks, 1998). Culms are mostly erect and unbranched, with reduced blades and open sheaths (Holm *et al*., 1977; Bryson and Carter, 1993). Pubescent at their base, leaf blades have a noticeably off-center whitish midvein and scabrous margins (Fig. 5). Varying in form, from loose to compact tufts, cogon grass is strongly rhizomatous with extensive, sharply pointed, creeping scaly rhizomes (Holm *et al*., 1977; Langeland and Burks, 1998). Panicles (6 to 22 cm long by 3.5 cm wide) are plume-like, cylindrical, dense, and silvery (Holm *et al*., 1977; Lippincott, 1997; Langeland and Burks, 1998). Spikelets are 3 to 6 cm long, crowded and paired on unequal stalks, with each spikelet surrounded by white hairs up to 1.8 mm in length (Bryson and Carter, 1993; Langeland and Burks, 1998)

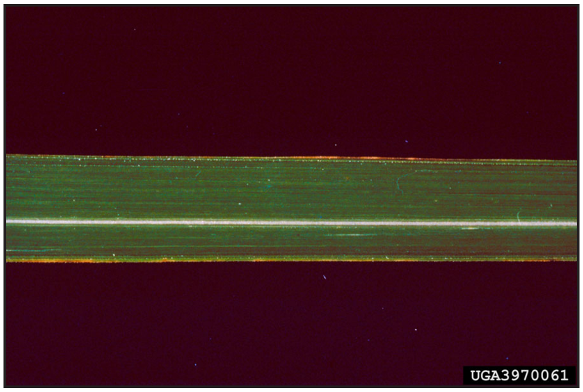

Figure 5. Portion of leaf blade showing off-center midrib and scabrous leaf margins. (From Coile and Shilling, 1993.)

Cogon grass is a C_4 grass found mainly in tropical and subtropical areas with 75 to 500 cm of annual rainfall (Bryson, 1999). Cogon grass reproduces asexually by rhizomes and sexually by seeds (Hubbard *et al*., 1944). *Imperata cylindrica* is the most morphologically variable species in the genus *Imperata* (Gabel, 1982). Rhizomes are very resistant to heat and breakage, and may penetrate soil up to 1.2 m deep, but generally occur in the top 0.15 m in heavy clay soils, and 0.4 m of sandy soils (Holm *et al*., 1977; Bryson and Carter, 1993). Rhizome biomass can reach 40 tons of fresh weight per hectare (Terry *et al*., 1997; English, 1998), and regrowth potential of roots is a critical issue in development of control methodologies, including biological control. Regeneration from rhizome segments as small as 2 mm has been observed. Success of segment regeneration is determined by the original location of the segment on the rhizome, including proximity to, or inclusion of, axillary and apical buds, as well as environmental conditions (Holm *et al*., 1977; Wilcut *et al*., 1988a; Gaffney, 1996; English, 1998). Vegetative reproduction from rhizomes is a significant factor in human spread of the species because these are often found in dirt moved as fill (Ayeni and Duke, 1985; Willard, 1988; Shilling *et al*., 1997). Cogon grass rhizomes exhibit apical dominance (English, 1998), which may be an important factor both in limiting the local spread of cogon grass via rhizomes (Wilcut *et al*., 1988a), and reducing the efficacy of herbicidal control due to sub-lethal herbicide sink activity in dormant axillary buds (Shilling *et al*., 1997; English, 1998).

Incapable of self-pollination (Gabel, 1982), *I. cylindrica* produces viable seed only when cross-pollinated (McDonald *et al*., 1996), and the success rate of outcrossing is low (Shilling *et al*., 1997). Cogon grass produces as many as 3,000 seeds per plant (Holm *et al*., 1977). Having no dormancy, seeds are highly germinable (90% or higher), but often with low spikelet fill (less than 40%) in natural populations. Seed viability is highest for seeds less than three months old (Shilling *et al*., 1997). Sexually produced seeds are capable of long distance dispersal, ranging from an average of 15 m (Holm *et al*., 1977) to 100 m (Shilling *et al*., 1997). Flowering is variable between individual plants and stands, but generally occurs in spring or fall, and often in response to a range of disturbances (e.g., burning, mowing, soil disturbance) throughout the year. Flowering has been observed throughout the year in most of Florida. (Holm *et al*., 1977; Willard, 1988). Cogon grass seedling survivorship is low with less than 20% of emergent seedlings surviving to one year.

Cogon grass has invaded a variety of habitats, from highly xeric uplands to fully shaded mesic sites. Sandhills, flatwoods, hardwood hammocks, sand dunes, grasslands, river margins, swamps, scrub, and wet pine savanna communities all are invaded by cogon grass. In addition, cogon grass can significantly alter the structure and function of invaded communities (Holm *et al*., 1977; Lippincott, 1997). While cogon grass is tolerant of wide variations in soil fertility, organic matter, and moisture, it grows best in relatively acidic soils (pH 4.7) (Hubbard *et al*., 1944; Wilcut *et al*., 1988a). Moosavi-nia and Dore (1979) found that increasing shade levels of more than 50% reduces shoot dry weight and both rhizome length and dry weight; causing an increase in the shoot/rhizome ratio. Temperature markedly affects shoot and rhizome growth, with increased growth occurring at 29°/23°C (day/night), compared to lower temperatures (Patterson *et al*., 1980). In general, rhizomes do not exhibit extreme cold hardiness, but stands of cogon grass have survived temperatures as low as –14°C (Wilcut *et al*., 1988b). In greenhouse studies, King and Grace (2000a) found cogon grass to be most sensitive to soil saturation during early establishment (following seed germination). Cogon grass invasion by seed may therefore be limited by excessive moisture in the spring, during early seedling development. Once established, cogon grass becomes increasingly tolerant of flooding. Cogon grass seed germination rates and survival rates of newly germinated seedlings were not significantly affected by gap size or disturbance type (King and Grace, 2000b). Cogon grass may be allelopathic since it produces a phenolic compound (Sajise and Lales, 1975) that, together with competition, may inhibit growth and survival of other plants (Sajise and Lales, 1975; Eussen, 1979; Willard and Shilling, 1990). However, Lippincott (1997) suggests that other explanations may exist for the competitive success of cogon grass and that the existence of allelopathy is not certain.

Analysis of Related Native Plants in the Eastern United States

The genus *Imperata* belongs to the tribe Andropogoneae, in the subtribe Saccharinae Griseb. (Clayton, 1972). Of the nine species of *Imperata* worldwide, two occur in the eastern United States – *I. cylindrica* and *Imperata brasiliensis* Trin. A third species, *Imperata brevifolia* Vasey, occurs in the western United States (Gabel, 1982). Though considered by Gabel (1982) to be native to Florida, South America, Central America, southern Mexico, and Cuba, *I. brasiliensis* is listed as an introduced Federal Noxious Weed in the United States, as well as a state-level noxious weed in Florida and North Carolina (USDA, 1999). *Imperata cylindrica* has been distinguished from *I. brasiliensis* based on number of stamens. *Imperata cylindrica* has two stamens and *I. brasiliensis* has one stamen (Gabel, 1982). However, overlapping variability often occurs in this character, and Hall (1998) has suggested the possibility that the two species may be the same. *Imperata brasiliensis* and *I. cylindrica* have undergone human-disturbance-associated range extension (Brook, 1989; Hall, 1998). Evidence of frequent hybridization between the two species has been observed (Gabel, 1982), and all seed produced by crossing the two species in a study by McDonald germinated (Shilling *et al.,* 1997).

Campbell (1985) agrees with Clayton (1972, 1981), placing *Imperata* Cirillo in the subtribe Saccharinae Griseb. Other genera in *Saccharinae* include *Erianthus* Michx. and *Microstegium* Nees. Dahlgren *et al.* (1985) placed *Imperata* in the *Saccharum* Group, including *Saccharum* L., *Imperata*, and *Eulaliopsis* Honda. Hitchcock and Chase (1951) consider *Miscanthus* Andersson, *Saccharum, Erianthus,* and *Microstegium* Nees closely related to *Imperata.*

Outside the genus *Imperata*, the species most closely related to *I. cylindrica* that are native to the eastern United States are five species in the genus *Erianthus* (Hitchcock and Chase, 1951; Clayton, 1972; Campbell, 1985). They are *Erianthus strictus* Baldwin (narrow plumegrass), *Erianthus contortus* Baldwin ex Elliot (bent-awn plumegrass), *Erianthus alopecuroides* (L.) Elliot (silver plumegrass), *Erianthus coarctatus* Fernald, and *Erianthus giganteus* (Walt.) Muhl. (sugarcane plumegrass). All five species occur in soil types and habitats that overlap with those of cogon grass.

While comparatively few native species are closely related to *I. cylindrica*, several notable non-native species should be mentioned. Mangoendihardjo and Soerjani (1978) felt that the biological control potential of cogon grass in Indonesia was limited by its close relationship to many graminaceous food plants. In the United States, the closeness of this relationship is of greatest concern with sugarcane (*Saccharum* spp.), with approximately 88% of domestic cane sugar production in the United States occurring in Florida, Louisiana, and Texas (Haley, 2000). Fertile, intergeneric hybrids have been procured by crossing species of *Imperata* with those of *Saccharum* (Gabel, 1982; Watson and Dallwitz, 1992).

Additionally, several species of the genera *Miscanthus* and *Microstegium* have been introduced into the eastern United States. *Miscanthus sinensis* (Andersson) has been identified as invading clearings in wooded areas throughout the eastern United States (Randall and Marinelli, 1996). *Microstegium vimineum* (Trin.) A. Camus, Japanese stilt grass, is an invasive, exotic grass currently established in sixteen eastern states (Swearington, 1997).

HISTORY OF BIOLOGICAL CONTROL EFFORTS IN THE EASTERN UNITED STATES

Area of Origin of Weed

The exact center of origin of *I. cylindrica* is in doubt, but is believed to be East Africa (Evans, 1987, 1991). *Imperata cylindrica* var. *major* originated in Southeast Asia and occurs throughout the tropical and warmer regions of the world, from Japan to southern China, through the Pacific islands, Australia, India, East Africa, and the southeastern United States (Holm *et al*., 1977). Differences in the areas of origin of the various introductions of *I. cylindrica* var. *major* in the United States are a likely source of genetic variation in the growth potential and range of different populations and ecotypes present in the United States (Patterson *et al*., 1980; Gabel, 1982).

Areas Surveyed for Natural Enemies

Despite the importance of the problems caused by cogon grass throughout the tropical areas of the world, biological control efforts have been few and rather piecemeal (Caunter, 1996). This weak effort can be explained, in large part, by the historical emphasis in weed biological control projects on insects as biological control agents and lack of host specific insects associated with weedy grasses (Evans, 1991; Julien and Griffiths, 1998). This has resulted in a general absence of attempted, and thus of successful, biological control projects against grasses (Waterhouse, 1999). Other complicating factors include existence of closely related grasses of economic or ecologic value (Holm *et al.,* 1977) and potential conflict of interest with groups that value cogon grass (Evans, 1991). Similarly, little information exists on the pathogens of cogon grass and their potential as biological control agents (Evans, 1991), even though pathogens often exhibit specific host associations (McFadyen, 1998). It is likely that fungi associated with cogon grass are more diverse and abundant than indicated by herbarium records (Evans, 1991; Charudattan, 1997; Minno and Minno, 2000).

Considerable scope exists for additional field surveys, given that *I. cylindrica* is distributed worldwide, has five major geographical varieties, and an undetermined center of origin. Locations of potential interest would include Southeast Asia, from which the common form *major* is believed to have come; East Africa, believed to be the center of origin; and the Mediterranean, where the plant is not a serious weed problem.

Ravenell (1985) lists twelve pathogenic fungi identified on cogon grass in Alabama. From 1994 to 1997, field surveys looking for diseased cogon grass or related grasses in Florida collected 70 fungal isolates. Recently, Minno and Minno (1999, 2000) surveyed cogon grass in Florida, Mississippi, and Alabama, looking for native or naturalized enemies.

Limited surveys also have been made in East Africa and Southeast Asia. Surveys of *I. cylindrica* in East Africa did not locate any suitably monophagous insects (Evans, 1991). In Egypt (Giza), Tawfik *et al.* (1976), and Ammar *et al.* (1977) periodically surveyed *I. cylindrica*, and respectively found one Hemiptera species, and three planthopper species.

A review of the literature on insects associated with *I. cylindica* in southeast Asia concluded that none of the recorded species were promising biological control agents (Syed, 1970). However, field surveys in Java from 1973 to 1976 identified 15 species of insects associated with *I. cylindrica* (Mangoendihardjo, 1980). Apart from the United States, field surveys for pathogens of *I. cylindica* have been made only in Malaysia (Caunter, 1996).

Natural Enemies Found

Literature records and on-line databases suggest an extensive number of potential natural enemies, including pathogens, arthropods, and other invertebrates found within and outside of North America. Outside the United States, 66 pathogens (primarily fungi), 42 insects, two nematodes, and one mite have been found on *I. cylindrica*. Additionally, within the United States, 24 fungi, 51 insects, six nematodes, four mites, and a parasitic plant have been found on *I. cylindrica*, primarily by Minno and Minno (1999, 2000).

Of the arthropods recorded on cogon grass worldwide, only one is repeatedly reported to be host specific to *I. cylindrica* – the gall midge *Orseolia javanica* Kieffer and van Leeuwen-Reijnvaan (syn. = *Orseoliellia javanica*). Introduction of this midge to infested areas outside of southeast Asia was recommended as early as 1975 (Mangoendihardjo, 1975), but no introductions were ever made. Other invertebrates from outside of the United States that may be host specific and damaging to cogon grass include the nematode *Heterodera sinensis* Chen, Zheng, and Peng (Chen *et al*., 1996), the mite *Aceria imperata* (Zaher and Abou-Awad) (Zaher and Abou-Awad, 1978), and two unidentified dipteran stem borers (Mangoendihardjo, 1980).

Evans (1987, 1991) suggested that some of the known pathogens of cogon grass should be considered for introduction to the United States as classical biological control agents. Promising species include the fungi *Colletotrichum caudatum (*Sacc.) Peck (Caunter, 1996), which recently was found on cogon grass in Florida (Minno and Minno, 2000); *Puccinia fragosoana* Beltrán (USDA, ARS, 2001); *Puccinia imperatae* Poirault (Evans, 1987); and *Sphacelotheca schweinfurthiana (*Thümen) Saccardo (Evans, 1987). Other fungi known as cogon grass pathogens pose greater difficulties because of conflicting or confusing taxonomy or insufficient information. Interestingly, the smut *S. schweinfurthiana* is common in the

Mediterranean region where *I. cylindrica* is not a serious problem (Evans, 1991). This smut has recently been found on *I. cylindrica* in Florida (Minno and Minno, 1999).

Of the pathogens detected in the United States, at least 11 fungal isolates collected from cogon and other grassy weeds in Florida have been tested for their pathogenicity to *I. cylindrica* in greenhouse trials. Of these, six (three *Bipolaris* spp., a *Drechslera* sp., and two *Exserohilum* spp.) merit further evaluation as potential bioherbicides (Charudattan, 1997). More recently Yandoc *et al.* (1999) have conducted greenhouse and miniplot trials with isolates of *Bipolaris sacchari* (E. Butler) Shoemaker and *Drechslera gigantea* (Heald and F. A. Wolf) Kaz. Ito. Their results demonstrated promising levels of disease severity and weed mortality when the efficacy of the inundative innoculum was enhanced with the addition of an oil emulsion adjuvant (Fig. 6). Further development of these two fungi as bioherbicides is continuing, but neither fungus is host specific.

Figure 6. High levels of disease and damage severity on an *Imperata cylindrica* mini-plot following treatment with a potential mycoherbicide consisting of a formulation of *Bipolaris sacchari* fungal spores, in an oil and water emulsion. (C. Yandoc, Department of Plant Pathology, University of Florida.)

Host Range Tests and Results

The only insect enemy of *I. cylindrica* that has been subjected to host range testing is the gall midge *O. javanica*. *O. javanica* was studied on corn, sorghum, five species of rice, and two other grasses, and found to be specific to *I. cylindrica* (Mangoendihardjo, 1980). Further host range testing is necessary.

The fungus, *C. caudatum* proved to be host specific to *I. cylindrica* in limited host range tests in Malaysia (Caunter and Wong, 1988), which led to an examination of its potential as a bioherbicide in Malaysia (Caunter, 1996). Applications of spore suspensions of this fungus failed to kill whole plants, but it may be possible to enhance disease severity with the addition of yeast or other amendments. Because the two fungi currently being investigated in the United States as potential bioherbicides (i.e., *B. sacchari* and *D. gigantea*) are not specific to *I. cylindrica*, host range testing of the bioherbicidal mixtures are planned (R. Charudattan, pers. comm.).

Releases Made

No releases have been made of any natural enemies.

BIOLOGY AND ECOLOGY OF KEY NATURAL ENEMIES

The alang-alang gall midge, *O. javanica*, (Fig. 7) has been considered the most important insect pest of *I. cylindrica* due to its host specificity (Mangoendihardjo, 1980; Soenarjo, 1986). No species in the genus *Orseolia* have been identified in North America (Gagné, 1989).

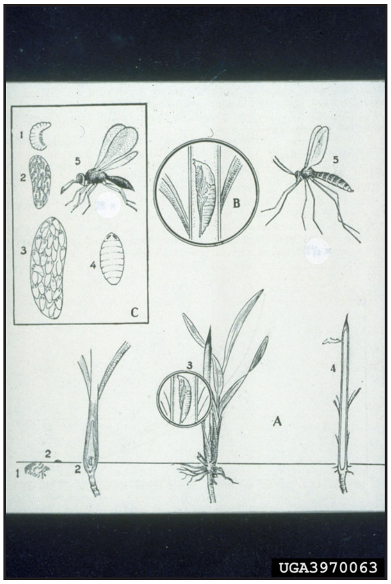

Figure 7. *Orseolia javonica* in *Imperata cylindrica*, (a) (1) eggs, (2) larva, (3) elongated gall, and (4) section of the gall following adult release, (5) adult; (b) section of gall showing the pupa; (c) life stages of chalcid wasp parasite of *O. javanica*. (From Soerjani, 1970.)

The life cycle of *O. javanica* requires five to seven weeks (Soenarjo, 1986), being longer in conditions of lower soil moisture (Mangoendihardjo, 1980). Mangoendihardjo (1980) found *O. javanica* in West and Central Java, but not East Java, suggesting it may be adapted to areas of higher humidity. In Indonesia, the highest degree of gall-midge infestation on *I. cylindrica* was observed from 250 to 300 m above sea level (Mangoendihardjo, 1980), although infestations occur up to an elevation of 800 m (Soenarjo, 1986). Densities of *O. javanica* were significantly higher in areas where *I. cylindrica* was regularly cut or slashed (Soerjani, 1970; Soenarjo, 1986). However, parasitism of *O. javanica* larvae by a chalcid wasp also increased in slashed areas (Mangoendihardjo, 1980).

Females can produce from 200 to 560 eggs, which hatch two to three days after being laid and have a 98% viability rate (Soerjani, 1970; Mangoendihardjo, 1975). After hatching, less than 2% of the larvae successfully enter the plant, primarily due to predation by ants (Mangoendihardjo, 1980). Resultant infestation of *I. cylindrica* by the gall midge varies from 0 to 18% (Mangoendihardjo, 1975).

The larva enters *I. cylindrica* between the lower leaf sheaths to penetrate the shoot apical meristem, where it forms a cell in which it develops and pupates (Soerjani, 1970). In laboratory studies, only 1% of the total eggs produced survived to adulthood (approximately 50% of the larvae that entered the plant) (Mangoendihardjo, 1980).

The potential of *O. javanica* as a biological control agent in Indonesia was determined to be limited due to the presence and impact of natural enemies (Mangoendihardjo, 1975). Key natural enemies of *O. javanica* include a parasite (Hymenoptera: Platygasteridae, *Platygaster* sp.), which has been found to attack more than 20% of field-collected larvae; and predaceous ants, which attack gravid females, eggs, and larvae (Mangoendihardjo, 1975). Three other hymenopteran larval parasites of *O. javanica* are *Obtusiclava* sp. (Pteromalidae), *Euplemes* sp. (Eupelimidae), and *Tetrastichus* sp. (Eulophidae) (Mangoendihardjo, 1980). Pupae are parasitized by the wasp *Platygaster oryzae* (Cameron) (Soenarjo, 1986). In the southeastern United States, the red imported fire ant (*Solenopsis invicta* Buren) is one potential predator that may reduce the potential of *O. javanica* to suppress *I. cylindrica*.

Infestation by *O. javanica* is likely to reduce photosynthesis due to leaf blade reduction, leading to lower rhizome carbohydrate reserves. Infestation by *O. javanica* also may vector various pathogens. However, because *O. javanica* does not directly harm the plant's rhizomes, it is unlikely to control the plant by itself (Brook, 1989).

RECOMMENDATIONS FOR FUTURE WORK

The gall midge *O. javanica* needs to be evaluated for potential introduction into the United States. It is likely to be highly host specific and may cause more damage to infested plants than suggested by the amount of tissue consumed. Removed from its native parasites and predators, *O. javanica* may prove to be an effective biocontrol agent in the United States, as occurred with the Australian bud-galling wasp, *Trichilogaster acaciaelongifoliae* Froggatt, released in South Africa against *Acacia longifolia* (Andr.) Willd. (Center *et al.,* 1995). However, gall midges are notoriously parasitized by generalist parasitoids after introduction, severely limiting their effectiveness (B. Blossey, pers. comm.).

Secondly, DNA fingerprinting (Amplified Fragment Length Polymorphisms) should be used to identify the native range of U.S. cogon grass varieties. This information could then be used to direct survey efforts to areas most likely to have the widest range of natural enemies (Evans, 1987).

Thirdly, intensive surveys of natural enemies of the native *I. brevifolia* in the southwestern United States might yield indigenous biological control agents able to attack *I. cylindrica* if introduced into the southeast. Interestingly, *I. brevifolia* is a minor component of the flora where it occurs in the southwest and has been difficult to cultivate, unlike cogon grass. However, preliminary, limited surveys of *I. brevifolia* in 2000 failed to identify any potentially useful natural enemies.

In addition to the above, work with existing and new pathogens is needed both in the area of developing effective bioherbicides and to explore the potential of possible introductions of host specific foreign pathogens.

Lastly, the most commonly practiced method of biological control of *I. cylindrica* in southeast Asia is the use of competitive vegetation (Soerjani, 1970). To control cogon grass in the United States, an integrated program of biological control and revegetation with more desirable species will be needed (Shilling *et al.,* 1998).

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