# MAPPING, CONTROL, AND REVEGETATION OF COGONGRASS INFESTATIONS ON ALABAMA RIGHT-OF-WAY

**ALDOT Research Project 930-486**

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## Alabama Department of Transportation

**and**

## Auburn University

## Alabama Agricultural Experiment Station

# MAPPING, CONTROL, AND REVEGETATION OF COGONGRASS INFESTATIONS ON ALABAMA RIGHT-OF-WAY

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August 2004

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ABSTRACT

Cogongrass is an undesired species on highway rights-of-way (ROW) due to its displacement of native and/or more manageable grasses, unsightly growth characteristic, and propensity for fire. Most importantly, ROWs provide corridors to un-infested areas, thereby expanding the range of this noxious weed. Two projects were located on Interstate 10 ROW in Baldwin Co. (AL), near Loxley (est. fall 2000) and Malbis (est. fall 2001). Both projects integrated herbicides with the subsequent revegetation of highly competitive and more desirable species. Mean control increased from 35% to 88% between a one and three year regime 12 months after treatment at Loxley. Mean control was greater at Malbis as control increased from 62% to 94% between the one and two year regimes. Fall herbicide treatments were ranked from highest control to least control as follows at Loxley: imazapyr alone, followed by the tank-mix of glyphosate plus imazapyr, followed by glyphosate alone. Fall-applied glyphosate plus imazapyr increased visual control and decreased stand density versus glyphosate alone in the study at Malbis. Spring re-treatment with glyphosate was needed to reduce density but not to increase visual control at Loxley, and was significant for neither visual control nor stand density at Malbis. The use of cover crops between fall and spring herbicide application was inconsistent in affecting control or stand density between both locations. The establishment of either bahiagrass or bermudagrass was achieved only at Malbis in a two year regime. A mowing by herbicide interaction study was also implemented to complement the Loxley and Malbis studies. Mowing alone neither positively nor negatively affected growth of cogongrass at frequencies up to twice per month. A sequential (spring followed summer) application of glyphosate gave complete above-ground control at the end of year one, however, regrowth was evident at the end of year two.

## INTRODUCTION

Cogongrass [*Imperata cylindrica* (L.) Beauv.] is an aggressive, perennial, warm-season grass that is rapidly invading the southeastern United States. Cogongrass is a non-native plant species in the U.S., recognized as a federal noxious weed under the Plant Protection Act[1]. Many states, including Alabama, include cogongrass on state noxious weed lists. The management and control of cogongrass is important from both an economic and ecological perspective. An understanding of its history, systematics and taxonomy, reproduction, habitat, and distribution is paramount to developing and maintaining control strategies.

**History.** Cogongrass arrived in the U.S. shortly after the turn of the twentieth century. Pendleton (1948) first reported the presence of cogongrass in North America, specifically in Puerto Rico and at the Florida Agricultural Experiment Station near Brooksville. Tabor (1952a) later reported that cogongrass was accidentally introduced near Grand Bay, Alabama, during the winter of 1911-1912, as packing material for satsuma orange (*Citrus unshiu* Marcow.) rootstock from Japan. Multiple introductions have occurred since that time including McNeil, Mississippi, and Gainesville, Florida (Patterson et al. 1983; Tabor 1949; Willard et al. 1990). Most attempts at introduction were intentional with the primary purpose to test its potential in forage development or soil stabilization. It should be noted that no state or federal entity has ever approved cogongrass for introduction or released cultivars for public use. Unauthorized acquisitions from plantings on agricultural experiment stations account for the majority of spread throughout Florida and Mississippi (Tabor 1952b). However, the inability of landmanagers to prevent escape from designated planting sites was quickly realized and, consequently, most intentional plantings were abandoned and spread occurred.

In its native range, cogongrass is indeed utilized as forage among other uses (Falvey 1981). In low input agricultural systems, cogongrass may support low density grazing, especially when supplemented with a legume or minerals (Falvey et al. 1981; Holmes et al. 1980). Cogongrass contains approximately 1.5 % N and has a crude protein level of less than ten percent (Falvey 1981). Typical crop usage in New Guinea, for example, involves burning, followed by grazing until the grass becomes too large and unpalatable, at which point the area is set aside for thatch production (Falvey 1981). Cogongrass is a lucrative thatch crop, as the leaves are better insulators than the traditional nipah (palm). Though cogongrass will not support high density beef cattle production, such as that found in the U.S., Falvey (1981) indicates that the vast prairies of native *Imperata* in Thailand and other countries are underutilized for subsistence forage production. In addition to ruminant forage value, Kencana and Hartiko (1980) reported that cogongrass could be used as a supplement for broiler chicken feed with positive results in growth and feed conversion. Other uses documented include paper making, medicinal tonics (rhizomes mainly), fuel, and packing material (Hubbard et al. 1944).

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[1]Plant Protection Act: Title 7, Section 7701 *et seq*. United States Code.

**Species Description.** At least two formal descriptions of the species *I. cylindrica* exist. Both Holm et al. (1977) and Hubbard et al. (1944) provide excellent descriptions of the species; therefore, only key characteristics are reviewed. Bryson and Carter (1993) summarized these characteristics best and the following description is adapted from their manuscript. Cogongrass is a perennial, $C_4$ grass (*Poaceae*) species belonging to the tribe *Andropogoneae*, subtribe *Saccharine*. Cogongrass may be found in loose to dense sods with slender, erect culms that sometimes appear stemless, arising from long, scaly, creeping rhizomes. Culms are six to 48 in. tall, rarely to 10 ft, and have one to four nodes. Nodes consist of a smooth or ciliate (fringed) sheath that may be variable in length, and a short, truncated ligule, 0.5-1 mm in length. Leaves characteristically narrow downward to a stout whitish midrib and taper from the middle to a sharp tip. The prominent midrib is distinctly off-center on older culms, however, this key feature for quick field identification is not always distinguishable on young or stressed culms (personal observation). Leaves vary in length with habitat (< 48 in.) and range from 0.25 to 0.75 in. wide. Blades are flat and smooth with hairs occurring only at the base and have scabrous margins. The panicle-type inflorescence is both solitary and terminal; it is cylindrical, distally tapered, and ranges from two to eight inches long and 0.2 to 1 inches in diameter. Individual spikelets are lanceolate to oblong (1.1 to 2.4 in.) and surrounded by silky hairs. Glumes are mostly equal, membranous, with three to nine nerves, long hairs on the lower side, and a callus base. Lemmas are 1.5 to 4 mm long, transparent, ovate, nerveless, with fine hairs and often toothed; paleas are broad (0.8 to 2 mm), and toothed with fine hairs. Each floret has two stamens; anthers are two to four mm long on slender filaments. The caryopsis is oblong, brown and may reach lengths of 1.3 mm.

Holm et al. (1977) list 107 synonyms or common names of *I. cylindrica*. The most common of those terms are alang-alang, cogongrass, lalang, and speargrass. In southern Alabama and Mississippi, *I. cylindrica* is known by the colloquialism “Japgrass,” in reference to the original introduction from Japan.

**Systematics.** Hubbard et al. (1944) acknowledges five groups or varieties of *I. cylindrica*, mostly based on geographical distribution, but also on floristics. The variety ‘Major’ is the most widely distributed, extending from Japan and southern China, through the Pacific Islands and Australia to India and eastern Africa. It is also the variety most often associated with introductions into the southeastern U.S. ‘Major’ has the smallest spikelets of all the cogongrass varieties. The variety ‘Africana’ ranges from Senegal and Sudan southward throughout Africa. ‘Africana’ may be distinguished from other varieties by the absence or near absence of hairs at the nodes. Variety ‘Europa’ extends from Portugal through southern Europe and the Mediterranean countries, including the arid regions of central Asia. Both ‘Africana’ and ‘Europa’ varieties produce larger spikelets than ‘Major,’ and, in addition, have larger anthers. ‘Europa’ has thinner, wider leaf blades that also help distinguish it from ‘Major.’ ‘Latifolia’ and ‘Condensata’ are varieties with the most limited distribution and are found only in northern India and coastal Chile, respectively. 'Condensata' resembles 'Europa,' but has larger ligules and a more finely pointed, flat leaf blade.

Three of nine species of *Imperata* are found in the U.S. In addition to *I. cylindrica*, Hitchcock and Chase (1950) include *I. braziliensis* Trin. (Brazilian satintail), and *I. brevifolia* Vasey. (California satintail). All three taxa are designated as federal noxious weeds and they occur on most state weed lists as well. Both *I. braziliensis* and *I. brevifolia* are described as native species by Hitchcock and Chase (1950), and are disjunct in their ranges; *I. brevifolia* being confined to desert regions of western Texas to southern California, Utah, Nevada, and Mexico, while *I. braziliensis* is native to the pinelands and prairies of the Everglades, southern Florida, and Alabama. The non-indigenous (introduced) *I. cylindrica* and the native I. *braziliensis* have overlapping ranges, and conflicts do exist as to the discrimination of these two species (Bryson and Carter 1993; Hall 1998). Formally, *I. cylindrica* has two anthers, whereas *I. braziliensis* has only one anther (Hall 1978). However, *I. cylindrica* is frequently found with only a single anther while *I. braziliensis* can be found with two[2]. Hall (1998) suggests frequent hybridization between the two species, thus anther number holds little taxonomic value. *I. braziliensis* could possibly exist as a native species in Florida, since its native range includes both Mexico and Cuba (Gabel 1982). Regardless, the introduction of *I. cylindrica* has resulted in the release of more aggressive genetic material into the U.S. genome (Gabel 1982; Hall 1998).

Al-Juboory and Hassawy (1980) have reported that cogongrass collections from Iraq varied greatly in height, density, and number of flowering heads, suggesting the presence of ecotypes. Patterson et al. (1980) stated that plants grown from propagules collected near McNeil, MS, were significantly smaller than plants grown from propagules collected near Mobile, AL. The Alabama introduction is generally regarded as having Japanese origin, while the Mississippi plants are thought to have originated in the Phillipines (Patterson et al. 1980). Collections from Capo-chici et al. (2003) in Alabama have been analyzed on the molecular level and they, too, also indicate the presence of multiple phenotypes and genotypes within close proximity to each other. Such data infers that populations in Alabama are not homogenous as might be expected from a single introduction or source of genetic material. Genetic diversity in *I. cylindrica* has also been reported in Japan, where clear differences in soil preference, node characteristics, flowering type (early versus late), and seed germination indicate distinct taxa, although none have been suggested (Mizuguti et al. 2002, 2003).

A horticultural variety of *I. cylindrica* var. 'Major,' Japanese bloodgrass, does exist and is presently planted and sold in some states (Bryson and Carter 1993; Dozier et al. 1998). Some literature refer to this plant as *I. cylindrica* var. 'Rubra,' however, no authority can be found to document this nomenclature. Japanese bloodgrass, sometimes sold under the cultivar designation 'Red Baron,' is a red-tipped ornamental that is supposedly both less aggressive and unable to produce flowers, thus making it unable to contribute to the gene pool of *I. cylindrica*

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[2]Charles Bryson 2004, personal communication. U.S.D.A.-Agricultural Research Service, Stoneville, MS.

(Santiago 1980). However, recent studies in Florida have demonstrated that red-tipped biotypes do, indeed, flower and may hybridize with the commonly occurring variety 'Major,' thereby increasing the genetic diversity of the species (Raymer 2002). Japanese bloodgrass will tolerate lower temperatures such as those found in the northern U.S. Furthermore, Bryson and Koger (2003) have been able to induce color change in both the weedy green type ('Major') and red biotypes by adjusting temperatures: at high temperatures, red types will revert to green; at low temperatures, green types will turn red. Though no hybridization is documented outside of controlled greenhouse studies, the potential to do so is implied, thus decreasing the temperature limitations of the genome that exists in the U.S.

**Reproduction.** The rapid spread of cogongrass in the U.S. can be attributed to its bi-modal propagation; sexually by wind-blown seed and asexually by rhizomes (Tabor 1949). Seed, which are produced in spring, are capable of traversing distances in excess of 50 ft, though long-distance dispersal is implicit (Dozier et al. 1998). Contrary to most warm-season grasses, spring anthesis is a unique feature of cogongrass. Exceptions to this spring flowering exist as cogongrass may initiate flowering in response to extreme environmental changes such as differences in day-night temperatures, herbicide application, or fire (Holm et al. 1977; Sajise 1972). Holm et al. (1977) describe the prolific nature of this species, as single plants have been reported to produce 3000 seeds.

Seed production is highly variable from year-to-year, depending on climate and human disturbance. In one seed collection study, significant quantities of seed were produced in only 1 of 3 years (Dickens 1973). When cogongrass does produce seed, it is generally viable. Dickens (1973) reported that seed collections during 1972 had greater than 70% viability immediately after harvest and a half-life (climate controlled) of 11 months. Shilling et al. (1997) also confirmed that properly stored seed remained highly viable (> 90%) for three months, however, half-life in this study did not exceed 7 months. Accordingly, others suggest seed-bed conditions are the primary determinant in germination and that seeds have a short half-life under the high humidity conditions found in the temperate southeastern U.S. (Dickens and Moore 1974). Shilling et al. (1997) report that cogongrass seed have no dormancy requirement. Dickens and Moore (1974) previously reported this fact and suggested an optimum temperature for germination near 86° F. Older literature de-emphasizes the importance of flowering and sexual reproduction, thereby suggesting that most cogongrass dispersal is through rhizomes and rhizome-contaminated soil (Sajise 1972; Eussen 1980). Most recent studies confirm that cogongrass produces many seed (Burnell et al. 2003a), although McDonald et al. (1996) suggest individual populations are clonal, and viable seed are produced only through cross-pollination of isolated, heterogenous populations. The work of McDonald et al. (1996) infer that long distance spread is primarily accomplished through seed dispersal, while growth of local colonies is asexual, through rhizomes. Work previously mentioned by Capo-chici et al. (2003) indicates long distance spread results from sexual reproduction due to the great diversity found in the genetic makeup of accessions.

The extensive rhizome system of cogongrass, which may completely occupy the upper 6 to 8 in. of soil, is reported by some to be its primary means of propagation and local spread (Dozier et al. 1998; Tabor 1952a; Willard 1988). In addition, the below:above ground ratio of cogongrass biomass is low and the rhizome mat may account for approximately 80% of the total plant biomass (personal observations). The plant's fibrous root system arises from the many nodes on the rhizomes. The highly branched system of rhizomes may form mats so dense that they are capable of excluding most other plant species. Rhizomes are tolerant of high temperatures but susceptible to cold to 25° F(Wilcut et al. 1988a). Although rhizomes have been reportedly found at depths in excess of one meter, Wilcut et al. (1988b) reported that regeneration of rhizome segments did not occur at depths greater than three inches. These data offer some insight as to why cogongrass is not generally associated with agricultural fields, where tillage constantly buries some rhizomes and exposes others to cold and/or dessication.

An extensive review of the vegetative propagation of cogongrass by Ayeni (1985) shows that rhizome development begins as quickly as the third leaf stage. Initial growth of rhizomes is downward (plagiotropic) until cataphylls (scale leaves) begin to develop. Horizontal growth (diageotropic) may ensue followed by upward growth (negatively orthogeotropic) at the five to six leaf stage. Rhizomes are apically dominant, with secondary shoots arising from the apical bud (Ayeni 1985; Wilcut et al. 1988b). Prior work by Dickens (1973) had shown that this secondary shoot formation may occur in as few as eight weeks. Secondary shoots and roots may form simultaneously (Ayeni 1985). Early studies suggested that shoots may form from the smallest of rhizome segments (Hubbard et al. 1944), which conflicts with the apical dominance described by Ayeni (1985) and further illustrated by Wilcut et al. (1988b). Ayeni and Duke (1985) demonstrated that regrowth ability increased with age of the rhizome segment and fragments weighing as little as 0.1 g were capable of regenerating the species. Gaffney (1996) confirmed this apical dominance in studies where rhizome apices were either left intact or removed. In those segments where the apex was undamaged, new shoots only emerged near the undamaged apex; if apices were removed, numerous shoots were produced along the length of the rhizome from axillary buds. These findings differ from Wilcut et al. (1988b) who reported that cogongrass lacks axillary bud formation along the length of the rhizome. The question of axillary bud development was further investigated by English (1998), with the confirmation that cogongrass does produce axillary buds, and position on the rhizome influences the degree of bud formation. Basal rhizome segments showed significantly less bud development versus medial and distal (nearer the apex) segments.

The rhizome system of cogongrass is undoubtedly a competitive strength of the species. Whether or not it is the primary means of dispersal and infestation is debated in the literature, but this unique characteristic is best summarized by Ayeni and Duke (1985) who stated, "Speargrass seems to have evolved, in the rhizome, a powerful mechanism for survival, persistence, and spread which will continue to ensure its existence in disturbed tropical environments for many more years to come."

**Habitat.** *I. cylindrica* occupies multiple habitats from sea level to an excess of 6000 ft in Indonesia, and from tropical regions to the semi-arid climates of middle Eastern countries such as Afghanistan (Holm et al. 1977). They further report that cogongrass may be found at latitudes of up to 45 degrees in both the northern (Japan) and southern (New Zealand) hemispheres. In the U.S., cogongrass is problematic in predominately non-agricultural settings. It infests mainly pastures and rangeland, reclaimed mining sites, roadsides and other rights-of-way, forests, and recreational and natural areas (Dickens 1974; Jose et al. 2002; Willard et al. 1990). Cogongrass has been reported as a weed in sand dunes, wetlands, both xeric and mesic pine savannas and sandhill communities, all of which are ecologically valuable and are endangered ecosystems in the southeastern U.S. (Brewer and Cralle 2003; King and Grace 2000a; Lippincott 1997). Efficient nutrient use and the ability to avoid dessication make cogongrass an ideal invader in marginal areas, where soil or drainage conditions might not favor many other species (Bryson and Carter 1993).

Cogongrass is a species native to the eastern hemisphere, where it covers near 500 million acres in Asia alone (Garrity et al. 1997). Worldwide, cogongrass infests over 1.2 billion acres and is considered the world's seventh worst weed (Holm et al. 1977). Cogongrass is highly adaptable to a wide range of soil and environmental conditions and frequently spreads over large areas, forming dense, monotypic stands (Garrity et al. 1997; Chikoye et al. 1999). These stands are referred to as "sheet *Imperata*" and occupy 21 million acres in Indonesia alone (Garrity et al. 1997). "Sheet *Imperata*" hold little value, as forage value is minimal and reclamation into agricultural or native forest systems is costly (Falvey and Hengmichai 1979; Kuusipalo et al. 1995).

Cogongrass thrives on multiple soil types, from deep sands to clay loams, and some literature suggests soils of low pH (<5) are favored (Chikoye et al. 2000; Wilcut et al. 1988b). However, the author has collected samples from moderately alkaline, highly calcitic soils with pH 8.1[3]. Snelder (2001) suggests that the primary soil factors affecting cogongrass growth are physical rather than chemical properties, properties such as infiltration, crusting, soil depth, and rock outcroppings. Soil nutrient levels may effect cogongrass growth. Brewer and Cralle (2003) found decreased growth and foliar biomass when P was added. Their research indicated that the negative correlation was not a physiological response in the cogongrass, rather an increase in recruitment of native legumes. Thus, cogongrass is an efficient user of P. Aspect and slope are to be considered as well (Chikoye et al. 2000). Cogongrass tolerates a wide range of moisture conditions, but generally prefers moderately well drained to well drained sites (Bryson and Carter 1993). In contrast, Tainton et al. (1983) report that cogongrass is common on moist sites with poorly drained soils in the Natal of South Africa. King and Grace (2000b) noted in greenhouse studies that cogongrass establishment, especially from seed, was hindered with increasing soil moisture, however, established plants tolerated seasonal flooding.

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[3]Sumter series: Fine-silty, carbonatic, thermic Rendollic Eutrudepts.

Studies suggest that cogongrass growth is best under warm conditions, with day/night temperature regimes near 86/77° F (Patterson 1980a; Wilcut et al. 1988a). As previously stated, rhizomes were reported killed with exposure to temperatures of 25° F . However, actual plantings over-wintered with temperatures reaching 7° F (Wilcut et al. 1988a). In a similar study, cogongrass was killed in Texas where low temperatures near -20° F were recorded (Wilcut et al. 1988a).

Cogongrass is relatively tolerant of shade (Cole and Cole 2000; King and Grace 2000a; Patterson 1980b). Gaffney (1996) reported the light compensation point of cogongrass to be 32 $\mu mol/m^2/s$, or two percent of ambient sunlight. Plants grown in full sunlight produced three times the dry matter as those grown in 56% sunlight and 20 times as much as those grown in 11% sunlight, however, all plants survived (Patterson 1980b). Little evidence of sun and shade ecotypes exist, however, cogongrass does exhibit a common adaptation to shade through increases in leaf area, leaf weight ratio, and leaf area ratio (Flint and Patterson 1980). Also, gap size happens to be irrelevant in cogongrass establishment. King and Grace (2000a) reported that gaps from 0-40 in. were colonized by cogongrass seedlings. In this study, disturbance type, specifically fire or tillage, were most important in successful establishment of cogongrass seedlings rather than gap size. Perhaps more troublesome are reports from Cole and Cole (2000) who indicated that red-tipped ornamental varieties actually performed well in shade. Considering information already presented regarding hybridization of red-tipped varieties with variety 'Major,' the potential for increased shade tolerance is understood.

The ability of cogongrass to occur in multiple habitats is also a function of its chemical ecology. According to Eussen and Wirjahardja (1973), the roots and rhizome system of cogongrass include an allelopathic mechanism. Their studies with *Cucumis sativus* indicated a negative correlation between growth of *C. sativus* and the number of tillers of cogongrass. Eussen and Wirjahardja (1973) also suggested that the activity of the allelopathic factor was greater at pH 6 or less. This pH dependency could explain why cogongrass prefers acidic soils (Chikoye et al. 2000; Wilcut et al. 1988b). Inderjit and Dakshini (1991) presented data suggesting that cogongrass emits four phenolic compounds that may negatively impact other plant species. These compounds were water-soluble and inhibited shoots, rhizomes, and seeds. Allelopathic compounds were also responsible for inhibiting the nitrogen-fixing bacteria associated with at least one legume, *Melilotus parvifolia*, as well as an overall reduction in the soil mycoflora (Inderjit and Dakshini 1991). Another study by Koger and Bryson (2003) demonstrated that both foliage and root residues of cogongrass inhibited the germination and growth of common bermudagrass [*Cynodon dactylon* (L.) Pers.] and Italian ryegrass (*Lolium multiflorum* Lam.). While inhibiting the growth of other species, intraspecific competition of cogongrass is minimal. Oladokun (1978) found that increasing the number of plants within a small area made no difference in the number of shoots/root, leaves/node, or overall internode length. This is contrary to other species that exhibited decreases in these characteristics with increasing density.

Cogongrass seedlings tend to be found only in areas where disturbance has released them from competition and prepared a seedbed (King and Grace 2000a). Cogongrass seedlings are generally less competitive than bahiagrass (*Paspalum notatum* Fluegge.) seedlings, but cogongrass plants arising from rhizomes are more competitive than bahiagrass seedlings (Shilling et al. 1997). Willard and Shilling (1990) also reported that cogongrass seedlings are unlikely to establish in areas with greater than 75% bahiagrass coverage. Eussen (1979) found that cogongrass was hardly affected by the presence of corn (*Zea mays* L.) or sorghum [*Sorghum bicolor* (L.) Moench.]; however, yields of the latter two were reduced greatly by the presence of cogongrass.

Not only is cogongrass able to invade multiple habitats, it often changes the characteristics of that habitat or ecosystem. Cogongrass is noted as a fire climax, or fire adapted species (Bryson and Carter 1993; Eussen and Wirjahardja 1973; Holm et al. 1977). Once infestation has occurred, periodic fire favors the perpetuation of cogongrass (Jose et al. 2002; Lippincott 1997). The rhizome system is mostly responsible for this attribute, as rhizomes are tolerant of both heat and dessication (Lippincott 1997; Wilcut et al. 1988a). Additionally, cogongrass-fueled fires burn hotter and higher than typical wildfires, thus eliminating some species such as longleaf pine (*Pinus palustris* Mill.) or the important forage legume goat's rue [*Theprosia virginiana* (L.) Pers.] that tolerate and depend on wildfire fueled by native species (Lippincott 1997; Platt and Gottschalk 2001). The elimination of fire-intolerant species, combined with the reduction of indigenous species tolerant to native-fueled fire precludes establishment of plants other than cogongrass. The increase in fine fuel loads and litter by cogongrass will change the fire characteristics of ecosystems, even those systems to which fire is already frequent (more than once a decade) such as the south Florida slash pine (*Pinus elliottii* Engelm.) or longleaf pine savannas (Platt and Gottschalk 2001). Perhaps more importantly, the arrival of cogongrass after clear-cutting, naturally occurring fire (i.e. lightning), or other catastrophic event will interrupt natural succession and prevent secondary forest establishment (Kessler 1999; R. Otsamo 2000). Peet et al. (1999) conducted studies on the burning of cogongrass in Nepal not for control, but rather for preservation of endemic *Imperata* grasslands for endangered animals and thatch materials. His studies concluded that fire prevented succession from grassland to forest and ensured a thatch crop for the next season. These results, though from an opposite perspective, agree with Platt and Gottschalk (2001) and many others who note that fire favors the establishment and continuation of cogongrass (Eussen and Wirjahardja 1973; Lippincott 1997).

**Distribution in Alabama and the Southeastern U.S.** In his initial report, Tabor (1952a) estimated that cogongrass could be found on approximately 500 acres in Mobile Co. Less than 20 years later, estimations increased to near 10,000 acres for Mobile Co. (Dickens 1974). The first formal survey of cogongrass in Alabama was conducted by Dickens (1974) of Auburn

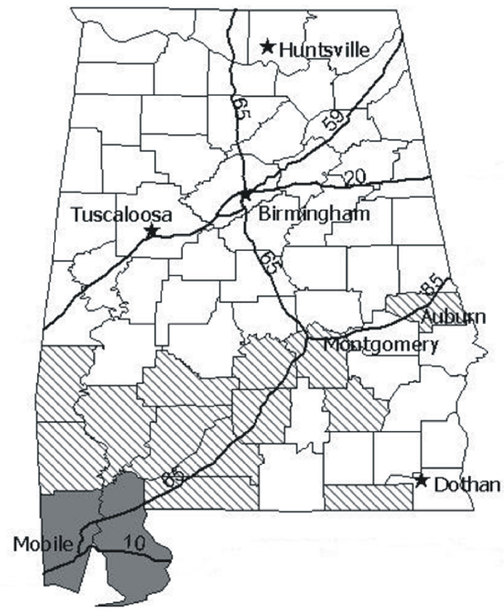


*Figure 1*. Cogongrass distribution in Alabama, 1985 (Dickens 1974; Wilcut et al. 1988a). Dark-shading indicates well-distributed infestations; slashed lines indicate scattered infestations.

University in 1971 and indicated that two counties, Mobile and Baldwin, contained well-distributed infestations, while six additional counties had scattered infestations. Wilcut et al. (1988a) amended this survey to include 7 more counties in 1985 (Fig. 1). A 1979 roadside survey in Mississippi revealed 19 counties infested, with those counties in the southeast corner of the state being most severely affected (Patterson and McWhorter 1980). From the intentional and accidental introductions mentioned, cogongrass has spread rapidly, with current estimations exceeding 500,000 acres in Alabama, Mississippi, and Florida (Faircloth et al. 2003a). Willard et al. (1990) suggest that since many patches of cogongrass on Florida interstate rights-of-way are isolated and occur in irregular intervals, that spread is primarily due to rhizome-contaminated soil through road construction activities. Wilcut et al. (1988a) suggest that spread in Alabama follows the pattern of prevailing winds (southwest to northeast) and the northward spread along the Interstate 65 corridor of south central Alabama is likely due to wind-blown seed.

**Management and Control of Rights-of-Way.** Highway and utility rights-of-way (ROW) connect even the most rural areas with major metropolitan areas in the United States. Perhaps just as importantly, these ROWs connect seaports, airports, and international borders with the remainder of the country. This network of ROW has been shown to be pathways for the movement of invasive plant species (Harper-Lore 2003). Rights-of-way, highways in particular, are conducive to invasive grass infestation for several reasons. Grasses are usually the desired species on many ROWs. Perennial species such as bahiagrass (*Paspalum notatum* Fluegge), common bermudagrass [*Cynodon dactylon* (L.) Pers.], and tall fescue (*Lolium arundinaceum* S. J. Darbyshire) are attractive, easy-to-maintain, provide erosion control, safe (low-growing for visibility), and pose a minimal fire hazard. Most of these grasses tolerate occasional mowing. Mechanical and herbicidal control of broadleaved plants is simple and cost-effective on ROW; however, control of an invasive grass within a desirable grass is both challenging and often costly to maintenance personnel.

Wilcut et al. (1988a) first suggested movement of cogongrass along the Interstate 65 ROW in Alabama via seed blown by the prevailing winds. Willard et al. (1990) also acknowledged the importance of ROW maintenance operations in cogongrass dispersal in Florida, however, his research indicated rhizome transport as the primary means of movement. As indicated by the previous researchers, cogongrass is an ideal invader of highway ROWs. Not only may seed move with prevailing winds, but vehicles offer the chance of long-distance dispersal. In addition to providing access to un-infested areas, the presence of cogongrass on ROWs is aesthetically unpleasing and poses safety concerns due to its fire hazard. Fire fueled by cogongrass is a liability concern for ROW managers, not only due to smoke management and the safety of motorists, but also due to property loss from adjoining landowners.

Control measures that could be utilized in ROW situations include both mechanical and herbicidal means. Sajise (1972) first reported that mowing cogongrass was only effective in removing aerial portions of plants. Further research indicated that mowing reduced above-ground foliage and total rhizome mass when repeated on a monthly schedule, but the grass remained viable at the end the season (Willard and Shilling 1990). This research would indicate that occasional mowing has little effect on the regenerative capacity of cogongrass. Burnell et al. (2003b) demonstrated that weekly mowing of cogongrass reduced the number of plants per unit area by 74%, however, much like Willard and Shilling (1990) cogongrass resprouted, even after 2 consecutive seasons of treatment.

Shallow tillage (< 3 in.), such as discing, may be effective if repeated frequently (Johnson 1999). However, Gaffney (1996) found that infrequent discings fragmented rhizomes and resulted in more vigorous shoot growth than before treatment. Repeated deep tillage (> 3 in.) may control cogongrass by inverting, burying, and exposing rhizomes but is not always possible on a ROW (Chikoye et al. 2000; Wilcut et al. 1988a). Both discing and deep tillage are also limited by the site conditions such as slope, drainage, and situational concerns (i.e. proximity to other desirable plants).

Effective herbicidal control of cogongrass is currently limited primarily to two compounds: glyphosate and imazapyr (Miller 2000; Peyton et al. 2003; Tanner et al. 1992). Numerous studies describe the activity of glyphosate on cogongrass (Dickens 1973; Dickens and Buchanan 1975; Miller 2000; Patterson and McWhorter 1980; Tanner et al. 1992; Willard et al 1997). Glyphosate has been reportedly used at rates up to 14 lb ae/acre for non-selective control in a variety of situations (Faircloth et al. 2003b; Miller 2000; Peyton et al. 2003). A standard protocol for glyphosate usage on ROW is 3 to 4 lb ae/acre applied as a spot treatment to actively-growing infestations (ALDOT 2002). Willard et al. (1996) demonstrated that 2 mowings or discings in combination with a single glyphosate application at 3 lb ae/acre reduced rhizome biomass > 80% one year after treatment. Application volumes ranging from 20 to 80 gal/acre showed no differences in glyphosate activity (Peyton et al. 2003). Re-treatment is necessary and should occur yearly until the rhizome system is depleted (Bryson and Carter 1993; Jose et al. 2002). Glyphosate is generally regarded as being a non-selective herbicide and many times application on ROW will result in collateral damage to desirable species, therefore, selective control of cogongrass within these grasses is often needed (Vencill 2002).

Several herbicides that specifically target grasses have been reviewed for cogongrass activity. Neither clethodim nor sethoxydim of the cyclohexanedione family showed any activity in a study by Mask et al. (2000). Fluazifop-butyl is the only herbicide of the aryloxyphenoxypropionate family that has activity on cogongrass and reports are mixed as to its efficacy. Mabb and Price (1986) first documented this herbicide's limited activity on cogongrass. Fluazifop-butyl has been noted to give in-season suppression of cogongrass growth, but no long-term control in the U.S. (MacDonald et al. 2002).

Imazapyr offers limited selective control of cogongrass in unimproved bahiagrass and bermudagrass (Johnson et al.1999; Shaner 1988). Willard et al. (1996, 1997) reported that imazapyr at 0.7 lb ai/acre controlled cogongrass up to two years after treatment. Imazapyr was significantly more effective at comparable rates than glyphosate in a study by Miller (2000). Johnson et al. (1999) obtained 82% control of cogongrass 18 months after treatment with sequential applications of imazapyr at 0.38 lb ai/acre. Mechanical treatments such as discing improved cogongrass control to 91% when used in combination with the above treatments (Johnson et al. 1999). The effectiveness of imazapyr was greater at higher diluent volumes (Willard et al. 1997) while Townson and Butler (1990) showed no difference in volume with glyphosate . Though many studies have quantified the effects of imazapyr on cogongrass, none detail the use of this compound for selective control or establishment of bahiagrass or bermudagrass on ROWs in cogongrass-infested areas.

Integrated vegetation management strategies were investigated for treating cogongrass infestations on highway ROW and restoring them to more desirable plant communities. Management strategies included herbicides, competitive exclusion utilizing grass and clover species, and mechanical control (mowing). Two studies were designed to compare multiple combinations of herbicides, both chemistry and timing, and competitive exclusion. A third study was designed to explore possible interaction between mowing and the herbicides imazapyr and glyphosate.

**Justification of Research.** Invasion of natural communities by non-native species threatens the preservation of many plant and animal species. A survey of National Park Service superintendents found that 61% described non-native, invasive plants as moderate or major problems in their parks (Randall 1996). Similarly, 60% of Nature Conservancy landmanagers responded that invasive weeds were among their top 10 management problems. White and Schwarz (1998) agreed that non-indigenous, invasive species are the most significant threats to biological diversity globally. Invasive species have an economic impact as well, as Pimental et al. (2002) reported that over $600 million was spent in fiscal year 2001 on all types of invasive organisms in the U.S. Mullahey et al. (1998) described the plight of another noxious weed, tropical soda apple (*Solanum viarum* Dunal.), in Florida. Tropical soda apple, a poisonous plant native to South America, was first reported in 1988. It was only in the late 1990's, when Florida cattle producers saw economic consequences from this plant, that serious attention was given and weed management strategies were developed. The presence of cogongrass has eclipsed that of tropical soda apple by nearly 75 years, yet unified research, education, and eradication programs remain on the horizon. Clearly, the need for ecological research on cogongrass is present, but there is a grave need for applied research into management tactics such that eradication programs may be enacted.

*I. cylindrica* is a serious pest of numerous crops world-wide including cassava, cotton (*Gossypium hirsutum* L.), cowpea (*Vigna unguiculata* (L.) Walp.), corn, peanut (*Arachis hypogaea* L.), and rice (*Oryza sativa* L.) (Holm et al. 1977; Chikoye et al. 2000). Plantation crops such as banana (*Musa acuminata* Colla.), rubber [*Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg.], and tea [*Camellia sinensis* (L.) Kuntze] are also negatively impacted by cogongrass (Eussen and Wirjahardja 1973). Cogongrass is particularly troublesome in West Africa and southeast Asia where subsistence farmers lack draft-powered mechanical controls and herbicides are cost and knowledge prohibitive (Chikoye et al. 2000; Soerjani 1970). Chikoye et al. (2000) estimated that in the West African savana-forest transition zone, greater than 50% of manual labor on farms was spent hand-weeding cogongrass. Despite these massive inputs, cogongrass reduces yields of important crops such as corn and cassava 50% and 80%, respectively, from their cogongrass-free potential. In addition to losses in agricultural productivity, vast tropical forests have been converted to cogongrass monocultures, like the "sheet *Imperata*" referred to previously. Such grasslands are self-perpetuating through altered fire regimes and reclamation is costly in labor, time, and money (Otsamo 2002).

In the U.S., row crops have yet to be affected by cogongrass due to intensive machine-powered cultivation. The rapid adoption of reduced tillage agricultural techniques could lead to cogongrass infestation, albeit, no reports of cogongrass infestation in such situations have been published. The concurrent increase in glyphosate usage through the planting of glyphosate-tolerant crops could be a major deterrent to cogongrass establishment in crops such as cotton and soybean [*Glycine max* (L.) Merr.]. Nonetheless, cogongrass is a serious pest on rights-of-way, industrial sites, pastures, orchards, forests, and wildlands (Bryson and Carter 1993; Jose et al. 2002; Miller 1998). The ecological consequences of cogongrass are also of concern. In the mild, subtropical climate of the southeastern U.S., cogongrass has the potential to establish monocultures, much like the vast grasslands of Indonesia and southeast Asia. The vastness of cogongrass monocultures that might establish in the Southeast would not be comparable to that found in Asia, but the effect would be the same: greatly diminished biological diversity of both plants and animals and the permanent alteration or loss of native and valuable ecosystems (Brewer and Cralle 2003; King and Grace 2000a; Lippincott 1997). Additional studies are needed to quantify the impacts of cogongrass on native plants and animals (Matlack 2002). Cogongrass-fueled wildfires are yet another concern and liability for landowners and right-of-way owners, especially near populated areas.

# I. MAPPING COGONGRASS ON ALABAMA RIGHTS-OF-WAY

## Materials and Methods

Survey work was begun in April 2001 and continued intermittently through January 2004. The majority of survey operations were conducted during the months of April, May, December, and January, however, surveys were continually conducted and infestations logged while the author traveled about the state for other reasons. During the spring months of April and May, cogongrass was flowering, thus identification was made easier. During the first winter of the survey, it was realized that dormant cogongrass was easily distinguishable from other common ROW grasses due to its unique foliage color and circular growth pattern, therefore, surveys also targeted the winter months of December and January.

State highways, U.S. (Federal) highways, and interstates, all of which were under the maintenance jurisdiction of the Alabama Department of Transportation (ALDOT), were visually inspected in counties where known locations of cogongrass were reported. Counties included in the survey were those in an area bounded by Interstates 59 and 85 to the north, and I-65 to the east. Surveys in counties located on the previously described border and found to have an infestation were expanded to include neighboring counties. A point location was defined as a single, contiguous population of cogongrass. Infestations were included if located on a ROW or within visual proximity, however, a survey of private property was not the intent. In certain portions of Baldwin, Escambia, and Mobile counties, near contiguous populations were found that exceeded 500 ft. in length, parallel to the ROW. For such areas, a point was logged for every 328 ft. (100 m) of infestation. Locations were also surveyed based on information from records of U.S.D.A.-Natural Resource Conservation Service personnel[4]. Upon location of an infestation, a global positioning system receiver (GPS)[5] was used to obtain latitude/ longitude information. Data were stored in a laptop computer and manipulated using geographic information system (GIS) software[6] linked directly to the GPS receiver. GPS data were downloaded to a desktop computer and maps generated using GIS software[7]. Data files were generated and shared with ALDOT officials on a county-by-county basis.

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[4]Information provided by Mr. Guy Karr, former Plant Protection Administrator, Alabama Department of Agriculture and Industries, P. O. Box 3336, Montgomery, AL 36109.

[5]AgGPS 114, Trimble Navigation Ltd., 9290 Bond St. Overland Park, KS 66214.

[6]MapInfo Professional v6.0, MapInfo Corp., One Global View, Troy, NY 12180.

[7]ArcView GIS 3.2a, Environmental Systems Research Institute, 3325 Springbank Lane, Suite 200, Charlotte, NC 28226.

## Results and Discussion

Point locations of cogongrass on state maintained ROW were found in 35 of 67 Alabama counties (Figure 2). Figure 3 illustrates the degree of infestation on a per county basis. The survey identified 668 locations where cogongrass was growing (Figure 4). The majority of infestations (406) occurred along the I-65 and I-10 ROW. Other roads that saw significant infestation levels were U.S. 82 in Tuscaloosa and Pickens counties, U.S. 84 in Monroe and Clarke counties, U.S. 45 from Citronelle (Mobile co.) to the MS state line, AL 10 from Greenville (Butler co.) to the MS state line, AL 167 in Pike co. near the Spring Hill community, and AL 17 from Chatom (Washinton co.) to Butler (Choctaw co.). Other notable locations identified were in Dekalb and Cleburne counties, demonstrating the northeastward expansion of this species. The point location found in Dekalb county was in excess of 34 degrees N latitude and at an altitude of 1550 ft., perhaps the most northerly wild population of *I. cylindrica* var. 'Major' recorded to date. The majority of infestations, 507 of 668 (76%), recorded in this survey were located immediately on a ROW. The remaining infestations were within visual proximity of a given ROW.

The number of point locations recorded from this survey greatly exceeded the number expected, especially for counties other than Baldwin, Escambia, and Mobile. Survey notes indicated that on average, locations were concentrated near intersections or interstate interchanges, where ROW operations are frequent. This would confirm the widely held theory that cogongrass prefers establishment into disturbed soils. Treatment should begin immediately to prevent further infestations. Data points on this survey would indicate that ROW may act as corridors for spread, thus treatment of these areas is critical to preventing the further expansion of cogongrass. Furthermore, ROW managers should be skilled in the identification of cogongrass and trained in prevention methods that will exclude cogongrass from establishment in their respective areas. These methods include the prudent selection of fill soil during earthwork operations, the immediate re-planting of disturbed areas to prevent establishment, and the cleaning of or quarantine of equipment as to movement between un-infested and infested areas.


*Figure 2*. Visual survey of state maintained highway rights-of-way conducted April 2001-January 2004. Shading indicates at least one confirmed infestation of cogongrass on a state-maintained right-of-way.

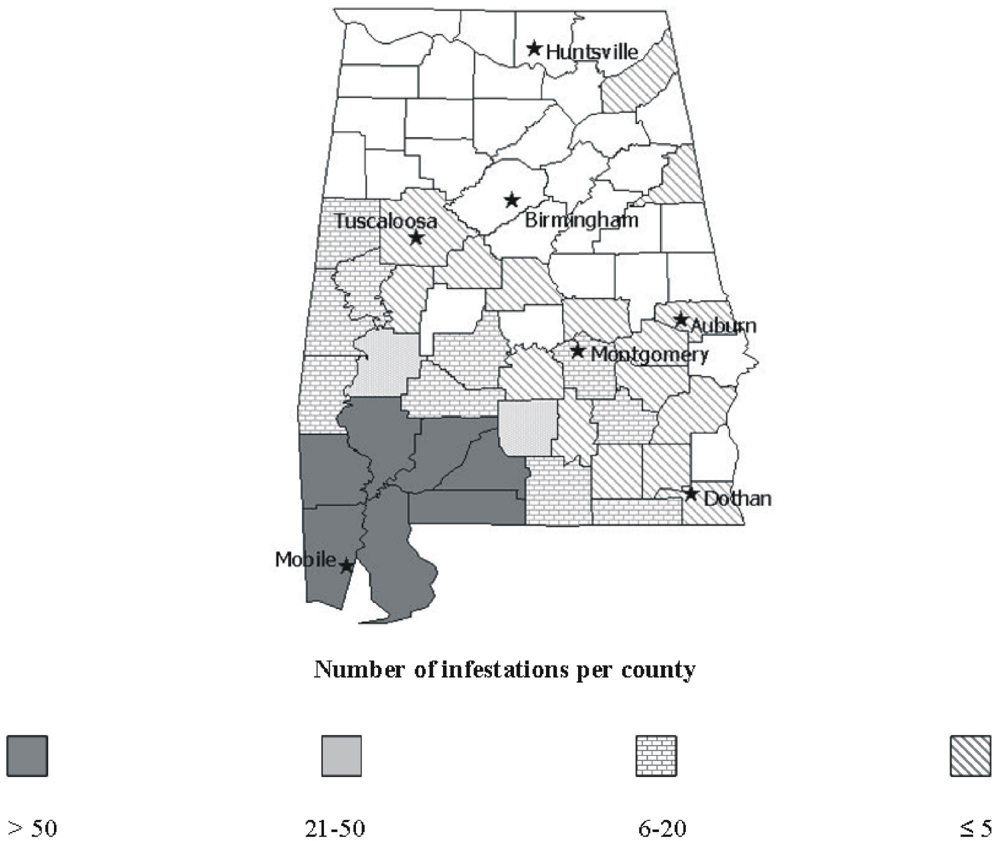


*Figure 3*. Degree of infestation in Alabama counties known to have populations of cogongrass, January 2004. Visual survey of state maintained highway rights-of-way conducted April 2001-January 2004.

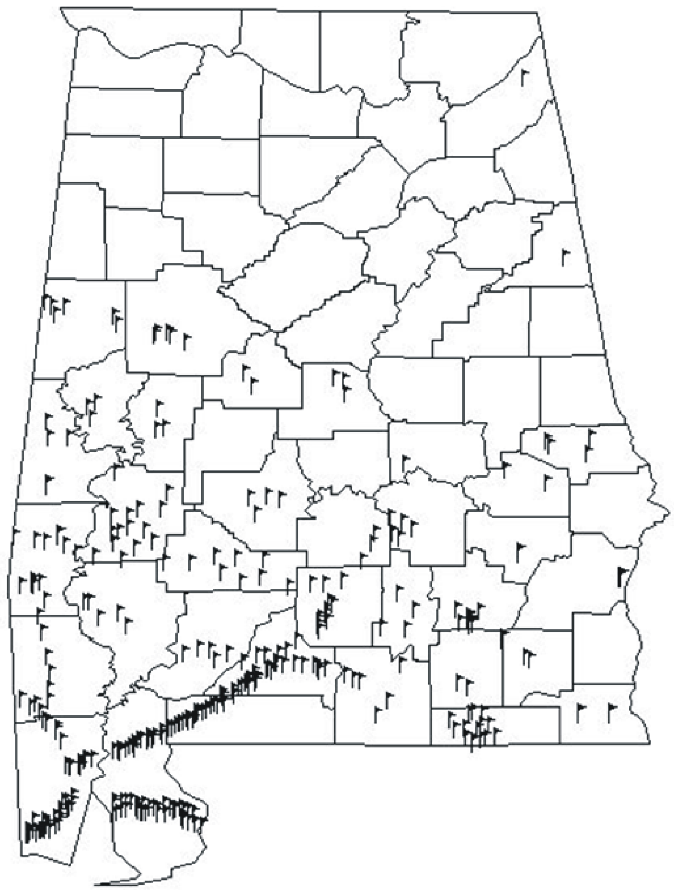

*Figure 4.* Point locations (668) of cogongrass on ALDOT rights-of-way. Visual survey of state maintained highway rights-of-way conducted April 2001-January 2004.

## II. CONTROL AND REVEGETATION

*Loxley Study*

### Materials and Methods

An initial field study was established to investigate cogongrass control and rehabilitation options in Baldwin Co. (AL) near the town of Loxley during the fall of 2000. The study area was located approximately 1.2 mi. east of the I-10 / AL Hwy. 59 interchange, on the shoulder of I-10 westbound lanes at mile marker 47. The study area was selected based on topography and a contiguous infestation of cogongrass large enough to implement the desired experimental plan. Soil was a loamy sand (pH 5.8), although a specific taxonomic designation was not available due to the nature of earthwork operations on the road shoulder. Site history consisted of annual herbicide treatment for broadleaved weed control using combinations of 2,4-D, dicamba, triclopyr, and/or MSMA, and bimonthly rotary mowing during the growing season (4x yearly)[8]. At the onset of the study, these maintenance treatments by Alabama Department of Transportation (ALDOT) personnel were ceased on the study area.

A single test treatments consisted of various combinations of herbicide and sowing of competitive species. Herbicides were glyphosate[9] and imazapyr[10] and the tank-mix combination of glyphosate plus imazapyr. Competitive species included bahiagrass (var. 'Pensacola'), bermudagrass, and the winter cover crops crimson clover (*Trifolium incarnatum* L. cv 'AU Robin') and annual ryegrass (*Lolium multiflorum* Lam. cv. 'Gulf'). A single treatment consisted of fall herbicide application and/or seeding followed by spring herbicide application and seeding. Fourteen different combinations were tested along with a non-treated check for 15 total treatments in a randomized complete block design with four replications. A listing of test treatments with herbicide rates, application timings, and seeding rates is shown in Table 1. Experimental units were plots 10 ft. wide by 20 ft. in length arranged perpendicular to the roadway. Other researchers have shown that effective cogongrass control programs involve multi-year treatment (Dickens 1973; Dozier et al. 1998; Shilling et al. 1997; Willard et al. 1996). In order to investigate multi-year treatments, the entire study was replicated three times such that a time factor could be examined. The three series were designated as 'regimes' and each consisted of 60 plots (15 treatments x four replications). At initiation, all three regimes were treated. In year two of the study, only the two year and three year regimes were retreated. During the third and final year of the study, only the three year regime was retreated. Thus, each

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[8] J. S. Watkins, District Engineer, 2nd District, 9th Division-Alabama Department of Transportation, Bay Minette.

[9] GlyPro Plus® (4 lb ai/gal), Dow Agrosciences LLC, Indianapolis, IN 46268.

[10] Arsenal AC® (4 lb ai/gal), BASF, 26 Davis Dr., Research Triangle Park, NC 27709.

of the original 15 test treatments could be evaluated using one, two, and three years of treatment (regimes).

Herbicides were applied in aqueous solution at 15 gal/acre diluent volume with a $CO_2$ powered, ATV-mounted sprayer at a speed of 5 mph. The spray boom had 6 nozzles with flat fan tips and was operated at pressures of 36 to 45 psi depending on nozzle tip selection Imazapyr was applied with a 0.25 % v/v nonionic surfactant[11] while the glyphosate formulation contained a surfactant. Herbicide applications were made in October and March of each year. In February of each study year, plots were mowed with a rotary mower. Seeds of replacement species were broadcast-applied using a rotary seeder mounted on an ATV traveling at 5 mph. Crimson clover was applied with a bacterium inoculant each year. Seeding was performed within two wk of herbicide application in both fall and spring, with the exception of fall 2002, when extreme drought conditions delayed planting until the first week of December (Appendix I). During the summers of 2001 and 2002, the study area was sprayed with a mixture of 2,4-D (1 lb ai/acre) and dicamba (0.38 lb ai/acre) to control a variety of broadleaved weeds recruited into plots.

Visual estimations of percent cogongrass control from 0 to 100, where 0 equals no control and 100 equals total control, were performed on whole plots at 12 month intervals beginning in the October 2001 through September 2003. Visual estimations were always conducted prior to any pending herbicide application or seeding operation. Cogongrass density was also determined by counting the number of stems in a 2.7 $ft^2$ subplot randomly placed near the approximate plot center, and were subsequently expanded to a per hectare basis. Stem counts were begun in October 2001 and repeated on a 12 month interval through September 2003. As with visual estimations, stem counts were performed in late August or early September, prior to fall treatment in October.

Data taken at the same rating interval, either 12 or 24 months after treatment (MAT), were analyzed across regimes. The 24 MAT rating interval did not include the 3 year regime, as data will be taken in the Fall of 2004. Prior to ANOVA, visual control data were arcsine square-root transformed. This procedure improved the homogeneity of variance based on inspection of the plotted residuals. Therefore transformed control data were subjected to ANOVA using mixed models techniques (SAS 2002) to test for the main effects of regime and treatment and their interaction. Subsequently, means were separated using Fisher's Protected LSD test at the 0.05 level, excluding the non-treated plots. Stand density data were non-transformed and subjected to the mixed models analysis previously defined. Non-orthogonal contrasts and significant differences were estimated ($P<0.05$) on pre-determined treatment groups for both the visual control and stand density data.

[11]TimberSurf 90®, UAP Timberland LLC, P. O. Box 557, Monticello, AR 71655.

## Results and Discussion

Analysis of variance indicated that there was a significant regime by treatment interaction present in the 12 MAT rating for both visual control and stand density data (Table 2). Accordingly, the data from each treatment are presented by regime (Tables 3 and 4). Visual control increased with each additional year of treatment 12 MAT (Table 3). The regime by treatment interaction was a magnitude response from each additional year of treatment (35%, 70%, and 88% mean control for the one two, and three year regimes, respectively). The maximum visual control obtained 12 MAT was 97% in the three year regime. Stand density decreased with each successive year of treatment (15.53, 3.12, and 0.90 million stems/acre mean density for the one, two, and three year regimes, respectively) (Table 4). The regime by treatment interaction for stand density was due also to the magnitude of the decrease between successive years of treatment. Two treatments did result in zero stems/acre in the three year regime. Analysis of treatment rankings for both visual control and density showed few consistencies between regimes, which would also account for the treatment by regime interaction (data not shown).

Imazapyr significantly increased visual control in the one (12%) and two (11%) year regimes but not in the three year regime (Table 5). The use of glyphosate alone in the fall herbicide application significantly decreased control 12 MAT, regardless of regime. The tank-mix combination of glyphosate plus imazapyr increased control between 9 and 11% for all three regimes. A follow-up spring application of glyphosate significantly increased control 25%, regardless of prior herbicide treatment in the one year regime, but not in the two or three year regimes. Repeated fall application of herbicide in both the two and three year regimes may account for the non-significance of spring glyphosate application in those regimes. Significant differences were not detected between crimson clover and ryegrass in either the one or two year regimes, but crimson clover decreased control 9% in the three year regime. Bahiagrass and bermudagrass did not establish in the study at Loxley (data not shown) and contrasts reflect this fact with no significant differences shown in any regime.

Density response was similar to visual control 12 MAT, with imazapyr significantly decreasing stand density in the one and two year regimes and glyphosate significantly increasing density in all regimes (Table 6). The tank mix combination of imazapyr plus glyphosate was not different than either herbicide applied alone in the one year regime, but decreased density in both the two and three year regimes. A spring application of glyphosate further reduced density by 7.39 and 0.479 million stems/acre in the one and three year regimes, respectively, regardless of prior herbicide application. The effects of cover crop and replacement species were only significant in the one year regime. It has been stated previously that neither bahiagrass nor bermudagrass established successfully. Therefore, the significant increase in stand density indicated for bahiagrass in the one year regime is an anomaly.

Similar findings for single glyphosate applications were reported by Dickens and Buchanan (1975). However, Tanner et al. (1992) reported 91% control up to 2 years with a single application of glyphosate in November. Age of the cogongrass population in either of the above studies was not reported, and may account for the discrepancies between studies. Willard et al. (1997) reported an 87% shoot reduction with two sequential applications of glyphosate one year after treatment. Weed control values in the study by Willard et al. (1997) also were higher than sequential applications (spring glyphosate re-treatment) found here. At the 12 MAT rating interval, only the three year regime had treatments that completely controlled cogongrass. Each of the treatments in the three year regime had a minimum of three sequential fall applications of herbicide, plus or minus spring re-treatment with glyphosate. No other studies describe results from a three year treatment regime.

Analysis of variance indicated a significant regime by treatment interaction for both visual control and stand density at the 24 MAT rating interval (Table 2). Data for both visual control and stand density were separated by regime and treatment for presentation (Tables 6 and 7). Cogongrass control increased from 4% to 55% between the one and two year regimes (Table 6). Maximum control in the 1 year regime was 19% versus 80% for the two year regime. A five-fold decrease in cogongrass density was found between the 1 and 2 year regimes 24 MAT (Table 7). The interaction of treatment and regime was expected and may be explained by the magnitude of the difference between regimes. This interaction illustrates that multiple year treatment regimes are necessary for the control of perennial species such as cogongrass and further illustrates the need to repeat evaluations beyond 12 months, which is a commonly used benchmark in weed science.

Visual control ratings 24 MAT were increased when imazapyr was used as the fall herbicide application (Table 8). As expected, contrasts revealed no other differences between treatment groups for the one year regime, as most treatments decreased to zero. These data agree with other research that reported effective long-term (> 12 months) cogongrass control was not obtained with single or even sequential herbicide treatments within the same year (Dickens 1973; Peyton et al. 2003; Shilling et al. 1997; Willard et al. 1996). Visual control in the two year regime was significantly increased with either imazapyr (14%) or the tank mix combination of glyphosate plus imazapyr (15%). Glyphosate alone as the fall herbicide application significantly decreased control. Spring glyphosate application, regardless of fall application, increased control 11%. Neither cover crop nor replacement grass affected visual control ratings significantly.

Cogongrass stand density was decreased by both imazapyr (5.71 million stems/acre) and spring glyphosate treatment (2.69 million stems/acre) while glyphosate increased density by 6.2 million stems/acre in the one year regime 24 MAT (Table 8). Spring re-treatment with glyphosate decreased density as well in the one year regime. However, in the two year regime, spring glyphosate treatment was not significant. Imazapyr, alone or in combination with glyphosate, significantly decreased cogongrass density in the two year regime. As found in the one year regime, glyphosate alone in the fall resulted in an increased stand density versus other herbicide combinations. Crimson clover increased stand density in the two year regime.

Evaluations 24 MAT are generally unrecorded in the literature. Miller (2000) evaluated glyphosate and imazapyr to two years after treatment, citing that control decreased 40 to 80% after year one, depending on location. This agrees with data presented that showed an approximate 30% reduction in control between 12 and 24 MAT ratings for the one year regime.

Data from Loxley indicate that multiple year treatment of cogongrass is necessary for control, with a three year regime giving both the greatest visual control and the lowest stand densities. Within the three year regime, the tank mix combination of glyphosate plus imazapyr consistently increased control and decreased density versus other fall-applied herbicides. Spring re-treatment with glyphosate was needed to reduce density but not to increase visual control. The establishment of either bahiagrass or bermudagrass was not achieved in this field study. Koger and Bryson (2003) demonstrated that leachates from cogongrass foliage and roots inhibited both germination and growth of common bermudagrass. In addition, the use of broadcast seeding methods could account for the lack of establishment of either grass species due to poor seed-soil contact at the time of planting.

*Table 1.* Fall and spring herbicide and seeding operations, Loxley Study.

| | Fall (October) | | Spring (March) | |
|---|---|---|---|---|
| Treatment | Herbicide | Seeding | Herbicide | Seeding |
| 1 | glyphosate[a] | bahiagrass[b] | -- | -- |
| 2 | glyphosate | bermudagrass | -- | -- |
| 3 | glyphosate | crimson clover | glyphosate | bahiagrass |
| 4 | glyphosate | crimson clover | glyphosate | bermudagrass |
| 5 | imazapyr | bahiagrass | -- | -- |
| 6 | imazapyr | bermudagrass | -- | -- |
| 7 | imazapyr | crimson clover | glyphosate | bahiagrass |
| 8 | imazapyr | crimson clover | glyphosate | bermudagrass |
| 9 | glyphosate+imazapyr | bahiagrass | -- | -- |
| 10 | glyphosate+imazapyr | bermudagrass | -- | -- |
| 11 | glyphosate+imazapyr | crimson clover | glyphosate | bahiagrass |
| 12 | glyphosate+imazapyr | crimson clover | glyphosate | bermudagrass |
| 13 | glyphosate+imazapyr | ryegrass | glyphosate | bahiagrass |
| 14 | glyphosate+imazapyr | ryegrass | glyphosate | bermudagrass |
| 15 | non-treated | -- | -- | -- |

[a]Glyphosate, GlyPro Plus®(4 lb ai/gal)-3.0 qt pr/acre; imazapyr, Arsenal AC®(4 lb ai/gal)-24 oz pr/acre; glyphosate (1.5 qt pr/acre) + imazapyr (10 oz pr/acre).

[b]Bahiagrass, *Paspalum notatum* var. 'Pensacola' (30 lb/acre); common bermudagrass, *Cynodon dactylon* (20 lb/acre); crimson clover, *Trifolium incarnatum* cv. 'AU Robin' (40 lb/acre); annual ryegrass, *Lolium multiflorum* cv. 'Gulf' (40 lb/acre).

*Table 2.* Analysis of variance table, Loxley study.

| | Visual control | | | Stand density | | |
|---|---|---|---|---|---|---|
| Effect | df | *F* Value | *P* > *F* [a] | df | *F* Value | *P* > *F* |
| | 12 months after treatment | | | | | |
| Regime | 2 | 240.82 | <.0001 | 2 | 470.84 | <.0001 |
| Treatment | 14 | 27.22 | <.0001 | 14 | 50.43 | <.0001 |
| Regime x treatment | 28 | 2.55 | 0.0002 | 28 | 16.14 | <.0001 |
| | 24 months after treatment | | | | | |
| Regime | 1 | 637.67 | <.0001 | 1 | 1761.74 | <.0001 |
| Treatment | 14 | 8.75 | <.0001 | 14 | 19.32 | <.0001 |
| Regime x treatment | 14 | 4.56 | <.0001 | 14 | 5.02 | <.0001 |

[a]Main effects considered significant for Type I error if $P \leq 0.05$; interaction considered significant if $P \leq 0.10$.

*Table 3.* Cogongrass control 12 months after treatment, Loxley.

| Treatment | | | | Visual weed control[a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fall herbicide | Fall seeding | Spring herbicide | Spring seeding | 1 yr regime | | 2 yr regime | | 3 yr regime | |
| | | | | % | | | | | |
| glyphosate[b] (G) | bahiagrass | -- | -- | 10 | e | 61 | bcd | 80 | efg |
| glyphosate | bermudagrass | -- | -- | 18 | de | 47 | d | 83 | def |
| glyphosate | crimson clover | glyphosate | bahiagrass | 25 | bcde | 49 | d | 78 | fg |
| glyphosate | crimson clover | glyphosate | bermudagrass | 22 | cde | 59 | cd | 75 | g |
| imazapyr (I) | bahiagrass | -- | -- | 31 | abcde | 71 | abc | 87 | bcde |
| imazapyr | bermudagrass | -- | -- | 42 | abcd | 72 | abc | 85 | cdef |
| imazapyr | crimson clover | glyphosate | bahiagrass | 52 | a | 84 | a | 91 | abc |
| imazapyr | crimson clover | glyphosate | bermudagrass | 46 | abc | 82 | a | 90 | abcd |
| G + I | bahiagrass | -- | -- | 22 | cde | 80 | ab | 90 | abcd |
| G + I | bermudagrass | -- | -- | 22 | cde | 74 | abc | 95 | ab |
| G + I | crimson clover | glyphosate | bahiagrass | 52 | a | 77 | abc | 88 | bcd |
| G + I | crimson clover | glyphosate | bermudagrass | 44 | abc | 72 | abc | 97 | a |
| G + I | ryegrass | glyphosate | bahiagrass | 49 | ab | 72 | abc | 95 | ab |
| G + I | ryegrass | glyphosate | bermudagrass | 50 | a | 73 | abc | 97 | a |
| non-treated[c] | | | | 0 | | 0 | | 0 | |

[a]Least square means in a column followed by the same letter not significantly different ($P \leq 0.05$).

[b]Gly-Pro Plus® (3 qt pr/acre); Arsenal AC® (24 oz pr/acre); Gly-Pro Plus®(1.5 qt pr/acre) + Arsenal AC (10 oz pr/acre); 'Pensacola' bahiagrass (30 lb/acre); common bermudagrass (20 lb/acre); 'AU Robin' crimson clover (40 lb/acre); 'Gulf' annual ryegrass (40 lb/acre).

[c]Non-treated plots excluded from statistical analysis.

*Table 4.* Cogongrass stand density 12 months after treatment, Loxley.

| Treatment | | | | Stand density[a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fall herbicide | Fall seeding | Spring herbicide | Spring seeding | 1 yr regime | | 2 yr regime | | 3 yr regime | |
| | | | | $10^6$ stems/acre | | | | | |
| glyphosate[b] (G) | bahiagrass | -- | -- | 26.44 | ab | 4.25 | bcd | 1.01 | cd |
| glyphosate | bermudagrass | -- | -- | 24.49 | ab | 6.87 | ab | 1.56 | b |
| glyphosate | crimson clover | glyphosate | bahiagrass | 21.82 | bc | 9.12 | a | 1.48 | b |
| glyphosate | crimson clover | glyphosate | bermudagrass | 18.31 | c | 9.17 | a | 1.16 | cd |
| imazapyr (I) | bahiagrass | -- | -- | 12.65 | d | 0.52 | d | 1.28 | bc |
| imazapyr | bermudagrass | -- | -- | 5.19 | f | 2.55 | cd | 2.10 | a |
| imazapyr | crimson clover | glyphosate | bahiagrass | 7.81 | ef | 0.27 | d | 0.89 | de |
| imazapyr | crimson clover | glyphosate | bermudagrass | 10.55 | de | 0.37 | d | 1.04 | cd |
| G + I | bahiagrass | -- | -- | 27.18 | a | 4.89 | bc | 0.77 | de |
| G + I | bermudagrass | -- | -- | 22.36 | bc | 1.53 | cd | 0.00 | g |
| G + I | crimson clover | glyphosate | bahiagrass | 19.3 | c | 0.02 | d | 0.54 | ef |
| G + I | crimson clover | glyphosate | bermudagrass | 10.43 | de | 2.27 | cd | 0.00 | g |
| G + I | ryegrass | glyphosate | bahiagrass | 7.76 | ef | 1.56 | cd | 0.35 | fg |
| G + I | ryegrass | glyphosate | bermudagrass | 3.09 | f | 0.35 | d | 0.44 | fg |
| non-treated[c] | | | | 34.84 | | 23.72 | | 26.19 | |

[a]Least square means in a column followed by the same letter not significantly different ($P \leq 0.05$).

[b]Gly-Pro Plus® (3 qt pr/acre); Arsenal AC® (24 oz pr/acre); Gly-Pro Plus®(1.5 qt pr/acre) + Arsenal AC (10 oz pr/acre); ‘Pensacola’ bahiagrass (30 lb/acre); common bermudagrass (20 lb/acre); ‘AU Robin’ crimson clover (40 lb/acre); ‘Gulf’ annual ryegrass (40 lb/acre).

[c]Non-treated plots excluded from statistical analysis.

*Table 5.* Non-orthogonal contrasts for treatment groups12 months after treatment, Loxley.

| Contrast[a] | 1 yr regime Difference | 1 yr regime *P > F* | 2 yr regime Difference | 2 yr regime *P > F* | 3 yr regime Difference | 3 yr regime *P > F* |
|---|---|---|---|---|---|---|
| | Visual control (%) | | | | | |
| glyphosate vs. others | -22 | <.0001 | -22 | <.0001 | -13 | <.0001 |
| imazapyr vs. others | 12 | 0.0271 | 11 | 0.0141 | 1.0 | 0.7399 |
| glyphosate + imazapyr vs. others | 9.0 | 0.0678 | 10 | 0.0156 | 11 | <.0001 |
| spring glyphosate vs. no spring glyphosate | 25 | 0.0002 | 4.0 | 0.3493 | -2.0 | 0.1434 |
| crimson clover vs ryegrass | -10 | 0.3025 | -2.0 | 0.6349 | -9.0 | 0.0001 |
| bahiagrass vs. bermudagrass | -1.0 | 0.8990 | 2.0 | 0.5651 | -2.0 | 0.2121 |
| | Stand density ($10^6$ stems/acre) | | | | | |
| glyphosate vs. others | 10.18 | <.0001 | 5.81 | <.0001 | 0.49 | 0.0149 |
| imazapyr vs. others | -9.17 | <.0001 | -3.14 | 0.0049 | 0.49 | 0.0149 |
| glyphosate + imazapyr vs. others | -0.86 | 0.3166 | -2.35 | 0.0125 | -0.94 | <.0001 |
| spring glyphosate vs. no spring glyphosate | -7.39 | <.0001 | -2.79 | 0.6063 | -0.47 | 0.0451 |
| crimson clover vs ryegrass | 9.32 | <.0001 | 2.64 | 0.0629 | 0.54 | 0.0907 |
| bahiagrass vs. bermudagrass | 3.56 | <.0001 | -0.32 | 0.7065 | 0.02 | 0.8625 |

[a]Values are the estimated significant differences ($P \leq 0.05$).

*Table 6.* Cogongrass control 24 months after treatment, Loxley.

| Treatment | | | | Visual weed control[a] | | | |
|---|---|---|---|---|---|---|---|
| Fall herbicide | Fall seeding | Spring herbicide | Spring seeding | 1 yr regime | | 2 yr regime | |
| | | | | % | | | |
| glyphosate[b] (G) | bahiagrass | -- | -- | 0.0 | b | 31 | fg |
| glyphosate | bermudagrass | -- | -- | 0.0 | b | 22 | g |
| glyphosate | crimson clover | glyphosate | bahiagrass | 0.0 | b | 27 | fg |
| glyphosate | crimson clover | glyphosate | bermudagrass | 0.0 | b | 42 | ef |
| imazapyr (I) | bahiagrass | -- | -- | 0.0 | b | 51 | de |
| imazapyr | bermudagrass | -- | -- | 6.0 | b | 53 | bcde |
| imazapyr | crimson clover | glyphosate | bahiagrass | 13 | ab | 79 | a |
| imazapyr | crimson clover | glyphosate | bermudagrass | 19 | a | 80 | a |
| G + I | bahiagrass | -- | -- | 0.0 | b | 68 | abcd |
| G + I | bermudagrass | -- | -- | 0.0 | b | 70 | ab |
| G + I | crimson clover | glyphosate | bahiagrass | 6.0 | b | 61 | bcd |
| G + I | crimson clover | glyphosate | bermudagrass | 0.0 | b | 65 | abcd |
| G + I | ryegrass | glyphosate | bahiagrass | 0.0 | b | 69 | abc |
| G + I | ryegrass | glyphosate | bermudagrass | 6.0 | b | 52 | cde |
| non-treated[c] | | | | 0.0 | | 0.0 | |

[a]Least square means in a column followed by the same letter not significantly different ($P \leq 0.05$).

[b]Gly-Pro Plus® (3 qt pr/acre); Arsenal AC® (24 oz pr/acre); Gly-Pro Plus®(1.5 qt pr/acre) + Arsenal AC (10 oz pr/acre); 'Pensacola' bahiagrass (30 lb/acre); common bermudagrass (20 lb/acre); 'AU Robin' crimson clover (40 lb/acre); 'Gulf' annual ryegrass (40 lb/acre).

[c]Non-treated plots excluded from statistical analysis.

*Table 7.* Cogongrass stand density 24 months after treatment, Loxley.

| Treatment | | | | Stand density[a] | | | |
|---|---|---|---|---|---|---|---|
| Fall herbicide | Fall seeding | Spring herbicide | Spring seeding | 1 yr regime | | 2 yr regime | |
| | | | | $10^6$ stems/acre | | | |
| glyphosate[b] (G) | bahiagrass | -- | -- | 29.4 | abc | 4.74 | bc |
| glyphosate | bermudagrass | -- | -- | 31.38 | ab | 7.44 | b |
| glyphosate | crimson clover | glyphosate | bahiagrass | 30.64 | ab | 13.39 | a |
| glyphosate | crimson clover | glyphosate | bermudagrass | 26.19 | cde | 15.44 | a |
| imazapyr (I) | bahiagrass | -- | -- | 21.79 | fghi | 1.24 | cd |
| imazapyr | bermudagrass | -- | -- | 21.05 | ghi | 2.42 | cd |
| imazapyr | crimson clover | glyphosate | bahiagrass | 19.67 | hi | 1.56 | cd |
| imazapyr | crimson clover | glyphosate | bermudagrass | 21.99 | fghi | 0.52 | d |
| G + I | bahiagrass | -- | -- | 31.88 | a | 4.87 | bc |
| G + I | bermudagrass | -- | -- | 23.75 | defg | 2.59 | cd |
| G + I | crimson clover | glyphosate | bahiagrass | 23.28 | efgh | 0.62 | d |
| G + I | crimson clover | glyphosate | bermudagrass | 25.45 | cdef | 3.61 | cd |
| G + I | ryegrass | glyphosate | bahiagrass | 27.43 | bcd | 1.56 | cd |
| G + I | ryegrass | glyphosate | bermudagrass | 18.53 | i | 0.40 | d |
| non-treated[c] | | | | 36.57 | | 32.86 | |

[a]Least square means in a column followed by the same letter not significantly different ($P \leq 0.05$).

[b]Gly-Pro Plus® (3 qt pr/acre); Arsenal AC® (24 oz pr/acre); Gly-Pro Plus®(1.5 qt pr/acre) + Arsenal AC (10 oz pr/acre); 'Pensacola' bahiagrass (30 lb/acre); common bermudagrass (20 lb/acre); 'AU Robin' crimson clover (40 lb/acre); 'Gulf' annual ryegrass (40 lb/acre).

[c]Non-treated plots excluded from statistical analysis.

*Table 8*. Non-orthogonal contrasts for treatment groups 24 months after treatment, Loxley.

| | 1 yr regime | | 2 yr regime | |
|---|---|---|---|---|
| Contrast[a] | Difference | *P* > *F* | Difference | *P* > *F* |
| | Visual control (%) | | | |
| glyphosate vs. others | -5.0 | 0.0585 | -32 | <.0001 |
| imazapyr vs. others | 9.0 | 0.0021 | 14 | <.0001 |
| glyphosate + imazapyr vs. others | -3.0 | 0.2322 | 15 | <.0001 |
| spring glyphosate vs. no spring glyphosate | 5.0 | 0.0594 | 11 | 0.0022 |
| crimson clover vs ryegrass | 3.0 | 0.3338 | 1.0 | 0.7523 |
| bahiagrass vs. bermudagrass | -1.5 | 0.4486 | 1.0 | 0.9268 |
| | Stand density ($10^6$ stems/acre) | | | |
| glyphosate vs. others | 6.20 | <.0001 | 8.38 | <.0001 |
| imazapyr vs. others | -5.71 | <.0001 | -4.00 | <.0001 |
| glyphosate + imazapyr vs. others | -0.42 | 0.7973 | -3.63 | <.0001 |
| spring glyphosate vs. no spring glyphosate | -2.69 | 0.0029 | 0.74 | 0.2495 |
| crimson clover vs ryegrass | 1.53 | 0.1902 | 4.77 | <.0001 |
| bahiagrass vs. bermudagrass | 1.95 | 0.0049 | -0.52 | 0.3514 |

[a]Values are the estimated significant differences ($P \leq 0.05$).

## III. CONTROL AND REVEGETATION

### *Malbis Study*

### Materials and Methods

A second field study was initiated in the fall of 2001 on Interstate 10 ROW near the Malbis community. The study area was located 0.5 mi. east of the I-10 / Co. Rd. 27 interchange in the median of the eastbound lanes at mile marker 40. The study area was selected for reasons similar to those stated previously for the Loxley Study. Soil was a loamy sand with pH 6.1. Site history was the same as that described for the Loxley Study.

Much like the Loxley study, the Malbis study examined an integrated approach to cogongrass control on ROWs with herbicides and the planting of aggressive replacement species. However, two key differences in plot maintenance practices existed between the two locations: 1) plots at Malbis were mowed 4x during the growing season (late May-early June, July, late Aug.-early Sept., and Nov.) and 2) all replacement species were drill-seeded. The study at Malbis was designed to more closely follow ALDOT protocols for mowing, and drill-seeding was used due to first season failures observed in the Loxley experiment. Experimental units were plots 10 ft. wide by 30 ft. in length and were arranged parallel to the roadway. Test treatments consisted of combinations of fall herbicide application and/or seeding followed by spring herbicide application and seeding. A complete listing of test treatments with rates and timings is shown in Table 9. Seven treatment combinations were tested plus a non-treated check for eight total treatments in a randomized complete block design with four replications. Herbicides were glyphosate or the tank-mix combination of glyphosate plus imazapyr. Competing species were a mixture of bahiagrass and bermudagrass, and the winter cover crops crimson clover and annual ryegrass. Bahiagrass and bermudagrass seed were mixed at 2:1 ratio with a final seeding rate of 30 lb/acre for planting, rather than each species planted alone as used at Loxley. The study was implemented in triplicate fashion with one, two, and three year regimes as described for the Loxley Study, such that a time factor could be studied.

Herbicide applications were made with the same equipment described previously. Seed of replacement species were sown using an eight ft.-wide grain drill[12]. Bahiagrass and bermudagrass were planted at a depth of 0.25 in., whereas crimson clover and ryegrass were sown between 0.75 and 1.0 in. Herbicide application dates and planting dates were similar to those at Loxley. Rotary mowing of plots was done by ALDOT maintenance personnel to a height of 4 in. All other maintenance operations by ALDOT personnel were ceased at the onset of the study.

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[12]John Deere Model 1560 No-Till Drill, John Deere Co., 2001 Deere Dr., Conyers, GA 30013.

Visual estimations of percent cogongrass control and percent cover by either bahiagrass or bermudagrass were performed at 12 month intervals beginning September 2002 through August 2003 Visual estimations were always conducted prior to any pending herbicide treatment or seeding operation. Cogongrass density was also determined by counting the number of stems in a randomly placed 2.7 $ft.^2$ subplot, and were subsequently expanded to a per hectare basis. Stem counts were begun in September 2002 and repeated in August 2003. As with visual estimations, stem counts were performed in late August or early September, prior to fall treatment in October. Data were analyzed as described previously for the Loxley study.

## Results and Discussion

Data analyzed included visual control ratings stand density, and desirable grass conversion for the one and two year regimes 12 MAT. The three year regime will not be presented until ratings are completed in the fall of 2004. All responses were significant for the main effects of treatment, regime, and the interaction of treatment by regime (Table 10). Therefore, treatment least square means are presented by regime for (Tables 11 and 12). Non-orthogonal contrasts are also presented by regime (Table 13). Mean visual control for the one and two year regimes was 62% and 94%, respectively (Table 11). The interaction effect is generally represented by the magnitude of difference between the regimes. Glyphosate plus imazapyr (fall) followed by fall grass seeding was the only treatment that had higher control when implemented in a one year regime versus a two year regime. No significant differences in stand density were detected by means separation procedures (0.05) for the one year regime (Table 12). However, differences were evident in the two year regime. As indicated in the Loxley study, treatment rankings changed between regimes and would account for the regime by treatment interaction evident (data not shown).

All plots treated with herbicide had increased visual control and decreased stand density versus the non-treated in both one and two year regimes (Table 13). Glyphosate alone as the fall herbicide application significantly decreased visual control and increased density versus a tank-mix combination with imazapyr in the one year regime. However, no difference in these two herbicide applications was detected in the two year regime. The use of a cover crop, regardless of species, increased visual control in the one year regime, but was not significant in the two year regime. Visual control and density results from the Malbis study align more closely with literature previously discussed for the Loxley study (Shilling et al. 1997; Willard et al. 1996 and 1997). Further evaluation in time is needed to clarify any potential treatment differences.

Conversion of cogongrass to bahiagrass or bermudagrass was not achieved in the one year regime as maximum conversion was 12% (data not shown). Maximum conversion was 60% bermudagrass in the two year regime (Table 14). All treated plots had significant conversion versus the non-treated. Conversion to either bahiagrass or bermudagrass was decreased significantly when glyphosate alone was the fall herbicide. The presence of imazapyr did not negatively effect the establishment of either bahiagrass or bermudagrass and was unexpected. The spring glyphosate application confounds the effect of spring seeding versus fall seeding, which would be useful information. Johnson (1999) reported that common bermudagrass planted into existing cogongrass, or in areas with cogongrass in close proximity, suppressed cogongrass regrowth 60%. The fact that bermudagrass established is contrary to reports from Koger and Bryson (2003) who demonstrated allelopathic effects of cogongrass leachates on common bermudagrass germination and growth. Drill-seeding of the bahiagrass:bermudagrass seed mixture improved seed-soil contact. Long-term results from 24 MAT should further indicate conversion and its effect on cogongrass re-growth.

Findings from both Loxley and Malbis agree with other research in that multiple applications of herbicide and re-treatment are necessary for successful cogongrass management (Bryson and Carter 1993; Johnson 1999; Senarthne et al. 2003). However, these studies differ from others in that treatments were evaluated up to 24 months after treatment and the same treatments were repeated through time, giving a more comprehensive view of long-term management strategies.

*Table 9*. Fall and spring herbicide and seeding operations, Malbis Study.

| | Fall (October) | | Spring (March) | |
|---|---|---|---|---|
| Treatment | Herbicide | Seeding | Herbicide | Seeding |
| 1 | non-treated | -- | -- | -- |
| 2 | glyphosate[a] | grass mix[b] | -- | -- |
| 3 | glyphosate+imazapyr | grass mix | -- | -- |
| 4 | glyphosate | crimson clover | glyphosate | grass mix |
| 5 | glyphosate+imazapyr | crimson clover | glyphosate | grass mix |
| 6 | glyphosate | ryegrass | glyphosate | grass mix |
| 7 | glyphosate+imazapyr | ryegrass | glyphosate | grass mix |
| 8 | glyphosate | -- | glyphosate | grass mix |

[a]Glyphosate, GlyPro Plus® (4 lb ai/gal)-3 qt pr/acre; GlyPro Plus® (1.5 qt pr/acre) + imazapyr (Arsenal AC®) - 12 oz pr/acre.

[b]Bahiagrass, *Paspalum notatum* var. 'Pensacola' (20 lb/acre) + common bermudagrass, *Cynodon dactylon* (10 lb/acre); crimson clover, *Trifolium incarnatum* cv. 'AU Robin' (40 lb/acre); annual ryegrass, *Lolium multiflorum* cv. 'Gulf' (40 lb/acre).

*Table 10.* Analysis of variance table 12 months after treatment, Malbis study.

| Effect | df | *F* Value | *P* > *F* [a] |
|---|---|---|---|
| | | Visual control | |
| Regime | 7 | 34.37 | <.0001 |
| Treatment | 1 | 28.41 | <.0001 |
| Regime x treatment | 7 | 7.69 | <.0001 |
| | | Stand density | |
| Regime | 7 | 5.09 | 0.0003 |
| Treatment | 1 | 110.85 | <.0001 |
| Regime x treatment | 7 | 2.73 | 0.0189 |
| | | Desirable grass conversion | |
| Regime | 7 | 63.58 | <.0001 |
| Treatment | 1 | 47.02 | <.0001 |
| Regime x treatment | 7 | 5.21 | 0.0264 |

[a]Main effects considered significant for Type I error if $P \leq 0.05$; interaction considered significant if $P \leq 0.10$.

*Table 11.* Cogongrass visual control 12 months after treatment, Malbis.

| Treatment | | | | Visual weed control[a] | | | |
|---|---|---|---|---|---|---|---|
| Fall herbicide | Fall seeding | Spring herbicide | Spring seeding | 1 yr regime | | 2 yr regime | |
| | | | | % | | | |
| glyphosate[b] | grass mix | -- | -- | 24 | e | 99 | a |
| glyphosate+imazapyr | grass mix | -- | -- | 83 | ab | 68 | b |
| glyphosate | crimson clover | glyphosate | grass mix | 62 | bc | 99 | a |
| glyphosate+imazapyr | crimson clover | glyphosate | grass mix | 90 | a | 97 | a |
| glyphosate | ryegrass | glyphosate | grass mix | 60 | cd | 99 | a |
| glyphosate+imazapyr | ryegrass | glyphosate | grass mix | 82 | ab | 96 | a |
| glyphosate | -- | glyphosate | grass mix | 33 | de | 98 | a |
| non-treated[c] | | | | 0 | | 0 | |

[a]Least square means in a column followed by the same letter not significantly different ($P \leq 0.05$).

[b]Glyphosate, Gly-Pro Plus® (3 qt pr/acre); glyphosate + imazapyr, Gly-Pro Plus® (1.5 qt pr/acre) + Arsenal AC® (12 oz pr/acre); grass mix, bahiagrass (20 lb/acre) + bermudagrass (10 lb/acre); crimson clover, ‘AU Robin’ (40 lb/acre); ryegrass, ‘Gulf’ (40 lb/acre).

[c]Non-treated plots excluded from statistical analysis.

*Table 12.* Cogongrass stand density 12 months after treatment, Malbis.

| Treatment | | | | Stand density[a] | | | |
|---|---|---|---|---|---|---|---|
| Fall herbicide | Fall seeding | Spring herbicide | Spring seeding | 1 yr regime | | 2 yr regime | |
| | | | | $10^6$ stems/acre | | | |
| glyphosate[b] | grass mix | -- | -- | 12.03 | a | 0.12 | a |
| glyphosate+imazapyr | grass mix | -- | -- | 8.5 | a | 0.35 | ab |
| glyphosate | crimson clover | glyphosate | grass mix | 11.93 | a | 0.07 | a |
| glyphosate+imazapyr | crimson clover | glyphosate | grass mix | 9.59 | a | 0.07 | a |
| glyphosate | ryegrass | glyphosate | grass mix | 12.63 | a | 0.69 | b |
| glyphosate+imazapyr | ryegrass | glyphosate | grass mix | 9.56 | a | 0.05 | a |
| glyphosate | -- | glyphosate | grass mix | 9.86 | a | 0.15 | a |
| non-treated[c] | | | | 28.42 | | 18.83 | |

[a]Least square means in a column followed by the same letter not significantly different ($P \leq 0.05$).

[b]Glyphosate, Gly-Pro Plus® (3 qt pr/acre); glyphosate + imazapyr, Gly-Pro Plus® (1.5 qt pr/acre) + Arsenal AC® (12 oz pr/acre); grass mix, bahiagrass (20 lb/acre) + bermudagrass (10 lb/acre); crimson clover, 'AU Robin' (40 lb/acre); ryegrass, 'Gulf' (40 lb/acre).

[c]Non-treated plots excluded from statistical analysis.

*Table 13.* Non-orthogonal contrasts for treatment groups 12 months after treatment, Malbis.

| Contrast[a] | 1 yr regime Difference | 1 yr regime $P > F$ | 2 yr regime Difference | 2 yr regime $P > F$ |
|---|---|---|---|---|
| | Visual control (%) | | | |
| glyphosate vs. glyphosate + imazapyr | -40 | <.0001 | 12 | 0.2307 |
| spring glyphosate vs. no spring glyphosate | 12 | 0.0802 | 14 | 0.1058 |
| cover crop vs. no cover crop | 27 | 0.0003 | 9 | 0.2307 |
| crimson clover vs ryegrass | 5 | 0.4636 | 0 | 1.0000 |
| treated vs. non-treated | 62 | <.0001 | 94 | <.0001 |
| | Stand density ($10^6$ stems/acre) | | | |
| glyphosate vs. glyphosate + imazapyr | 2.40 | 0.0325 | 0.10 | 0.5456 |
| spring glyphosate vs. no spring glyphosate | 0.44 | 0.9440 | -0.02 | 0.8585 |
| cover crop vs. no cover crop | 0.79 | 0.8264 | 0.02 | 0.9261 |
| crimson clover vs ryegrass | -0.35 | 0.9321 | -0.30 | 0.3387 |
| treated vs. non-treated | -17.84 | 0.0092 | -17.32 | 0.0461 |

[a]Values are the estimated significant differences ($P \leq 0.05$).

*Table 14.* Right-of-way conversion in the two year regime 12 months after treatment, Malbis.

| Treatment or contrast | | | | Desirable grass conversion[a] | | |
|---|---|---|---|---|---|---|
| Fall herbicide | Fall seeding | Spring herbicide | Spring seeding | Species | Coverage | |
| | | | | | —— % —— | |
| glyphosate[b] | grass mix | -- | -- | bahiagrass | 17 | bc |
| glyphosate+imazapyr | grass mix | -- | -- | bermudagrass | 58 | a |
| glyphosate | crimson clover | glyphosate | grass mix | bahiagrass | 4 | cd |
| glyphosate+imazapyr | crimson clover | glyphosate | grass mix | bahiagrass | 56 | a |
| glyphosate | ryegrass | glyphosate | grass mix | bermudagrass | 35 | b |
| glyphosate+imazapyr | ryegrass | glyphosate | grass mix | bermudagrass | 60 | a |
| glyphosate | -- | glyphosate | grass mix | bahiagrass | 31 | b |
| non-treated[c] | | | | | 0 | |
| | | | | Difference[d] | *P > F* | |
| glyphosate vs. glyphosate + imazapyr | | | | -36 | <.0001 | |
| spring glyphosate vs. no spring glyphosate | | | | 0 | 0.9136 | |
| cover crop vs. no cover crop | | | | 3 | 0.1007 | |
| treated vs. non-treated | | | | 37 | <.0001 | |

[a]Least square means in a column followed by the same letter not significantly different ($P \leq 0.05$).

[b]Glyphosate, Gly-Pro Plus® (3 qt pr/acre); glyphosate + imazapyr, Gly-Pro Plus® (1.5 qt pr/acre) + Arsenal AC® (12 oz pr/acre); grass mix, bahiagrass (20 lb/acre) + bermudagrass (10 lb/acre); crimson clover, 'AU Robin' (40 lb/acre); ryegrass, 'Gulf' (40 lb/acre).

[c]Non-treated plots excluded from statistical analysis.

[d]Values are the estimated significant differences ($P \leq 0.05$).

## IV. MOWING-HERBICIDE INTERACTIONS

*Theodore*

### Materials and Methods

Due to the prevalence of mowing as a standard ROW maintenance operation, a field study was designed to investigate cogongrass response to mowing frequency and interactions with herbicide application. The study site was located on the property of Degussa Corp., in Mobile Co., AL, near the town of Theodore. Soil at the site was a Bama fine sandy loam (Fine-loamy, siliceous, subactive, thermic Typic Paleudults) with pH 5.6 and organic matter 1.2%. The study site, previously in row crop agriculture but fallowed since the late 1980s, was heavily infested with cogongrass and a woody component of chinese privet (*Ligustrum sinense* Lour.), wax myrtle (*Myrica cerifera* L.), tallowtree [*Triadica sebifera* (L.) Small], and yaupon (*Ilex vomitoria* Aiton). This wooody component was cut and removed by hand in spring 2001, leaving a contiguous stand of cogongrass. Cut stumps were subsequently treated with a 30% triclopyr solution in oil to prevent sprouting.

The experiment was a factorial arrangement that tested five mowing schedules and four herbicide applications in a randomized complete block design with four replications. Mowing schedules were none, once every three months, once every two months, once per month, and twice per month. Herbicide applications were spring-applied glyphosate (3 lb ai/acre), spring applied imazapyr (0.5 lb ai/acre), spring and summer-applied glyphosate (1.5 lb ai/acre) each application), and none. Experimental units were plots 10 ft. wide by 20 ft. in length. Mowing height was 3 in. and was accomplished using a 8 ft. flail mower[13] powered by a 65 hp tractor.

Plots were established on May 2, 2002 and herbicides were applied on the following day. Herbicides were applied with a $CO_2$-powered, ATV-mounted sprayer in aqueous solution of 20 gal/acre. The spray boom was equipped with ten nozzles, each with a 11003 flat fan nozzle tip, and was operated at a pressure of 52 psi. The initial mowing occurred seven days after herbicide application and all plots scheduled except the non-treated were mowed. Mowing was continued throughout the growing season according to the established protocol through October 9, 2002. Summer glyphosate application occurred on July 30, 2002. The mowing schedule was repeated in 2003 minus the herbicide application, beginning on May 5 and continuing through October 20 that same year.

Visual estimations of percent cogongrass control were recorded at the end of each growing season (November 2002 and 2003). Cogongrass density, as expressed by stand count, was measured also at the end of each growing season. Density was measured by counting the number of stems in a 2.7 $ft.^2$ subplot randomly placed near the center of the plot and expanded to a per acre basis. Prior to ANOVA, percent control data were arcsine square-root transformed. This procedure did not improve the homogeneity of variance based on inspection of the plotted

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[13]Alamo SHD88 Flail, Alamo Corp., P.O. Box 549, Seguin, TX 78156.

residuals. Mixed models analysis techniques were utilized to test the main effects of mowing and herbicide and their interaction. Orthogonal contrasts were planned to compare factor differences at the 0.05 level.

## Results and Discussion

The main effect of herbicide was significant for both 2002 and 2003, while the interaction between mowing and herbicide was not significant (Table 15). At the end of both the 2002 and 2003 seasons, frequency of mowing had no measurable effect on either visual control of cogongrass or density as reflected in stems/acre (Table 16). During the first season, the sequential application of glyphosate gave 99% control of cogongrass and resulted in total elimination of above-ground stems, regardless of mowing frequency. At the end of 2003, re-growth into all plots was evident as the highest control level obtained was 69%. Sequential glyphosate applications reduced cogongrass density to 1.01 million stems/acre.

Monthly mowings reduced above-ground cogongrass foliage mass in a similar study by Willard and Shilling (1990), however, no herbicide interactions were tested. In another study, Willard et al. (1996) reported that mowing combined with a single glyphosate application reduced biomass >80% after one season. Data from this study are similar to Willard et al. (1996), however, the rate of glyphosate used in their study was higher (4.0 lb vs. 3.0 lb ai/acre).

Possible reasons for a lack of mowing effect could be related to mowing height. An 3 in. mowing height was chosen to imitate common mowing heights on ROWs. Mowing heights less than 3 in. are both uncommon and economically unfeasible due to the need for multiple passes over the site. With the exception of the initial spring mowing, too little biomass was removed at each mowing to impose a stress on the cogongrass rhizomes. Burnell et al. (2003b) reported that weekly mowings to ground level reduced cogongrass density from $3.71 \times 10^6$ to $0.5 \times 10^6$ stems/acre in a single season. These researchers also reported that cogongrass regrowth in mowed plots the following season was unchanged from the non-treated. However, with the exception of small, isolated infestations of cogongrass, heights less than 3 in. and high mowing frequency ($\geq$ 1x/month) are not practical for ROW management.

*Table 15.* Analysis of variance table for mowing-herbicide interaction study, Theodore.

| | Visual control | | | Stand density | | |
|---|---|---|---|---|---|---|
| Effect | df | *F* Value | *P* > *F* [a] | df | *F* Value | *P* > *F* |
| | | | 2002 | | | |
| Mowing | 4 | 1.49 | NS | 4 | 6.37 | NS |
| Herbicide | 3 | 119.001 | <.0001 | 3 | 26.54 | 0.0307 |
| Mowing x herbicide | 12 | 2.07 | NS | 12 | 3.36 | NS |
| | | | 2003 | | | |
| Mowing | 4 | 0.87 | NS | 4 | 4.15 | NS |
| Herbicide | 3 | 25.23 | 0.0189 | 3 | 42.89 | 0.0257 |
| Mowing x herbicide | 12 | 1.79 | NS | 12 | 10.06 | NS |

[a]Main effects considered significant for Type I error if $P \leq 0.05$. Interactions considered significant for Type I error if $P \leq 0.10$.

*Table 16.* Effects of herbicide on cogongrass control, Theodore[ab].

| Herbicide treatment | 2002 | | 2003 | |
|---|---|---|---|---|
| | Visual control (%) | | | |
| No herbicide | 13 | d | 4 | b |
| Spring-applied glyphosate[c] | 61 | c | 15 | b |
| Spring-applied imazapyr | 82 | b | 19 | b |
| Sequential glyphosate applications[d] | 99 | a | 69 | a |
| | Stand density ($10^6$ stems/acre) | | | |
| No herbicide | 21.30 | a | 21.77 | a |
| Spring-applied glyphosate | 5.71 | b | 15.89 | a |
| Spring-applied imazapyr | 1.63 | b | 12.60 | a |
| Sequential glyphosate applications | 0.00 | c | 1.01 | b |

[a]Data pooled across mowing schedule due to the absence of main effects or interactions.
[b]Means in a column followed by the same letter not significantly different ($P \leq 0.05$).
[c]Glyphosate, Gly-Pro Plus® (3 qt pr/acre); imazapyr, Arsenal AC® (16 oz pr/acre); glyphosate sequential, Gly-Pro Plus® (1.5 qt pr/acre, each).
[d]Application dates: spring, May 2, 2002; summer sequential, July 30, 2002.

## SUMMARY AND RECOMMENDATIONS

Control of cogongrass was achieved with a 3 year regime up to 12 MAT. A tank-mix combination of glyphosate plus imazapyr applied in the fall increased visual control and decreased stand density, while not affecting bahiagrass or bermudagrass conversion at one location. Spring re-treatment with glyphosate increased visual control but did not decrease density at Loxley, and was not significant at Malbis. Conversion to more desirable grass was achieved at Malbis only, where drill-seeding was used. Neither bahiagrass nor bermudagrass was favored. Continued monitoring of both the Loxley and Malbis study areas is needed to adequately assess the impact of treatments on a perennial species such as cogongrass. As outlined previously, one of the objectives of this research was development of BMPs for cogongrass infestations on ROWs. Recommendations are as follows:

1) Care should be taken to prevent or exclude cogongrass infestations in unaffected areas; this includes, but is not limited to prudent selection of fill soil for earthwork operations and moratoria on the movement of soil out of infested areas, or areas within close proximity to known infestations.

2) The cleaning of earthwork and mowing machinery to remove propagules when moving between infested and un-infested areas.

3) Treatment of infestations with glyphosate ($\geq$3 lb ai/acre) or glyphosate plus imazapyr (1.5 + 0.38 lb ai/acre) in the fall, followed by drill-seeding of a cover crop, followed by spring treatment of regrowth with glyphosate ($\geq$3 lb ai/acre) and drill-seeding of a bermudagrass:bahiagrass seed mixture (2:1) at 30 lb/acre. Herbicide application should be made in at least 15 gal/acre of solution to ensure adequate coverage. This treatment program should be repeated yearly for 3 years.

4) Mowing of infestations as outlined in typical ROW protocols does neither affect growth or survival nor interferes with herbicide application. Anecdotal evidence suggests mowing should not be conducted during anthesis to restrict the movement of seed. Mowing will not affect the treatment regime outline above.

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APPENDIX I. Monthly rainfall recorded in Fairhope, AL: Oct. 2000 - Mar. 2004[a].

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm | | | | | | | | | | | |
| 2000 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 10.0 | 187 | 93.0 |
| 2001 | 89.0 | 84.0 | 223 | 2.00 | 13.0 | 356 | 248 | 230 | 111 | 90.0 | 42.0 | 69.0 |
| 2002 | 126 | 65.0 | 113 | 86.0 | 68.0 | 72.0 | 281 | 145 | 369 | 215 | 145 | 126 |
| 2003 | 63.0 | 174 | 126 | 71.0 | 130 | 236 | 276[b] | n/a | n/a | n/a | 92.0 | 106 |
| 2004 | 137 | 199 | 14.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |

[a]Data provided by Agricultural Weather Information Service (http://www.awis.com), P.O. Box 3267, Auburn, AL 36831.
[b]Recording ceased 7/21/2003 through 10/28/2003.

APPENDIX II. Monthly rainfall recorded in Theodore, AL: April 2001 - Mar. 2004 [a].

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm | | | | | | | | | | | |
| 2001 | 78.0 | 67.0 | 182 | 8.00 | 8.00 | n/a[b] | 229 | 160 | 81.0 | n/a | 53.0 | 71.0 |
| 2002 | 86.0 | 97.0 | 81.0 | 33.0 | 41.0 | 64.0 | 195 | 162 | 285 | n/a | 46.0 | n/a |
| 2003 | 8.30 | 168 | 49.0 | 55.0 | 132 | 173 | 15 | 130 | 31 | 130 | 33.0 | 97.0 |
| 2004 | 111 | 196 | 10.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |

[a]Data provided by Degussa Corporation, 4201 Degussa Rd., Theodore, AL 36590.
[b]Data not available.