ASSESSMENT OF HYDROPLANTING TECHNIQUES AND HERBICIDE TOLERANCE OF TWO NATIVE HAWAIIAN GROUNDCOVERS WITH ROADSIDE RE-VEGETATION POTENTIAL

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ABSTRACT

Roadside re-vegetation utilizing native groundcovers is a new initiative in Hawai‘i. To develop establishment and maintenance protocols, large-scale propagation and selective weed control techniques for potential species need to be tested. This study evaluated hydroplanting techniques and screened pre- and post-emergence herbicides for establishing *Fimbristylis cymosa* and *Sporobolus virginicus*. Hydroplanting trials indicate that *F. cymosa* can be efficiently established through hydroseeding while *S. virginicus* can be hydromulched using auxin treated apical cuttings. Oxadiazon and oryzalin can be safely used in transplanted *F. cymosa* plugs but not seedlings. Fluazifop-p-butyl and aminopyralid can be safely applied in plants ≥ 28 days old while sulfosulfuron should only be spot sprayed. For *S. virginicus*, oxadiazon, oxyfluorfen, sulfosulfuron and aminopyralid can be used for transplanted plugs while carfentrazone + MCPA + mecoprop + dicamba and triclopyr should only be spot sprayed. Information gathered from the study has been incorporated into establishment protocols for the two species.

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CHAPTER 1

INTRODUCTION

It is well established that roads severely impact the landscape by contributing to runoff and erosion, altering wildlife patterns, fragmenting habitats and facilitating the spread of alien vegetation (Tyser et al., 1998). The removal of native topsoil and vegetation during road construction and development drastically alters the local ecology and makes the area more prone to erosion. As a result, the bare surface creates a hazard for both the environment and motorists. One of the earliest and most practical strategies that have been developed to mitigate the negative impacts of roads is through roadside re-vegetation.

Re-vegetation of road corridors was done primarily to increase motorist's safety, mitigate soil erosion along roadways and prevent siltation in adjacent waterways. Conventional roadside re-vegetation utilizes non-native plant species because these are cost effective, readily available and quick to establish on disturbed sites (Landis et al., 2005). Although these plants possess desirable characteristics for re-vegetation, their introduction and establishment can lead to potential problems. Non-native plants, whether domesticated or weedy, can cause disruptions to local ecosystem functions (Burton and Burton, 2001) by competing with and/or displacing indigenous flora (Tyser et al., 1998). The invasive multiflora rose (*Rosa multiflora*), originally planted along roadsides in Virginia and elsewhere, is one example of an introduced species to that has escaped and invaded natural habitats (Forman et al., 2003). Because of these negative impacts as well as the increasing cost of roadside maintenance, re-vegetation research has recently focused on utilizing native plants.

Native species re-vegetation along roadsides is increasing in popularity (Landis et al., 2005). The need and demand for commercially available native species is growing (Jenkins et al., 2004) and they are increasingly requested for use on re-vegetation and restoration projects following land disturbance (Brindle, 2003). Studies have shown that re-vegetating road corridors with native plant species not only enhances roadside aesthetics, but it also conserves local biodiversity, mitigates the spread of invasive weeds and reduces roadside maintenance costs. In recent years, the Federal Highway Administration (FHWA) has taken the lead in proactive environmental stewardship by promoting the use of native species in roadside re-vegetation and roadside landscaping projects (Harper-Lore, 1996; Steinfield et al., 2007a). Increased adoption over the past 20 years has led to the development of native plant lists and establishment protocols for several states such as Texas (Markwaldt, 2005), Minnesota (Harper-Lore, 1996) and Utah (Hansen and McKell, 1991)

In Hawai'i, the concept of roadside re-vegetation using native plants is relatively new. Due to the dearth of research conducted on the roadside suitability of native Hawaiian plants, the state has yet to develop lists of appropriate species and establishment protocols as of February 2009. Large scale planting techniques such as hydroseeding or hydromulching as well as selective weed control during roadside establishment are important aspects that need to be explored or refined for successful re-vegetation with native Hawaiian plants.

The Hawai'i Department of Transportation (HDOT) has provided funding to develop protocols for native groundcover establishment. This masters thesis, funded in part by the HDOT, has evaluated propagation and selective weed control options for large-scale establishment of two native Hawaiian groundcovers, namely *Sporobolus virginicus* (ʻakiʻaki) and *Fimbristylis cymosa* (mauʻu ʻakiʻaki). This study examined the following: 1) the success of different hydroplanting techniques in establishing *Fimbristylis cymosa*; 2) the potential of utilizing *Sporobolus virginicus* stem cuttings as a propagation material for hydromulch planting and 3) the tolerance of the two species to different roadside right-of-way pre and post-emergent herbicides.

Review of Related Literature

An Overview of Roadside Vegetation Management in the United States

Management of rights-of-way vegetation is done for a variety of reasons including safety, aesthetics and fire control (Scanlon, 1991). The earliest efforts at managing roadside vegetation integrated manual methods of cutting and pulling with biological methods of allowing grazing animals such as goats and sheep to maintain grasses, forbs, and palatable brush species (Berger, 2005). Today, a number of tools are available to efficiently manage vegetation on the roadsides. These include mechanical, cultural and biological methods (e.g. mowing, herbicides, planting of native species, etc.).

Over the years, U.S. roadsides have used various approaches to roadside vegetation management. In the 1930s, the front yard approach to managing vegetation was adopted. This management method, which declared that 'roadsides should be maintained as if they were *our nation's frontyards*', became the unofficial policy for many years (DOT-FHWA, 2004; Forman et al., 2003; Harper-Lore and Wilson, 2000).

Innovations in agriculture during the 1950s provided new tools (e.g., mowers, farm equipment and herbicides) that made roadside maintenance easier. This 'agricultural approach' of maintaining the roadsides resulted in the well-manicured, "front yard" look of roadsides. By the mid 1960s, management of roadside vegetation became especially active with the addition of roadside beautification in the Transportation Appropriation Act (DOT-FHWA, 2004; Forman et al., 2003).

The energy crunch of the 1970s forced highway maintenance crews to cut back on costly fuel use and look for alternative ways to manage roadside vegetation (Harper-Lore, 1996). Reduced mowing frequencies and spot spraying led to positive environmental and economic impacts. This included increased habitat for wildlife, enhanced natural beauty, minimized use of herbicides and reduced maintenance dollars (DOT-FHWA, 2004). By the 1990s, the search for a cost-effective and ecologically sound approach led to the formulation and adoption of integrated roadside vegetation management (IRVM). Basing its principles on integrated pest management, IRVM employs multiple strategies to maintain vegetation. Toward the end of the 20th century, roadside vegetation management focused on conservation by preserving native plant diversity and controlling invasive plants on roadsides.

The Use of Native Species on the Roadside

The concept of using native plants on roadsides has been advocated since the early days of roadside development. One of the earliest efforts to promote native plants on roadsides was in 1932, when the Texas Department of Transportation (TXDOT) hired its first landscape architect to maintain, preserve and encourage wildflowers and other native plants along rights-of-way (Landis et al., 2005; Markwaldt, 2005). At that time, information on native plants was lacking so activities were limited to protection and management of native plants that had colonized the roadsides.

Because of limited agronomic/horticultural information and problems encountered during establishment, native plants have not been used in highway landscaping up until the 1960s. Landis et al. (2005) adds that the lack of published research, case studies or guidelines for using native plants was due to the prevalent use of non-native grasses, because they were cheap, readily available and easy to establish on disturbed sites. It is only in recent years that research on native plants has gained momentum because of increased interest and concern for environmental protection and preservation.

Using native plants is the most environmentally sound and aesthetically pleasing way of re-establishing vegetation (Rorison and Hunt, 1980). Compared to introduced plant species, natives are better adapted to local conditions; have greater resistance to insects and pathogens; provide better habitat and forage for roadside compatible wildlife compared to introduced plant species; help in conservation of gene-pool resources and provide aesthetics that blend in with adjacent natural environments (Daar and King, 1997). Using natives on disturbed areas such as roadsides minimizes the opportunities for establishment and spread of noxious or invasive species, thus preventing highways from becoming corridors for the transport of problematic species (Landis et al., 2005). Huxtable and Whalley (1999) noted that re-vegetation with native grasses can result in swards with lower maintenance costs of re-seeding, fertilizer application, and spraying of weeds.

Factors Affecting Native Plant Establishment

Success in establishing native plants on any roadside re-vegetation project is influenced by several factors. Current literature highlights a number of establishment aspects including the choice of plant species, planting methods (Hallock et al., 2003; Montalvo et al., 2002), site conditions (Huxtable and Whalley, 1999; Landis et al., 2005; Petersen et al., 2004; Potvin, 1993; Sindel et al., 1993) and cultural techniques (Hagon and Groves, 1977; Muzzi et al., 1997; Paschke et al., 2000; Petersen et al., 2004; Tyser et al., 1998).

Proper selection of native plants for re-vegetation is an important step towards successful establishment. Several factors need to be considered before actual planting begins. Oftentimes, the choice of species to use in re-vegetation is dictated by site characteristics. Conducting a site analysis is therefore essential for providing basic information needed in evaluating potential species. A site inventory analysis includes examination of climate, native vegetation, and microsite parameters such as soils, topography, aspect and possible toxic conditions (Gray and Sotir, 1996).

In addition to site factors, several plant characteristics should also be considered during the selection process. These include tolerance to a range of moisture, temperature and soil conditions; compatibility with existing maintenance and land management practices; tolerance to herbicides; low potential to become a weed problem; good germination and re-seeding ability as well as low plant height (Hilditch et al., 1988; Huxtable and Whalley, 1999; Petersen et al., 2004).

Planting techniques can greatly affect the success of native plant establishment and also the amount of sediment in runoff (Hallock et al., 2003). Not all seeding methods are appropriate for all environments and combinations of species (Montalvo et al., 2002); thus, choosing the right planting techniques for vegetative establishment requires careful consideration.

Two recent studies by Montalvo et al. (2002) and Hallock et al. (2003) examined the effect of seed size and vegetative materials (sods, plugs) on the success of different planting methods. Montalvo et al. (2002) observed the effects of three different seeding methods in combination with other soil factors such as ripping and soil fertility on the establishment of a native seed mix. Six native species, which represented different seed sizes and life histories, were sown using three planting methods (hydroseeding, imprinting and drilling). These methods were observed for differences in plant density. Based on the results of the study, optimum seeding methods were found to vary with seed size. Small seeded species tend to establish better when hydroseeded while in the case of large-seeded species, imprinting or drilling worked better than hydroseeding.

Establishment studies conducted by Hallock et al. (2003) evaluated the effectiveness of several vegetative planting techniques to minimize soil erosion. The study, which tested the different planting techniques on slanted planter boxes, utilized flats or sod strips, plugs, hydroseed and compost applications to control erosion. Treatment combinations employing plantings of either flats or plugs (on the top slope, the toe or both) were tested. Parameters such as vegetative cover, erosion and water quality were measured while the boxes were subjected to both natural and simulated rainfall (Hallock et al., 2003). The results of the study suggest the importance of planting dense vegetation on the top and base of the slope in order to reduce sediment load during the establishment phase. Hallock et al. (2003) further recommended that planting flats on the top and base of the slope and applying jute netting and hydroseeding on the mid-slope were the best methods for encouraging native plant establishment while minimizing erosion.

Site conditions such as rainfall, temperature, soil and microsite (small pockets within the environment) availability are important factors that should be considered not only during plant selection but also during establishment. Taking note of these *in situ* conditions will aid in determining measures/practices to apply when establishing or maintaining a particular plant species.

A number of studies have been conducted to examine the effects of different site conditions on native species establishment. Huxtable and Whalley (1999) conducted field trials to assess emergence and survival of three native grass species (*Danthonia richardsonii* cv. 'Tarana', *Microlaena stipoides* and *Chloris truncata*) under natural rainfall conditions and roadside environments (top of bank, old dirt road, flat unripped and flat ripped). Based on the results of the study, emergence of the three species was highest in roadside environments with topsoil in contrast with areas containing only subsoil. Given adequate rainfall, the three native grass species had the best chance of successful establishment if sown in spring on a cultivated bed of topsoil (Huxtable and Whalley, 1999).

Different cultural techniques or practices such as fertilization, tillage, irrigation and weed control affect native plant establishment. Fertilizer studies have shown rather mixed results. In examining re-vegetation methods for high-elevation roadsides, Petersen et al. (2004) observed that the addition of fertilizers facilitated more rapid establishment of seeded grasses following disturbance, increasing soil cover and soil stability on steep and unstable slopes. Addition of organic fertilizer, in combination with mulch, also proved to enhance vegetation cover in planted roadcut slopes (Paschke et al., 2000). In contrast, Hagon and Groves (1977) found no significant effect of fertilizer addition on emergence and survival of four native grasses (*Themeda australis*, *Bothriochloa macra*, *Danthonia* spp. and *Stipa bigeniculata*) in the field. Jenkins et al (2004) also did not see any significant impacts of fertilization in increasing cover of four native Florida grasses.

Establishment studies conducted by Potvin (1993), indicated that tillage alone or in combination with irrigation increased the survival of native grass seedlings. Muzzi et al (1997) observed a positive effect of tilling when associated with sowing. Deep soil ripping can also increase the growth and reproductive potential of seeded species and may improve the long-term success of re-vegetation projects (Montalvo et al., 2002).

Increased establishment of native plants occurred with the application of some form of weed control. Tillage and clipping of vegetation around seedlings reduced weed competition and subsequently increased seedling establishment (Potvin, 1993). Tyser et al. (1998) examined the effects of broadleaf herbicide application and several seeding treatments on re-vegetation of a roadside segment in Glacier National Park, Montana. The results indicated that broadleaf herbicide treatments had both desirable and undesirable effects. Although broadleaf herbicide application promoted native graminoid coverage, its selectivity decreased native forb coverage and increased alien graminoid coverage.

Hydroseeding

Hydroseeding or hydraulic planting is an efficient method of large-scale plant establishment, which involves the use of a water carrier for the application of seed under pressure (Beard, 1973). The basic hydroseeding technique simply sprays the seed-water mixture onto a prepared planting surface. When other materials such as mulch, tackifiers and fertilizers are applied together without the seed or when the mulch mixture is applied to cover a planted surface, the process is called hydromulching.

Specialized equipment, called a hydroseeder is used to accomplish hydroseeding operations. A hydroseeder consists essentially of a large capacity sprayer attached to a large, single-nozzle delivery system (Turgeon, 1991). Basic parts include a pump, hose, nozzle and a 500 to 1500 gallon (1893 to 5678 liters) tank fitted with paddle or liquid type agitators (Beard, 1973) to provide continuous mixing of the slurry.

Unlike other methods of plant establishment, hydroseeding applies seeds, fertilizers, mulches and other materials in a single operation (Turgeon, 1991). It is particularly well adapted for re-vegetating huge tracks of land, as well as for poor or barren land of sand or rock and generally for steep, denuded slopes, which are often difficult to re-vegetate (Merlin et al., 1999). Several benefits of hydromulching include protecting the soil from erosion; increasing rainfall infiltration; reducing the rate of drying of the soil surface after rain thereby improving germination of seeds and establishment of plants; and addition of organic matter to the soil as the hydromulch breaks down (Landloch, 2004).

Seeds of commercially available fast-growing grasses and legumes were traditionally used as planting materials for hydroseeding (Matesanz et al., 2006). With the growing interest in the use of native plants for re-vegetation, research and development of native seed mixes for hydroseeding operations have increased. Various studies have examined the different components of hydroseeding in order to develop protocols suited for a given species and situation.

Seed characteristics such as viability and dormancy are important factors to consider when hydroplanting native seeds. Conducting a standard seed germination test is essential for determining the percentage of viable seeds in a sample that have potential to germinate under favorable conditions (Elias et al., 2006). Results from the seed germination test provide information for developing optimum seeding rates.

Understanding seed dormancy mechanisms of a specific species gives background information for developing preconditioning treatments to promote uniform germination. Seed treatments are used to overcome seed dormancy or provide optimum conditions for seed germination (Ralph, 2003). Seed preconditioning treatments include a variety of physical (wet stratification, scarification, prechilling and heat treatment) and chemical methods (gibberellic acid, KNO_3 and smoke application).

Conservation and use of native Hawaiian plants

Hawai‘i’s native plant species are a unique and special resource that should not be lost (Tamimi, 1999). Protection and conservation of native Hawaiian plants is fast becoming a very important concern with the increasing threats of urbanization and invasive species proliferation. Three important tasks are involved in protecting native Hawaiian plants. These include (1) reducing and/or eliminating the threats to native ecosystems, (2) generating and maintaining genetic backup, and (3) putting endangered plants back into the wild (outplanting) (Tamimi, 1999).

While *in situ* conservation and restoration efforts are being done in Hawai‘i’s remaining natural reserves, one simple way of protecting Hawai‘i’s native flora is through its cultivation in urban areas. Using native Hawaiian plants in designed projects is a form of protection because it generates a genetic back-up (Tamimi, 1999). In addition, encouraging people to grow native species instead of introduced plants reduces the threats of invasive species.

In recent years, native Hawaiian plants have been used in several applications including landscaping, phytoremediation and erosion control. In terms of landscape use, a number of plant species have been recommended for cultivation in private as well as public spaces (e.g. Bornhorst and Rauch, 2003). The passage of Hawaii Administrative Rules Pertaining to Act 73 and 236 encouraged the widespread cultivation of native plant species. These state laws, which require the use of native Hawaiian plants in state funded projects, were created to protect rare and common native plants, increase their populations and promote public awareness of these plants (Tamimi, 1999). In addition to state laws encouraging the planting of natives, interest in the use of native Hawaiian plants as ornamentals has also been largely influenced by the cultural value these plants possess.

Besides ornamental uses, native Hawaiian plants have also been employed in phytoremediation and erosion control. Paquin et al. (2004) evaluated a number of native Hawaiian plant species for remediation capability. In the study, several native species showed promising results in remediating soils contaminated with explosives, hydrocarbons, ethylene dibromide and 1-2-dichloropropane (DCP). Native Hawaiian plants have also been successfully utilized for erosion control and soil stabilization on the island of Kaho‘olawe and on several riparian zones around O‘ahu, Maui and Hawai‘i (Crago et al., 2004)

Roadside use of native Hawaiian plants

Despite the widespread popularity of native species roadside re-vegetation on the U.S. mainland, this concept is still relatively new to Hawai‘i. Incorporating native plant species in landscaping of road shoulders has only been done recently by the Hawai‘i Department of Transportation (HDOT). In their roadside projects, a handful of native shrubs such as beach naupaka (*Scaevola taccada*) and groundcovers such as pohinahina (*Vitex rotundifolia*) and a prostrate growing naio (*Myoporum sandwicense*) have been successfully established in select sections of the H1 freeway (Dacus, 2006). Similar highway landscaping projects utilizing native plants have also been done on Mokulele Highway in Maui. In this particular project, *Sporobolus virginicus* has been used as a utility turf on the highway shoulder.

Constraints in roadside use of native Hawaiian plants

Although roadside projects previously discussed have been done with some degree of success, the lack of research on large-scale field propagation, establishment and weed control has led to some problems. This lack of information has kept labor, installation and maintenance costs high. In the Mokulele project for example (Figure 1.1), outplanted *Sporobolus virginicus* plugs took an unusual 3 years to establish because of the lack of information on roadside establishment and difficulties in weed control and irrigation (Palomino, 2006). The cost of establishing *Sporobolus virginicus* was estimated at $142,600 per hectare compared to traditional Bermudagrass (*Cynodon dactylon*) which costs only $87,700 (Tanji, 2008). With current practices being too expensive, intensive and laborious, large-scale establishment of native Hawaiian plants would not be cost-effective. Unless native species are screened and new propagation, establishment and weed control protocols are developed, the re-vegetation of native plants in Hawai‘i roadsides will not be quickly realized.

With HDOT's plans of further reducing roadside maintenance costs by incorporating native plants in its plant palette, a research study to develop establishment protocols specific for native Hawaiian plants was funded. This masters thesis explored large-scale propagation techniques and selective weed control options for *Sporobolus* *virginicus* and *Fimbristylis cymosa*. Listed below are species descriptions, current literature and constraints to roadside use on each of the two native groundcovers:

Sporobolus virginicus (ʻakiʻaki)

Taxonomy and distribution. Sporobolus virginicus (L.) Kunth (Figure 1.2) is an indigenous perennial, rhizomatous, C_4 chloridoid grass with a broad distribution along tropical and subtropical shorelines (Bell and O'Leary, 2003). In Hawaiʻi, it is commonly found on sand dunes and coastal sites of all main islands (Wagner et al., 1999).

Propagation. S. virginicus is propagated mostly through vegetative means (e.g. division of clumps). It is commercially available in Florida, the Carribean and Australia in the form of sprigs, sods or plugs. Stem cuttings can be successfully rooted by using Dip ʻN Grow ® (Dip 'N Grow, Inc., Clackamas OR) at a dilution of 1:20 (equivalent to 500 ppm IBA and 250 ppm NAA) (Koob, 2000). However, there has been no study that dealt with quantifying rooting success in stem cuttings.

Uses. Because of its ability to thrive in saline soils, *Sporobolus virginicus* has been used as a non-conventional forage crop for both saline and arid sites in Australia and in the Middle East (Ashour et al., 1997). It has also been used in reclaiming and stabilizing salt affected lands (Semple et al., 2004).

In recent years, *S. virginicus* has been utilized as a lawn grass, particularly in areas where soil salinity or quality of irrigation water is a problem. A turf development program in the Caribbean has screened ecotypes and released a cultivar called "Saltfine®" (Depew and Tillman, 2006). In Australia, two bred cultivars called "Ozlawn" and "Nathus Green" have also been registered by another private company. For these two cultivars, uptake by the general lawn market was very limited because of a long establishment period (taking up to 2 years), weed management problems and intolerance to close mowing (Martin, 2004). Although some ecotypes may not perform satisfactorily as a lawn grass, the species in general can be potentially used as a low maintenance turf on roadsides, particularly on saline areas. This has been demonstrated locally in Maui where this species was used to re-vegetate the roadside right-of-way of the Mokulele Highway (Palomino, 2006).

Constraints to roadside use. Aside from outplanting/establishment by plugs, there is a lack of published studies on other large-scale propagation and establishment methods (e.g. hydromulching of cut stems, selective weed control). Formal evaluation in the form of field/roadside studies has not been conducted yet. Though the use of rooting agents, such as auxin to enhance rooting has been recommended, a quantified study on rooting enhancement has not been done. Determining the soaking time for optimal rooting and the application of this in hydromulch establishment has yet to be evaluated.

Fimbristylis cymosa (mau‘u ‘aki‘aki)

Taxonomy and distribution. Fimbristylis cymosa R. Br. is a tuft growing perennial sedge with short rhizomes and stiff leathery leaves (Figure 1.3). It is an indigenous coastal sedge commonly growing on sandy beaches and rocky outcrops along the coast. In Hawai‘i it is documented in all the main islands except Kaho‘olawe; elsewhere, it is widely distributed across the Pacific basin including Australia, western Malesia (Malay Peninsula, Sumatra, Java, Borneo), Pacific Islands and the Neotropics (Wagner et al., 1999). Two indigenous subspecies are recognized, and both occur nearly throughout the full range of the species (Wagner et al., 1999).

Uses. Although this species is recommended in landscaping (Tamimi, 1999) and riparian restoration (Crago et al., 2004), actual field establishment trial/studies have not been conducted. Current literature is limited and only two studies have been found on propagation and germination. Studies conducted by Koob (2000) indicate that the species can be propagated through seeds and division of clumps. On the other hand, germination studies by Vazquez et al. (1998) revealed that germination was enhanced on algae substrate as opposed to germination on sand or cotton substrate.

Constraints to roadside use. Knowledge of large-scale propagation, particularly establishment through hydroseeding and selective weed control options for this species is limited because of the lack of published literature.

Figures

Figure 1.1. A lack of post-establishment management protocols has led to weed invasions in *Sporobolus virginicus* plantings at the Mokulele Highway, Maui.

Figure 1.2. *Sporobolus virginicus* growing *in situ*. This species has formed a thick mat on sand dunes of the Kihei Coast, Maui.

Figure 1.3. *Fimbristylis cymosa* stockplants cultivated at the H1-University off-ramp. This species has sometimes been used as a groundcover for landscaped areas.

CHAPTER 2

ASSESSMENT OF THREE HYDROPLANTING TECHNIQUES FOR ROADSDIE ESTABLISHMENT OF *FIMBRISTYLIS CYMOSA* R. BR. (MAU'U 'AKI 'AKI), A NATIVE HAWAIIAN SEDGE

Introduction

Roadside re-vegetation using native species is often a large-scale operation that requires effective and efficient propagation and establishment techniques. Prior to roadside use, large-scale planting protocols for native species need to be tested and developed. A well established method of large-scale plant establishment is through hydroplanting. First developed as hydroseeding in 1938 by the Connecticut State Highway Department, it was used as a means to plant difficult sites such as steep slopes and other areas on the roadside (Button, 1966; Pill and Nesnow, 1999). Today, hydroplanting goes beyond re-vegetation of steep slopes. It has been widely accepted and used for establishing turf in residential and other high value landscapes (Pill and Nesnow, 1999) and has also found applications in green roofs (vegetation grown on roofs) (Spall, 1998).

Hydroplanting makes use of a water carrier to apply seeds or vegetative plant parts through a pump and delivered using a nozzle (Beard, 1973). The system is generally composed of a large tank (100 to 200 gallons = 378 to 757 liters) connected to a pump which provides hydraulic agitation and applies the seed-water mixture via a hose with a nozzle attachment. Aside from applying the basic seed and water mixture (hydroseeding), hydroplanting mixes may also contain mulch made of wood fiber, recycled paper or straw; fertilizer and/or biostimulants. If the hydroplanting operation involves the application of vegetative plant parts such as grass sprigs or rhizomes, the process is called hydrosprigging.

Hydroplanting operations in Hawai‘i are done mainly for erosion control purposes and for establishing turf in high value areas such as golf courses, resorts and residential lots. In Hawai‘i, species hydroplanted for erosion control/roadside re-vegetation have primarily been non-native fast growing grasses. Currently, there is limited knowledge on hydroplanting-compatible native Hawaiian species. Developing hydroplanting techniques for these species offers an opportunity to utilize them for large-scale re-vegetation/erosion control and restoration projects.

A native Hawaiian species with potential for use with hydroplanting is *Fimbristylis cymosa* R. Br. Referred to as mau‘u ‘aki ‘aki in Hawaiian (Wagner et al., 1999), this coastal sedge is a potential groundcover because it is easy to propagate via seed, is low growing and drought/salt tolerant. Although this is a recommended native species for landscapes (Tamimi, 1999) and riparian restoration (Crago et al., 2004), actual field establishment trials/studies have not been conducted. In this study three hydroplanting methods (handsowing-hydromulching, hydroseeding and hydroplanting of seedlings) were evaluated in terms of percent coverage over a 6 month establishment period.

Materials and Methods

Planting materials

Stock plants of *Fimbristylis cymosa* (HA#5866, 9079806) were sourced from the Natural Resource and Conservation Service’s (NRCS) Ho‘olehua Plant Materials Center in Moloka‘i. In June 2006, a soilless nursery was setup at the Magoon Research Facility to increase plant material for the propagation study. Bare rooted clumps of the sedge were planted in commercially available growing media composed of a mix of compost and volcanic cinder (Menehune Magic Black Cinder Blends, Hawaiian Earth Products). Stock plants were allowed to establish for 6 months before seed harvesting was done.

Seed counts and seed germination tests

Prior to field evaluation of hydroplanting techniques, seed counts and a seed germination test were conducted to estimate the number of seeds per unit weight and the average percent germination of seeds. Inflorescences of *Fimbristylis cymosa* were harvested and then oven dried. Seeds were extracted from crushed seed heads through a combination of sieving and air-blowing until most of the plant residue was removed. Seeds were stored dry at approximately 10°C until ready for use.

To estimate the number of seeds contained per unit weight, five 0.02 g samples of seed were manually counted. The mean seed count per sample was used for estimating the amount of seed needed for the hydroplanting experiment.

In addition to seed counts, a seed germination test was also conducted to determine the percent germinable seed for a given sample. One hundred seeds were sown in each of four Petri dishes (100 mm diameter, unsealed) lined with moistened filter paper (Whatman #3, Whatman International). The sown seeds were allowed to germinate inside an incubator (Percival Scientific, Inc., Perry, IA) with alternating dark and light periods (12 hours each) as well as fluctuating day (26°C) and night (20°C) temperatures. Seed germination was evaluated on a weekly basis. Seeds that had ≥ 2 mm radicle or shoot protrusion were counted as germinated. Cumulative percent germination was recorded after 1 month.

Field assessment of hydroplanting techniques

Three hydroplanting techniques, which consisted of handsown (evenly laid down on the surface) 2 month old seedlings capped with hydromulch, hydroplanted 2 month old seedlings and hydroseeding (Figure 2.1) were evaluated in terms of plant count and percent visual cover from September 2007 to March 2008. *F. cymosa* seeds and plantlets were prepared two months prior to the application of the hydroplanting treatments. For treatments involving plantlets, seeds were sown in galvanized iron trays filled with a mixture containing 40% (by volume) black volcanic cinder and 60% (by volume) commercially available potting mix (Promix®, Premier Horticulture). Seeding rate was approximately 0.85 grams/m^2 or an average of 0.15 grams of seed per tray (~2250 seeds). Seeds were allowed to germinate and grow for 2 months under overhead sprinkler irrigation and full sun conditions.

To prepare the planting surface for the hydromulch treatments, 4 raised plots (3.05 m x 3.05 m x 5.08 cm) framed with polyvinylchloride (PVC) pipes were installed at the H1-University Avenue off ramp cloverleaf. The PVC frames were laid out on weed cloth-covered ground. To keep the growing medium in place, the bottom of each plot was lined with a layer of plastic sheeting. Drainage was provided by slashing the plastic sheeting on the low spots of the plot. To ensure a weed free environment, commercially available compost was used as the growing media for this experiment. After the addition of compost, the plots were limed (Dolomite 65 AG, Chemical Lime Company) at a rate of 2.241 tons per hectare (54.7% $CaCO_3$, 42.6% $MgCO_3$) and fertilized with treble superphosphate (0-46-0) at a rate of 224 kilograms P per hectare. Growing medium was kept moist prior to planting.

A day prior to hydromulching, the seedling clumps were separated into individual plantlets by teasing it apart underwater. Individual plants were cleaned and kept moist until ready for use. Approximately 70 grams of plantlets (equivalent to 616 plants) were used in both handsown seedlings capped with hydromulch and hydroplanted seedling treatments. This is equivalent to a sowing rate/planting density of 199 plants/m^2. For the hydroseeded treatment, 0.1 grams of sedge seed (containing approximately 1,490 seeds) was used to provide a seeding density equivalent to 481 seeds/m^2 (Figure 2.2).

Except for handsown seedlings capped with hydromulch, all materials in each of the two other treatments were mixed together and applied using a hydroseeder. Table 2.1 lists the amount of tackifier (C:tac, Hamilton Manufacturing Inc.), paper mulch (NaturesOwn, Hamilton Manufacturing Inc.) and water used for each treatment. The hydromulch system (Turbo Turf Modular Hydroseeding System Model No. HS-50-M, Turbo Technologies, Inc.) used for applying the treatments consisted of a 190 liter tank and a 5 x 5 cm centrifugal pump applying approximately 114 liters per minute. To reduce contamination of treatments within each plot during the planting operation, areas other than the treatment were covered with weed cloth. Also, the hydroseeding machine was completely flushed with water before the next treatment was prepared. Treatments were randomly allocated within 4 blocks with 1 replicate of each treatment in each block. Each treatment covered 3.1 square meters of experimental area per block.

During the first 4 months of establishment, irrigation was applied 3 times a day (early morning, noon and late afternoon) for 5 minutes to prevent the hydromulch from drying out. After 4 months, irrigation was reduced and applied once a day (early mornings) for 10 minutes. Due to the presence of a moisture gradient (induced by prevailing tradewinds) within each block, 3 permanent sample areas were established in each experimental unit. The size of the sample areas were 30.5 cm x 30.5 cm. Supplemental hand weeding was also done during the 6 month observation period to remove competition and to improve the accuracy of visual cover ratings.

Plant counts per sample area were collected during the first 2 months after planting. Monthly percent visual cover was measured by superimposing 100 square grids on digital photographs of a sample area (Figure 2.3). Sample areas were photographed at a constant height to make sure that the cropped sample square dimensions were 1570 x 1570 pixels. Collection of percent visual cover was facilitated by viewing the photos in digital imaging software (Adobe Photoshop CS2, Adobe Systems Inc.). Estimations were done by counting the number of squares fully covered with leaves/vegetation.

Statistical analysis was carried out using Statistix® 9.0 (Analytical Software, Tallahassee, FL). Plant count and percent cover data collected during the study period were analyzed monthly using analysis of variance. Data analysis that revealed significant treatment effects were subjected to Tukey HSD all pairwise comparisons test to separate treatment means.

Results

Seed counts and seed germination test

Based on five samples, the average number of seeds per 0.02 grams was 298 or approximately 15,000 seeds per gram. The average percent germination for *Fimbristylis cymosa* after 1 month of incubation was 91± 2.5%. Seeding density of the hydroseeding treatment therefore contained approximately 437 live/viable seed per square meter.

Plant counts

Plant count data revealed significant differences between planting methods during the first ($F = 162.35$, $P < 0.01$) and the second ($F = 57.06$, $P < 0.01$) months. For the first 2 months after planting, the hydroseeding treatment exhibited the highest seedling density based on plant counts (Figure 2.4). Hydroseeded treatments had an average density of 264.3 plants/m^2 during the first month that increased slightly to 268.8 plants/m^2 during the second month. Percent survival based on initial (live/viable) seeding density revealed that approximately 62% of the seedlings survived after 2 months.

Handsown treatments had an average density of 70.7 plants/m^2 during the first month, increasing to 80.6 plants/m^2 for the second month. Mean plant counts for handsown treatments at the first and second months were significantly lower than that obtained in the hydroseeded treatments. Percent survival of handsown seedlings based on initial plant density (199 plants/m^2) was 41% during the second month of observation.

The lowest mean plant counts and percent survival throughout the whole experiment was observed in the hydroplanted treatment. Mean plant density was calculated at 1.8 plants/m^2 for the first month and increased to 2.7 plants/m^2 on the second month. An estimated 1% of the initial plants survived the hydroplanting operation after the second month of observation.

Percent visual cover

Estimated percent visual cover of the three planting methods were significantly different within each month analyzed. Tukey HSD all pairwise comparison tests per month revealed that hydroseeded and handsown treatments did not significantly differ for each month analyzed (Figure 2.5). At the final observation date (6 months after planting), hydroseeded plots exhibited an average percent visual cover of 69%, while handsown plots had an average percent cover of 53%. Hydroplanted seedlings had the lowest value with only 7% cover six months after planting. Figure 2.6 shows the progression of the hydroplanting treatments over the six month observation period.

Discussion

Both the hydroseeding and handsowing-hydromulching treatments were successful in establishing a percent visual cover greater than 50% within 6 months. Although these two methods were statistically comparable, hydroseeding seems to be the best method for establishing plants as it was more efficient and practical. In contrast to the handsowing-hydromulching method, hydroseeding requires less time and resources to establish the same percent visual cover. The hydroseeding operation does the job in just one step by mixing all the materials in one tank and applying it directly to the prepared planting surface. In contrast, the handsowing-hydromulching method requires a 3 step process that includes producing the seedlings, then distributing them evenly over the planting area followed by application of the hydromulch cap.

Another advantage of hydroseeding *F. cymosa* is that it makes use of seeds instead of seedlings. Using seeds is favored because seeds of this species are small in size, readily germinable and more convenient to store. *F. cymosa* seeds are very small (~1 mm in diameter) and a gram can contain as much as 15,000 seeds. This makes hydroseeding more efficient since it employed a larger number of plant propagules that resulted in greater plant density, higher percent survival and percent cover. The amount of viable seeds contained in the hydroseeding rate was almost double that of treatments utilizing seedlings. In contrast to seeds, *F. cymosa* seedlings are bulky, perishable and require extensive preparation and resources prior to planting.

Despite having a larger sized propagule and more mature development, handsown seedlings did not surpass hydroseeding in terms of percent visual cover. The contributing factors for this may be lower initial planting density compared to hydroseeding, higher seedling mortality and slow recovery due to transplanting shock.

Failure of the hydroplanted seedlings to produce vegetative cover may have been due to severe mechanical damage incurred by seedlings as they passed through the pump. During the hydroplanting process, seedling pieces were often seen being extruded by the hydromulcher (Figure 2.7). The hydromulching equipment used for the experiment is not recommended to deliver larger vegetative pieces such as the seedlings of *F. cymosa*.

In summary, both hydroseeding and the handsowing-hydromulching operations can be used for establishing *F. cymosa* plantings. Though the two methods both resulted in same percent cover after 6 months, the hydroseeding procedure appears to be a better method of planting since it would take less time and resources for establishment. The small seed size of *F. cymosa* eased planting operations by reducing the bulk of planting materials and by streamlining it into a one-step operation. The hydroseeding mortality rate (38%) is also much lower than handsowing/hydromulching (59%) and hydroplanting of seedlings (99%). Hydroseeding requires less time, labor and resources for establishing *F. cymosa*.

Tables

Table 2.1. Amount of planting material, tackifier (C:tac, Hamilton Manufacturing), paper mulch (NaturesOwn, Hamilton Manufacturing Inc.) and water used for each of the hydroplanting treatments. The hydroplanting materials were applied using the Turbo Turf Modular Hydroseeding System (Model No. HS-50-M). Each batch of hydromulch covered 3.1 square meters of experimental area per block.

Hydroplanting treatments	Planting material	Tackifier	Mulch	Water
Handsown seedlings + hydromulch cap	70 g seedlings (199 plants/m^2)	3.3 g	1.36 kg (4400 kg/ha)	51 liters
Hydroplanting (plantlets)	70 g seedlings (199 plants/m^2)	3.3 g	1.36 kg (4400 kg/ha)	51 liters
Hydroseed	0.1 g seeds (481 plants/m^2)	1.65 g	0.682 kg (2200 kg/ha)	25 liters

Figures

Figure 2.1. The three hydroplanting techniques evaluated in this study: a) handsown seedlings covered with mulch; b) hydroseeding and c) hydroplanted seedlings.

Figure 2.2. The amount of seed used in the hydroseeding treatment. The vial contains 0.1 grams or approximately 1500 seeds.

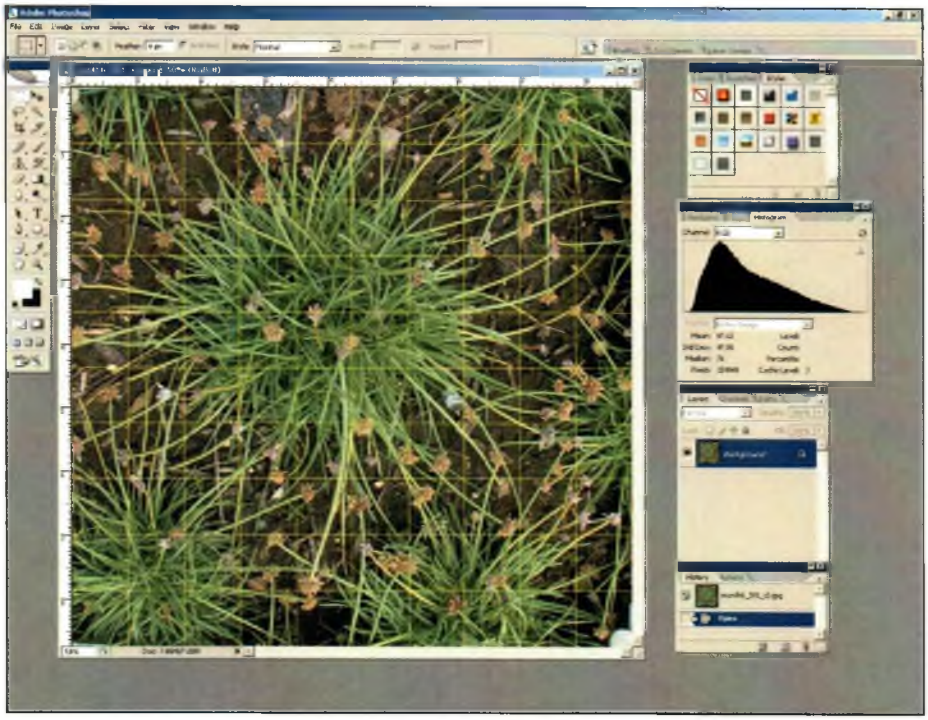

Figure 2.3. Estimating percent visual cover in Adobe Photoshop. Digital photographs of the sample were superimposed with 100 square grids. Percent visual cover was estimated by counting the number of squares occupied by foliage.

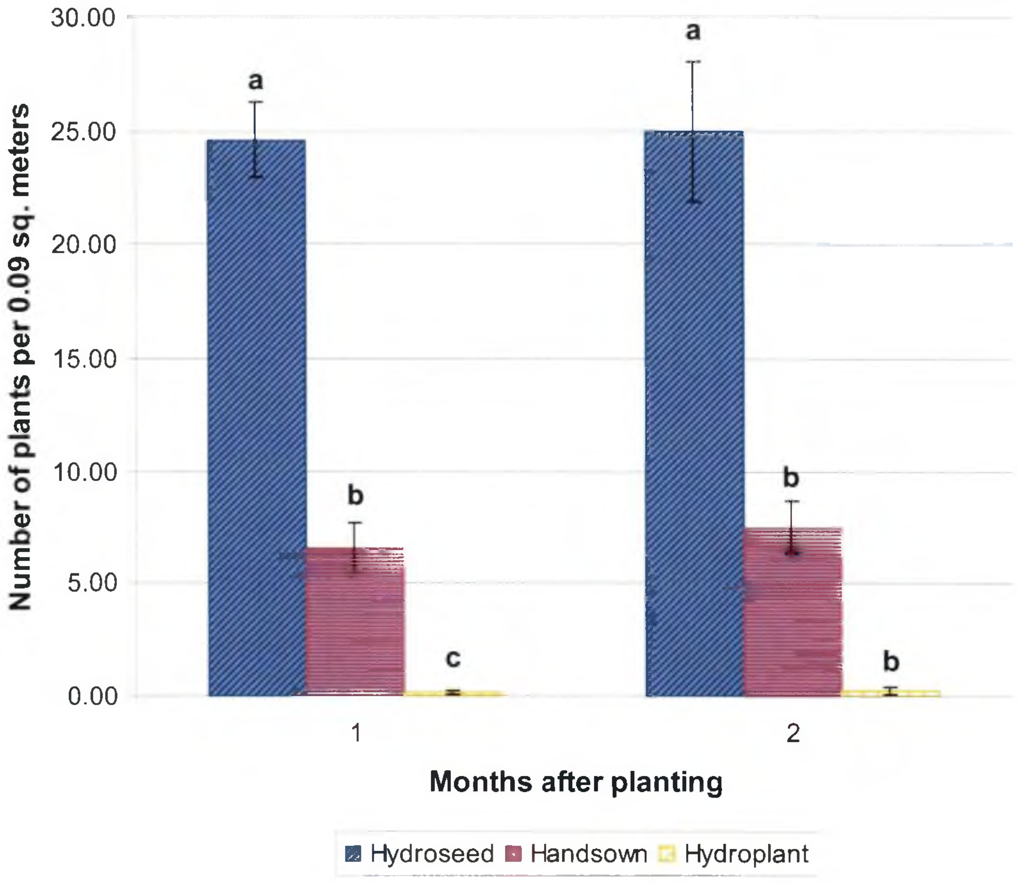

Figure 2.4. Mean plant number in the hydroplanting treatments two months after planting. Hydroseeded treatments had the highest number of plants for the first and second months after planting. Columns with the same letter within each month are not significantly different ($P < 0.01$). Standard errors of the means added to each bar ($n = 12$).

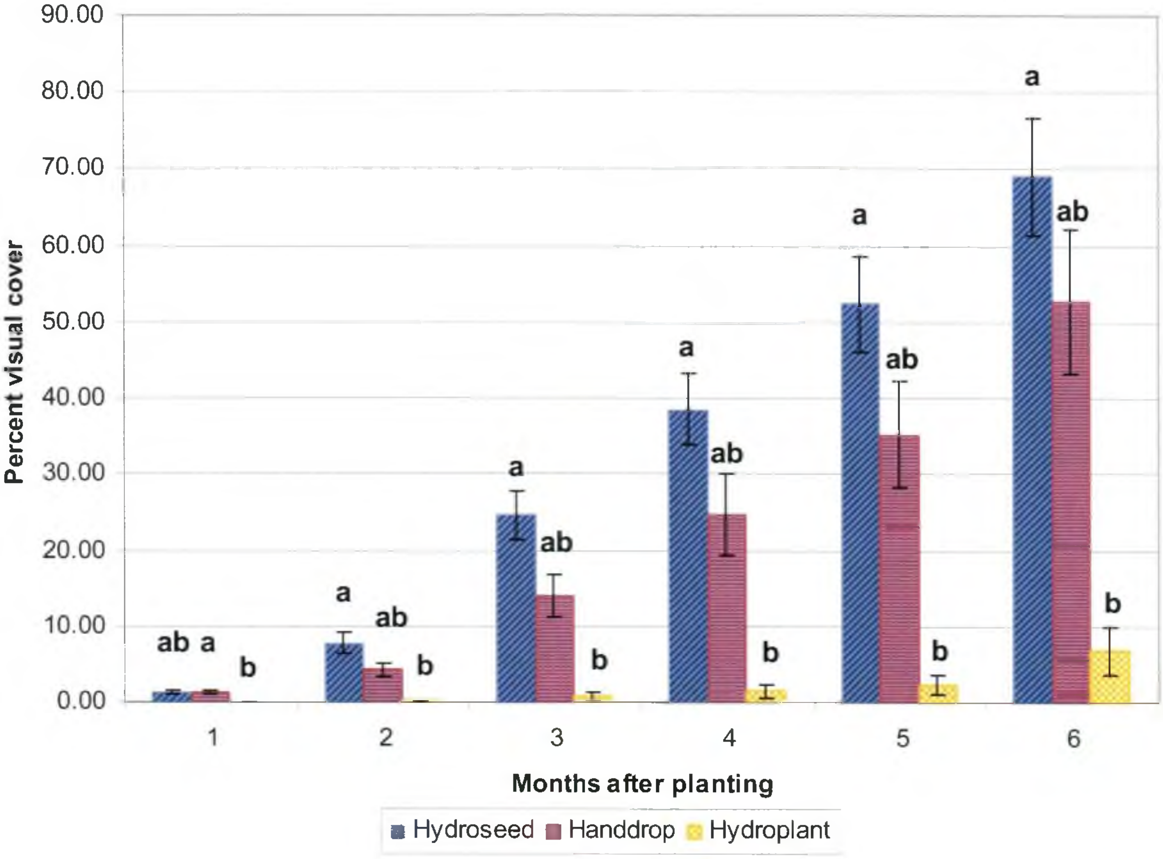

Figure 2.5. Average visual percent cover of each hydroplanting treatment over a period of six months. Hydroseeded plots consistently attained the highest percent cover after the first month of observation. Columns with the same letter within each month are not significantly different ($P < 0.05$ for months 1, 4, 5 and 6; $P < 0.01$ for months 2 and 3). Standard errors of the means added to each bar ($n = 12$).

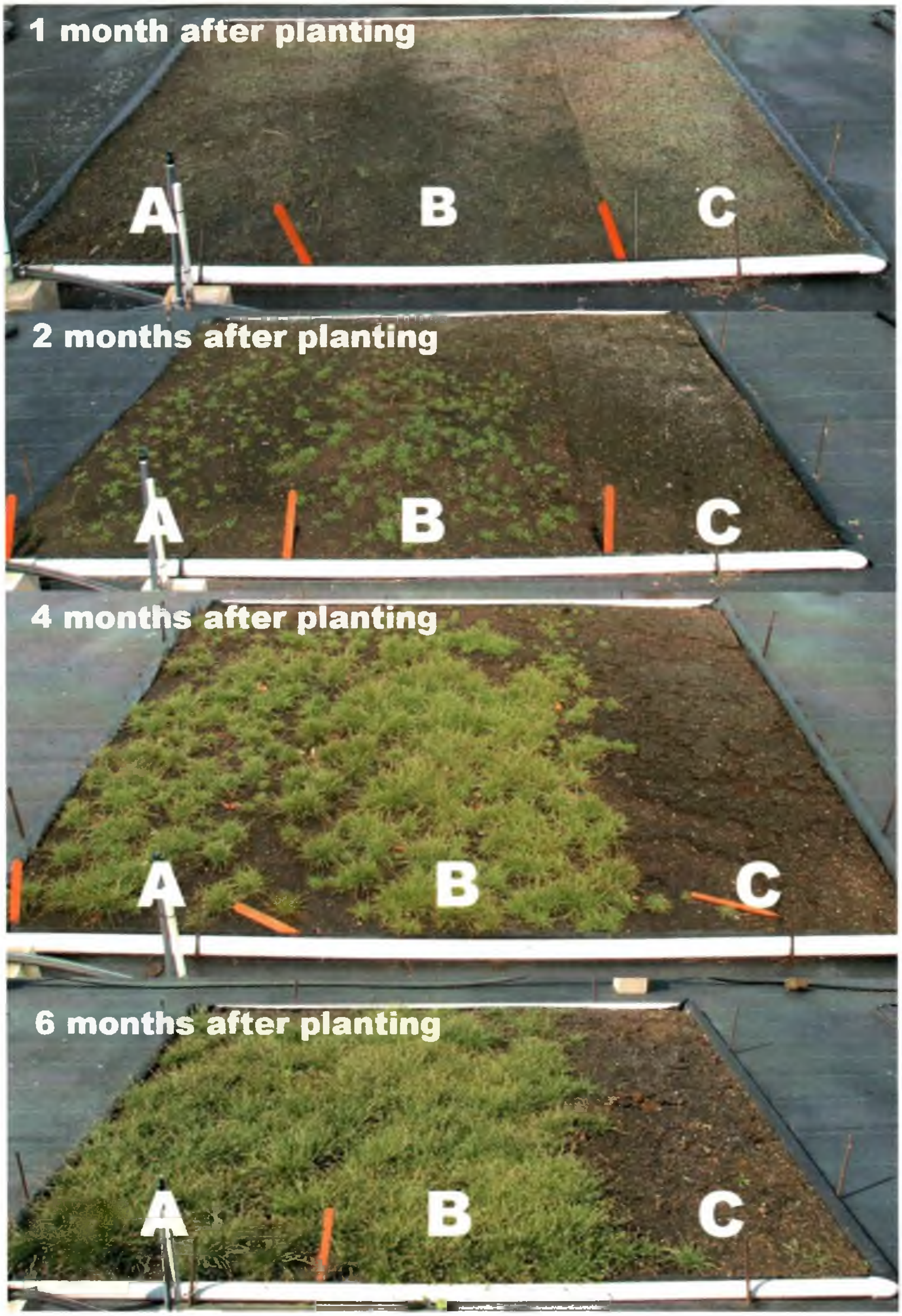

Figure 2.6. Hydroplanting treatments over the period of six months: A) Handsown seedlings covered with hydromulch; B) Hydroseeding; C) Hydroplanted seedlings. Photos were taken at 1, 2, 4 and 6 months after planting.

Figure 2.7. Mechanical damage incurred by hydroplanted seedlings during the planting process.

CHAPTER 3

EVALUATION OF *SPOROBOLUS VIRGINICUS* (L.) KUNTH ('AKI 'AKI) STEM CUTTINGS AS A PROPAGATION MATERIAL FOR HYDROMULCH PLANTING

Introduction

Developing a reliable and efficient means of propagation is essential before a native groundcover species can be utilized for roadside re-vegetation purposes. In the case of *Sporobolus virginicus*, the focus of improvement is on vegetative propagation. Since this species produces a very sparse amount of viable seed (USDA-NCRS, 2007), vegetative propagation is the only practical way to increase planting materials. While sod, whole plants, rhizomatous slips and stolons can be used to propagate this species, terminal stem cuttings are the propagation material of choice for large scale re-vegetation efforts. Using terminal cuttings is advantageous since it makes harvesting of materials easier without the need of removing the stock plants and disturbing the root zone. Keeping the stock plants intact allows vigorous re-growth to ensure regular production of planting materials.

Though the use of *Sporobolus* stem cuttings has been mentioned in literature, no one has quantitatively described the rooting success of various plant parts. To enhance the rooting of cuttings, a quick basal application of commercially available auxinic rooting solutions is recommended (Burchett et al., 1999; Koob, 2000).

Despite being widely used as a restoration and erosion control species, the majority of re-vegetation projects described in the literature make use of nursery propagated *S. virginicus* plugs. Due to limited availability and lack of alternative propagation methods, outplanting of *S. virginicus* plugs has been the common practice in Hawaii (personal observation on Maui, 2008). Although outplanting of glasshouse- or nursery-prepared native plant species is a well established and reliable method (Douglas et al., 2007), it can be time consuming and laborious. Large-scale projects such as roadside re-vegetation can be a daunting challenge because of the amount of labor and resources required for both nursery operations (i.e. propagation and establishment in plugs) and roadside establishment. Since labor costs can comprise up to 80 percent of propagation expenditures, considerable savings can be made if propagation techniques are streamlined and rooting success is improved (Hartmann et al., 2002). An alternative way of improving large scale planting and establishment of *S. virginicus* is through hydromulch capping of stem cuttings. This method has been practiced locally in Maui to re-vegetate the remaining portions of the newly widened Mokulele Highway (personal on-site inspection, 2008) (Figure 3.1). Developing a direct planting method which incorporates both pre-treatment of cuttings with auxin and hydromulch capping will not only improve the efficiency of roadside planting and establishment operations but it would also protect the newly planted surface from erosion. Before evaluating an in-field sprigging operation under a hydromulch planting condition, a good understanding of the rooting capability of *Sporobolus virginicus* sprigs is necessary. The first component of this study evaluated the rooting capability of differently sourced stem cuttings (apical or basal) as influenced by soaking duration in a commercially available auxin solution. The study then proceeded to the evaluation of the rooting success of auxin pre-soaked *Sporobolus virginicus* sprigs under a simulated hydromulch planting operation.

Materials and methods

Planting material

Sporobolus virginicus (HA# 5802, 9079745) stock plants were sourced from the NRCS Ho‘olehua Plant Materials Center in Moloka‘i. In June 2006, a nursery was set up at the Magoon Research Facility to increase planting material before propagation studies were conducted. Plots for increasing stock plants were constructed from PVC pipes joined together to form rectangular frames. The PVC frames were laid out on weed cloth-covered ground and then lined with a layer of weed cloth and plastic sheeting. After providing drainage holes on the lowest portions, the plots were filled with growing media composed of a mix of compost and volcanic cinder (Menehune Magic Black Cinder Blends, Hawaiian Earth Products). Bare rooted clumps of the grass were planted, irrigated regularly and allowed to establish for 6 months before stem sections were harvested.

Rooting of apical and basal cuttings as affected by soaking

The rooting response of apical and basal stem cuttings to durations of soaking (5 second dip and 3 hour soak) in rooting solution were assessed from May to July 2007 at the Magoon Research Facility. Stem sections, approximately 50 cm long, were harvested from nursery grown stock plants. Apical cuttings with ten leaves and basal cuttings with 3 nodes were collected from the harvested stem sections (Figure 3.2). The lower 4-5 leaves of the apical cuttings and all of the leaves of the basal cuttings were stripped off to expose the nodes. Cuttings were soaked for two periods of time (5 seconds and 3 hours) in a 1:20 dilution (500 ppm indole butyric acid and 250 ppm naphthalene acetic acid) of commercially available rooting solution (Dip 'N Grow®, Dip 'N Grow Inc.). A set of untreated cuttings (no soak) that served as the control were also prepared. Both treated (soaked) and untreated cuttings were planted vertically in pots containing a mixture of black cinder (40% by volume) and potting medium (Pro-mix®, Premier Horticulture). Each treatment, containing 10 cuttings per pot, was replicated 4 times. Treatments were laid out in a randomized complete block design inside a shade house with periodic misting (Figure 3.3). After 21 days in the shade/mist house, the treatments were transferred to full sun conditions (with regular overhead irrigation) to allow further root development. Two weeks after exposure to full sun, rooting data which included percent rooting, mean root length (longest root) and mean root density scores (1 – dead, 2 – alive but no root, 3 – few roots, 4 – moderate rooting, 5 – dense rooting) were collected.

Rooting response of apical cuttings under hydromulch planting conditions

From June to July 2008, the rooting response of apical stem cuttings to three soaking durations (5 seconds, 4 hours and 24 hours in rooting solution) were evaluated under a simulated hydromulch planting operation. Apical stem cuttings, approximately 20 cm long and containing 10 leaves with 10 to 11 nodes were collected from stock plants grown at the Magoon Research Facility.

Soaking solutions which contained a mix of 500 ppm indole butyric acid and 250 ppm naphthalene acetic acid were prepared in a similar fashion as the initial soaking study. A day prior to planting, cuttings for the 24 hour soaking period were prepared and immersed in the rooting solution. Stem cuttings used for the short soak treatments (5 second dip and 4 hour soak) and the controls (untreated) were prepared on the day of planting. To prevent desiccation, all treated and untreated cuttings used in the study were wrapped in moist paper towels and stored in an air conditioned room prior to planting.

For each treatment (replicated 5 times), ten cuttings were laid down horizontally on plastic trays (25.5 x 51.5 cm) filled with moistened potting mix (Pro-mix®, Premier Horticulture). The trays with stem cuttings were then transferred to a weed cloth covered area (3.7 m x 4.1 m) and hydromulched at a rate of 3300 kg/ha using a hydromulcher/hydroseeder (Turbo Turf Modular Hydroseeding System Model No. HS-50-M, Turbo Technologies, Inc.) (Figure 3.4). Table 3.1 lists the amount of paper mulch (NaturesOwn, Hamilton Manufacturing Inc.), straw mulch (HydroStraw, HydroStraw LLC) and tackifier (C:tac, Hamilton Manufacturing Inc.) used to make the 95 liter hydromulch mixture.

After hydromulching, the trays were transferred to an area protected from winds and then laid out in a randomized complete block design. To keep the trays constantly moist, overhead irrigation was turned on four times a day for six minutes. Forty five days (1.5 months) after planting, data on percent rooting, mean rooting index, number of new green shoots per cutting and root dry mass were recorded.

Analysis of variance was performed for each data set using Statistix 9 (Analytical Software, Tallahassee, FL) statistical analysis software. Data sets from the first study were analyzed as a 2 (apical vs. basal) x 3 (soaking times) factorial while data sets in the second study were analyzed as a randomized complete block design. Tukey HSD all pairwise comparison tests were performed on data sets showing significant treatment interactions or effects.

Results

Rooting of apical and basal cuttings as affected by soaking

There was a significant interaction of soaking time and plant part for all rooting characteristics. Apical portions soaked for 3 hours exhibited the highest percent rooting followed by apical cuttings dipped for 5 seconds and basal cuttings soaked for 3 hours (Table 3.3). Soaking of apical cuttings for 3 hours significantly increased rooting percentage from 60 (control) to 92.5%. For basal cuttings, no significant improvements in rooting percentage were observed in both the 5 second dip and the 3 hour soak.

The longest roots were observed in apical cuttings soaked for 3 hours in auxin (Table 3.4). Roots in this treatment were 82% longer compared to roots of untreated apical cuttings. There were no significant differences in root length of treated (soaked/dipped in auxin) and untreated basal cuttings. Mean root density scores were higher in auxin treated apical portions than in the control or other treatments (Table 3.5 and Figure 3.5). No improvement in root density scores were obtained with soaking or dipping of basal cuttings in rooting solution.

Rooting of apical cuttings under hydromulch planting conditions

A significant increase in mean percent rooting of hydrocapped *Sporobolus* cuttings was observed with longer soaking times in rooting solution ($F = 5.33$, $P = 0.01$). Cuttings soaked for 24 hours exhibited the highest rooting percentage at 88% (Figure 3.6). Untreated cuttings exhibited the lowest mean percent rooting with only 50% of the cuttings rooted. Those soaked for 4 hours or less showed rooting percentages that were not significantly different from untreated cuttings.

Overall rooting scores significantly increased with longer soaking times in auxin ($F = 7.10$, $P < 0.01$). The highest overall rooting score was observed in cuttings soaked for 24 hours. This was significantly higher compared to scores obtained from untreated cuttings (no auxin and no soak) (Figure 3.7). Rooting scores of the 4-hour soaking time and the 5 second quick dip was not significantly different than untreated cuttings.

A significant difference between root dry mass of the soaking treatments was recorded ($F = 4.00$, $P = 0.03$). The highest root dry mass was obtained from cuttings soaked for 4 hours while the lowest root dry mass was observed from cuttings dipped for 5 seconds (Figure 3.8). Although a significant difference between root dry mass of dipped cuttings and those soaked for 4 hours were detected, no significant differences were observed when treated cuttings were compared to untreated cuttings.

In addition to rooting characteristics, the total number of shoots per cutting (apical and axillary) significantly increased with longer soaking times ($F = 5.30$, $P = 0.01$). Cuttings soaked for 24 hours obtained the highest number of shoots per cutting (2.78 shoots) (Figures 3.9 and 3.10). This was significantly higher than untreated cuttings (1.86 shoots) and cuttings dipped for 5 seconds (1.68 shoots). Numbers of green shoots per cutting recorded in the 4-hour soak and those dipped for 5 seconds were not significantly different from values observed in untreated cuttings. Figure 3.10 visually summarizes the differences in rooting and shoot number of the different soaking periods.

Discussion

Results from the two experiments support the feasibility of using hydromulch covered apical cuttings as a method for field establishment of *Sporobolus virginicus*. In the first experiment, apical cuttings demonstrated higher rooting potential than basal cuttings. Improved rooting characteristics of apical cuttings may be attributed in part to the presence of leaves. It has been long known that leaves have a strong stimulatory effect on rooting through carbohydrate supplementation and auxin production (Hartmann et al., 2002). Other substances or factors which are non-carbohydrate or non-auxin, such as phenolic compounds synthesized in the leaves, may also be involved in rooting (Davis et al., 1988). Improved rooting capability of cuttings with leaves have been reported in tree species such as *Irvingia gabonensis* (Shiembo et al., 1996), *Pausinystalia johimbe* (Tchoundjeu et al., 2004), *Milicia excelsa* (Ofori et al., 1996) and *Prunus africana* (Tchoundjeu et al., 2002). In these studies, significantly higher rooting percentages were obtained in leafy cuttings in contrast to leafless cuttings, which had little to no rooting.

Another factor that influenced rooting of *Sporobolus* cuttings was pre-soaking in auxin solution. Exogenous application of auxin in cuttings has been known to increase percentage rooting, hasten root initiation and increase uniformity in rooting (Hartmann et al., 2002). In the second experiment, soaking the cuttings in rooting solution for 24 hours greatly improved propagation efficiency since rooting percentage significantly increased from 50 to 88%. Pre-soaking for 24 hours provided ample time for the auxin to be absorbed into the stem tissue thereby boosting endogenous auxin levels.

Although rooting in this species has been achieved by Koob (2000) and Burchett et al. (1999) with auxin quick-dips, the rooting percentage of quick-dip treatments for the first and second experiments did not significantly differ from that of untreated cuttings. There are probably three reasons why the quick dip treatments did not show a marked improvement in rooting percentage: 1) the concentration of rooting solution for the quick-dip was too diluted to have an effect; 2) the applied auxin did not get absorbed in time and was washed off during planting or hydromulching process and 3) there might be some variability in cuttings used in the study. Ways to improve rooting success of the quick-dip method may be through the addition of wetting agents or modification of the formula into a gel form. Another method of auxin application that might be as effective but less cumbersome would be foliar spraying of a more dilute auxin solution or adding auxin to the hydromulch cap. Foliar applied auxin has been used in the propagation of ornamental species such as chrysanthemum, begonia, dieffenbachia, heath and hibiscus (Hartmann et al., 2002).

The second experiment showed that successful rooting of direct planted *S. virginicus* apical cuttings can be achieved under irrigated field conditions. The hydromulch planting process, which is similar to turf establishment from stolons or sprigs, is a more efficient way to establish the native groundcover than using rooted transplants since it bypasses nursery operations thereby reducing time and resources spent for propagation and establishment. Another benefit of the hydromulch planting method is that horizontally planted cuttings seem to produce more shoots than vertically planted cuttings (personal observation). As many as three axillary shoots were produced by each cutting in the second experiment. Producing more shoots per cutting increases the number of potential plants and increases stand vigor leading to improved survival and rapid fill in.

In summary, these two experiments demonstrated that apical stem cuttings are better than basal cuttings for directly establishing *Sporobolus virginicus*. Rooting success can be further improved with pre-soaking in an auxin solution (500 ppm indole butyric acid and 250 ppm naphthalene acetic acid) for 24 hours. Utilizing this planting method for re-vegetation makes it easier and more efficient to establish plantings on a large scale. It saves time and resources by eliminating nursery establishment of planting materials prior to planting. This method is also advantageous since stockplants are allowed to re-grow from undisturbed root systems with basal stem portions available for new shoot growth.

Tables

Table 3.1. Amount of tackifier, paper and straw mulch added to a volume of 95 liters to hydromulch treated and untreated *Sporobolus* apical cuttings.

Hydromulch component	Amounts used
Tackifier	16.9 grams
Paper mulch	3.4 kg
Straw mulch	1.6 kg

Table 3.2. Effects of soaking period and plant part on mean rooting percentage of *Sporobolus virginicus*.

Soaking period	Mean Rooting Percentage*	
	Apical	Basal
Untreated	60 (9.1) bc	56 (3.5) bc
5 second dip	85 (2.9) a	50 (8.2) c
3 hour soak	93 (2.5) a	78 (7.6) ab
F value	4.78	
P value	0.02	

* Means presented are original means with standard errors in parentheses (n = 4). Tukey HSD grouping is based on arc sine transformed means. Means within columns and rows followed by the same letters are not significant (P = 0.05).

Table 3.3. Effects of soaking period and plant part on mean length of longest root of *Sporobolus virginicus*.

Soaking period	Mean Length of Longest Root (cm)*	
	Apical	Basal
Untreated	12 (1.9) bc	9 (1.1) c
5 second dip	20 (2.4) ab	5 (0.8) c
3 hour soak	22 (2.1) a	11 (2.4) c
F value	5.39	
P value	0.02	

* Means presented are original means with standard errors in parentheses (n = 4). Means within columns and rows followed by the same letters are not significant (P = 0.05).

Table 3.4. Effects of soaking period and plant part on mean root density scores of *Sporobolus virginicus*.

Soaking period	Mean Root Density Score*	
	Apical	Basal
Untreated	3 (0.1) b	3 (0.1) b
5 second dip	4 (0.1) a	3 (0.1) b
3 hour soak	4 (0.1) a	3 (0.2) b
F value	9.20	
P value	< 0.01	

* Means presented are original means with standard errors in parentheses (n = 4). Means within columns and rows followed by the same letters are not significant (P = 0.01).

Figures

Figure 3.1. Hydromulch capping of untreated *S. virginicus* stem cuttings along the Mokulele Highway near Kihei, Maui (February 2008). Although this method of planting has already been employed in the field, studies on rooting success need to be conducted in order to efficiently utilize planting materials.

Figure 3.2. Planting material used for the plant part by soaking time experiment. A) Fifty centimeter stem sections from which B) 10 node apical and 3 node basal cuttings were collected.

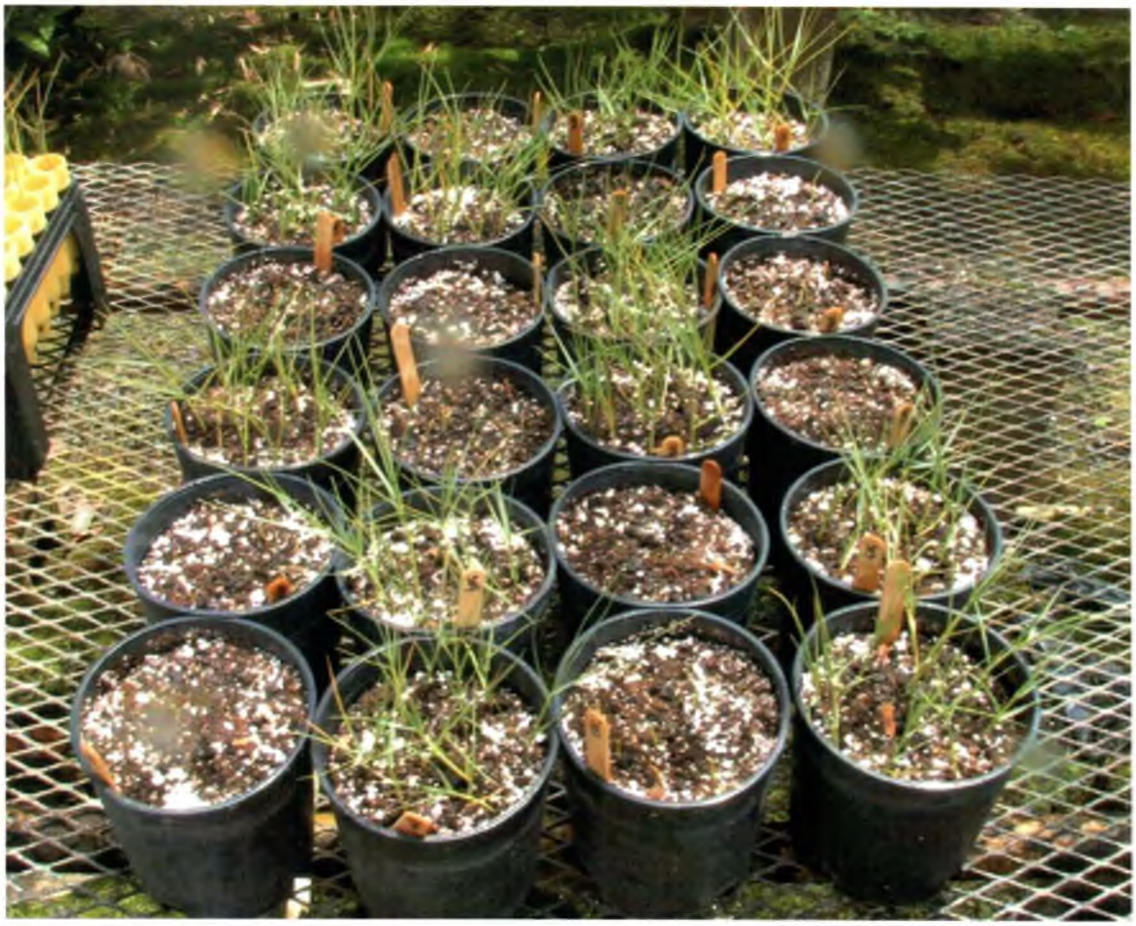

Figure 3.3. Treatment setup in the mist house. Cuttings were left in the mist/shade house for two weeks before transferring to full sun conditions.

Figure 3.4. The hydromulch capping process for *Sporobolus* apical cuttings. A) Treated and untreated cuttings were laid out horizontally on plastic trays filled with moistened potting mix and then B) covered hydromulch (3300 kg/ha).

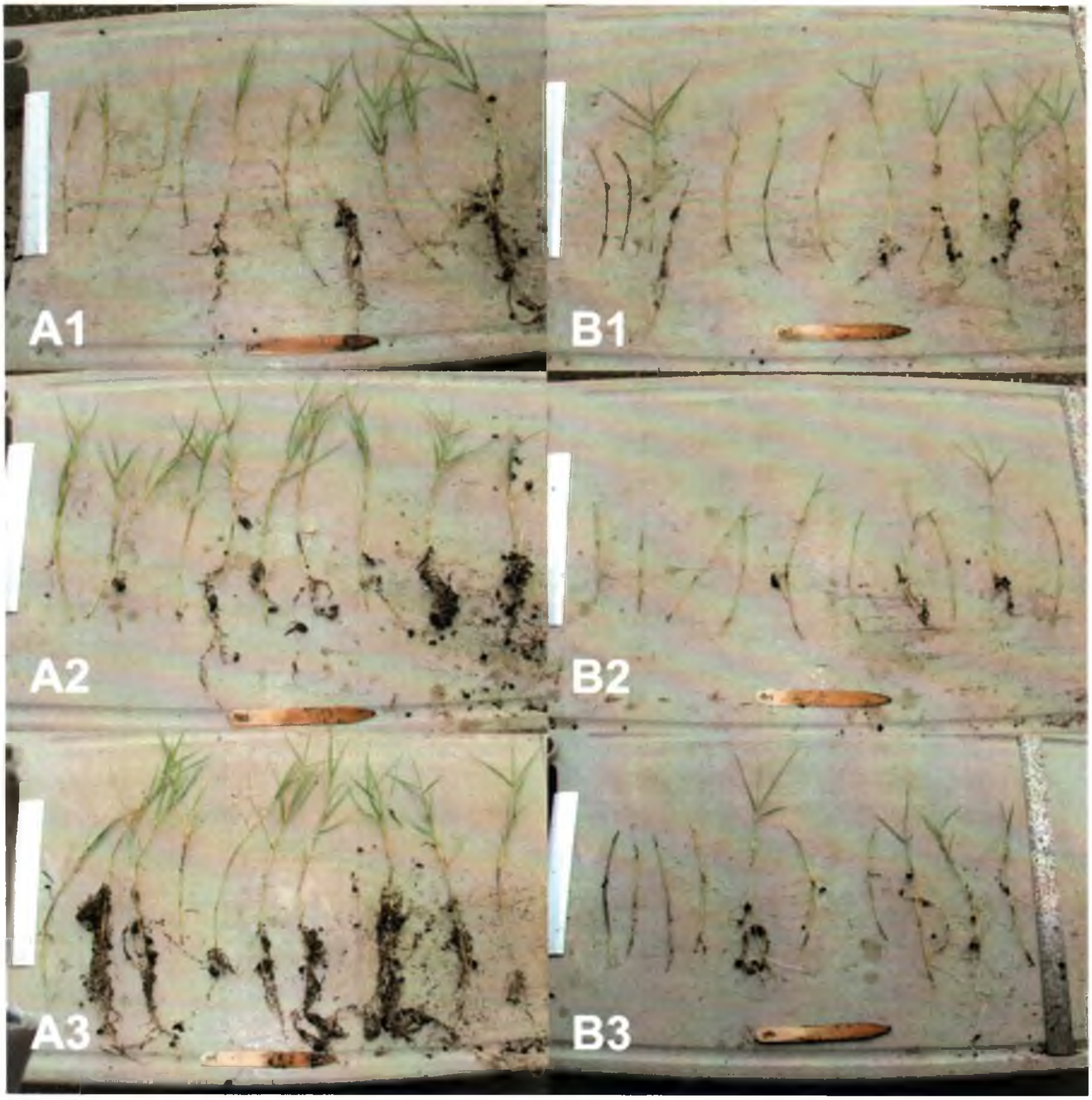

Figure 3.5. Extent of rooting in apical (A) and basal (B) ‘aki‘aki stem cuttings as affected by the following soaking durations: untreated (1); 5 second dip (2) and 3 hours (3). Higher rooting percentages and more profuse rooting was observed in apical cuttings in contrast to basal cuttings.

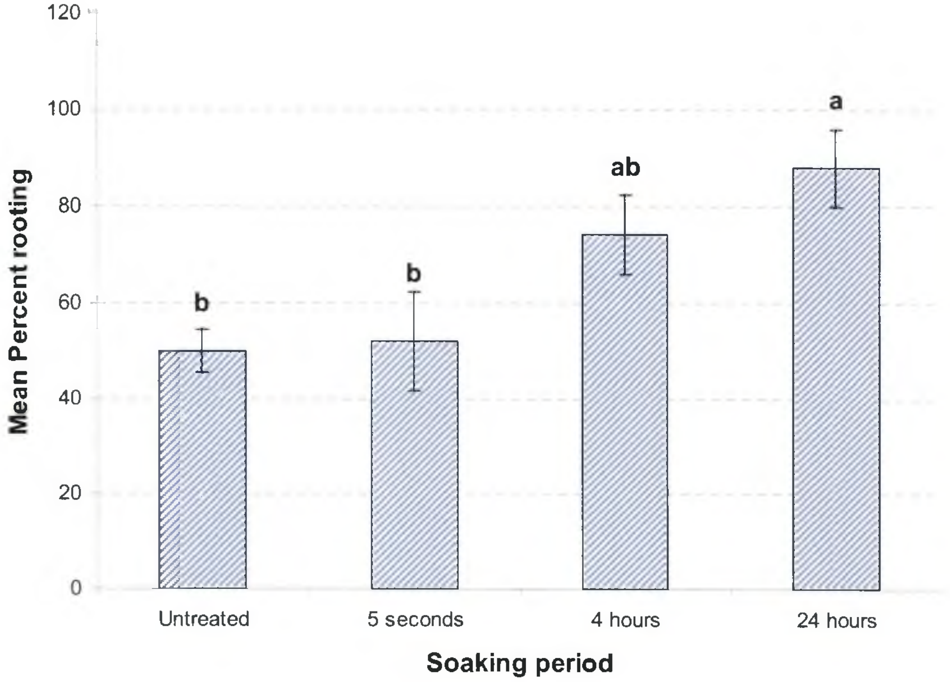

Figure 3.6. Effect of soaking time on the percent rooting of hydrocapped *Sporobolus virginicus* cuttings. Bars with common letters are not significantly different at the 5% level. Standard errors of the means added to each bar (n = 5).

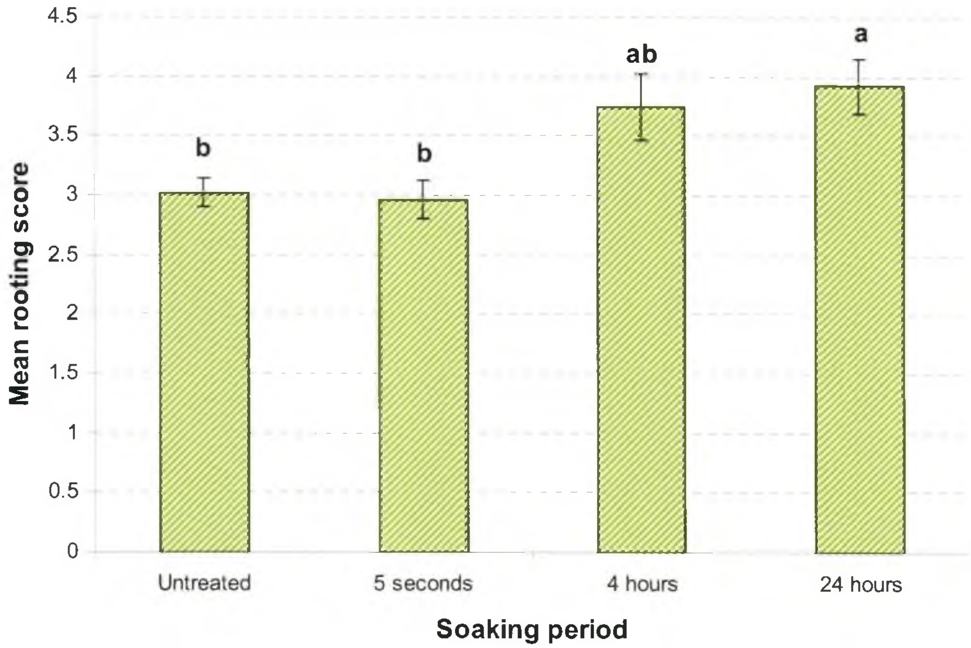

Figure 3.7. Effect of soaking time on the mean rooting scores of hydrocapped *Sporobolus virginicus* cuttings. Bars with common letters are not significantly different at the 1% level. Standard errors of the means added to each bar (n = 5).

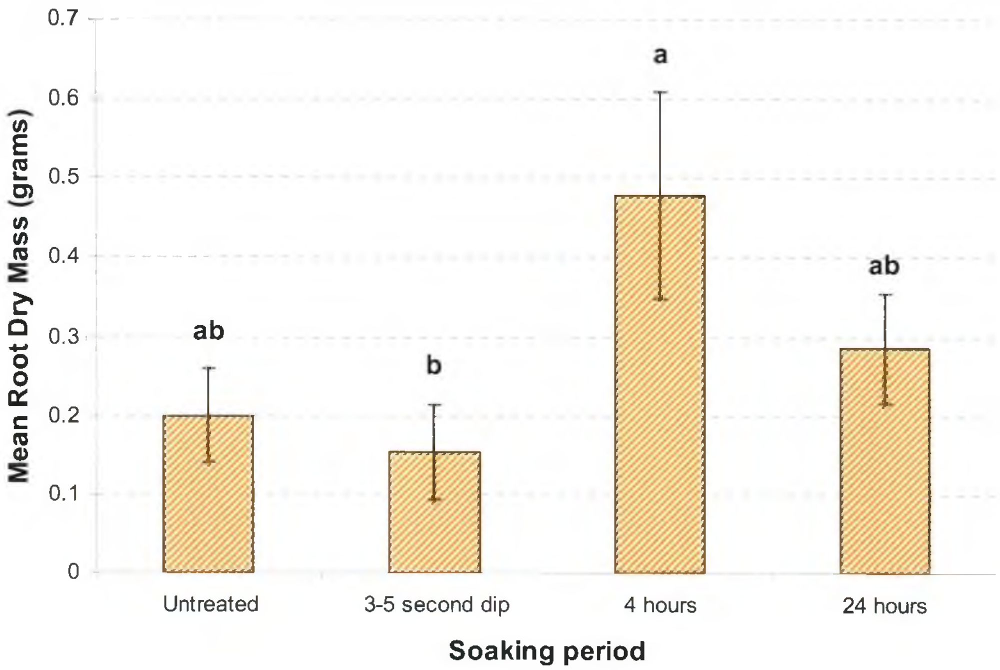

Figure 3.8. Effect of soaking time on total root drymass of hydrocapped *Sporobolus virginicus* cuttings. Bars with common letters are not significantly different at the 5% level. Standard errors of the means added to each bar (n = 5).

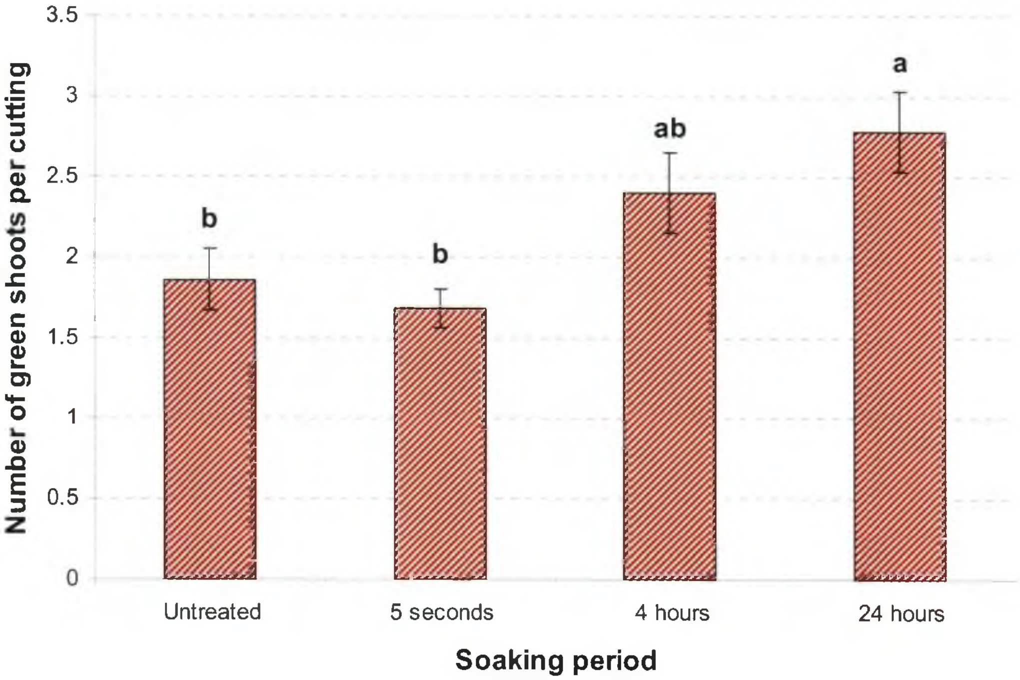

Figure 3.9. Effect of soaking time on the number of green shoots per cutting of hydrocapped *Sporobolus virginicus*. Bars with common letters are not significantly different at the 5% level. Standard errors of the means added to each bar (n = 5).

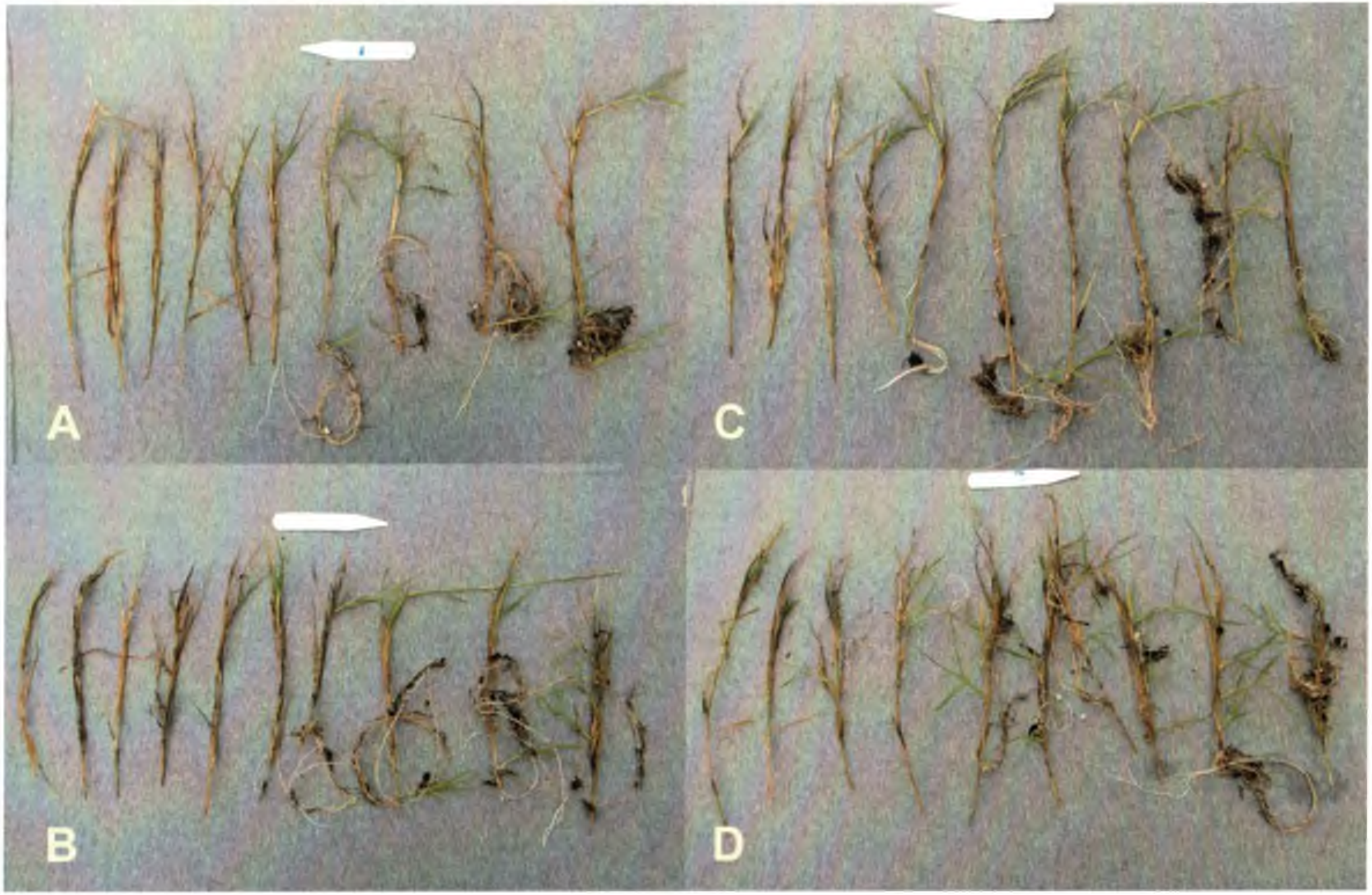

Figure 3.10. Extent of rooting and shoot growth of apical cuttings 45 days after planting and application of hydromulch cap: A) untreated, B) 5 second dip, C) 4 hour soak and D) 24 hour soak. Cuttings soaked for 24 hours achieved the highest rooting percentages.

CHAPTER 4

TOLERANCE OF *FIMBRISTYLIS CYMOSA* R. BR. (MAU‘U ‘AKI ‘AKI) TO PRE- AND POST- EMERGENCE HERBICIDES

Introduction

Weed control is an essential aspect of native groundcover establishment and maintenance on roadsides. Providing a weed-free environment from the time of planting up to canopy closing is important for strengthening a desired native groundcover’s competitive ability against weeds and weed invasions. Herbicides are weed control tools commonly used in the establishment and management of roadside vegetation. They have been recommended as tools, not only for reducing exotic vegetation in heavily invaded systems but also for reducing the weed seed bank prior to native plant establishment (Corbin et al., 2004). Before roadside re-vegetation of a specific native species commences, building basic information on herbicide tolerance is vital in order to identify pre- and post-emergence herbicides that are safe to selectively manage unwanted species.

Very few studies have been conducted on the herbicide tolerance of native Hawaiian plants. Much of the published research has focused mainly on invasive weed control in natural areas and weed control for seed production purposes. To achieve successful roadside re-vegetation with *Fimbristylis cymosa* (mau‘u ‘aki‘aki), a weed management protocol during and after groundcover establishment must be developed. This study focused on two areas namely: 1) evaluating tolerance of *Fimbristylis cymosa* to several pre- and post-emergence herbicides labeled for roadside right-of-way use and 2) determining the optimal timing of herbicide application under a simulated hydroseeding establishment condition.

Materials and Methods

The herbicide tolerance study for *F. cymosa* was divided into three main sections namely: 1) tolerance of transplanted plugs to pre-emergence herbicides; 2) tolerance of seedlings and field established plants to post-emergence herbicides; and 3) tolerance of hydroseeded *F. cymosa* to pre- and post-emergence herbicides applied at different times after sowing.

Planting material

All *F. cymosa* plants (HA#5866, 9079806) used in the study were obtained from the NRCS Plant Materials Center in Moloka‘i. Before experiments on O‘ahu were conducted, a soilless nursery was setup in June 2006 at the Magoon Research Facility. Bare rooted clumps of the sedge were planted in commercially available growing media composed of a mix of compost and volcanic cinder (Menehune Magic Black Cinder Blends, Hawaiian Earth Products). Stock plants were allowed to establish for 6 months before seed harvesting and seedling/plug production commenced.

In May 2007, additional field plantings were established at the H1-University Avenue off-ramp cloverleaf to increase seed for hydroseeding. One year after establishing the stock plants, mature inflorescences of the sedge were harvested, crushed, dried and stored dry at approximately 10°C as minimally processed raw seed (pieces of stem and leaves removed).

Pre-emergence herbicide screening for transplanted plugs

Screening for tolerance to pre-emergence herbicides was carried out at the NRCS Plant Materials Center in Moloka‘i from November 2005 to June 2006. The study was conducted on experimental field plots containing Holomua silt loam (clayey, kaolinitic, isothermic Typic Torrox). Two hundred ninety one days after sowing in 72 cell trays, mature *F. cymosa* plants (~ 6 cm in diameter) were transplanted in field plots (4.6 meters long x 1.8 meters wide) as a single row with in-row spacing of 0.61 meters. After planting, overhead irrigation was supplied consistently to ensure maximum growth and establishment.

A day after transplanting, pre-emergence herbicide spray treatments (Table 4.1) were applied using a 3 nozzle boom (nozzles spaced 50.8 cm apart) fitted with three 8004 LP Teejet Spray Systems nozzle tips (Spraying Systems Co., Wheaton, IL). The 3 liter sprayer, powered by an electric diaphragm pump was calibrated to apply 374.2 liters per hectare at 103.4 KPa. To ensure that no cross contamination of herbicides occured, the spray system was thoroughly rinsed with water between treatment changes. The experimental design was laid out as a randomized complete block with 4 replications.

Fourteen days after planting, the entire experimental area was fertilized at a rate of 56.04 kg N/ha, 24.49 kg P/ha and 46.52 kg K/ha as 16-16-16 with minors (1% Mg, 1% S, 1.5% B and 1% Fe) (Hikiola Cooperative, Hoolehua, Hawaii). Forty three days after the first spray application (43 DAS), plots were hand weeded and sprayed for the second time with the pre-emergence treatments.

Visual plant vigor ratings (0 = dead to 100 = maximum attainable vigor) were recorded at 43, 71, 120 and 211 DAS. At the last round of data collection (211 DAS), seedheads from two representative plants were collected, combined and counted as a measure of vigor.

Analysis of variance using Statistix® 9 statistical analysis software (Analytical Software, Tallahasee, FL) was performed on visual plant vigor ratings and seedhead counts. Since vigor data collected at 120 and 211 DAS showed significance for non-additivity, arc sine transformation of the two data sets were done before they were reanalyzed (Gomez and Gomez, 1984). Tukey HSD pairwise comparison tests were performed on each data set showing significance in the analysis of variance.

Post-emergence herbicide screening for seedlings and field established plants

Evaluating the safety of fluazifop-p-butyl and triclopyr on plants of different age classes

The tolerance of *F. cymosa* plants and seedlings to spray applications of fluazifop-p-butyl (Fusilade® II Turf and Ornamental, Zeneca Ag Products) and triclopyr (Garlon® 4, Dow AgroSciences) was conducted from September to October 2007 at the Magoon Research Facility in Manoa. Fluazifop-p-butyl is used to control grasses while triclopyr is used primarily for broadleaf weed control. Both are used to control living plants via foliar spray applications.

Nursery established seedlings (43 and 98 days after sowing) and mature flowering plants (224 days after sowing) were grown in 72-cell styrofoam trays (34.5 x 67 cm) filled with a potting mix composed of a 60:40 ratio (by volume) of Promix® (Premier Horticulture) and black cinder (Menehune Magic, Hawaiian Earth Products). Each tray contained a row of six plants per age class. Minimum and maximum label rates of fluazifop-p-butyl (0.28 and 0.42 kg a.i./ha) and triclopyr (4.48 and 8.97 kg a.i./ha) were prepared in 3 liter plastic bottles (Table 4.2). To promote uniform coverage and increase the herbicide's foliar penetration, a wetting agent (0.25% by vol. crop oil) was added to each herbicide treatment. Two non-herbicide treatments were also included in this experiment: an untreated control (water) and a wetting agent only treatment (0.25% vol. crop oil). All treatments were applied as 20 ml per tray using a Meter Jet spray gun (Spraying Systems Co., Wheaton, IL) attached to a backpack sprayer (Birchmeier, Birchmeier Sprühtechnik AG). The Meter Jet gun delivered the same spray volume with each trigger pull, regardless of pressure. To ensure that there was no contamination between treatments, the Meter Jet spray gun was thoroughly rinsed after each treatment. The different treatments were also physically separated to prevent cross contamination from spray drift. Once the treatments were applied, treated foliage was allowed to dry for 3 to 4 hours and then laid out in a 2 way factorial (3 age classes x 6 herbicide treatments) with 4 replications.

Twenty eight days after spraying (28 DAS), percent foliar injury ratings (0 = no visual injury to 100 = complete plant death) were recorded and a combined aboveground dry biomass of six plants was also collected.

Analysis of variance appropriate for the 3 (plant age) x 6 (herbicide) factorial treatment arrangement was performed using Statistix® 9 statistical analysis software (Analytical Software, Tallahasee, FL). Errors in the assumptions of variance analysis (e.g. unequal variance) were visually confirmed in the residual plots. In order to accomodate these errors, foliar injury ratings were arc sine transformed while dry weight data were log transformed before it was reanalyzed (Gomez and Gomez, 1984). Tukey HSD pairwise comparison tests were performed on significant interactions or factors.

Screening of post-emergence herbicides in field grown plants

Post-emergence herbicide tolerance of field grown *F. cymosa* was conducted at the Waimanalo Research Station from July to September 2008. The experiment was conducted on field plots containing two soil types. The eastern half of the experimental plot consists of Haleiwa silty clay (fine, mixed, isohyperthermic Typic Haplustoll) while the western half consists of Waialua clay (very fine, kaolinitic, isohyperthermic Typic Haplustoll).

Land preparation began one year before the study was conducted. The area was limed (Dolomite 10 AG, Chemical Lime Company) at a rate of 2,185 kg/ha (54.7% $CaCO_3$, 42.6% $MgCO_3$) and fertilized with 112.09 kg N/ha, 48.98 kg P/ha and 93.03 kg K/ha as 08-08-08 (United Horticultural Supply) and 225.14 kg P/ha as treble superphosphate (0-46-0). After incorporating the soil amendments, the land was allowed to fallow for 6 to 7 months. In the following rainy season, growing weeds were subsequently killed with repeated spray applications of glyphosate (Roundup Pro®, Monsanto Company; applied as a 2% solution of the formulated product) and triclopyr (Garlon® 4, Dow AgroSciences; applied as a 1% solution of formulated product) in an attempt to exhaust the weed seed bank. Two months before planting, the land was divided into 5 rectangular plots; one of which was allocated for the study. Each plot measures 4.9 m wide by 42.7 m long and was laid out along the soil and shade gradient. Plots were separated by a 1.2 m wide weed cloth to accommodate the overhead irrigation system. The irrigation heads designed to throw water 6.1 m away were alternately spaced on each side of the plot.

After any remaining weeds were hoed, one year old plugs of the sedge were planted at an in-row spacing of 0.61 m along five rows spaced 0.91 m apart. Immediately after planting, the plots were fertilized with 112.09 kg N/ha and 93.03 kg K/ha as 18-0-18 with minors (United Horticultural Supply, Loveland Products Inc.). In addition to fertilizer applications, the plot was also treated with a granular formulation of oxadiazon (Ronstar® G, Bayer Environmental Science) at a rate of 224.17 kg a.i./ha to control germinating weed seeds.

Seventy days after planting, the 4.9 m x 42.7 m plot was divided into smaller 1.8 m x 4.9 m experimental units containing 15 plants (3 rows with 5 plants each). Spray treatments were allocated into each unit, in a randomized complete block design with 4 replications. The post-emergence herbicide spray treatments which consisted of 1.23 kg a.i./ha aminopyralid (Milestone® VM, Dow AgroSciences); 1.63 kg a.i./ha Powerzone® (0.02 kg a.i./ha carfentrazone-ethyl + 1.24 kg a.i./ha MCPA + 0.25 kg a.i./ha mecoprop + 0.12 kg a.i./ha dicamba, PBI/Gordon Corporation); 1.22 kg a.i./ha Speedzone® (0.02 kg a.i./ha carfentrazone-ethyl + 0.86 kg a.i./ha 2,4-D + 0.27 kg a.i./ha mecoprop + 0.07 kg a.i./ha dicamba, PBI/Gordon Corporation) and 0.07 kg a.i./ha sulfosulfuron (Certainty®, Monsanto) were applied using the same spray parameters and equipment described in the pre-emergence study (See Table 4.3 for a detailed description of herbicide treatments). After treatment application, irrigation was put on hold for 13 hours to allow herbicide absorption.

Due to a mistake in reading label rates (the label rate for Milestone® VM was confused for Milestone® VM Plus), the aminopyralid treatment in this experiment was overapplied (25x the recommended label rate). Right after this post-emergence experiment was conducted, a follow-up study using the right rates of aminopyralid was performed on the control plots (see next section for details).

Visual ratings of vigor (0 = dead to 100 = maximum attainable vigor), foliar injury (0 = no injury to 100 = whole plant necrosis/chlorosis) and green color (0 =

brown/chlorotic to 100 = maximum attainable green color) as well as percent mortality were recorded 5 weeks after treatment application.

Analysis of variance using Statistix® 9 statistical analysis software (Analytical Software, Tallahasee, FL) was performed on vigor, injury and green color ratings as well as plant mortality data. Tukey HSD pairwise comparison tests were performed on each data set showing significance in the analysis of variance.

Tolerance of field grown plants to two rates of aminopyralid

Due to an overapplication of aminopyralid in the previous experiment, a follow-up study on the tolerance of *F. cymosa* to high and low rates of aminopyralid was performed. The experiment was setup on untreated control plots of the previous post-emergence screening study. The 15 plants contained within each control plot were divided into 5 rows containing 3 mature plants. Three treatments were evaluated and these consisted of 0.07 and 0.12 kg a.i./ha aminopyralid plus an untreated control. Treatments were randomly allocated in three of the five rows of plants available in each plot. The experiment was laid out as a randomized complete block with the control plots from the previous experiment serving as blocks (n = 4). The two aminopyralid rates, prepared in 3 liter plastic bottles, were applied using a single nozzle boom fitted with one 8004 LP Teejet Spray Systems nozzle tip (Spraying Systems Co., Wheaton, IL). The backpack sprayer (Birchmeier, Birchmeier Sprühtechnik AG) was calibrated to apply 374.2 liters per hectare at 89.7 KPa. After treatment application, irrigation was put on hold for 13 hours to allow herbicide absorption.

Visual ratings of vigor (0 = dead to 100 = maximum attainable vigor), foliar injury (0 = no injury to 100 = complete plant death) and green color (0 = yellow/brown to

100 = maximum attainable green color) were recorded 5 weeks after treatment application.

Analysis of variance using Statistix® 9 statistical analysis software (Analytical Software, Tallahasee, FL) was performed on vigor, foliar injury and green color ratings. Square root transformation was performed on percent foliar injury data prior to reanalysis in order to remove significant non-additivity of the data set. Tukey HSD pairwise comparison tests were performed on data sets showing significance in the analysis of variance.

Timing of pre- and post-emergence herbicide application on hydroseeded *F. cymosa*

After the separate herbicide tolerance studies were carried out, a final experiment was conducted to determine application timing of both pre- and post-emergence herbicides on newly hydroseeded *F. cymosa*. The study was conducted at the Waimanalo Research Station from August to November 2008 on a 4.9 m wide by 42.7 m long field plot prepared as in the post-emergence study.

A seed count-germination study was started at the same time as the hydroseeding study to determine the amount of live, germinable seed contained in a given weight of raw seed (crushed dried seedheads with just the stem and leaf pieces removed). Five 0.2 gram samples of raw seed were collected and sown separately on Petri dishes (100 mm in diameter, unsealed) lined with moistened filter paper (Whatman #3, Whatman International). The sown seeds were allowed to germinate inside an incubator (Percival Scientific, Inc., Perry, IA) with alternating dark and light periods (12 hours each) as well as fluctuating day and night temperatures (20 to 26°C). The number of germinable seeds per sample was recorded by counting and removing germinated seeds on a weekly basis.

Accumulated data collected within 4 weeks of monitoring was averaged to get the mean number of germinable seed per given weight of the raw seed. Based on this study a 0.2 gram sample of raw seed contained an average of 55 germinable seeds.

Before the hydroseeding operation was conducted, any remaining weeds were removed from the field. The plot was divided into two 4.3 m wide by 18.3 m long sections to ensure even and accurate distribution of the hydroseeding slurry. The hydroseeding operation was accomplished using a 190 liter capacity hydroseeder (Turbo Turf Modular Hydroseeding System Model No. HS-50-M). To facilitate mixing of a batch of hydroseeding slurry, both 3.9 kg straw mulch (HydroStraw, HydroStraw LLC) and 7.8 kg paper mulch (NaturesOwn, Hamilton Manufacturing Inc.) were pre-wetted in buckets. The mulching materials including 200 grams of raw seed (contains approximately 55,000 germinable seeds) and 16.9 grams of tackifier (C:tac, Hamilton Manufacturing Inc.) were slowly added while the hydroseeder was turned on and partially filled with water. After all components were mixed in, the hydroseeder was filled to capacity with water in order to make one batch of slurry. One batch of hydroseeding slurry evenly covered an area of 78 m^2 and sowed 705 viable seeds/m^2. To keep the plots constantly moist and to facilitate *F. cymosa* seed germination, overhead irrigation was turned on several times during the day (1.5 hours at 3:00 am and 15 minutes at 11:00 am, 2:00 pm and 5:00 pm).

The application of pre- and post-emergence herbicide treatments (Table 4.4) commenced 1 week after the hydroseeding operation was conducted. Prior to herbicide application, the plot was divided into four 18.3 m long x 2.1 m wide blocks. Each block was subsequently divided into ten 1.8 m x 2.1 m experimental units. Herbicide treatments were randomly allocated to each unit within the block. The pre-emergence herbicides, oxadiazon (Chipco Ronstar® WP, Bayer CropScience; applied at 2.24 kg a.i./ha) and oryzalin (Surflan® AS, United Phosphorus Inc.; applied at 2.24 kg a.i./ha) were applied at 7 and 14 days after hydroseeding (DAH) to control any germinating weed seeds. At 28 and 42 DAH, another batch of treatments which consisted of a post-emergence herbicide mix containing aminopyralid (Milestone® VM, Dow AgroSciences; applied at 0.1 kg a.i./ha) and fluazifop-p-butyl (Fusilade® DX, Syngenta; applied at 0.28 kg a.i./ha), with or without a pre-emergence herbicide (oxadiazon applied at 2.24 kg a.i./ha) were sprayed to control both emerged and germinating weeds. A soluble preparation of oxadiazon (Ronstar® WP, Bayer CropScience; applied at 2.24 kg a.i./ha) was sprayed together with aminopyralid + fluazifop-p-butyl at 28 DAH. At 42 DAH, a granular preparation of oxadiazon (Ronstar® G, Bayer CropScience; applied at 2.24 kg a.i./ha) was manually broadcast before the aminopyralid + fluazifop-p-butyl mix was sprayed. At 56 DAH, the post-emergence herbicide mix (aminopyralid + fluazifop-p-butyl) was applied to control most weeds that had emerged. Fluazifop-p-butyl was used to control grassy weeds while aminopyralid was used to control most broadleaf weeds. Also at this time (56 DAH), weeds in the untreated (control) plots were cut to about 20 cm from the ground to prevent extreme shading and ease plant count measurements at 92 DAH. Using a 1 x 1 m square frame, plant counts per square meter were collected at 92 DAH as a measure of tolerance to pre- and post-emergence herbicide application.

Analysis of variance was performed on plant count data using Statistix® 9 statistical analysis software (Analytical Software, Tallahasee, FL). Since plant count data showed significance for non-additivity, a logarithmic transformation was performed before it was reanalyzed. Because most of the data entries were small values (e.g. less than 10) all data entries were transformed using the formula, $\log(x+1)$, where x = original data (Gomez and Gomez, 1984). Tukey HSD pairwise comparison tests were performed on plant count data to separate treatment means.

Results

Pre-emergence herbicide screening for transplanted plugs

Ratings taken during the observation period revealed that separate applications of oxadiazon and oryzalin did not significantly reduce the vigor of transplanted plugs (Table 4.5). Vigor ratings of both high and low rates of oxadiazon and the high rate oryzalin were not significantly different from untreated plants at 43 ($F = 4.56$, $P < 0.01$), 71 ($F = 8.67$, $P < 0.01$) and 120 ($F = 6.17$, $P < 0.01$) DAS. In contrast, the high rate oxadiazon + oryzalin had the lowest vigor rating at the same observation periods. Vigor ratings collected during the last evaluation date (211 DAS) showed a drastic decline in values of untreated plots due to weed pressure (Figure 4.1). At 211 DAS, the high rate of oryzalin exhibited the highest vigor rating ($F = 2.84$, $P = 0.03$). The rest of the pre-emergence herbicide treatments had vigor ratings that were not significantly different from untreated (control) plants. Although no significant differences were observed in seedhead counts of the pre-emergence herbicide treatments, the lowest mean values were observed in both high and low rates of the oxadiazon + oryzalin treatments (Table 4.5).

Post-emergence herbicide screening for nursery and field established plants

Evaluating the safety of fluazifop-p-butyl and triclopyr on plants of different age classes.

Four weeks after treatment application (28 DAS), significant differences in foliar injuries were observed between herbicide treatments ($F = 1382.63$, $P < 0.01$) but not between age ($F = 0.27$, $P = 0.77$) or the age by treatment interactions ($F = 0.29$, $P = 0.99$). Visual injury ratings recorded in both high and low rates of triclopyr were greater than 98% (Table 4.6). Regardless of age, all triclopyr treated plants were killed while fluazifop-p-butyl and crop oil treatments did not exhibit any visual injury (0%) (Figure 4.2).

Significant age by treatment interactions were observed in aboveground biomass of *F. cymosa* plants ($F = 3.49$, $P < 0.01$). Within each age level, aboveground dry biomass of plants treated with triclopyr were significantly lower than those observed in the non treated control, crop oil and fluazifop-p-butyl treatments (Table 4.7). Within each age group, no significant differences were observed between aboveground biomass of fluazifop-p-butyl, crop oil and untreated plants.

Screening of post-emergence herbicides in field grown transplants.

Percent vigor data collected 5 weeks after treatment application indicate that the plants treated with the 4 post-emergence herbicides had significantly lower values compared to untreated plants (Table 4.8). The sulfosulfuron treatment exhibited the lowest percent vigor rating (36%) with plants showing severe stunting. Plants treated with the two carfentrazone based herbicides had a higher average vigor rating of 54%. However, these were not significantly different from vigor ratings observed in the sulfosulfuron treated plants. Among the herbicide treatments evaluated, aminopyralid

(25x) treated plants attained the highest vigor rating (61%) 5 weeks after spray applications.

High injury ratings were observed in the carfentrazone + 2,4-D + mecoprop + dicamba treated plants 5 weeks after treatment application (Table 4.8). It was also the only post-emergence treatment that had significantly high injury ratings when compared to untreated plants. The least injurious of all the post-emergence herbicides tested was sulfosulfuron. Plants treated with sulfosulfuron consistently attained low weekly visual injury ratings as opposed to the other post-emergence herbicides tested.

The development of leaf injury in each of the post-emergence herbicide treatments had different characteristics (Figure 4.3). Plants sprayed with carfentrazone-based treatments exhibited whole-plant yellowing which progressed rapidly into severe leaf necrosis or plant death. Aminopyralid (25x) treated plants had a similar progression of injury but the rate of leaf necrosis was much slower. At five weeks after application, aminopyralid (25x) treated plants continued to exhibit severe yellowing and foliar malformations with limited development of leaf necrosis. In contrast to the three broadleaf herbicides, foliar injury development in sulfosulfuron was different. While most of the leaf tissue remained green, localized dark brown to black spots gradually coalesce and dry up. The result is a localized leaf necrosis.

In terms of green color ratings, the sulfosulfuron treatment exhibited the highest values of any post-emergence herbicide tested. Mean green color ratings observed in sulfosulfuron treated plants were not significantly different from those in untreated plants (Table 4.8). In contrast, carfentrazone + 2,4-D + mecoprop + dicamba treated plants attained the lowest percent green color (21%). Aminopyralid (25x) and carfentrazone +

MCPA + mecoprop + dicamba treated plants had higher mean percent green color compared the carfentrazone + 2,4-D + mecoprop + dicamba treatments. However, their values were significantly lower compared to untreated plants.

Although no significant differences were observed in percent mortality between treated and untreated plants, mean values revealed that both aminopyralid (25x) and the two carfentrazone based herbicide treatments exhibited greater than 15% mortality (Table 4.8). Carfentrazone + 2,4-D + mecoprop + dicamba treated plants obtained the highest mean percent mortality followed by both the aminopyralid (25x) and carfentrazone + MCPA + mecoprop + dicamba treatments. In contrast, sulfosulfuron was the only post-emergence treatment that did not exhibit plant mortality.

Based on visual ratings and percent mortality recorded, overall ranking of herbicides from most to least injurious are as follows: carfentrazone + 2,4-D + mecoprop + dicamba > carfentrazone + MCPA + mecoprop + dicamba > aminopyralid (25x) > sulfosulfuron > untreated.

Tolerance of field grown plants to two rates of aminopyralid

Visual ratings recorded 5 weeks after herbicide application indicate non-significant treatment differences in plant vigor ($F = 0.94$, $P = 0.44$) and significant treatment differences in both foliar injury ($F = 18.85$, $P < 0.01$) and green color ($F = 5.62$, $P < 0.05$) (Table 4.9).

In terms of mean plant vigor, values observed in both untreated and aminopyralid-treated plants were all greater than 90%. Although significantly higher foliar injuries were recorded in both rates of aminopyralid than in untreated plants, the injury was slight and not likely to result in significant loss in plant health. Foliar injuries observed in aminopyralid treatments ranged from 1 to 2 % while untreated plants did not exhibit foliar injuries.

Significantly lower green color ratings were observed in the high rate of aminopyralid than in untreated plants. In contrast, green color ratings recorded in the low rate of aminopyralid were not significantly different from those obtained in control plants. Although green color ratings showed significant treatment differences, the range of values observed were above the acceptable green color range (> 90%).

Timing of pre- and post-emergence herbicide application on hydroseeded *F. cymosa*

Significant differences between mean plant counts of each herbicide treatment combinations ($F = 25.57$, $P < 0.01$) were observed at 92 DAH (Table 4.10). Oryzalin, applied during the first two weeks after hydroseeding had significantly higher number of plants compared to those treated with oxadiazon at the same dates. Plant counts observed in the oryzalin treatments did not significantly differ from that of untreated plots. Oxadiazon applications from 7 to 28 DAH (with or without post-emergence herbicides) had the lowest plant counts among the treatments tested.

The addition of a wettable formulation of oxadiazon in the post-emergence spray at 28 DAH resulted in complete death of plants. In contrast, plant counts observed in the post-emergence only treatments (applied at 28 DAH) did not significantly differ with untreated control plots. The wettable formulation of oxadiazon, when applied together with aminopyralid + fluazifop-p-butyl, caused severe damage to foliar tissue (Figure 4.4). This eventually led to the complete mortality of seedlings in the treatment plots at 92 DAH. Applying granular oxadiazon right before post-emergence spray applications (at 42 DAH) also caused severe foliar damage (Figure 4.5). However, plant survival in this treatment was significantly higher than those observed in the wettable formulation as some live plants were still recorded at 92 DAH. Plant counts observed in post-emergence only treatments were not significantly different from those recorded in untreated plots. When post-emergence only applications (28, 42 and 56 DAH) were compared to each other, no significant differences between plant counts were observed.

In terms of weed control, visual observations of treatments with oxadiazon generally showed better weed controlling capability than oryzalin or post-emergence only (aminopyralid + fluazifop-p-butyl) applications. Aminopyralid + fluazifop-p-butyl had good control of grassy weeds and also some broadleaf species such as *Leucaena leucocephala*, *Portulaca oleracea*, *Macroptilium atropurpureum* and *Amaranthus* spp. However, the post-emergence mix did not control spurge species (*Chamaesyce* spp.). Figures 4.6 and 4.7 visually summarize weed control and plant density as affected by the different herbicide treatments.

Discussion

Pre-emergence herbicide screening for *Fimbristylis cymosa*

The results from the pre-emergence study indicate the potential use of oxadiazon and oryzalin in establishing transplanted *F. cymosa* plugs. Both high and low rates of the two herbicides provided excellent weed control which lasted until the final evaluation date (211 DAS). Although the herbicide treatments may show some degree of growth inhibition, seedhead production of the plants was not significantly affected. In addition, growth inhibition seems to dissipate after 71 DAS, probably due to herbicide breakdown in the soil. Vencill (2002) notes that the typical field half life of oryzalin and oxadiazon are 20 and 60 days, respectively. If the least reduction of plant vigor is desired, applying either herbicide alone and at the low rates is recommended.

Based on the results gathered from this study, both oryzalin and oxadiazon can be safely used for pre-emergence weed control in transplanted *F. cymosa* plugs.

Post-emergence herbicide screening for *Fimbristylis cymosa*

Evaluating the safety of fluazifop-p-butyl and triclopyr on plants of different age classes

Final visual injury ratings and aboveground dry biomass show that triclopyr application was not safe for broadleaf weed control in *F. cymosa*. Both high and low rates of triclopyr caused severe injury that led to the death of plants. Although triclopyr is labeled for post-emergence broadleaf weed control, certain sedge species have shown sensitivity to or have been controlled by triclopyr sprays. A handful of published papers have reported the effects of triclopyr on sedge species, mostly the weedy species. Gabor et al. (1995) reported a decline in the number of native sedge species (*Carex* spp.) with the application of triclopyr (12 kg/ha) to control purple loosestrife in a wetland setting. In transplanted rice, triclopyr applied at 325g/ha and 625g/ha provided very good control of *Cyperus iria* and *Fimbristylis miliacea* (Rohitashav et al., 2004).

In contrast to triclopyr, the fluazifop-p-butyl sprays were not detrimental to *F. cymosa*. No visual injuries were recorded in plants treated with either high or low rates of fluazifop-p-butyl. There was also no significant difference between aboveground dry biomass of untreated plants and those observed in fluazifop-p-butyl treated plants. This indicates that growth of the sedge was not inhibited by its application.

Results obtained from crop oil only treatments have also shown that the wetting agent did not affect *F. cymosa* growth. Plants treated with crop oil had no detectable visual injury and it also had a final dry mass that did not significantly differ from that of the control.

Overall, this study shows that while triclopyr cannot be used for broadleaf weed control in *F. cymosa* plantings, fluazifop-p-butyl can be safely used to selectively control grassy weeds. It can be applied as an over the top spray in as early as 43 days after sowing without causing injury to the plant.

Screening of post-emergence herbicides in field grown plants

Final visual ratings indicate that field established *F. cymosa* was sensitive to the 4 post-emergence herbicides. Herbicide treated plants exhibited phytotoxicity symptoms ranging from a reduction in plant vigor and percent green color to increased foliar injury/necrosis and mortality. Carfentrazone + 2,4-D + mecoprop + dicamba was the most injurious herbicide since it exhibited high percent foliar injury and low percent green color. In addition, it also had the highest mean plant mortality after the 5-week observation period. The rapid development of injury symptoms was primarily due to carfentrazone-ethyl, one of the four active ingredients in the herbicide formulation. Functioning as a protoporphyrinogen inhibitor, carfentrazone-ethyl primarily controls broadleaf weeds through contact action (Boydston, 2004). The herbicide is fast absorbed by the leaves and the plants become necrotic and die shortly after treatment (Vencill, 2002). This probably caused the quick development of a 'bronzed' appearance in the two carfentrazone-based treatments. On the other hand, auxinic herbicides in the formulation, primarily dichloroacetic acid (2,4-D) probably contributed to whole plant yellowing which eventually led to severe necrosis and plant death.

Slightly less injurious than carfentrazone + 2,4-D + mecoprop + dicamba was carfentrazone + MCPA + mecoprop + dicamba. Since the amount of carfentrazone in this formulation is less than that of carfentrazone + 2,4-D + mecoprop + dicamba, the extent of foliar damage was slightly reduced. The primary auxinic herbicide, (4-chloro-2-methylphenoxy)acetic acid (MCPA) might have also affected the extent of foliar injury incurred by the plants.

Although aminopyralid (25x) was rated as the third most injurious herbicide based on visual ratings and plant mortality, its results may be different if the correct maximum label rate is used. Due to errors committed during herbicide spray preparation, the actual amount of aminopyralid applied to the treatment plots was 25 times higher than the recommended maximum label rate. In spite of the over application, the development of leaf necrosis in aminopyralid treated plants were much slower compared to carfentrazone + 2,4-D + mecoprop + dicamba. Most plants remained alive and exhibited severe chlorosis during the five week observation period.

Despite causing a severe reduction in vigor of *Fimbristylis* transplants, sulfosulfuron was ranked as the least injurious of all the herbicides tested. Plots treated with sulfosulfuron had zero mortality, low foliar injury ratings and high percent green color ratings. It is quite surprising that *F. cymosa* was able to tolerate sulfosulfuron, an acetolactate synthase inhibitor used mainly for controlling sedge species such as *Kyllingia* spp. (Anonymous, 2008a) and *Cyperus rotundus* (Anonymous, 2008a; Eizenberg et al., 2003). Herbicide damage caused by sulfosulfuron is often characterized by apical growth inhibition, progressing to leaf necrosis and total plant collapse

(Eizenberg et al., 2003; Vencill, 2002). A reduction in shoot biomass and overall growth characterize species that are sensitive to sulfosulfuron (Monaco and Creech, 2004).

Since most of the herbicides evaluated caused moderate to severe plant injury, use of these herbicides in *Fimbristylis* plantings should only be limited to spot spray treatments. Of the three broadleaf post-emergence herbicides evaluated in the study, aminopyralid appears to be the most promising since mortality rates were low (15%) despite an over application of the chemical. On the other hand, sulfosulfuron can also be used in *Fimbristylis* plantings as a spot spray treatment to control problematic sedge species such as purple nutsedge (*Cyperus rotundus*).

Tolerance of field grown plants to two rates of aminopyralid

Visual ratings recorded 5 weeks after treatment application generally indicate that mature *F. cymosa* plants were indeed tolerant to both high and low recommended rates of aminopyralid. Vigor ratings did not indicate any inhibitory effects of aminopyralid to *F. cymosa* plants. Although significant differences were detected in foliar injury levels and in green color ratings of aminopyralid-treated plants, the values were not substantial enough to cause detrimental impacts to mature plants.

Based on this study, high and low recommended rates of aminopyralid can be safely used as an over the top spray for broadleaf weed control in mature *Fimbristylis cymosa* plantings.

Timing of pre- and post-emergence herbicide application on hydroseeded *F. cymosa*

Final plant counts reveal that pre-emergence herbicide application is not advisable during the establishment period (7 to 42 DAH). Applying pre-emergence herbicides during the first two weeks after hydroseeding or combining them with post-emergence herbicides at 28 and 42 DAH resulted in low plant counts per square meter. Oxadiazon was particularly injurious as it killed a majority of germinating seeds during the first two weeks after hydroseeding. Spray and granular formulations of oxadiazon, applied at the seedling stage, also caused severe leaf dessication and necrosis which led to an increase in mortality of *F. cymosa* plants. Applications of oryzalin during the first 2 weeks also reduced seedling density, but at a lower extent compared to oxadiazon. Although oryzalin could have been used for pre-emergence control at 28, 42 and 56 DAH, it was not compatible with the post-emergence herbicide mix of aminopyralid and fluazifop-p-butyl. Mixing oryzalin with these two post-emergence herbicides led to the coagulation of the spray solution.

While the pre-emergence herbicides, oryzalin and oxadiazon cannot be used for weed control in newly hydroseeded *F. cymosa*, the post-emergence herbicides, aminopyralid and fluazifop-p-butyl can be safely used as early as 28 DAH. Plant count data and visual observations indicate that the two post-emergence herbicides seem to have little to no detrimental impact on *F. cymosa* seedlings. Although slight yellowing and contortion of plants can be observed two weeks after spraying the post-emergence mix, the plants were able to fully recover afterwards. As observed in the previous post-emergence tolerance studies, aminopyralid and fluazifop-p-butyl can selectively control most broadleaf and grassy weeds. Certain species of spurges (*Chamaesyce* spp.) however, were not controlled by aminopyralid (data not presented).

Tables

Table 4.1. Label recommended application rates of the two pre-emergence herbicides evaluated on transplanted *Fimbristylis cymosa* plugs. The herbicide treatments were applied using a 3 nozzle boom attached to an electric sprayer calibrated to apply 374.2 liters per hectare at 103.4 KPa.

Herbicide treatments	Application rate kg a.i./hectare	Amount of product per hectare	Amount ml/3 liters or grams
1 Oxadiazon (Ronstar® 50WP)	2.24	4.48 kg	36 grams
2 Oxadiazon (Ronstar® 50WP)	4.48	8.97 kg	72 grams
3 Oryzalin (Surflan® 4 AS)	2.24	2.34 liters	37.5 ml
4 Oryzalin (Surflan® 4 AS)	4.48	4.68 liters	75.0 ml
5 Oxadiazon + Oryzalin	2.24 + 2.24	4.48 kg + 2.34 liters	36 grams + 37.5 ml
6 Oxadiazon + Oryzalin	4.48 + 4.48	8.97 kg + 4.68 liters	72 grams + 75.0 ml
7 Untreated control	-	-	-

Table 4.2. Label recommended application rates of the two post-emergence herbicides evaluated in three different age classes (43, 98 and 224 days after planting) of *Fimbristylis cymosa*. The herbicide treatments were applied at a rate of 20 ml per tray using a Meter Jet spray gun attached to backpack sprayer.

Herbicide treatments	Application rate kg a.i./hectare	Amount ml/3 liters
1 Fluazifop-p-butyl (Fusilade® II T&O)	0.28	4.05
2 Fluazifop-p-butyl (Fusilade® II T&O)	0.42	6.15
3 Triclopyr (Garlon® 4)	4.48	30
4 Triclopyr (Garlon® 4)	8.97	60
5 0.25% vol. crop oil	-	7.5
6 Control (water)	-	-

Table 4.3. Label recommended application rates of the four post-emergence herbicides evaluated on field established *Fimbristylis cymosa* transplants. The herbicide treatments were applied using a 3 nozzle boom attached to an electric sprayer calibrated to apply 374.2 liters per hectare at 103.4 KPa.

Herbicides Treatments	Application rate kg ai/ha	Amount of product per hectare	Amount ml/3 liter	1% MSO crop oil
1 Aminopyralid (Milestone® VM)	1.23 (overapplied)	9.36 liters	75.0	30 ml
2 Carferntrazone-ethyl + MCPA, 2-ethylhexyl ester + Mecoprop-acid + Dicamba acid (Powerzone®)	0.02 + 1.24 + 0.25 + 0.12	4.68 liters	37.50	30 ml
3 Carfentrazone-ethyl + 2,4-D, 2-ethylhexyl ester + Mecoprop-p acid + Dicamba acid (Speedzone®)	0.02 + 0.86 + 0.27 + 0.07	4.68 liters	37.50	30 ml
4 Sulfosulfuron (Certainty®)	0.07	87.5 grams	0.7 grams	30 ml
5 Untreated control	-	-	-	-

Table 4.4. Application rates and timing of the different pre- and post-emergence herbicides evaluated on hydroseeded *Fimbristylis cymosa*. The herbicide treatments, except the granular formulation of oxadiazon, were applied using a 3 nozzle boom attached to an electric sprayer calibrated to apply 374.2 liters per hectare at 103.4 KPa.

Herbicide Treatment	Herbicide rate (kg a.i./ha)	Application timing (days after hydroseeding)	Grams/ml for 3 liters
Oxadiazon (wettable powder, Ronstar® 50 WSP)	2.24	7	36 g
Oryzalin (Surflan® 4 AS)	2.24	7	37.5 ml
Oxadiazon (wettable powder, Ronstar 50 WSP)	2.24	14	36 g
Oryzalin (Surflan® 4 AS)	2.24	14	37.5 ml
Oxadiazon (wettable powder, Ronstar® 50 WSP) Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	2.24 0.1 0.28	28	36 g 3.2 ml 9.4 ml
Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	0.1 0.28	28	3.2 ml 9.4 ml
Oxadiazon (granular broadcast, Ronstar® G) Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	2.24 0.1 0.28	42	43.74 g (applied per plot) 3.2 ml 9.4 ml
Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	0.1 0.28	42	3.2 ml 9.4 ml
Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	0.1 0.28	56	3.2 ml 9.4 ml
Untreated	n/a	n/a	n/a

Table 4.5. Visual vigor ratings and seedhead count of *Fimbristylis cymosa* transplants as affected by herbicide treatments. Vigor ratings were recorded at 43, 71, 120 and 211 days after spray application (DAS) while combined seedhead counts from two representative plants were collected at 211 DAS.

Herbicide Treatment	Rate	Vigor Rating (%)*				Seedhead count (sum of 2 plants)^{ns}
		43 DAS	71 DAS	120 DAS	211 DAS	211 DAS
Oxadiazon	2.24 kg/ha	58 (7.5) ab	64 (4.7) ab	75 (4.6) ab	80 (3.5) ab	114 (8.1)
	4.48 kg/ha	59 (9.6) ab	54 (10.7) ab	67 (10.2) ab	66 (10.7) ab	108 (22.7)
Oryzalin	2.24 kg/ha	71 (9.4) ab	43 (11.1) b	76 (3.8) ab	63 (18.3) ab	99 (8.7)
	4.48 kg/ha	69 (5.1) ab	58 (4.7) ab	89 (3.1) a	90 (0.0) a	124 (11.6)
Oxadiazon + Oryzalin	2.24 kg/ha + 2.24 kg/ha	66 (7.2) ab	50 (7.4) b	60 (5.4) ab	66 (5.2) ab	80 (6.7)
Oxadiazon + Oryzalin	4.48 kg/ha + 4.48 kg/ha	44 (3.1) b	23 (9.6) b	44 (13.8) b	55 (11.7) ab	72 (22.0)
Untreated	n/a	89 (1.3) a	93 (2.5) a	90 (5.5) a	54 (9.4) b	74 (15.7)
F value		4.56	8.67	6.17	2.84	2.39
P value		<0.01	<0.01	<0.01	0.03	0.07

* Means within a column followed by the same letter are not significantly different. Tukey HSD mean separation for vigor ratings at 43 and 71 DAS are based on original means while mean separation for 120 and 211 DAS are based on arc sine transformed data. All means presented are original means with standard errors in parentheses (n = 4).

^{ns} Treatment means are not significantly different.

Table 4.6. Mean percent foliar injury of *Fimbristylis cymosa* 28 days after spraying the post-emergence herbicide treatments.

Herbicide Treatments	Application Rate	Injury (%)*
1 Fluazifop-p-butyl (Fusilade® II T&O)	0.28 kg a.i./ha	0 (0.0) b
2 Fluazifop-p-butyl (Fusilade® II T&O)	0.42 kg a.i./ha	0 (0.0) b
3 Triclopyr (Garlon® 4)	4.48 kg a.i./ha	99.5 (0.26) a
4 Triclopyr (Garlon® 4)	8.97 kg a.i./ha	99.5 (0.42) a
5 0.25% vol. crop oil	0.25% vol	0 (0.0) b
6 Control (water)	n/a	0 (0.0) b

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Mean separation for visual injury was based on arcsine transformed data. Means presented are original means with standard errors in parentheses ($n = 12$).

Table 4.7. Aboveground dry biomass of the different *Fimbristylis* age classes 28 days after post-emergence herbicide treatment application.

Herbicide Treatments	Rate	Combined aboveground dry biomass of 6 plants (grams)* 28 days after treatment application		
		224 DAS	98 DAS	43 DAS
Fluazifop-p-butyl	0.28 kg a.i./ha	7.3 (0.44) a	2.3 (0.27) cd	0.7 (0.12) ef
	0.42 kg a.i./ha	6.2 (0.18) a	2.0 (0.21) d	0.8 (0.08) ef
Triclopyr	4.48 kg a.i./ha	3.2 (0.16) bc	0.4 (0.10) efg	0.04 (0.01) g
	8.97 kg a.i./ha	4.0 (0.66) b	0.3 (0.03) fg	0.05 (0.01) g
Crop oil	0.25% vol	6.1 (0.20) a	2.0 (0.12) d	0.86 (0.08) e
Non treated	n/a	7.2 (0.56) a	1.8 (0.11) d	0.67 (0.09) ef

* Means within columns and rows followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Mean separation for aboveground biomass was based on log transformed data. Means presented are original means with standard errors in parentheses ($n = 4$).

Table 4.8. Percent vigor, foliar injury, green color and mortality of *Fimbristylis* plants 5 weeks after the 4 post-emergence herbicide treatments were applied.

Treatment	Rate (kg a.i./ha)	Vigor* (%)	Foliar injury* (%)	Green color* (%)	Mortality* (%)
Aminopyralid (overapplied)	1.23	61 (4.3) b	53 (14.0) ab	39 (8.3) c	17 (5.8) ab
Carfentrazone + MCPA + mecoprop + dicamba	1.63	54 (8.5) bc	46 (13.6) ab	44 (9.4) bc	17 (6.9) ab
Carfentrazone + 2,4-D + mecoprop + dicamba	1.22	54 (6.9) bc	74 (3.8) a	21(4.3) c	23 (5.8) a
Sulfosulfuron	0.07	36 (5.5) c	16 (2.4) b	79 (6.3) ab	0 (0.0) b
Untreated	-	89 (3.1) a	5 (0.5) b	95 (0.0) a	0 (0.0) b

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Means presented are original means with standard errors in parentheses (n = 4).

Table 4.9. Vigor, foliar injury and green color ratings of mature *Fimbristylis cymosa* 5 weeks after application of aminopyralid. All means presented are original means with standard errors of means in parentheses (n = 4).

Herbicide Treatments	Application rate kg a.i./ha	Vigor (%)^{ns}	Injury (%)**	Green color (%)*
Aminopyralid 1x	0.07	92 (0.7)	1 (0.0) a	95 (0.0) ab
Aminopyralid 2x	0.12	91 (0.8)	2 (0.5) a	93 (1.2) b
Untreated	n/a	94 (3.2)	0 (0.0) b	97 (0.9) a

^{ns} mean weekly vigor ratings between treatments were not significant.

** Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Mean separation is based on arc sine transformed data.

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.05$.

Table 4.10. Mean plant count per square meter of the different pre- and post-emergence treatments at 92 DAH.

Herbicide Treatment	Herbicide rate (kg a.i./ha)	Application timing (days after hydroseeding)	Grams/ml for 3 liters	Mean plant count per m^2*
Oxadiazon (wettable powder, Ronstar® 50 WSP)	2.24	7	36 g	1.2 (0.25) c
Oryzalin (Surflan® 4 AS)	2.24	7	37.5 ml	11.1 (3.35) ab
Oxadiazon (wettable powder, Ronstar 50 WSP)	2.24	14	36 g	1.0 (0.00) c
Oryzalin (Surflan® 4 AS)	2.24	14	37.5 ml	19.2 (3.45) ab
Oxadiazon (wettable powder, Ronstar® 50 WSP) Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	2.24 0.1 0.28	28	36 g 3.2 ml 9.4 ml	1.0 (0.00) c
Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	0.1 0.28	28	3.2 ml 9.4 ml	73.9 (29.89) ab
Oxadiazon (granular broadcast, Ronstar® G) Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	2.24 0.1 0.28	42	43.74 g (per plot) 3.2 ml 9.4 ml	9.6 (11.30) b
Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	0.1 0.28	42	3.2 ml 9.4 ml	36.2 (29.32) ab
Aminopyralid (Milestone® VM) Fluazifop-p-butyl (Fusilade® DX)	0.1 0.28	56	3.2 ml 9.4 ml	86.2 (23.77) a
Untreated	n/a	n/a	n/a	70.6 (39.69) ab

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Mean separation is based on log transformed means. Means presented are based on the antilog of the transformed mean with standard errors in parentheses ($n = 4$).

Figures

Figure 4.1. Visual comparison of weed control in plots (top) and vigor of representative plants (bottom) after two subsequent applications of pre-emergence herbicides. At 211 DAS, untreated plots (left) were weedy while plots treated with pre-emergence herbicides remained almost weed free. Both the high rate of oxadiazon (3rd from the left) and oxadiazon + oryzalin (next page) have noticeably stunted plants in comparison to the other treatments.

Figure 4.1 continued. Visual comparison of weed control in plots (top) and vigor of representative plants (bottom) after two subsequent applications of pre-emergence herbicides.

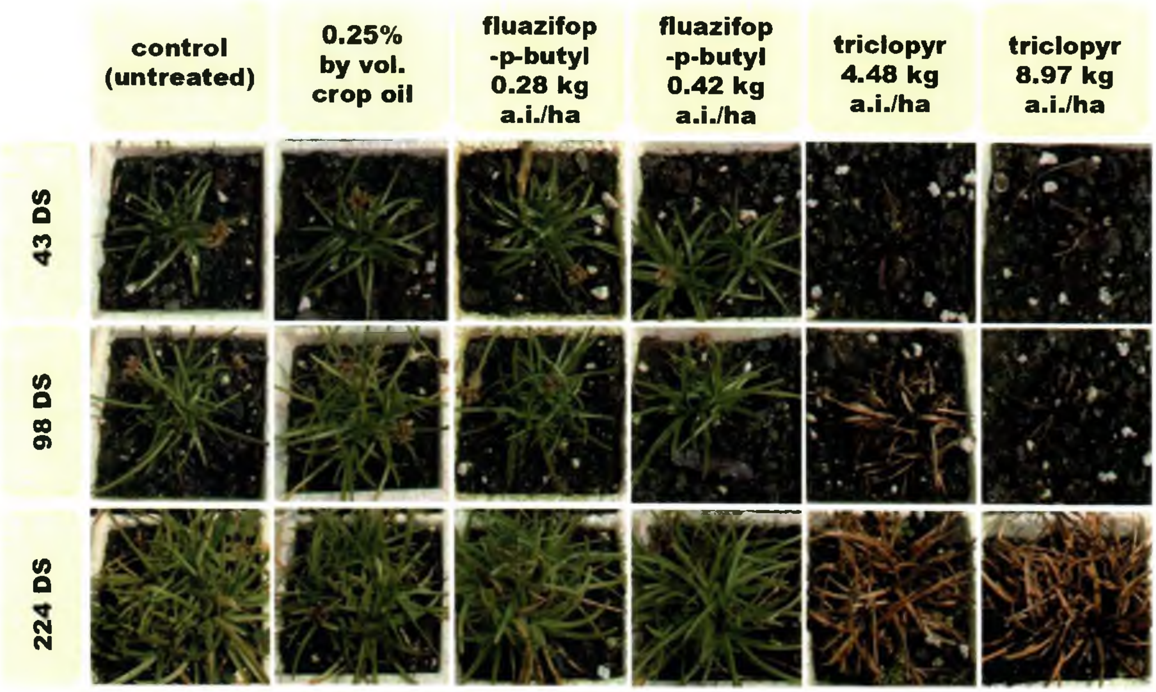

Figure 4.2. Visual comparison of the post-emergence herbicide treatments (top) 28 days after spraying the three age classes (DS = days after sowing, left) of *Fimbristylis cymosa*. Spray applications of both high and low rates of triclopyr resulted in plant death while fluazifop-p-butyl and crop oil sprays did not cause any injury to plants.

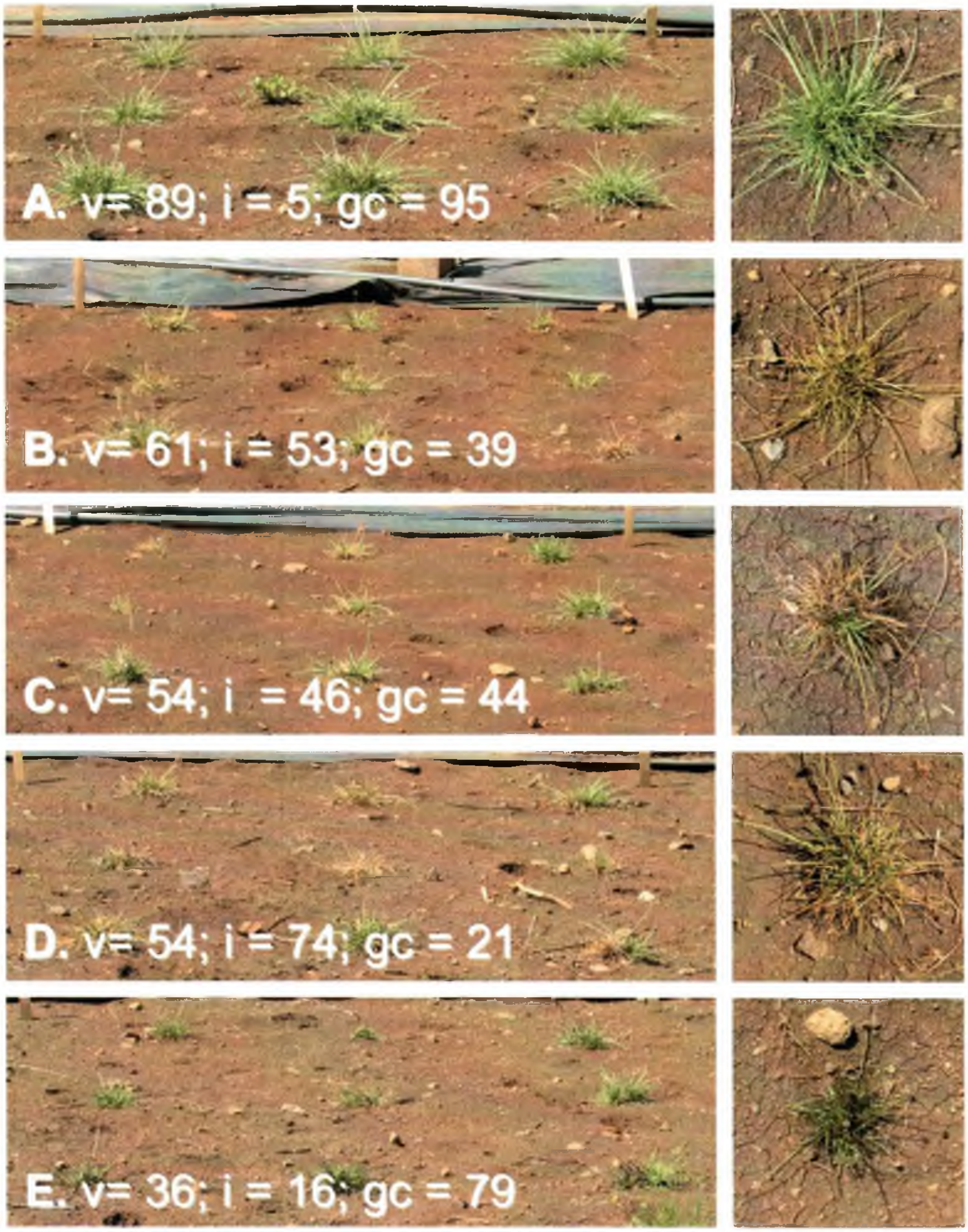

Figure 4.3. Representative plants and corresponding visual ratings (v = vigor; i = injury and gc = green color) 5 weeks after spraying the post-emergence herbicide treatments: A) untreated; B) aminopyralid applied at 1.23 kg a.i./ha; C) carfentrazone + MCPA + mecoprop + dicamba applied at 1.63 kg a.i./ha; D) carfentrazone + 2,4-D + mecoprop + dicamba applied at 1.22 kg a.i./ha; and E) sulfosulfuron applied at 0.07 kg a.i./ha. The two carfentrazone-based treatments exhibited whole plant yellowing which progressed rapidly into severe leaf necrosis or plant death. Aminopyralid treatments exhibited severe yellowing and foliar malformations with limited necrosis. Sulfosulfuron treatments exhibited severe stunting and localized leaf necrosis.

Figure 4.4. A comparison of seedling damage 4 days after post-emergence spray application (0.1 kg a.i./ha aminopyralid + 0.28 kg a.i./ha fluazifop-p-butyl) with (left) or without (right) a wettable powder formulation of oxadiazon. Adding oxadiazon (2.24 kg a.i./ha) in the post-emergence herbicide spray (at 28 DAH) caused severe foliar damage that lead to significantly low plant counts. In contrast, seedlings sprayed with only the post-emergence herbicides (aminopyralid + fluazifop-p-butyl) exhibited slight yellowing and contortion of the leaves (right photo).

Figure 4.5. A comparison of seedling damage 1 week after post-emergence spray application (0.1 kg a.i./ha aminopyralid + 0.28 kg a.i./ha fluazifop-p-butyl) with (left) or without (right) a broadcast application of granular oxadiazon (2.24 kg a.i./ha). Foliar damage caused by the application of granular oxadiazon (at 42 DAH) was similar to those observed in treatments sprayed with the wettable formulation.

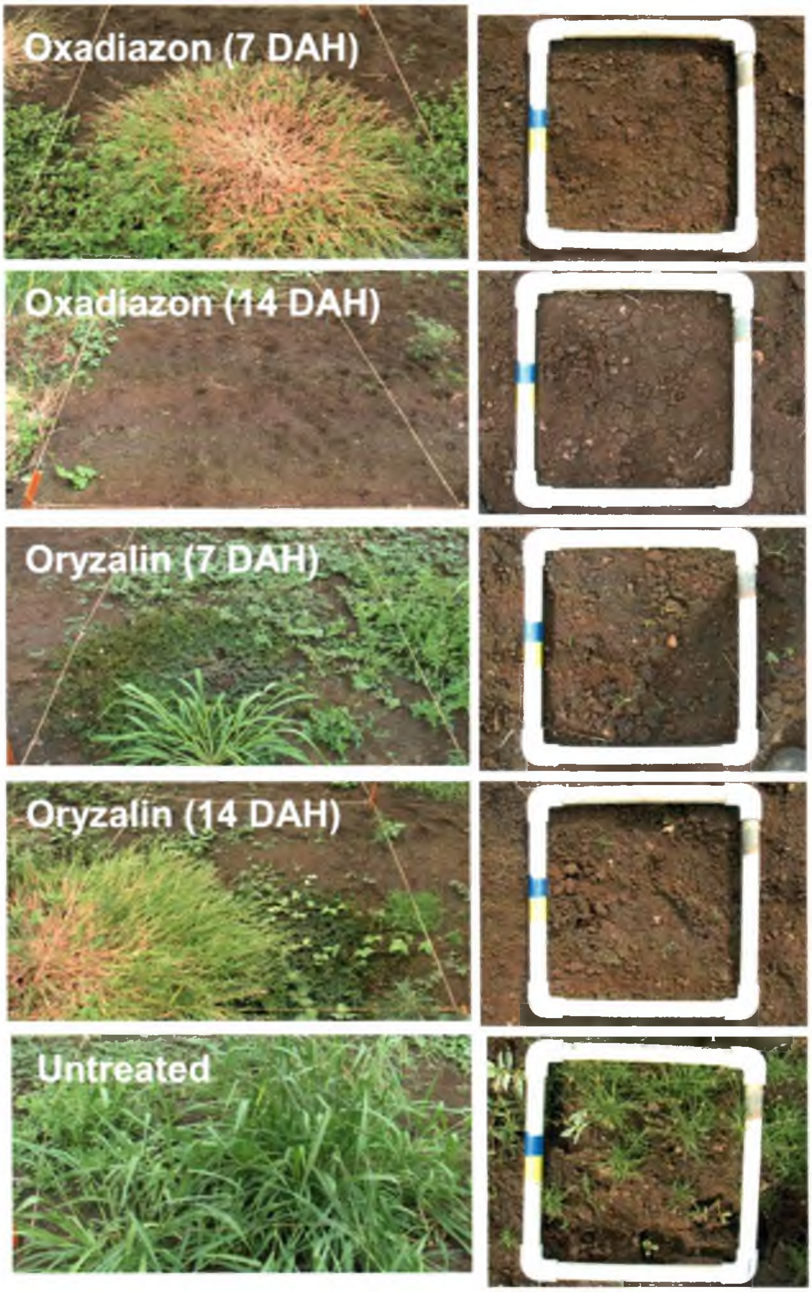

Figure 4.6. Visual comparison of weed control and plant density (0.3 x 0.3 m square) of plots treated with pre-emergence herbicides (photo taken at 92 DAH). Application of 2.24 kg a.i./ha oxadiazon and 2.24 kg a.i./ha oryzalin during the first two weeks after hydroseeding (7 and 14 DAH) severely reduced plant density of *F. cymosa*. Oxadiazon treatments had little to no plants present in the plots on the evaluation date.

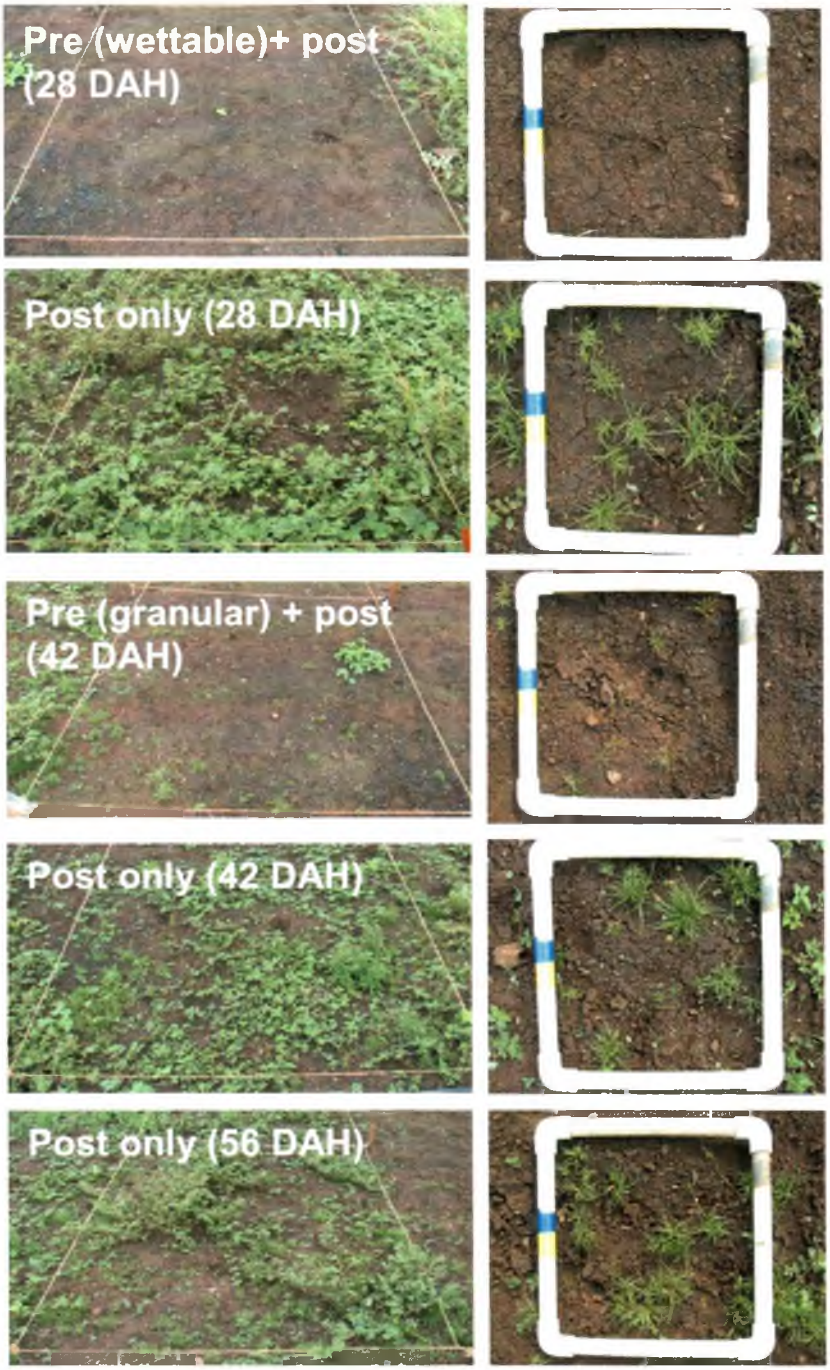

Figure 4.7. Visual comparison of weed control and plant density (0.3 x 0.3 m square) in plots treated at different dates with pre- (2.24 kg a.i./ha oxadiazon, as wettable or granular formulation) and post-emergence herbicides (0.1 kg a.i./ha aminopyralid + 0.28 kg a.i./ha fluazifop-p-butyl). At 92 DAH, treatments applied with wettable and granular formulations of oxadiazon (2.24 kg a.i./ha) have noticeably reduced *Fimbristylis* plant density. Invasion of weedy spurge species can also be seen in the post-emergence only treatments.

CHAPTER 5

TOLERANCE OF *SPOROBOLUS VIRGINICUS* (L.) KUNTH ('AKI 'AKI) TO PRE- AND POST- EMERGENCE HERBICIDES

Introduction

Generating basic information on herbicide tolerance of a native re-vegetation species lays the groundwork for developing weed management protocols and strategies during establishment and maintenance. In order to achieve successful roadside re-vegetation using native Hawaiian plants, screening of pre- and post-emergence herbicides is necessary. Currently, little is known about the tolerance of *Sporobolus virginicus* to various roadside right of way herbicides. This salt and moderately drought tolerant grass has potential use as a low maintenance turf for roadside slope and streambank stabilization (USDA-NCRS, 2007). Although this species has already been used for roadside re-vegetation on the Mokulele Highway in Maui, pre- and post-establishment weed control for this project was particularly problematic. Because of a lack of information on suitable herbicides, weed control options were limited and established plantings eventually succumbed to heavy weed invasions. The objective of this study was to build basic information on *Sporobolus virginicus* pre- and post-emergence herbicide tolerance so that a weed management protocol for its establishment can be developed.

Materials and Methods

The herbicide tolerance study for *S. virginicus* was divided into two sections, namely: 1) tolerance of transplanted plugs to pre-emergence herbicides and 2) tolerance of established plants to post-emergence herbicides. Both studies were conducted at the

Waimanalo Research Station from May to September 2008 (pre-emergence study) and from July to October 2008 (post-emergence study).

Planting material

S. virginicus plants (HA# 5802, 9079745) established at the Magoon Research Facility in Manoa were used as stock plants for the study (see Chapter 3 for details on stock plant establishment). Propagation of grass plugs commenced one year before the study was conducted. Plants were vegetatively propagated through division of clumps (3-stemmed, 35 to 40 cm tall) or from apical stem cuttings. To enhance rooting, clumps or cuttings were soaked in a 1:20 dilution (500 ppm indole butyric acid and 250 ppm naphthalene acetic acid) of commercially available rooting solution (Dip 'N Grow®, Clacklamas, OR). The treated materials were planted in dibble tubes filled with 60:40 by volume ratio of potting mix (Pro-mix®, Premier Horticulture) and black cinder (Menehune Magic, Hawaiian Earth Products). Planted cuttings or clumps were allowed to root for one month under constant mist and then transferred to a sprinkler irrigated holding area under full sun conditions.

Pre-emergence herbicide screening for transplanted *Sporobolus virginicus* plugs

The pre-emergence study was conducted on two adjacent field plots measuring 4.9 m wide by 42.7 m long. Methods of land preparation and irrigation installation were the same as those described in the field grown *Fimbristylis cymosa* post-emergence study (see Chapter 4). In addition to an overhead irrigation system, three sub-irrigation lines (buried approximately 0.4 m deep) were also installed in the plots prior to planting. The two outermost lines were spaced 0.91 m away from the edge of the plot. The central drip line was spaced at 2.4 m from the edge of the plot.

S. virginicus grass plugs were planted along the 3 drip lines at an in-row spacing of 0.61 m. The plots were fertilized immediately with 112.1 kg N/ha and 93.04 kg K/ha as 18-0-18 with minors (United Horticultural Supply, Loveland Products Inc.).

The experiment was laid out in a randomized complete block design with 4 replicates. Each treatment plot measured 1.8 meters wide by 4.9 meters long and contained 12 grass plugs arranged in rows of 3. All pre-emergence herbicide treatments (Table 5.1) except the salt treatment were applied 2 days after planting. The granular herbicides, oxadiazon (2.24 and 4.48 kg a.i./ha) and isoxaben + trifluralin (2.24 + 0.56 kg a.i./ha and 4.48 + 1.12 kg a.i./ha) were applied by hand, making sure that the herbicides were broadcast uniformly. The spray herbicides, dithiopyr (0.28 and 0.56 kg a.i./ha) and oxyfluorfen (0.28 and 0.56 kg a.i./ha) were applied using a 3 nozzle boom (nozzles spaced 50.8 cm apart) fitted with three 8004 LP Teejet Spray Systems nozzle tips (Spraying Systems Co., Wheaton, IL). The 3 liter sprayer, powered by an electric diaphragm pump was calibrated to apply 374.2 liters per hectare at 103.4 KPa. To ensure that no cross contamination of herbicides occur, the spray system was thoroughly rinsed with water between treatment changes.

Due to an unforeseen problem in irrigation scheduling, the entire field experiment was not irrigated for about 1 week after planting. Irrigation was restored during the subsequent weeks and was set to open 5 days per week with watering occuring every morning and afternoon. Subirrigation lines ran for 20 minutes while overhead irrigation lines opened for 1 hour.

Broadcast application of the granular salt treatment (Morton® Table Salt applied at 448 kg a.i./ha) was conducted 28 days after planting when majority of the weed seedlings were present.

At 37 days after herbicide application (37 DAH1), percent maximum vigor (0 = dead to 100 = maximum attainable vigor), percent of treated foliage showing injury (0 = no injury to 100 = complete foliar injury) and percent control ratings of specific weed species (0 = no control to 100 = complete control) were recorded in each treatment plot. At 70 DAH1, timed weeding per treatment plot was conducted to return the plots back to weed-free condition. Also, a combined aboveground dry biomass from 3 representative plants was taken 5 cm from the ground level. Immediately after representative samples of aboveground biomass were taken, all remaining non-sampled plants were trimmed in a similar fashion with the top growth removed from the experimental area. A reapplication of pre-emergence herbicide treatments (including the table salt treatment) occurred at 82 DAH1 (0 DAH2). Five weeks after the 2nd application of treatments (38 DAH2) maximum vigor, foliar injury and percent weed control ratings were recorded. Timed-weeding of each treatment plot and a combined aboveground dry biomass of sampling unit were also recorded at this final evaluation date.

Analysis of variance using Statistix® 9 statistical analysis software (Analytical Software, Tallahasee, FL) was performed for all data sets collected. Data sets showing significance for non-additivity were transformed prior to re-analysis. Using techniques prescribed by Gomez and Gomez (1984), all data sets collected at 37 DAH1 as well as weed control ratings for *Phyllanthus debilis* and *Portulaca oleracea* (collected at 38 DAH2) were arc sine transformed. Timed weeding data collected at 70DAH1 and 38

DAH2 were log transformed. Tukey HSD pairwise comparison tests were performed on vigor and injury ratings, timed weeding and aboveground biomass. For percent control of specific weed species, means were separated using the Least Significant Difference test.

Post-emergence broadleaf herbicide screening for established *Sporobolus virginicus* plants

Post-emergence herbicide screening for *S. virginicus* was conducted on a 4.9 m wide by 42.7 m long plot adjacent to the pre-emergence study. Field preparation and planting of the grass plugs was done following the procedures and dimensions specified in the pre-emergence study (see previous section). After planting, the plots were fertilized with 98.1 kg N/ha and 81.4 kg K/ha as 18-0-18 with minors (United Horticultural Supply, Loveland Products Inc.). Oxadiazon (Chipco Ronstar® G, Bayer CropScience) was also applied at a rate of 4.48 kg a.i./hectare to control emerging weeds during establishment. Post-emergence herbicide spray treatments (Table 5.2) were applied 70 days after planting (70 DAP) and consisted of 1.23 kg a.i./ha aminopyralid (overapplied at 25x the label recommended rate due to confusion between 2 product labels; Milestone® VM, Dow AgroSciences), 3.36 kg a.i./ha triclopyr (Garlon® 4, Dow AgroSciences), 1.63 kg a.i./ha Powerzone® (0.02 kg a.i./ha carfentrazone-ethyl + 1.24 kg a.i./ha MCPA + 0.25 kg a.i./ha mecoprop + 0.12 kg a.i./ha dicamba, PBI/Gordon Corporation) and 0.07 kg a.i./ha sulfosulfuron (Certainty®, Monsanto) were laid out and applied in a randomized complete block design with 4 replicates. Each treatment plot measured 1.8 m wide x 4.9 m long and contained twelve grass plugs arranged in rows of 3. The treatments were applied using a 3 nozzle boom (nozzles spaced 50.8 cm apart) fitted with three 8004 LP Teejet Spray Systems nozzle tips (Spraying Systems Co., Wheaton, IL). The three liter sprayer, powered by an electric diaphragm pump was calibrated to apply 374.2 liters per hectare at 103.4 KPa. To ensure that no cross contamination of herbicides occur, the spray system was thoroughly rinsed with water between treatment changes. After spraying, irrigation was put on hold for 13 hours to allow herbicide absorption.

Percent maximum plant vigor (0 = dead to 100 = maximum attainable vigor), percent of treated foliage showing injury or abnormal growth (0 = no foliar injury to 100 = whole plant necrosis/chlorosis) and percent maximum green color (0 = brown/chlorotic to 100 = maximum attainable green color) were collected 28 days after herbicide application (28 DAH1). Post-emergence herbicide treatments were applied a second time 35 days after the initial treatment application (0 DAH2). Vigor, injury and green color ratings were recorded 4 weeks after the second application was conducted (28 DAH2). Also, a combined aboveground dry biomass (top growth approximately 5 cm above the soil surface) from 3 representative plants were collected, dried and weighed.

Analysis of variance using Statistix® 9 statistical analysis software (Analytical Software, Tallahasee, FL) was performed for all herbicide tolerance ratings and aboveground dry biomass data collected at 28 DAH1 and 28 DAH2. Data sets showing significance for non-additivity were transformed using appropriate techniques prescribed by Gomez and Gomez (1984). Foliar injury data collected at 28 DAH1 were square-root transformed while aboveground biomass data were log transformed before reanalysis. Tukey HSD pairwise comparison tests were performed on each data set showing significance in the analysis of variance.

Results

Pre-emergence herbicide screening for transplanted *Sporobolus virginicus*

Crop tolerance and weed control efficacy at 37 DAH1

Overall plant vigor and maximum foliage injury ratings did not indicate any significant inhibition in growth ($F = 0.98$, $P = 0.48$) nor damage to leaf tissue ($F = 0.97$, $P = 0.48$) due to pre-emergence herbicide application (Table 5.3). Mean plant vigor ratings ranged from 82 to 69%, with the low rate of oxyfluorfen having the highest mean plant vigor while dithiopyr at the high rate having the lowest mean plant vigor. Mean foliage injury ratings ranged below 5% with only the high rate of dithiopyr having the highest value of 15%.

Although a total of 14 weed species were observed at 37 DAH1 (Table 5.4), only 7 species were abundant enough throughout the experimental area to provide reliable weed species control ratings in response to herbicide treatments (Table 5.5). For the control of *Indigofera hendecaphylla*, all herbicides including table salt proved to be effective with both high and low rates of oxadiazon and oxyfluorfen providing complete control (100%). Except for table salt, all pre-emergence treatments provided acceptable control of *Eleusine indica* and *Portulaca oleracea*. Complete control of *Eleusine indica* was observed in the high rate of dithiopyr and both high and low rates of oxadiazon and trifluralin + isoxaben. For *Portulaca oleracea*, complete control was observed in the high rate of trifluralin + isoxaben and both high and low rates of oxyfluorfen and oxadiazon. Treatments with either high or low application rates of oxyfluorfen or oxadiazon were also effective in controlling *Phyllanthus debilis*. Complete control of *Phyllanthus debilis* was observed in both rates of oxyfluorfen and the high rate of oxadiazon. Both high and low rates of oxadiazon and the high rates of oxyfluorfen and trifluralin + isoxaben were effective for controlling *Crotalaria* species. Complete control of *Crotalaria* sp. was observed in the low rate of oxadiazon and in both high and low rates of trifluralin + isoxaben. Significant control of *Mimosa pudica* was observed in both high and low rates of oxadiazon and the high rates of dithiopyr, oxfluorfen and trifluralin + isoxaben. Complete control of *Mimosa pudica* was only observed in the high rate of oxadiazon. Both rates of oxadiazon controlled *Leucaena leucocephala*.

In contrast to the pre-emergence herbicides used in the study, table salt did not exhibit acceptable control ratings for most weed species. Except for *Indigofera hendecaphylla*, percent control values of the table salt treatment did not significantly differ with that of the untreated control. The only noticeable change in salt treated plots was that of its surface soil characteristics. The application of salt caused the surface soil to become puddled when wet and created a thin impervious layer that cracked when it was dried (Figure 5.1).

Based on weed control values recorded at 37 DAH1, the overall performance of the pre-emergence treatments from best to worst are as follows: high rate of oxadiazon = low rate of oxadiazon > high rate of oxyfluorfen > high rate of trifluralin + isoxaben > low rate of oxyfluorfen > low rate of trifluralin + isoxaben > high rate of dithiopyr > low rate of dithiopyr > table salt > untreated.

Timed weeding and aboveground biomass at 70 DAH1

Results obtained from the timed weeding activity indicate significant differences between treatments ($F = 12.43$, $P < 0.01$). Both high and low rates of oxadiazon and oxyfluorfen and the high rate of trifluralin + isoxaben exhibited significantly shorter weeding times than untreated plots. Oxadiazon, applied at the high rate, took the least time to return plots to weed-free condition (Table 5.6). The low rate of oxadiazon, the high rate of trifluralin + isoxaben and both rates of oxyfluorfen took less than six minutes per person to return the plots to weed free condition. Weeding times recorded in both rates of dithiopyr, salt and the low rate of trifluralin + isoxaben did not significantly differ from those recorded in untreated plots. The salt treatment took the longest time to weed among all pre-emergence treatments tested.

Aboveground dry biomass collected 70 DAH1 did not indicate significant differences between the pre-emergence treatments ($F = 1.20$, $P = 0.34$). The low rate of oxyfluorfen exhibited the highest biomass while untreated plots exhibited the lowest biomass (Table 5.7).

Crop tolerance, weed control efficacy, timed weeding and biomass at 38 DAH2

Vigor ratings recorded at 38 DAH2 revealed significant treatment effects ($F = 5.61$, $P < 0.01$). Plant vigor was the highest in the high rate of oxadiazon (86%) followed by the low rate of oxadiazon (82%) and the high rate of oxyfluorfen (75%). The lowest vigor ratings were observed in the table salt treatments (38%). Ratings for foliar injury were not significantly different ($F = 1.2$, $P = 0.35$). Injury ratings were slight and ranged between 0 to 1% (Table 5.8).

Significant differences in control values were detected in four weed species namely *Indigofera hendecaphylla* ($F = 7.9$, $P < 0.01$), *Mimosa pudica* ($F = 4.4$, $P < 0.01$), *Phyllanthus debilis* ($F = 7.9$, $P < 0.01$) and *Portulaca oleracea* ($F = 25.7$, $P < 0.01$) (Table 5.9). Both high and low rates of oxadiazon and oxyfluorfen and the high rate of dithiopyr and trifluralin + isoxaben were effective in controlling *Indigofera* *hendecaphylla*. Complete control of this species was observed in the high rate of oxyfluorfen and both rates of oxadiazon. Both rates of oxadiazon provided 100% control of *Mimosa pudica*. Effective control of *Phyllanthus debilis* was observed in both high and low rates of oxyfluorfen and oxadiazon. All pre-emergence herbicides including table salt exhibited significant control of *Portulaca oleracea*. However, all herbicides provided significantly higher percent control values (> 90%) than the table salt treatment. Complete control of *Portulaca oleracea* was observed in the high and low rates of oxyfluorfen and oxadiazon and in the low rate of dithiopyr and trifluralin + isoxaben.

Aboveground biomass collected at 38 DAH2 yielded significant differences between the pre-emergence treatments ($F = 8.98$, $P < 0.01$). The high rate of oxadiazon obtained the highest aboveground dry biomass followed by the low rates of oxadiazon and oxyfluorfen. Both high and low rates of oxadiazon were the only pre-emergence treatments to exhibit significantly higher crop biomass than untreated plants (Table 5.10). Aboveground biomass collected from the rest of the treatments were not significantly different from those of untreated plants. Dithiopyr, applied at the low rate had the lowest crop biomass among the pre-emergence herbicides tested. Table salt had the least amount of biomass; exhibiting a lower mean value compared to untreated plants.

Both high and low rates of oxadiazon and the high rate of oxyfluorfen took the least time to return plots to a weed-free condition ($F = 58.57$, $P < 0.01$) (Table 5.11). The high rate of oxadiazon took an average time of 0.33 minutes per person, while the low rate of oxadiazon and the high rate of oxyfluorfen took 0.75 and 0.95 minutes per person, respectively. Untreated and salt-treated plots took the most time to weed with 25.97 and 16.30 minutes/person, respectively.

Based on data collected at 38 DAH2, the overall performance of the pre-emergence treatments from best to worst are as follows: high rate of oxadiazon > low rate of oxadiazon > high rate of oxyfluorfen > low rate of oxyfluorfen > high rate of dithiopyr >low rate of trifluralin + isoxaben > high rate of trifluralin + isoxaben = low rate of dithiopyr > table salt = untreated. Figure 5.2 visually illustrates the degree of weediness in each treatment plot at 38 DAH2.

Post-emergence broadleaf herbicide screening for established *Sporobolus virginicus* plants

Foliar injury ratings recorded 4 weeks after the first post-emergence application (28 DAH1) revealed significant differences between treatments ($F = 24.53$, $P < 0.01$). Triclopyr, carfentrazone + MCPA + mecoprop + dicamba and aminopyralid (25x) had significantly higher injury ratings compared to untreated plants (Table 5.12). In contrast, injury ratings recorded in sulfosulfuron were not significantly different from those observed in untreated plants. Foliar injury ratings at this evaluation date were relatively low and ranged from 5.50 to 0.25%.

Foliar injury ratings of all treatments generally increased at the second evaluation date (28 DAH2). Triclopyr and aminopyralid (25x) caused significant foliar injury ($F = 172.18$, $P < 0.01$) after the second application (Table 5.12). The triclopyr treatment exhibited severe leaf necrosis while aminopyralid (25x) treated plants showed severe chlorosis (Figure 5.3). Although aminopyralid (25x) treated plants had a slightly lower mean injury rating, it did not significantly differ from the triclopyr treated plants. Injury levels recorded in plants sprayed with carfentrazone + MCPA + mecoprop + dicamba and sulfosulfuron were significantly lower than those observed in the triclopyr and aminopyralid (25x) treatments. Injury ratings recorded in sulfusulfuron treated plants were low and did not significantly differ from untreated plants.

Significant differences for green color ratings were recorded on the first (28 DAH1) and second (28 DAH2) evaluation dates (Table 5.13). During the first evaluation date, triclopyr, aminopyralid (25x) and carfentrazone + MCPA + mecoprop + dicamba had significantly lower green color ratings compared to sulfosulfuron and untreated plants. Triclopyr exhibited the lowest green color rating at 53%, followed by aminopyralid (25x) (59%) and carfentrazone + MCPA + mecoprop + dicamba (64%). Green color ratings of sulfosulfuron did not significantly differ with that of untreated plants. During the second evaluation date, green color ratings of triclopyr and aminopyralid (25x) decreased even further. Triclopyr treated plants dropped from 53 to 23% while aminopyralid (25x) treatments declined from 59 to 30%. The carfentrazone + MCPA + mecoprop + dicamba treatment did not exhibit a drastic change in green color ratings as opposed to triclopyr and aminopyralid (25x) treated plants. The final green color rating of the carfentrazone + MCPA + mecoprop + dicamba treatment was significantly higher compared to those recorded in triclopyr and aminopyralid (25x). The highest green color ratings among the post-emergence herbicides tested was again recorded in the sulfosulfuron treatment. Mean green color ratings obtained from sulfosulfuron were not significantly different from those observed in untreated plants.

Vigor ratings on the first evaluation date revealed that triclopyr was the only post-emergence herbicide to exhibit significantly reduced vigor (Table 5.14). During the second evaluation date, further reductions in plant vigor of triclopyr and aminopyralid (25x) treated plants were recorded. Triclopyr exhibited the lowest plant vigor at 29%

followed by aminopyralid (25x) at 44%. Vigor ratings recorded in carfentrazone + MCPA + mecoprop + dicamba and sulfosulfuron treated plants were significantly higher than triclopyr and aminopyralid and did not significantly differ with those observed in untreated plants.

After two sequential applications of the post-emergence herbicides, significant differences in aboveground dry biomass were recorded ($F = 25.48$, $P < 0.01$). Triclopyr, carfentrazone + MCPA + mecoprop + dicamba and aminopyralid (25x) caused significantly lower aboveground dry biomass than sulfosulfuron and untreated plants (Table 5.15). The lowest aboveground dry biomass was observed in the triclopyr treatment followed by the carfentrazone + MCPA + mecoprop + dicamba and aminopyralid (25x) treatments. Although a 47% decrease in aboveground dry biomass was recorded in sulfosulfuron treated plants, this was not significantly different from those obtained in untreated plants.

Based on visual ratings and aboveground dry biomass collected after two sequential post-emergence treatment applications, overall ranking of the post-emergence herbicides from most to least injurious are as follows: triclopyr > aminopyralid (25x) > carfentrazone + MCPA + mecoprop + dicamba > sulfosulfuron > untreated.

Discussion

Pre-emergence herbicide screening for transplanted *Sporobolus virginicus*

Visual ratings, aboveground biomass and weeding times indicate that the two most effective and safest pre-emergence herbicides were oxadiazon and oxyfluorfen.

Oxadiazon, applied at the high rate controlled the most weed species; consistently attained the highest weed control values; and provided the shortest weeding times. Plants treated with the high rate of oxadiazon also provided the highest aboveground biomass. At the lower rate, oxadiazon completely controlled fewer weed species but nonetheless exhibited excellent weed control as evidenced by a short weeding time (< 1 minute) and high aboveground biomass of treated *Sporobolus* plants.

Oxyfluorfen, applied at the high or low rates were also effective and safe for use in transplanted *Sporobolus virginicus* plugs. Although some weed species like *Leucaena leucocephala* and *Mimosa pudica* may not be effectively controlled by oxyfluorfen, high control ratings for most weed species were still attained. This is evidenced by short weeding times (< 2 minutes) recorded in the oxyfluorfen treatments. In terms of safety, oxyfluorfen application did little to inhibit the growth of *Sporobolus* transplants. Even after two applications, high aboveground biomass was observed in the oxyfluorfen treatments.

Weed control and aboveground crop biomass results obtained from oxyfluorfen and oxadiazon treated plants were comparable to those reported in garlic (Qasem, 1996) and marjoram (Qasem and Foy, 2006). Post plant application of oxyfluorfen and oxadiazon at the 3-4 leaf stage in garlic resulted in high shoot dry weights and bulb yields (Qasem, 1996). In marjoram, post plant application of both pre-emergence herbicides effectively controlled weeds as well as significantly increased shoot fresh and dry weight yields.

The least effective pre-emergence herbicide treatments evaluated in this study were trifluralin + isoxaben and dithiopyr. These two herbicides controlled fewer weed species and generally had lower weed control values and longer weeding times than oxadiazon and oxyfluorfen. The lowest aboveground biomasses among the pre-emergence herbicides tested were also observed in trifluralin + isoxaben and dithiopyr treatments. Although weed pressure may be a contributing factor to this, visual observations indicate that weed infestation was minimal and may not have caused this significant decrease in aboveground biomass. One probable cause of this decrease might be from herbicide application. Besides aboveground biomass, low mean vigor ratings (<65%) at 38 DAH2 also suggests the inhibitory effects of the two pre-emergence herbicides. Growth inhibition, caused by these two herbicides, has also been observed in weed control/plant establishment studies done in other crops. For Tifway bermudagrass and zoysiagrass a 25 and 20% suppression in establishment was observed in a post plant application of the full rate of dithiopyr (0.6 kg/ha) (Fagerness et al., 2002). On the other hand, trifluralin + isoxaben, applied at the high rate (4.5 + 1.12 kg/ha), decreased frond length and frond number of *Cyrtomium falcatrum* 'Rochfordianum' (rochford's Japanese holly fern) by 66% and 72%, respectively (Fain et al., 2006).

Of all the treatments tested, salt application was the least effective for weed control. Although a slight decrease in the incidence of certain weed species were observed, the degree of control by salt application did not match those of pre-emergence herbicides.

Slight stunting due to salt-mediated water stress was observed in weeds but also in the *Sporobolus* transplants. Distinct soil structure changes resulted in puddling/cracking of the soil surface in table salt treated plots, due to the sodium ions dipersing the soil particles. Soil dispersion rather than flocculation happens when the large, hydrated sodium ions cannot bind closely to clay particles to effectively neutralize clay's inherent negative charge (Bright and Addison, 2002). This is especially apparent in soils having a high clay content (i.e., swelling clays like montmorillonite) (Bright and Addison, 2002). Due to these effects, it is not advisable to use salt for controlling weedy species, particularly in clayey soils.

Overall, the study revealed differences between pre-emergence herbicide treatments in terms of weed control efficacy and impact on *Sporobolus* growth. Oxadiazon and oxyfluorfen provided an optimum growing environment for establishing *Sporobolus* transplants through excellent pre-emergence control of weeds. Both oxadiazon and oxyfluorfen significantly controlled most broadleaf and grassy weed species and allowed for the highest level of aboveground biomass. In contrast, trifluralin + isoxaben and dithiopyr applications had lower weed control efficacy and were detrimental to plant growth. The application of table salt did little to control weeds in transplanted *Sporobolus* plantings. Salt treatment is not advisable as it can alter soil structure and drainage, particularly on clayey soils.

Post-emergence herbicide screening for established *Sporobolus virginicus* plants

Varying degrees of tolerance to the different post-emergence herbicide treatments were observed in established *Sporobolus* transplants. Triclopyr was the most injurious and caused severe reductions in plant vigor, green color and aboveground biomass. The injuries caused by triclopyr in this study has also been reported in warm season turfgrass (Hurto et al., 1984) and some forage grass species (Bovey et al., 1984; Butler and Muir, 2006). For the bermudagrass cultivars, OKS 91-11 and Midlawn, the application of a similar rate of triclopyr (3.8 kg a.i./ha) caused turfgrass injury exceeding 25% (Bell et al., 2000). On the other hand, reductions in biomass were observed in ‘Coastal’ bermudagrass (*Cynodon dactylon*) (Butler and Muir, 2006) and mature buffel grass

(*Cenchrus ciliaris*) (Bovey et al., 1984) with the application of 1.68 kg a.i./ha and 2.2 kg a.i./ha, respectively.

Despite exhibiting phytotoxic symptoms from two herbicide applications, triclopyr treated *Sporobolus* plants remained alive. This tolerance to high rates may indicate the possibility of using lower recommended rates as spot spray treatments. Since application rates in weed control studies done in turfgrass range from 0.56 to 1.12 kg a.i./ha, it is recommended that future experiments use this range of rates to determine the optimum amount which provide an acceptable level of injury.

Aminopyralid, applied 25 times the recommended rate, was the second most injurious herbicide evaluated in this study. This treatment caused a severe reduction in green color and vigor ratings as well as in aboveground biomass of the test plants. Despite the over application of aminopyralid, severe herbicide injury did not lead to complete plant death at 5 weeks after the second application. This may be an indication that aminopyralid could be a useful weed control tool if applied at the recommended rates. Prior to the completion of this study, adjacent plots of the pre-emergence study were sprayed with the recommended rate of aminopyralid (0.12 kg a.i./ha). Weekly observations in these non-replicated plots reveal that overall herbicide injury was only slight and the plants exhibited normal growth (personal observation). To verify this, it is suggested that a replicated tolerance study should be conducted using the recommended rate of aminopyralid.

In contrast to triclopyr and aminopyralid, applications of carfentrazone + MCPA + mecoprop + dicamba were less injurious to established *Sporobolus* transplants. Despite causing some foliar injury to plants, damage did not exceed 17% even after two applications. Vigor, green color and aboveground biomass also indicate that it is less injurious than triclopyr and aminopyralid treatments. Due to foliar injuries, this herbicide should only be used for spot spray applications.

The least injurious of all the post-emergence herbicides evaluated was sulfosulfuron. Visual ratings and aboveground biomass exhibited by sulfosulfuron treated plants did not significantly differ with those in untreated plants, even after two applications. Sulfosulfuron appears to be safest for use in *Sporobolus virginicus* and is an excellent post-emergence herbicide for controlling sedge species, particularly *Cyperus rotundus*.

In summary, established *Sporobolus* plantings exhibited different degrees of tolerance to the four post-emergence herbicides. Sulfosulfuron can be safely used as an over-the-top spray for sedge control while carfentrazone + MCPA + mecoprop + dicamba should be considered only as a directed spot spray treatment to control broadleaf weeds and minimize crop injury. Although the high rate of triclopyr and the overapplication of aminopyralid (25x) caused significant injury and growth reduction in *Sporobolus virginicus*, it did not kill the entire plant. Further studies on lower recommended rates should be done to determine efficacy and safety of these two herbicides.

Tables

Table 5.1. Recommended application rates of the five pre-emergence herbicides evaluated on transplanted *Sporobolus virginicus* plugs. Granular herbicides were broadcasted uniformly by hand while spray treatments were applied using a 3 nozzle boom attached to an electric sprayer calibrated to apply 374.2 liters per hectare at 103.4 KPa.

Pre-emergence herbicide treatments and tradenames	Amount ml/3 liters	Granular for 1.8 x 4.9 m plots (grams)	Amount per hectare	Application rate kg a.i./hectare
1 Oxadiazon (1x) (Ronstar® G)	n/a	100	112 kg/ha	2.24
2 Oxadiazon (2x) (Ronstar® G)	n/a	200	224 kg/ha	4.48
3 Trifluralin + isoxaben (1x) (Snapshot® 2.5 TG)	n/a	100	112 kg/ha	2.80
4 Trifluralin + isoxaben (2x) (Snapshot® 2.5 TG)	n/a	200	224 kg/ha	5.60
5 Dithiopyr (1x) (Dimension® 2EW)	9.4 ml	n/a	1.17 liters/ha	0.28
6 Dithiopyr (2x) (Dimension® 2EW)	18.8 ml	n/a	2.34 liters/ha	0.56
7 Oxyfluorfen (1x) (GoalTender®)	4.1ml	n/a	0.58 liters/ha	0.28
8 Oxyfluorfen (2x) (GoalTender®)	9.4 ml	n/a	1.17 liters/ha	0.56
9 Sodium chloride (Table salt)	n/a	400	448 kg/ha	448
10 Untreated control	-	-	-	-

Table 5.2. Recommended application rates of four post-emergence herbicides evaluated on field established *Sporobolus virginicus* transplants. The treatments were applied using a 3 nozzle boom attached to an electric sprayer calibrated to apply 374.2 liters per hectare at 103.4 KPa.

Post-emergence herbicide treatments and tradenames	Application rate kg a.i./ha	Amount per 3 liters	1% MSO crop oil	Amount per hectare
1 Aminopyralid (Milestone® VM)	1.23 (overapplied)	75.0 ml	30 ml	9.36 liters
2 Triclopyr (Garlon® 4)	3.36	56.2 ml	30 ml	7.02 liters
3 Carferntrazone + MCPA + mecoprop + dicamba (Powerzone®)	1.63	37.50 ml	30 ml	4.68 liters
4 Sulfosulfuron (Certainty®)	0.07	0.7 grams	30 ml	87.5 grams
5 Untreated control	-	-	-	-

Table 5.3. Overall vigor and foliage injury ratings of pre-emergence treatments at 37 DAH1. Both ratings were recorded on a visual scale of 0 to 100. For percent vigor, 0 = dead and 100 = maximum attainable vigor. For percent foliar injury, 0 = no injury and 100 = whole plant chlorosis/necrosis.

Treatments	Vigor (%)^{ns}	Foliar Injury (%)^{ns}
Dithiopyr (0.28 kg a.i./ha)	72 (4.7)	5 (0.4)
Dithiopyr (0.56 kg a.i./ha)	69 (10.0)	15 (11.8)
Oxyfluorfen (0.28 kg a.i./ha)	83 (2.5)	3 (0.9)
Oxyfluorfen (0.56 kg a.i./ha)	82 (2.6)	2 (0.7)
Oxadiazon (2.24 kg a.i./ha)	78 (1.2)	2 (0.4)
Oxadiazon (4.48 kg a.i./ha)	69 (13.0)	2 (0.4)
Salt (448 kg a.i./ha)	75 (4.9)	4 (2.0)
Trifluralin + isoxaben (2.80 kg a.i./ha)	75 (2.3)	6 (1.7)
Trifluralin + isoxaben (5.60 kg a.i./ha)	75 (2.9)	3 (0.8)
Untreated	77 (2.2)	4 (2.1)

^{ns}Treatment effects were not significant. Means presented are original means with standard errors in parentheses (n = 4)

Table 5.4. Weed species observed in the experimental area at 37 DAH1. Due to sporadic and uneven distribution of weeds, only half of the species observed provided reliable control ratings (species in bold letters).

Scientific name	Common name
Amaranthus viridis	Slender amaranth
Bidens pilosa	Beggar tick
Commelina benghalensis	Benghal dayflower
Crotalaria spp.	**Crotalaria**
Echinochloa colona	Jungle rice
Eleusine indica	**Goosegrass**
Emilia fosbergii	Flora's paintbrush
Indigofera hendecaphylla	**Creeping indigo**
Ipomoea triloba	Little bell
Leucaena leucocephala	**Koa haole**
Mimosa pudica	**Sensitive plant**
Panicum maximum	Guineagrass
Phyllanthus debilis	**Niuri**
Portulaca oleracea	**Common purslane**

Table 5.5. The effect of the different pre-emergence herbicide treatments on the percent control values of *Crotalaria* spp., *Eleusine indica*, *Indigofera hendecaphylla*, *Leucaena leucocephala*, *Mimosa pudica*, *Portulaca oleracea*, and *Phyllanthus debilis* at 37 DAH1.

Treatments	Mean percent control*						
	Crotalaria spp	*Eleusine indica*	*Indigofera hendecaphylla*	*Leucaena leucocephala*	*Mimosa pudica*	*Portulaca oleracea*	*Phyllanthus debilis*
Dithiopyr (0.28 kg a.i./ha)	69 (15.5) bc	94 (6.0) a	87 (8.6) a	74 (1.9) c	52 (13.7) cd	89 (6.6) ab	65 (15.4) bc
Dithiopyr (0.56 kg a.i./ha)	85 (5.1) abc	100 (0.0) a	94 (5.7) a	80 (6.8) abc	96 (3.9) ab	94 (5.7) ab	78 (15.0) abc
Oxyfluorfen (0.28 kg a.i./ha)	82 (10.8) abc	89 (10.8) a	100 (0.0) a	77 (7.6) bc	68 (14.6) bcd	100 (0.0) a	100 (0.0) a
Oxyfluorfen (0.56 kg a.i./ha)	96 (3.9) ab	93 (7.1) a	100 (0.0) a	62 (8.9) c	81 (8.9) abc	100 (0.0) a	100 (0.0) a
Oxadiazon (2.24 kg a.i./ha)	100 (0.0) a	100 (0.0) a	100 (0.0) a	100 (0.0) a	96 (3.9) ab	100 (0.0) a	93 (7.1) ab
Oxadiazon (4.48 kg a.i./ha)	92 (4.9) ab	100 (0.0) a	100 (0.0) a	96 (3.9) ab	100 (0.0) a	100 (0.0) a	100 (0.0) a
Salt (448 kg a.i./ha)	68 (8.3) bc	61 (15.2) b	86 (8.3) a	76 (9.0) bc	53 (8.7) cd	71 (15.7) bc	67 (9.6) bc
Trifluralin + isoxaben (2.80 kg a.i./ha)	100 (0.0) a	100 (0.0) a	81 (11.7) a	71 (4.8) c	79 (7.8) abcd	93 (7.1) ab	74 (3.7) abc
Trifluralin + isoxaben (5.60 kg a.i./ha)	100 (0.0) a	100 (0.0) a	88 (12.3) a	81 (6.3) abc	96 (3.9) ab	100 (0.0) a	79 (13.2) abc
Untreated	60 (11.4) c	54 (9.8) b	59 (15.2) b	78 (7.2) bc	49 (12.3) d	60 (11.1) c	61 (14.2) c

* Means within columns followed by the same letters are not significantly different as determined by least significant difference test at $P < 0.01$ for *Crotolaria*, *Eleusine*, *Leucaena*, *Mimosa*, *Portulaca* and *Phyllanthus* and at $P < 0.05$ for *Indigofera*. Means presented are arc sine transformed means with standard errors in parentheses ($n = 4$).

Table 5.6. Timed weeding (for 8.8 m^2) values in *Sporobolus virginicus* 70 days after the first application of treatments (70 DAH1).

Treatment	Time to Weed Free (8.8 m^2) (minutes/person)***
Dithiopyr (0.28 kg a.i./ha)	14.6 (3.95) abc
Dithiopyr (0.56 kg a.i./ha)	6.7 (2.60) bcd
Oxyfluorfen (0.28 kg a.i./ha)	5.3 (0.88) cd
Oxyfluorfen (0.56 kg a.i./ha)	4.1 (0.99) cd
Oxadiazon (2.24 kg a.i./ha)	4.1 (1.50) cd
Oxadiazon (4.48 kg a.i./ha)	1.9 (1.05) d
Salt (448 kg a.i./ha)	22.4 (2.90) a
Trifluralin + isoxaben (2.80 kg a.i./ha)	7.6 (0.61) abc
Trifluralin + isoxaben (5.60 kg a.i./ha)	4.7 (0.65) cd
Untreated	20.5 (3.80) ab

*** Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Mean separation was based on log transformed data. Means presented are original means with standard errors in parentheses (n = 4).

Table 5.7. Total aboveground dry biomass (standard errors in parentheses; n = 4) of three representative *Sporobolus virginicus* plants 70 days after the first application of treatments (70 DAH1).

Treatment	Total aboveground dry biomass of 3 representative plants (grams) harvested at 70 DAH1^{ns}
Dithiopyr (0.28 kg a.i./ha)	33.3 (10.02)
Dithiopyr (0.56 kg a.i./ha)	36.0 (6.68)
Oxyfluorfen (0.28 kg a.i./ha)	57.5 (20.02)
Oxyfluorfen (0.56 kg a.i./ha)	43.3 (2.75)
Oxadiazon (2.24 kg a.i./ha)	52.5 (10.18)
Oxadiazon (4.48 kg a.i./ha)	50.5 (5.68)
Salt (448 kg a.i./ha)	31.0 (10.16)
Trifluralin + isoxaben (2.80 kg a.i./ha)	41.0 (3.74)
Trifluralin + isoxaben (5.60 kg a.i./ha)	34.8 (5.07)
Untreated	27.3 (3.25)

^{ns} Treatment effects were not significant.

Table 5.8. Vigor and foliar injury ratings of *Sporobolus virginicus* 38 days after the 2nd herbicide application (38 DAH2). Both ratings were recorded on a visual scale of 0 to 100. For percent vigor, 0 = dead and 100 = maximum attainable vigor. For percent foliar injury, 0 = no injury and 100 = whole plant chlorosis/necrosis. All means presented are original means with standard errors in parentheses (n = 4).

Treatment	Vigor (%)*	Foliar Injury (%)^{ns}
Dithiopyr (0.28 kg a.i./ha)	49 (12.1) abc	0.5 (0.29)
Dithiopyr (0.56 kg a.i./ha)	65 (7.9) abc	0.3 (0.25)
Oxyfluorfen (0.28 kg a.i./ha)	74 (10.5) abc	0.0 (0.00)
Oxyfluorfen (0.56 kg a.i./ha)	75 (7.4) abc	1.0 (0.58)
Oxadiazon (2.24 kg a.i./ha)	85 (2.9) ab	0.3 (0.33)
Oxadiazon (4.48 kg a.i./ha)	86 (2.4) a	0.5 (0.29)
Salt (448 kg a.i./ha)	38 (3.2) c	0.3 (0.25)
Trifluralin + isoxaben (2.80 kg a.i./ha)	65 (7.4) abc	0.3 (0.25)
Trifluralin + isoxaben (5.60 kg a.i./ha)	58 (8.5) abc	0.8 (0.25)
Untreated	43 (2.5) bc	0.0 (0.00)

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$.

^{ns} no significant differences were observed between treatment means.

Table 5.9. Control values of *Indigofera hendecaphylla*, *Mimosa pudica*, *Phyllanthus debilis* and *Portulaca oleracea* in response to pre-emergence herbicides at 38 DAH2.

Treatment	Mean Percent Control*			
	I. hendecaphylla	*M. pudica*	*P. debilis*	*P. oleracea*
Dithiopyr (0.28 kg a.i./ha)	60 (20.9) ab	20 (16.8) b	14 (14.2) c	95 (4.5) a
Dithiopyr (0.56 kg a.i./ha)	80 (10.8) ab	65 (20.9) ab	46 (21.5) bc	93 (7.1) a
Oxyfluorfen (0.28 kg a.i./ha)	97 (1.2) a	24 (23.8) b	89 (6.2) ab	100 (0.0) a
Oxyfluorfen (0.56 kg a.i./ha)	100 (0.0) a	50 (28.6) ab	100 (0.0) a	100 (0.0) a
Oxadiazon (2.24 kg a.i./ha)	100 (0.0) a	100 (0.0) a	94 (6.0) ab	100 (0.0) a
Oxadiazon (4.48 kg a.i./ha)	100 (0.0) a	100 (0.0) a	100 (0.0) a	100 (0.0) a
Salt (448 kg a.i./ha)	35 (23.5) bc	18 (17.5) b	37 (22.2) c	29 (17.7) b
Trifluralin + isoxaben (2.80 kg a.i./ha)	72 (18.6) ab	31 (17.1) b	41 (24.7) c	95 (4.5) a
Trifluralin + isoxaben (5.60 kg a.i./ha)	94 (6.3) a	65 (19.4) ab	43 (22.9) bc	93 (7.1) a
Untreated	5 (5.0) c	5 (5.0) b	14 (5.6) c	0 (0.0) c

* Means within column followed by the same letters are not significantly different as determined by least significant difference test at $P < 0.01$. Means (standard errors in parentheses) and mean separation presented for *Indigofera hendecaphylla* and *Mimosa pudica* are based on original means. Means (standard errors in parentheses) and mean separation presented for *Phyllanthus debilis* and *Portulaca oleracea* are based on arc sine transformed means ($n = 4$).

Table 5.10. Total aboveground dry biomass of three representative *Sporobolus virginicus* plants 38 days after the reapplication of the different pre-emergence treatments (38 DAH2).

Treatment	Aboveground dry biomass of three representative plants* (grams)
Dithiopyr (0.28 kg a.i./ha)	70.3 (18.47) bc
Dithiopyr (0.56 kg a.i./ha)	97.8 (17.70) bc
Oxyfluorfen (0.28 kg a.i./ha)	152.3 (36.17) abc
Oxyfluorfen (0.56 kg a.i./ha)	125.8 (4.37) abc
Oxadiazon (2.24 kg a.i./ha)	183.3 (25.11) ab
Oxadiazon (4.48 kg a.i./ha)	238.5 (10.84) a
Salt (448 kg a.i./ha)	35.0 (4.34) c
Trifluralin + isoxaben (2.80 kg a.i./ha)	123.0 (28.12) abc
Trifluralin + isoxaben (5.60 kg a.i./ha)	97.3 (15.70) bc
Untreated	46.5 (15.31) c

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Means presented are original means with standard errors in parentheses ($n = 4$).

Table 5.11. Timed weeding (for 8.8 m^2) values in *Sporobolus virginicus* 38 days after the 2nd application of herbicides (38 DAH2).

Treatment	Time to weed free condition (minutes/person)**
Dithiopyr (0.28 kg a.i./ha)	6.5 (1.88) b
Dithiopyr (0.56 kg a.i./ha)	2.9 (0.84) bcd
Oxyfluorfen (0.28 kg a.i./ha)	2.1 (0.46) cde
Oxyfluorfen (0.56 kg a.i./ha)	1.0 (0.39) def
Oxadiazon (2.24 kg a.i./ha)	0.3 (0.14) f
Oxadiazon (4.48 kg a.i./ha)	0.8 (0.47) ef
Salt (448 kg a.i./ha)	16.3 (2.97) a
Trifluralin + isoxaben (2.80 kg a.i./ha)	5.0 (0.83) bc
Trifluralin + isoxaben (5.60 kg a.i./ha)	3.7 (1.04) bc
Untreated	26.0 (3.88) a

** Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Mean separation was based on log transformed data. Data presented are based on original means with standard errors in parentheses ($n = 4$).

Table 5.12. Foliar injury ratings of *Sporobolus virginicus* plants 28 days after the 1st and the 2nd application of post-emergence herbicide treatments (28 DAH1 and 28 DAH2). Ratings were recorded on a visual scale of 0 to 100, where 0 = no injury and 100 = whole plant chlorosis/necrosis.

Treatment	Rate (kg a.i./ha)	Injury (%)*	
		28 DAH1	28 DAH2
Sulfosulfuron	0.07	0.8 (0.48) bc	2.8 (0.85) bc
Triclopyr	3.36	6.5 (0.87) a	63.8 (2.40) a
Aminopyralid (25x)	1.23	3.3 (1.03) ab	58.8 (3.15) a
Carfentrazone + MCPA + mecoprop + dicamba acid	1.64	5.5 (1.66) a	16.3 (2.39) b
Untreated	-	0.3 (0.25) c	1.3 (0.25) c
F value		24.5	172.2
P value		< 0.01	< 0.01

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Mean separation was based on the following: square root transformed data for 28 DAH1 and original data for 28 DAH2. All means presented are original means with standard errors in parentheses ($n = 4$).

Table 5.13. Green color ratings of *Sporobolus virginicus* plants 28 days after the 1st and 2nd application of post-emergence herbicide treatments (28 DAH1 and 28 DAH2). Ratings were recorded on a visual scale of 0 to 100, where 0 = brown or yellow and 100 = maximum attainable green color.

Treatment	Rate (kg a.i./ha)	Green color (%)*	
		28 DAH1	28 DAH2
Sulfosulfuron	0.07	88.8 (2.39) a	93.3 (1.18) a
Triclopyr	3.36	52.5 (2.50) b	22.5 (3.23) c
Aminopyralid (25x)	1.23	58.8 (2.39) b	30.0 (0.00) c
Carfentrazone + MCPA + mecoprop + dicamba acid	1.64	63.8 (2.39) b	62.5 (3.23) b
Untreated	-	91.3 (2.39) a	95.3 (1.60) a
F value		56.44	215.24
P value		< 0.01	< 0.01

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. All means presented are original means with standard errors in parentheses ($n = 4$).

Table 5.14. Vigor ratings of *Sporobolus virginicus* plants 28 days after the 1st and 2nd applications of post-emergence herbicide treatments (28 DAH1 and 28 DAH2). Ratings were recorded on a visual scale of 0 to 100, where 0 = dead and 100 = maximum attainable vigor.

Treatment	Rate (kg a.i./ha)	Vigor (%)*	
		28 DAH1	28 DAH2
Sulfosulfuron	0.07	77.5 (6.61) ab	81.3 (4.27) a
Triclopyr	3.36	50.0 (6.12) b	28.8 (8.98) c
Aminopyralid (25x)	1.23	62.5 (6.61) ab	43.8 (3.75) bc
Carfentrazone + MCPA + mecoprop + dicamba acid	1.64	57.5 (8.29) ab	65.0 (2.04) ab
Untreated	-	88.8 (4.27) a	90.8 (3.94) a
F value		5.84	22.25
P value		< 0.01	< 0.01

* Means within columns followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. All means presented are original means with standard errors in parentheses ($n = 4$).

Table 5.15. Total aboveground dry biomass of three representative *Sporobolus virginicus* plants after two sequential applications of post-emergence herbicides (28 DAH2).

Treatment	Rate (kg a.i./ha)	Total aboveground biomass of 3 representative plants (grams)*
Sulfosulfuron (Certainty)	0.07	361.3 (72.81) ab
Triclopyr (Garlon 4)	3.36	108.0 (18.13) c
Aminopyralid (Milestone VM)	1.23	217.3 (10.32) bc
Carfentrazone + MCPA + mecoprop + dicamba acid	1.64	212.8 (15.72) bc
Untreated	-	680.8 (89.97) a

* Means followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.01$. Mean separation was based on log transformed data. Presented means are original means. All means presented are original means with standard errors in parentheses ($n = 4$).

Figures

Figure 5.1. Altered surface soil structure of table salt treated plots. Salt application (448 kg a.i./ha) caused the soil to disperse and lose its structure, creating a puddled surface when wet and a cracked surface when dry.

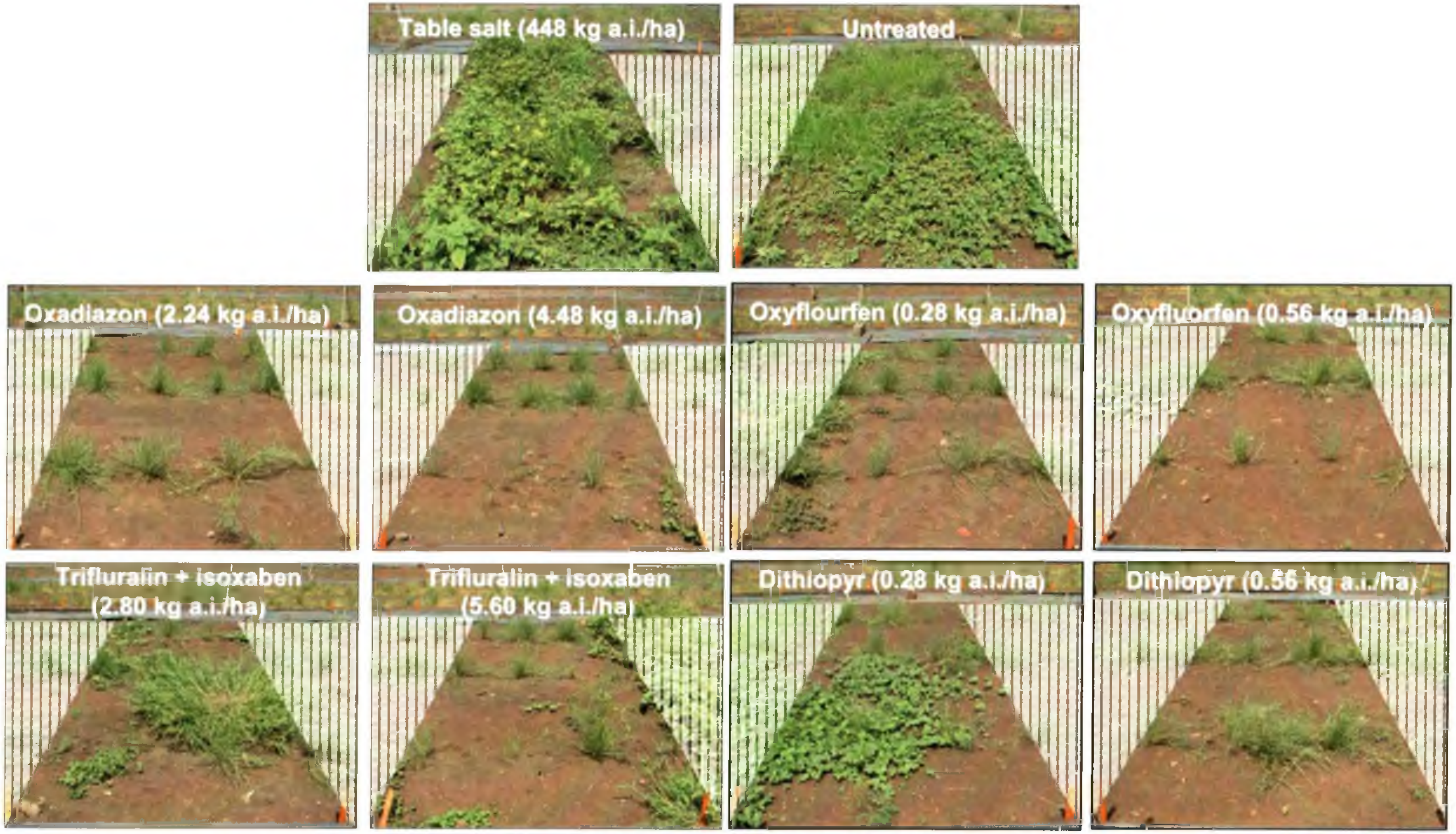

Figure 5.2. Visual comparison of the different pre-emergence treatments at 38 days after the 2nd application of pre-emergence herbicides (38 DAH2). Both high and low rates of oxadiazon and oxyfluorfen provided excellent weed control in contrast to table salt and other pre-emergence herbicides.

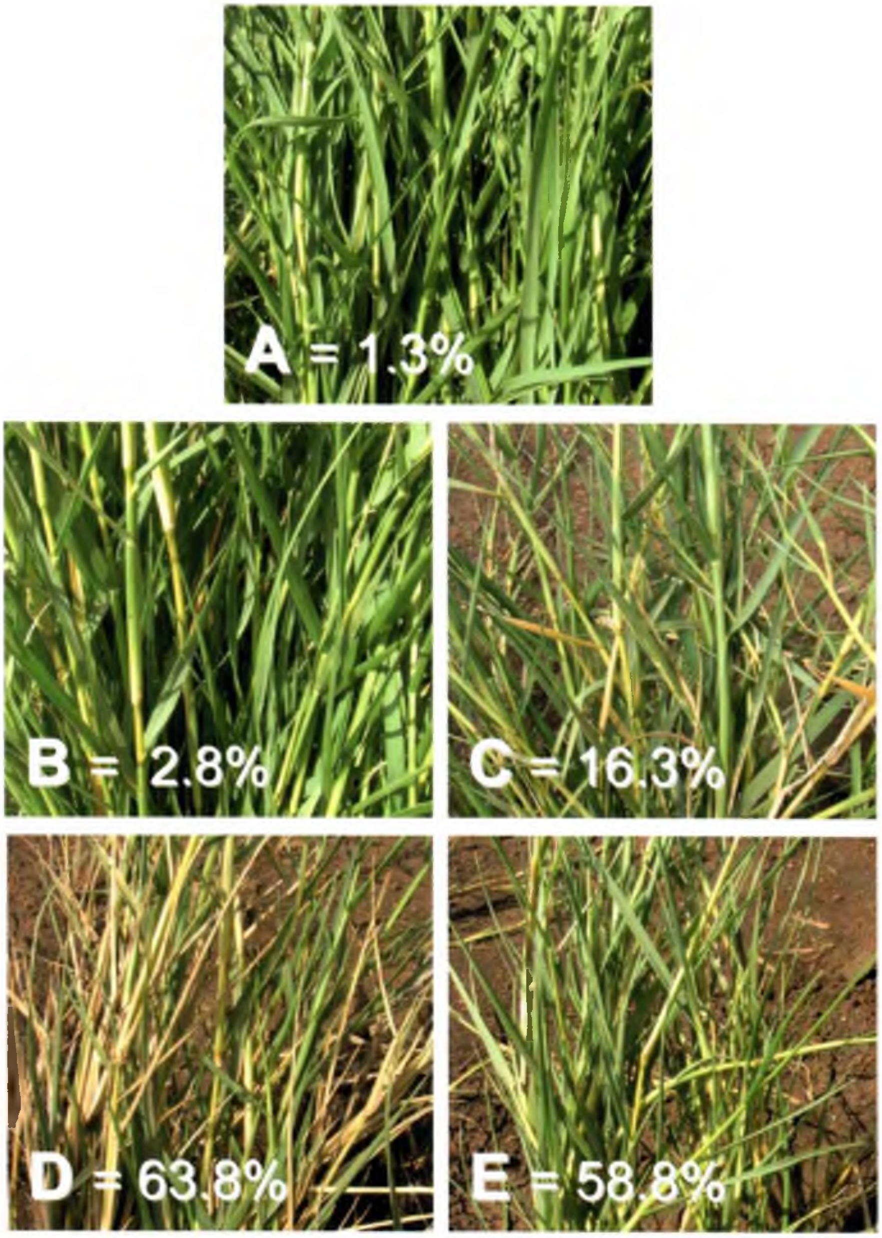

Figure 5.3. Characteristic leaf injury and numerical injury ratings incurred by *Sporobolus virginicus* after two subsequent applications of different post-emergence herbicides treatments: A) untreated B) 0.07 kg a.i./ha sulfosulfuron C) 1.63 kg a.i./ha carfentrazone + MCPA + mecoprop + dicamba D) 3.36 kg a.i./ha triclopyr E) 1.23 kg a.i./ha aminopyralid. Photographs were taken 28 days after the 2nd application of treatments (28 DAH2).

CHAPTER 6

CONCLUSIONS AND SUGGESTED PROTOCOLS FOR ESTABLISHMENT

In conclusion, this study revealed the potential use of hydroplanting techniques and selective herbicide applications for roadside establishment of *Fimbristylis cymosa* and *Sporobolus virginicus*.

Propagation studies conducted in both species show general compatibility to hydroplanting. For *F. cymosa*, using seeds over seedlings in the hydroplanting process was more efficient and convenient since seeds are storable, non-bulky and do not require preparation time in the nursery. Mortality rates of hydroseeded *F. cymosa* were lower compared to hydroplanting or hydromulch capping of seedlings. For *S. virginicus*, stem cuttings were the planting material of choice since viable seed production is very limited. Rooting studies indicate that using apical cuttings over leafless basal cuttings was more advantageous since rooting characteristics (percent rooting, root density scores and longest root length) were significantly improved compared to the latter. Soaking of apical cuttings for 24 hours in a rooting solution (500 ppm indole butyric acid and 250 ppm naphthalene acetic acid) prior to hydromulch capping significantly improved rooting characteristics and increased axillary shoot number. This increases stand vigor leading to greater cutting survival and rapid rate of fill in.

Herbicide tolerance studies conducted on each of the two native species show safety in some pre- and post-emergence herbicides. For pre-emergence weed control in *F. cymosa*, the herbicides oxadiazon and oryzalin exhibited safety for weed control in transplanted plugs but not for seedlings less than 56 days old. For post-emergence grassy weed control, fluazifop-p-butyl can be safely applied to both *F. cymosa* seedlings and mature plants. Post-emergence broadleaf herbicides evaluated in this study also indicate that the recommended rates of aminopyralid were safe to use as an over the top spray in *F. cymosa*. Broadleaf weed control using aminopyralid can be done as early as 28 days after hydroseeding. Sulfosulfuron can also be used for sedge control, but due to moderate injury incurred by plants, application of this herbicide should be limited only to spot spraying.

Although all pre-emergence herbicides (except table salt) exhibited acceptable weed control ratings for *S. virginicus*, only oxadiazon and oxyfluorfen showed exceptional weed control and herbicide safety. For post-emergence weed control in *S. virginicus*, sulfosulfuron was tested to be safe for controlling sedge species. Carfentrazone + MCPA + mecoprop + dicamba and triclopyr were injurious to *S. virginicus* and should only be used as a spot spray treatment. Although the overapplication of aminopyralid was injurious for *S. virginicus*, test applications at the prescribed rates seem to have little to no negative impact on plants.

Overall, this study demonstrated new and alternative methods of propagation and weed control for the two native Hawaiian groundcover species. Although this study generated at lot of essential information for these two groundcovers, further studies should be done in order to refine establishment methods (e.g. optimum seeding/planting rates, planting methods for steep/flat slopes, timing of herbicide application, and further screening of weed control tools) and develop maintenance protocols. Detailed studies on other species (e.g. perennial herbs, shrubs and trees) should also be done to expand the choice of planting materials and to fully integrate native Hawaiian species in re-vegetation strategies.

Suggested establishment protocol for *Fimbristylis cymosa* and *Sporobolus virginicus*

Site inventory and preparation

Site inventory and preparation prior to planting is important as this can greatly affect plant selection, planting and establishment as well as weed/pest incidence. As every site is unique, conducting a thorough inventory of the site's characteristics will provide the necessary information on how re-vegetation will be carried out on a particular area. Knowing about a site's available and limiting resources will help identify factors that can be utilized or improved during the re-vegetation process. An understanding of the site's climate, topography, soil characteristics as well as proximity to irrigation sources will aid in selecting appropriate native species; methods of planting (e.g. hydroseed or plugging); soil amendments and preparation (e.g. fertilization, mulching, tillage, weed control) as well as timing of planting/establishment (Steinfeld et al., 2007b). An inventory of existing vegetation will also help identify non-native and native plants that need to be removed, conserved or used for propagation. Knowledge about existing non-native plants on site will also dictate the type of weed control tools (e.g. herbicides, mowing, burning) that should be used to effectively remove them.

Basic site preparation prior to planting requires clearing out of debris (e.g. trash and dead plant material) that would interfere in the planting process. Providing a bare surface for planting is important for species that are sown or hydromulched because it promotes good soil-plant material contact.

Conducting sequential flushing and killing of weeds months prior to planting will also help reduce the weed seed bank. This should be done least 3 times prior to planting in order to reduce weed incidence during the establishment process (Joseph DeFrank, personal communication). To facilitate the removal of weeds on site, supplemental overhead irrigation should be installed to encourage active weed growth prior to herbicide application. A spray mix of glyphosate (Roundup Pro®, Monsanto Company, applied as a 2% solution of formulated product) and triclopyr (Garlon® 4, Dow AgroSciences, applied as a 2% solution of formulated product) is recommended for controlling grass, broadleaf weeds and other woody species that might interfere with native plant establishment.

Planting materials/seeds

Sourcing, collection and propagation of planting materials is critical for a native re-vegetation project. Collections of planting materials should be located near the site and should possess some degree of genetic variability (Steinfeld et al., 2007b). Native planting materials should be collected at least 1 to 3 years prior to project implementation (Steinfeld et al., 2007b). This provides ample time for establishing stock plants and increasing seed/planting materials prior to actual planting.

Preparation of Fimbristylis cymosa seed nursery and planting materials

The seed nursery for *F. cymosa* can be established either in the field or on planters filled with compost using plants grown from collected seeds (see Chapter 2 for details on planter preparation). To produce weed-free seeds of *F. cymosa* on a field setting, stock plants should be grown on irrigated fields covered with weedcloth or plastic mulch (Figure 1.3). Seed harvesting can begin in approximately one year for direct seeded plants or six months from plug established plants. Inflorescences that are easily crushed by hand are ideal for harvesting. Seed head harvesting can be done manually or by cut-and-vacuum operations using a motorized hedge trimmer and a leaf blower/vacuum. The harvested seed heads should be dried, crushed (by hand or by a leaf vacuum/blower) and stored at approximately 10°C either as raw seed (leaves and stalks removed) or as sieved seed (containing minimal amount of trash). Seed germination tests should be conducted to determine percent viability of each batch of harvested inflorescences. For raw seed used for hydroseeding, an average germination count of 4 samples (0.2 grams) needs to be conducted to determine the average amount of germinable seeds for a given weight. This provides the information necessary for developing a seeding rate for a particular hydroseeding project. Generally, extracted *F. cymosa* seeds can be stored for one year without losing viability (Baldos, unpublished data).

For preparing *F. cymosa* plugs, seeds are germinated in trays filled with moistened potting mix. Seedlings are allowed to grow for 1 to 2 months before they are transplanted individually in multi-cell trays filled with potting mix and fertilizer. Plants are allowed to grow for 2 months before they are hardened and transplanted in the field.

Preparation of Sporobolus virginicus stockplant and planting material

S. virgincus stockplants can be grown from bare-rooted plants or plugs and established either in field rows or in constructed planter boxes filled with compost (see planting material section on Chapter 5). For field-established stockplants, proper land preparation prior to planting is essential to produce weed free cuttings. Stem cuttings can be gathered from stock plants after one year of establishment. Harvesting of cuttings can be done using a hand-held shear or a motorized hedge trimmer. The top 30 cm growth of the stock plants are cut, collected and kept moist and cool until they are used in hydromulch planting or plug production.

S. virginicus plugs can be prepared either by using the top 30 cm growth of stockplants or a 3 stemmed plant obtained by dividing a grass clump. Prior to treatment with rooting hormone, the leaves of the lower half of the cuttings are removed. Cuttings/3 stemmed plant are soaked for 24 hours in a solution of 500 ppm indolebutyric acid and 250 ppm naphthalene acetic acid before sticking them in pots or dibble tubes filled with a 40:60 ratio (by volume) of black cinder and potting mix. The newly planted cuttings are placed inside a mist chamber and allowed to root for one month before moving them out in irrigated full sun conditions. Plugs are kept under nursery conditions for another month before they are hardened prior to planting.

Planting and establishment

Planting and establishment techniques implemented in a re-vegetation project vary with type of planting materials and site conditions. Depending on the project site's terrain, several methods may be used or modified to suit specific needs or limitations.

Another important factor that needs to be considered during the planting and establishment phase is the timing of outplanting. Planting operations should be conducted at a time when environmental conditions are favorable for plant growth. In Hawai'i, the availability of water is a major limitation for plant establishment on roadsides. In order to maximize soil moisture availability and plant survival while saving on watering costs, it is important to perform planting and establishment operations during the onset of the wetter, winter months (November to February).

Planting and establishment of Fimbristylis cymosa

F. cymosa plantings can be accomplished using either outplanted plug plants or by hydroseeding. The use of plug plants is ideal for establishing weed-free field seed nurseries on plastic mulch or for establishing plantings in small pockets and areas (e.g. ditches and roadside swales). The recommended spacing for planting plugs is 30 centimeters.

Seeding is generally favored for establishing large-scale roadside plantings of *F. cymosa*. Raw or sieved seed can be sown by hand or mechanically by using a fertilizer spreader or a hydroseeder. The amount of raw or sieved seed applied may vary depending on the results of germination tests conducted on the batches of seed produced. Generally, the rate of seeding should be at least double the actual amount of viable seed in order to account for seed predation and seedling mortality during establishment. Based on the experiments conducted in Chapters 2 and 4, *F. cymosa* recommended seeding rates can range from 500 to 800 viable seeds per square meter (0.05 grams pure seed per square meter) while mulching and tackifier rates should be at least 2200 and 2 kg/ha, respectively. Depending on site conditions, the amount of mulching material and tackifier may vary. Steeper slopes and erosive soils generally require more mulch and tackifier than flat areas. The type and ratio of mulching material used in hydroseeding can also vary with site conditions. Pure paper mulch can be used if wetter conditions for the seeds are preferred. For less saturated conditions, a mix of straw (33% by weight) and paper mulch (67% by weight) can be used. In order to facilitate mixing of hydroseeding slurry, it is suggested that mulching materials should first be pre-wetted in buckets. The hydroseeder should be partially filled with water and turned on while tackifier, mulch and seed are added.

To ensure even distribution of seeds and mulch on a set area, the batch of hydroseeding slurry must be divided into several light applications. The first light application should have covered the set area before another pass is initiated.

After sowing, the hydroseeded area should be kept constantly moist for the first two months in order to provide optimum conditions for the seeds to germinate and grow. In the succeeding months, supplemental irrigation is slowly withheld until plants are fully established (~1 year after planting).

Planting and establishment of Sporobolus virginicus

Establishment of *S. virginicus* plantings can be accomplished using plugs or hydromulched stem cuttings. Like *F. cymosa*, *S. virginicus* plugs are ideal for stockplant production and small scale re-vegetation (e.g. ditches and roadside swales). Recommended minimum spacing for *S. virginicus* plugs is 30 cm.

Hydromulching of pre-treated stem cuttings is suggested for large-scale re-vegetation. Prior to field planting and hydromulching, apical stem cuttings, at least 20 cm in length, are harvested and soaked for 24 hours in a commercially available rooting solution (1:20 dilution of Dip 'N Grow®). After soaking, the cuttings are evenly spread flat on to a prepared planting surface and then covered with hydromulch slurry at a rate of 3300 kg mulch/ha (33% straw mulch and 67% paper mulch) and 11 kg tackifier/ha. Stems need to have good contact with the soil to ensure maximum root initiation and establishment.

The hydroseeded area should be kept constantly wet for the first 1-2 months after planting to prevent dessication of cuttings and promote rooting. In the succeeding months, supplemental irrigation should be slowly withheld until plants are fully established (~ 1 year after planting)

Weed control and management

Weed control is a very important component of successful native groundcover establishment and maintenance. Early prevention, control and management of weeds are critical and should start several months before actual planting is initiated. Depending on the severity of infestation, weeds can be managed with two or more combinations of methods/strategies. Methods of weed control relevant to successful native groundcover establishment can be divided into three categories namely: a) prevention b) mechanical and c) chemical weed control.

Prevention is a weed control strategy that aims to limit the build up of weeds in the field or keep new weeds from invading an area (Monaco et al., 2002). This strategy can be helpful for managing weeds in newly constructed areas and in areas where a specific weed has not established or proliferated. Prevention can be done by: 1) planting weed free materials; 2) using clean tools and equipment and 3) preventing existing weeds from vegetatively proliferating or recharging the seedbank (Anderson, 1996).

Using mechanical methods is another strategy that makes use of physical means to control weeds in the re-vegetation site. They may involve physical removal (e.g. hand weeding, hoeing, cutting, or burning) or environmental modification (e.g. mulching) to kill the weeds. Success rates of mechanical methods may vary and may or may not be applicable for a certain situation.

Chemical methods are the most common and most widely used strategy for controlling weeds. They solely involve the application of selective or broad spectrum herbicides. In the establishment of native groundcovers, herbicides play an essential role in land preparation and post-plant maintenance activities. During pre-plant land preparation, initial application of post-emergence herbicides such as glyphosate (2% solution of Roundup®) and triclopyr (2% solution of Garlon® 4) aids in clearing the site of unwanted vegetation. Subsequent spray applications of these herbicides in conjunction with weed flushes stimulated by supplemental irrigation will also help reduce the weed seed bank. Having good control of weeds prior to planting will help reduce the incidence of weed infestations during plant establishment.

Post plant applications of pre- and post-emergence herbicides are important for keeping weeds in check while the native groundcovers are establishing. For *F. cymosa* and *S. virginicus*, several of these herbicides have been tested and can be safely used for selective weed control.

Pre- and post-emergence herbicides for weed control in Fimbristylis cymosa

For establishing mature *F. cymosa* plugs, spray applications of either oxadiazon (Ronstar® 50 WP at 2 to 4 kg a.i./ha) or oryzalin (Surflan® AP at 2 to 4 kg a.i./ha) immediately after planting can provide excellent pre-emergence control of weeds. Fluazifop-p-butyl (Fusilade® II T&O) applied 0.28 to 0.42 kg a.i./ha can provide good control of growing grassy weeds in both plug established or hydroseeded *F. cymosa* plantings. Aminopyralid (Milestone® VM) at 0.07 to 0.12 kg a.i./ha can also provide good broadleaf weed control in both types of plantings. Both post-emergence herbicides can be mixed and applied as early as 28 days after hydroseeding to control both grassy and broadleaf weeds. For post-emergence sedge control, sulfosulfuron (Certainty®

applied up to 0.07 kg a.i./ha) can be applied as a spot spray treatment in establishing plugs.

Pre- and post-emergence herbicides for weed control in Sporobolus virginicus

Pre-emergence herbicides that can be safely used in newly planted *S. virginicus* plugs are oxadiazon (Ronstar® G, applied at 2.24 to 4.48 kg a.i./ha) and oxyfluorfen (Goal®, applied at 0.28 to 0.56 kg a.i./ha). Applications of either herbicides after planting can provide good weed control for up to 70 days without compromising the growth of the plant. Aminopyralid (Milestone® VM, applied at 0.07 to 0.12 kg a.i./ha) and sulfosulfuron (Certainty®, applied at up to 0.07 kg a.i./ha) can be safely applied as an over the top spray for post-emergence control of broadleaves and sedges, respectively. Triclopyr (Garlon® 4, applied up to 3.36 kg a.i./ha) and carfentrazone + MCPA + mecoprop + dicamba (Powerzone®, applied up to 1.64 kg a.i./ha) can also be applied for broadleaf weed control in *S. virginicus* plantings, but should only be limited to spot spray applications to minimize injury to the entire planting.

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