EVALUATION OF PRE-EMERGENCE HERBICIDES CONTAINED WITHIN A HYDROMULCH CAP TO DETERMINE WEED CONTROL AND SAFETY FOR TWO NATIVE HAWAIIAN GRASSES IN A SIMULATED ROADSIDE ENVIRONMENT

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAIʻI IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

TROPICAL PLANT AND SOIL SCIENCES

May 2011

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Acknowledgements

I would like to express my gratitude to all of those who have provided support throughout my Masters of Science education. I would like to sincerely thank my advisor, Dr. Joseph DeFrank, for always being available to help and guide me throughout this process. I appreciate the skills and knowledge in which he has imparted to me both in terms of research and life. I would also like to thank the Magoon Research and Instructional Facility supervisor, Craig Okazaki, for assisting in many aspects throughout all of my research and my time as a graduate student. I truly appreciate the mental and physical support that he has offered and the flexibility of the facility during my education. Thank you to the USDA Natural Resource Conservation Service, Plant Materials Center in Hoolehua, Molokai. Glenn Sakamoto, Kawika Duvauchelle, Keni Reyes and other staff at the PMC were always helpful in the planning aspects, technical assistance and research ideas during my project. I appreciate the valuable input that my committee members Kent Kobayashi and James Leary have offered to me to help succeed in this process. Lastly, but definitely not least, I would like to thank my fiancée for always enduring my stresses and struggles, yet continually offering support, wisdom and encouragement. And of course, my family for their love and continual support in all of my ventures, thank you for making me who I am today.

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Chapter 1

Review of Related Literature

Roadside Vegetation History in the United States

Roads appear as major conspicuous objects in aerial views and photographs, and their ecological effects spread through the landscape. Few environmental scientists, from population ecologists to stream or landscape ecologists, recognize the sleeping giant, road ecology. This major frontier and its applications to planning, conservation, management, design, and policy are great challenges for science and society (Forman and Alexander 1998).

The term road corridor refers to the road surface plus its maintained roadsides and any parallel vegetated strips, such as a median strip between lanes in a highway. Road corridors cover approximately 1% of the United States, equal to the area of Austria or South Carolina (Forman and Alexander 1998). However, the area directly affected ecologically is much greater. The ecological effects of roads impact about 15% of the land area of the US, an area equivalent in size to all the protected areas of the country combined, approximately 130 million hectares (Wilkinson et al. 2008). In the United States, public roads total more than 6.2 million km and 60% of the land area of the eastern part of the country is within 400 m of a road. Ten percent of the road length is in national forests, and one percent is interstate highways (Forman 2000).

Roadsides and road-related disturbances often represent an “extreme” restoration ecology challenge. Steep slopes, little or no topsoil, high erosion by wind and water, lack of beneficial microorganisms, rapid invasion by weeds, high exposure to winds, and constant visibility to the driving public are some of the factors that add to the challenge. Many of the lessons to be learned in these harsh conditions are applicable to restoration efforts on other drastically disturbed sites.

Roadside environments provide a distinctive habitat often supporting weedy and invasive plant species which are absent from natural communities (Gelbard and Belnap 2003). It is well accepted that roadsides function as movement corridors, acting as primary dispersion corridors for exotic plant dispersal. The assumption that roadsides serve as dispersal corridors in regional invasions is widely accepted (Brothers 1992).

Native Roadside Planting Initiatives

Traditionally, roadside re-vegetation was accomplished by utilizing exotic plant species because they are cost effective, readily available and quick to establish on disturbed sites (Landis et al. 2005). Re-vegetating road corridors with locally adapted species may mitigate some of the negative ecological effects of roads, by creating native wildlife habitat. Although alien species have commonly been used for roadside re-vegetation, these species may be relatively susceptible to environmental stress and may also hinder establishment of indigenous flora (Wilson 1989). In general, use of native species for roadside re-vegetation is preferable for both ecological and aesthetic reasons. Re-vegetation practices of disturbed habitats with native plants is gaining support from restoration ecologists (Tormo, Bochet and García-Fayos 2007).

In addition, re-vegetating with natives minimizes opportunities for noxious or invasive species to establish on roadsides, thus limiting the impact of highways as corridors for the transport of problematic species (Landis et al. 2005). Along with the reduction in invasive plant dispersal potential, the establishment of native species has on roadways many other potential benefits that include: 1) prevention of new weed species from becoming established; 2) reduced long-term mowing requirements; 3) reduced use of herbicides; 4) reduced flash point for fires by the presence of green plant material, a less dense canopy and/or low-growing stature; 5) reduction in current weed populations; 6) increased plant species diversity; 7) increased control of sediment transport (erosion control); 8) increased duration of green plant tissue during summer and fall and 9) improved or changed aesthetic value that more closely matches natural landscapes (Young and Claassen 2007) . The benefits of the reintroduction of native plants are well documented, and are an ongoing effort throughout the past decades in the United States.

In 1932, 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. By 1934, directives were issued to delay all mowing, unless essential for safety, until spring and early summer wildflower seasons were over. This practice has expanded into a full scale vegetation management system. With a combination of selective mowing and herbicide application, wildflower preservation and seeding, and active public awareness have been important components of the TxDOT highway beautification program (Markwardt 2005). Former First Lady, Lady Bird Johnson brought attention to highway corridors in what has been called the Highway Beautification Act of 1965. Her quest was to save and promote the natural beauty of Texas' wildflowers, which were previously overlooked. Johnson's highway beautification program was funded by a tax of about the three cents of each dollar spent and used for acquisition and maintenance of natural areas adjacent to the highway. These "beauty spots" are currently our scenic overlooks, rest areas, and State entrances that underscore each State's regional beauty (DOT-FWHA, 2004).

Lady bird Johnson's influence was incorporated in to the 1987 highway bill titled: The Surface Transportation and Uniform Relocation Assistance Act. This bill included a requirement for the planting of native wildflowers on roadways. At that point in time many restorations of native plants on roadsides have occurred, but the greatest threat to native re-vegetation was beginning to be realized as the spread of non-native invasive plants. It is no longer possible to talk about the preservation of native plants without considering the weeds that threaten them (DOT-FWHA, 2004).

Building on the progress made through Johnson's native wildflower initiatives, President Bill Clinton signed Executive Memorandum on Environmentally and Economically Beneficial Practices on Federal Landscaped Grounds in 1994. This memorandum called for the usage of regionally sourced native plants and landscaping practices that conserve water and prevent pollution at federal facilities and federally funded projects (The White House 1994). In 1999, President Clinton issued an executive order that focused on interagency cooperation to prevention spread of invasive plant species, combined with restoration of native plants (Wilson and Harper-Lore 2000).

These initiatives provided the governmental support and funding to launch federal and state roadside re-vegetation programs which focus on the control of invasive species and replacement with locally sourced native plants. Currently, United States Department of Transportation initiatives are calling for increased native plant re-vegetation along roadways (DOT-FWHA 2008). There are both long term economic and environmental benefits yielded by the control of exotic species and re-implementation of native plants. Although there are initiatives calling for increased native roadside re-vegetation, efficient and practical planting techniques must be developed to accommodate large scale re-vegetation efforts.

Re-vegetation Planting Techniques

The potential for excessive erosion is greatest in the period between soil disturbance and re-establishment of vegetation or other permanent cover. To provide temporary protection and minimize soil erosion during this period, mulches are often applied to recently disturbed sites. Straw, shredded paper, wood chips, and gravel have all been widely used for mulching (Holt et al. 2005). Although there are many alternative planting techniques for re-vegetation efforts, typical roadside conditions benefit from the immediate soil stabilization provided by hydromulch applications. The basic hydroseeding technique simply sprays the seed-water mixture onto a prepared planting surface. When other materials such as mulch, tackifiers (soil binding agents) 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 (Baldos 2009). Hydroseeding has been the most widespread method used for roadside re-vegetation in the past few decades (Bochet, Garcia-Fayos and Tormo 2010)

Weed Control During Establishment

Despite the popularity and promising re-vegetation potential of hydromulching techniques, other factors need to be considered in order to achieve successful vegetation establishment. Competition from weedy species severely decreases native plant survival and establishment potential, and thus must be addressed when developing effective planting protocols. Properly applied pre-emergence herbicides can greatly increase the success of native plant establishment (Tjelmeland, Lloyd-Reilley and Fulbright 2008). Established native species resist weed invasion (Borman, Krueger and Johnson 1991), and they use resources efficiently, leaving fewer resources available for weed recruitment (Herron et al. 2001). Although establishing native plants might eventually improve weed suppression, initial weed competition is a major problem with re-vegetation and restoration efforts (Blumenthal and Jordan 2001). Native grass species have been shown to be tolerant to many herbicides used for broadleaf weed control (Wilson et al. 2010). Wilson et al. concluded that the effect of herbicides on perennial grass cover, bare ground, and total weed cover significantly increased native plant growth and decreased weed pressure Thus, a major challenge to native plant utilization involves the development of protocols that maximize the effectiveness of herbicides labeled for use on highway rights of way.

Chemical Weed Control Formulations

Oxadiazon is a pre-emergence herbicide which controls annual grasses, broadleaf weeds and annual sedges through the inhibition of protoporphyrinogen oxidase (Ronstar®, Bayer Environmental Science). Oxadiazon has a very low solubility in water and a slow release rate from its carrier in granular formulations. Though it provides control of a broad spectrum of weeds, there are some that it does not control well (Kuhns 1992). Alternately, different formulations of the same chemical active ingredient may result in different weed control and efficacy. The novel formulation technology by Chapple et al. describes the substantial increases in the efficacy of relatively water insoluble pesticides formulated as solids (in final form as SC's and WP's). Data from laboratory, glasshouse and field trials demonstrate this concept, with a general 50% gain in efficiency of use of various herbicides and insecticides (Chapple, Taylor and Arnold 2010). By utilizing alternative forms of the same active ingredient, such as Oxadiazon granular, wettable powder or suspension concentrate varying effects on weed control and safety could be demonstrated.

Re-vegetation efforts in Hawaii

As a result of Federal Department of Transportation initiatives for native roadside planting mandates, many states are increasing native plant utilization on roadsides. Although efforts to use native Hawaiian plants were initiated as early as the mid 1990s, it was not until 2006 that studies for developing species-specific roadside establishment protocols were conducted (Baldos, DeFrank and Sakamoto 2010). Many native Hawaiian plants such as *Myoporum*, *Dodonaea, Vitex, Sida, Scaevola,* and *Sapindus* have a broad range of elevation adaptation. Thus they can be grown in coastal, inland, and upland Hawaiian conditions (Bornhorst 1994). Native species with a wide range of location adaptability represent roadside re-vegetation candidates with a high potential for successful establishment and long term persistence.

The native grass *Sporobolus virginicus* (Akiaki grass), has been planted on Maui along the Mokulele highway corridor. In this project *S. virginicus* transplanted plugs took an unusual 3 years to establish because of the lack of information on roadside establishment and difficulties in weed control and irrigation (Baldos et al. 2010). The cost of establishing *S. virginicus* was estimated at $142,600 per hectare compared to traditional Bermudagrass (*Cynodon dactylon*) which costs only $87,700 (Baldos et al. 2010). The Mokulele planting exemplifies the need for well developed roadside native planting establishment protocols, which incorporate techniques for large scale plantings and weed control. In this thesis, herbicides will be characterized for safety and effectiveness during the establishment of native Hawaiian species identified as candidates for road side plantings

Sporobolus virginicus (L.) Kunth

Sporobolus virginicus (Akiaki) is a perennial, coastal salt marsh grass that spreads by rhizomes, forming extensive colonies, and has potential as a low maintenance ground cover in saline areas (Marcum and Murdoch 1992). In Hawaii, *S. virginicus* is typically found in low lying areas with an abundant source of subsurface water. The potential of *S. virginicus* to establish and thrive in high saline soils is a valuable aspect in restoration along costal roadways.

S. virginicus has been evaluated as a forage crop for use in saline affected soils in Egypt (Ashour et al. 1997) and a reclamation candidate for severely saline sites in Australia (Semple et al. 2006). In the Caribbean, salt tolerant strains of *S. virginicus* were evaluated to determine improved types of halophytic grass species suitable for use as turfgrass on lawns, sports fields, and golf courses (Depew and Tillman 2006). Saline tolerance for re-vegetation candidates is important to consider while screening species for use in Hawaii.

The Maui roadside *S. virginicus* planting along the Mokulele road corridor utilized a well adapted species but neglected to factor heavy weed pressure during establishment (Joseph DeFrank, personal communication, 2011). In Hawaii, *S. virginicus* rooted plugs were tolerant to oxadiazon applied at a rate of 4.48 kg active ingredient/ha (Baldos et al. 2010).

Heteropogon contortus

Heteropogon contortus (Pili grass) is a drought-tolerant, fire-adapted, C4 perennial bunchgrass that relies on pseudogamously stimulated apomictic seeds for reproduction (Brown and Emery 1958). Sites where *H. contortus* is well adapted are seasonally dry, experiencing short periods of rainfall (mostly between October and April, <1000 mm mean annual precipitation) followed by long periods of drought (Goergen and Daehler 2001).

Current re-vegetation efforts utilizing *H. contortus* are found throughout the world. In China, *H. contortus* is being evaluated to determine re-vegetation potential in heavily degraded, drought prone common quarries (Liang et al. 2009). *H. contortus* is widespread and both ecologically and economically important in Australia forage and rangeland production (Grice and McIntyre 1995). Due to the drought tolerance and ability to grow under low fertility soils, *H. contortus* in Hawaii has been extensively used as a restoration and erosion control species for severely degraded sites. One of the most notable and oldest continuing projects that utilize *H. contortus* in Hawaii is the re-vegetation and restoration efforts conducted by the Kahoolawe Island Reserve Commission (KIRC) on the island of Kahoolawe. Kahoolawe Restoration projects with *H. contortus* have been successful within 2-4 years where brush fires and an adequate seed source is present (Daehler and Goergen 2005).

In Hawaii, many introduced African grasses have invaded disturbed habitats; one of the most aggressive of these is *Pennisetum setaceum* (Fountain Grass). In recent decades, *P. setaceum* has replaced the native grass, *H. contortus* in many arid habitats on Oahu and Hawaii (Daehler and Carino 1998). To help emphasize its importance in Hawaii’s conservation efforts, *H. contortus* has been classified as an ‘extinction prone’ grassland species because of its dependence on recruitment from short-lived seeds (O'Connor and Pickett 1992). In addition to its significance as a conservation species, *H. contortus* is culturally significant in Hawaii since ancient Hawaiians used it for roof construction, floor coverings and torches (Okamura 1980). The cultural and conservation attributes of *H.*

contortus contribute to its acceptance as a desirable species for roadside plantings in Hawaii.

Chapter 2

The response of weeds and cut stems of *Sporobolus virginicus* (L.) Kunth (a native Hawaiian ground cover) to two forms of oxadiazon applied as a component of a hydromulch cap in a simulated roadside planting.

Introduction

Developing reliable and efficient roadside re-vegetation establishment protocols for native Hawaiian grasses is essential for long term survival. In the case of *Sporobolus virginicus*, it has been found that this species produces a very sparse amount of viable seed (USDA-NRCS, 2007). Despite the widespread re-vegetation efforts using *S. virginicus***,** previous projects have used nursery grown plants for plug transplanting. Transplanting plugs is a very costly and time consuming practice due to the limited availability of nursery grown stock plants. Vegetative propagation of terminal cuttings is superior to harvesting or transplanting processes which disturb root systems of the stock plant. Harvesting through terminal cuttings also yields more vigorous growth in the stock plant and ensures a regular yield of production material (Baldos et al. 2009). If was found that optimal rooting of terminal cuttings was obtained after a 24 hour soak in a rooting hormone (Baldos et al. 2009).

The potential for excessive erosion is greatest in the period between soil disturbance and re-establishment of vegetation or other permanent cover (Holt et al. 2005). The pre-revegetation erosion issue is mitigated by the immediate soil stability provided by hydromulch covering. Utilizing a hydromulch cap also allows the user to customize the components of the mixture to suit the specific planting needs. In the case of *S. Virginicus,* establishment can be severely impeded by invasive weed competition. The roadside planting on Maui along the Mokulele road corridor utilized *S. virginicus*, a well adapted species but contractors neglected to factor heavy weed pressure during establishment. A 2010 study conducted in Hawaii by Baldos et al. found that *S. virginicus* plugs treated with the high label rate of oxadiazon (4.48 kg ai ha^{-1}) exhibited exceptional weed control and safety during establishment (Baldos et al. 2010). In order to mitigate the weed competition, pre-emergence herbicides must be utilized at the time of planting.

By utilizing methods determined by Baldos, combined with efficient planting techniques, *S. virginicus* has a high probability of establishment success on roadsides in Hawaii. Developing a stem cutting propagation method which incorporates both pre-treatment of cuttings, hydromulch capping and weed control techniques will not only improve the efficiency of roadside planting and establishment operations but it would also immediately protect the newly planted surface from erosion. This study will evaluate the response of weeds and cut stems of *S. virginicus* to different rates and forms the pre-emergence herbicide oxadiazon, as a component in the hydromulch cap.

Materials and Methods

Plant Material

Sporobolus virginicus (HA-4840/ACC. # 9079840) stock plants were received from the United States Department of Agriculture (USDA) Natural Resource and Conservation Service (NRCS) Plant Materials Center (PMC), located in Hoolehua, Molokai. The original native collection location of the *S. virginicus* was from Moomomi, Molokai (Glenn Sakamoto, personal communication, 2010).

Experimental Design

The experiment was conducted at the USDA NRCS PMC in Hoolehua, Molokai, where the first run was conducted during the period 7/2009 to 12/2009 and the second conducted during the period 7/2010 to 12/2010. The replicated experiments in time were conducted following the same design, location and protocols. The second replicate was installed in a field adjacent to the first trial to eliminate possibility of residual chemical effects in the soil. The experimental design was installed as a randomized complete block, with blocks arranged along the vector of the prevailing trade winds. The design consisted of five treatments and four replications (Figure 2.1). The treatment plots (1.83 m. x 4.57 m) were set up as a two way factorial with two rates of oxadiazon, 2.25 kg ai ha^{-1} and 3.36 kg ai ha^{-1} and two forms of oxadiazon, granular and suspension concentrate, with one untreated treatment.

Meteorological and Irrigation Data

During the first five days of both trials, overhead irrigation was scheduled to come on at 7:00 am, 9:00 am, 11:00 am, 1:00 pm, 3:00 pm, and 5:00 pm for 15 minutes at each start time. During the evening, the start times were scheduled at 7:00 pm, 11:00 pm, and 3:00 am for five minutes at each start time. After five days the daytime irrigation was reduced from 15 minutes to 10 minutes and all of the night watering cycles were stopped. At 35 days after planting all remaining irrigation times were reduced by 20% from 10 minutes to 8 minutes per cycle.

Meteorological data was collected from the USDA NRCS Research Station, which was located 100 m from the experimental field. The mean ambient daily temperature value for the duration of the first trial in 2009 was 24.6° C, compared to the mean ambient temperature of the second trial of 24.0° C. Natural mean rainfall throughout the duration of the first trial was 25.4 mm compared to 26.3 mm in the second experiment.

Vegetative Material Handling

The *S. virginicus* plant material was harvested from the NRCS PMC stock plots by removing 11.3 m^2 of the aboveground growing shoots approximately 40-60 cm in length (Figure 2.2). After harvesting the material, the vegetative cuttings were soaked in a diluted Dip N Grow (Dip N Grow®, Clackamas, Oregon) rooting hormone (1.0% Indole-3-butyric acid, 0.5% 1-Napthaleneacetic acid) and water solution (1:35) for 24 hours (Figure 2.3) (Baldos et al. 2009). After the soaking period, 0.68 kg of fresh stems were placed on the center 1.22 m. x 4.57 m. portion of each plot that was 1.83 m. x 4.57 m. in size. The cut stems were placed within the plots at a rate of 1236 kg ha^{-1}, ensuring that the stems were making full contact with the soil surface (Figure 2.4).

Hydromulch Material

Each treatment with plot size of 1.83 m. x 4.57 m, with four replications totals an area of 33.4 m^2 to be covered with the hydromulch cap. With a maximum hydromulch tank size of 303 liters, the total area that can be treated is 48.3 m^2 of hydromulch per batch (Figure 2.5). The protocol was designed to apply 265 liters of mixture applied across four replicated treatments (66 liters per plot) with 38 liters of mixture discarded because as the hydromulch tank runs low the pump can no longer draw the mix consistently. Individual tanks were prepared for each treatment, with fresh water flushes between batches. Components for the 303 liter batch consist of 5.7 kg of Nature's Own Organic® paper, 5.2 kg of Hydro® straw, 54 g of Hamilton Manufacturing® tackifier, 123 g of 22N-2P-9K fertilizer and the pre-emergence oxadiazon (Table 2.1) (Ronstar, Bayer Crop Science). The herbicide treatments used in this experiment were composed of oxadiazon at two rates (2.25 kg ai ha^{-1} and 3.36 kg ai ha^{-1}), using two forms, a suspension concentrate (SC) and granular (G).

Data Collection

The weed pressure and establishment success of *S. virginicus* was evaluated at three times throughout duration of the experiment.   Although the experimental installation and protocols were the same between the replicated trials, the data collection dates differed. During the first trial, 36 days after planting (DAP) counts of new green growing apical tips were counted in a representative one m^2 plot as an indicator of new growth and visual percent weed control was assessed to determine weed pressure ratings. At 47 DAP; growing apical tips in a m^2 were counted again along with a timed hand weeding to remove all weed species from the entire plot to quantitatively determine weed pressure. After data was collected at this date, 112 kg ha^{-1} of nitrogen, in formulation of 22-2-9 fertilizer was applied to the entire experiment, equaling 8 kg of fertilizer for the experiment. Oxadiazon in granular formulation was also applied between the row space of the treatments and along the borders to reduce weed infestations from outside of the experimental plots. The final data collection date was at 110 DAP, in which a timed return to weed free status was recorded and fresh weed biomass for the entire plot was collected as a measure of weed pressure. During the same collection date at 110 DAP the visual percent cover of *S. virginicus* was assessed along with aboveground biomass from a randomly placed one m^2 plot. The aboveground biomass of *S. virginicus* was dried to a constant weight at 67° C.

The same data collection points were evaluated for the second replicated trial but the times of the collections were at 42 DAP (counts of new shoots), 78 DAP (shoot counts and timed weeding) and 127 DAP (timed weeding followed by biomass sampling).

Data Analysis

All of the data collected was analyzed using the statistical software package MSTAT (Michigan State University, Crop and Soil Sciences). The data were analyzed by expressing the treatment values as percent of the control. Data sets were analyzed as a two factor randomized complete block design combined experiment over years (2). Data with no significant interactions between formulation, rate and year were able to be pooled over years for discussion. When significant interactions were detected, Duncan's multiple range test was performed.

Results

New Apical Shoot Counts (Trial one 36 DAP, Trial two 42 DAP)

The ANOVA indicates that there was not a significant interaction for the effects of herbicide rate and formulation over years. Thus, allowing for the pooling of means over both years for discussion of the effects of form and rate on shoot number. The ANOVA indicates that the number of shoots was significantly affected by the formulation of the oxadiazon (F = 13.82, P = 0.001). Shoot numbers were 323.5 % of the control for the granular formulation and 165.4 % of the control for the suspension concentrate, meaning there were more shoots produced in the treatments with the granular form of oxadiazon. The rates of the herbicide applications did not have a significant effect on shoot numbers (Table 2.2) (Appendix A).

Percent Weed Control (Trial one 36 DAP, Trial two 42 DAP)

Weed control in all of the chemical treatments was 100 % (no weeds) compared to that of the control with 0 % control (heavy weed pressure) at 36 DAP for trial one and 42 DAP for trial two (data not presented). The weed pressure in this rating was based on the four predominant weed species consistently found throughout the experiments. The four weeds rated for control were *Amaranth spp*., *paspalum spp*., and *Emilia fosbergii* (pualele) and *Eleusine indica* (goosegrass).

Time to weed free status (Trial one 47 DAP, Trial two 78 DAP)

The ANOVA indicated that there is not a significant interaction between the effects of herbicide rate and formulation over years (F = 1.82, P = 0.19). Thus allowing for the pooling of means over both years for discussion of the effects of formulation and rate on the time needed to return the plots to a weed free status. The ANOVA indicates that herbicide form did not significantly affect weeding times but rate of application did (F = 73.3

P = 0.001) (Figure 2.7). Pooling means across herbicide form indicates that at oxadiazon applied at 2.24 kg ai ha^{-1} required weeding times that were 9.9 % of the control, while the 3.36 kg ai ha^{-1} level required times that were 7.2 % of the control, meaning that the low rate of application had significantly greater weed pressure (Table 2.3) (Appendix A).

New Apical Shoot Counts (Trial one 47 DAP, Trial two 78 DAP)

The ANOVA indicates that there was not a significant interaction between the effects of herbicide rate and formulation over years (F = 2.23, P = 0.15). Thus allowing for the pooling of means over both years for discussion of the effects of form and rate on counts of new green apical shoots. The pooled means for apical shoot counts in year one were 159 % of the control and 308 % of the control in the second year. Significantly greater shoot counts were found in the second run of the experiment (F = 20.2, P = 0.0003). Shoot counts were significantly affected by the formulation of oxadiazon. Shoot counts for the granular formulation were 279 % of the control and 186 % of the control with the suspension concentrate, meaning that the granular formulation allowed for the production of more apical shoots. Apical shoots counts were not significantly affected by rates of herbicide application (Table 2.4) (Appendix A).

Time to Weed Free Status (Trial one 110 DAP, Trial two 127 DAP)

The ANOVA indicates that there is a significant interaction between the effects of herbicide rate and formulations over years (F = 7.5, P = 0.013).). Thus, allowing for a composite of the means over both years to compare the effects of formulation and rate. Based on the results of Duncan's multiple range test, no significant differences in weeding time means were detected in treatment means in the first trial. In the second trial (2010) we found differences that were unable to be explained by treatment effects. In the second trial, the low rate of the granule application required the lowest weeding times of all other treatments. The low rate of the suspension concentrate required higher weeding times than the high rate of the SC form, a result that was anticipated (Table 2.5). It was revealed that the experimental field was exposed to heavy weed concentrations in patches prior to our experimental usage which could have attributed to the wide variation in the soil seed bank (Figure 2.8) (Appendix A).

Fresh Weed Biomass (Trial one 110 DAP, Trial two 127 DAP)

The ANOVA indicated that there was not a significant interaction between the effects of oxadiazon formulation and rate over years (F = 3.70, P = 0.07). Thus allowing for the pooling of means over both years for discussion of the effects of form and rate of oxadiazon on fresh weed weight harvested from the experimental plots. Based on the ANOVA, weed weight was not significantly different between trial one and two of the experiment. Weed weight was significantly affected by the formulation of oxadiazon (F = 5.20, P = 0.03). The pooled means for the granular formulation were 21 % of the control and 32 % of the control for the suspension concentrate, indicating that there was less weed pressure in the treatments with the granular formulation of oxadiazon. No significant differences in rate of application were identified in the ANOVA (Table 2.6) (Appendix A).

S. virginicus dry aboveground Biomass (Trial one 110 DAP, Trial two 127 DAP)

In this section, data was expressed as actual dry weights instead of percent of control, due to complete loss of *S. virginicus* in the control plots imposed by heavy weed pressure. The ANOVA indicated that there was not a significant interaction between the effects of oxadiazon formulation and rate over years (F = 1.291, P = 0.26). Thus allowing for the pooling of means over both years for discussion of the effects of form and rate of oxadiazon on *S. virginicus* dry aboveground biomass. Based on the ANOVA there was a significant interaction of formulation by rate (F = 9.43, P = 0.007). The eight means of the interaction (Form x Rate) were separated based on Duncan's multiple range test (Table 2.7). Specifically, in the granular formulation *S. virginicus* dry weight was significantly greater with the 2.24 kg ai ha^{-1} rate, but in the suspension concentrate dry weight was not affected by rate of application (Figure 2.9) (Appendix A).

Percent Visual Cover (Trial one 110 DAP, Trial two 127 DAP)

In this section, data is expressed as the actual recorded % visual cover instead of percent of control, due to complete loss of *S. virginicus* in the control plots imposed by heavy weed pressure. The ANOVA indicated that there was not a significant interaction between the effects of oxadiazon formulation and rate over years (F = 3.80, P = 0.07). Thus allowing for the pooling of means over both years for discussion of the effects of formulation and rate of oxadiazon on percent visual coverage of *S. virginicus* in the experimental plots. Based on the ANOVA there was not a significant difference between percent cover between trial one and trial two of the experiment. The ANOVA stated that there was a significant effect of oxadiazon formulation on the percent cover (F = 7.65, P = 0.012). The pooled means for the granular formulation were 76 % of the control and 68 % of the control with the suspension formulation, meaning that better growth was achieved with the granular formulation (Figure 2.9). No significant differences were determined in percent cover based on rate of application (Table 2.8) (Appendix A).

Discussion

The results indicate that weed control and *S. virginicus* growth are significantly affected by applying pre-emergence herbicides (oxadiazon) as a component of the hydromulch cap at time of planting. The rates of oxadiazon used in these experiments did not have a significant effect on the growth of *S. virginicus*. Weed control in the early establishment period was complete in all herbicide treated plots. Initially (36 and 42 DAP) weed control was greater with the high rate of oxadiazon application. In the later establishment period (110 and 127 DAP) based on fresh weed biomass, the granular formulation provided better weed control compared to the suspension concentrate (Figure 2.10).

For *S. virginicus* roadside planting applications it appears be more beneficial to utilize the granular formulation of oxadiazon because it suppresses weeds better in the long term and allows for improved growth over the SC formulation. The increased weed control efficacy of the granular oxadiazon may be due to the extended dispersal and release time of chemical from a carrier granule. Previous studies by Johnson determined that granules compared to liquid formulations, resulted in higher concentrations of herbicide dispersal in the soil, which resulted in better weed control (Johnson, Wyse and Lueschen 1989). In our experimentation, it was determined that the extended control of weeds provided by the granular formulation was superior to the suspension concentrate.

However, with large hydromulch applications it will be easier to integrate the suspension formulation in the hydromulch mixture than the granular formulation because as dry components are added, the viscosity of the mixture increases creating a greater chance of blockages forming within the pump apparatus. A large volume of granular oxadiazon is needed to add to the tank to equal the same active ingredient rate as needed with a small volume of suspension concentrate. The margin of error also increases when utilizing granular substances within the hydromulch tank because it is imperative that homogeneity of chemical exists to ensure even application.

This research supports the following protocol be followed for *S. virginicus* establishment. Before harvesting *S. virginicus* cuttings, ensure stock material is well fertilized and watered for one month prior to harvesting. Once *S. virginicus* green stems 40-60 cm in length are harvested, soak stems in a diluted root hormone solution (1:35) for a period of 24 hours in a cool shady area. During planting, spread the cut stems so that complete contact with the soil surface is achieved. Stems that are piled on top of each other or protruding upright were observed to either dry out or fail to produce roots. When stems are spread on planting surface, cover with just enough hydromulch cap to hold the cut stems firmly to the soil surface (Figure 2.6). Too thick of a hydromulch covering (exceeding the rates used in this experiment) will exclude light that is absorbed by leaves and green stems resulting in reduced rooting and subsequent growth causing stems to not establish (based on visual observations, no data was collected to support this claim). The hydromulch cap applied to cut stems should include oxadiazon in the granular formulation so that a rate of 2.24 kg ai ha^{-1} is achieved. Agitation within the hydromulch tank is imperative to ensure components and herbicide are in a homogenous state before the hydromulch is applied. Irrigation levels should ensure that the ground remains wet but not pooling during the initial establishment rooting period. Once *S. virginicus* is established irrigation levels can be reduced (specific times can be found in materials and methods section). Around two months after planting, a light hand weeding should be completed and the planting site should be fertilized. At this time another application of oxadiazon in granular formulation can be applied if continued weed suppression is necessary. Post emergent herbicides can be applied after 4-5 months if weeds are emerging within the *S. virginicus* stand (Baldos 2009).

Successful new plantings of *S. virginicus* needs to incorporate the use of vigorous stock plant to supply healthy cut stems, hormone soak to enhance rooting, a light hydromulch cap containing the granular formulation of oxadiazon and a reliable irrigation that provides complete coverage of the entire planting. Optimizing these factors will greatly improve the success rate for landscape contractors that need to install large scale planting of *S. virginicus*.

Tables

Table 2.1. Components needed for a 303 liter batch of hydromulch with herbicide treatments.

Tank mix components	Finished mixture (liters)
	303 (48 m^2)
Paper mulch	11.5 kg
Straw mulch	5.2 kg
C- Tac, tackifier	54.0 g
Ferts 22-2-9 56 kg N ha^{-1}	123.9 g
Treatments contain the hydromulch components above with the herbicides amounts below	
1 Non-treated	-
2 Ronstar G 2.24 kg ai ha^{-1}	541.9 g
3 Ronstar G 3.36 kg ai ha^{-1}	812.9 g
4 Ronstar Flo 2.24 kg ai ha^{-1}	28.4 ml
5 Ronstar Flo 3.36 kg ai ha^{-1}	42.8 ml

Table 2.2. Means of *S. virginicus* shoot counts recorded 36 days after planting (DAP) (2009) and 42 DAP (2010) in response to pre-emergence herbicides in the hydromulch cap. The F-test for the Year x Herbicide Form x Rate interaction was not significant. Treatment factors of Year and Form had a highly significant effect on new shoot numbers.

TABLE OF SHOOT COUNT MEANS

Year	Form[1]	Rate[2]	Means[3]	Treatment[4]	Untreated[5]
1	-	-	182.6**	11.5	7.6
2	-	-	306.3**	6.6	2.9
-	1	-	323.5**	11.7	5.2
-	2	-	165.4**	7.2	5.2
-	-	1	247.3	9.7	5.2
-	-	2	241.6	9.2	5.2

* Indicates significant differences at the 5% level

** Indicates significant differences at the 1% level

[1]= Form 1 is granular, Form 2 is suspension concentrate

[2]= Rate 1 is 2.24 kg ai ha^{-1} , Rate 2 is 3.36 kg ai ha^{-1}

[3]= Means are expressed as % of the control (control value / treatment value x 100)

[4]= Recorded treatment values

[5]= Recorded untreated values

Table 2.3. Means of the times needed to return the experimental plots to a weed free status recorded 47 DAP (2009) and 78 DAP (2010) in response to pre-emergence herbicides in the hydromulch cap. The F-test for the Year x Herbicide Form x Rate interaction was not significant. Treatment factors of year and rate had a significant effect on weeding time.

TABLE OF MEANS FOR RETURN TO WEED FREE TIMES (s)

Year	Form[1]	Rate[2]	Means[3]	Treatment[4]	Untreated[5]
1	-	-	3.62**	135	1383
2	-	-	13.5**	50.1	1072
-	1	-	8.56	98.6	1227
-	2	-	8.62	87.4	1227
-	-	1	9.94*	108	1227
-	-	2	7.25*	77.4	1227

* Indicates significant differences at the 5% level

** Indicates significant differences at the 1% level

[1]= Form 1 is granular, Form 2 is suspension concentrate

[2]= Rate 1 is 2.24 kg ai ha^{-1} , Rate 2 is 3.36 kg ai ha^{-1}

[3]= Means are expressed as % of the control (control value / treatment value x 100)

[4]= Recorded treatment values

[5]= Recorded untreated values

Table 2.4. Means of *S. virginicus* shoot counts recorded 47 DAP (2009) and 78 DAP (2010) in response to pre-emergence herbicides in the hydromulch cap. The F-test for the Year x Herbicide Form x Rate interaction was not significant. Treatment factors of year and form had a highly significant effect on new shoot numbers.

TABLE OF SHOOT COUNT MEANS

Year	Form[1]	Rate[2]	Means[3]	Treatment[4]	Untreated[5]
1	-	-	158.6**	18.4	13.4
2	-	-	307.6**	34.3	8.6
-	1	-	279.8**	42.1	11
-	2	-	186.4**	31.5	11
-	-	1	230.2	26.1	11
-	-	2	236.0	26.5	11

* Indicates significant differences at the 5% level

** Indicates significant differences at the 1% level

[1]= Form 1 is granular, Form 2 is suspension concentrate

[2]= Rate 1 is 2.24 kg ai ha^{-1} , Rate 2 is 3.36 kg ai ha^{-1}

[3]= Means are expressed as % of the control (control value / treatment value x 100)

[4]= Recorded treatment values

[5]= Recorded untreated value

Table 2.5. Means of the times needed to return the experimental plots to a weed free status recorded 110 DAP (2009) and 127 DAP (2010) in response to pre-emergence herbicides in the hydromulch cap. The F-test for the Year x Herbicide Form x Rate interaction was significant. The resulting means were analyzed using Duncan's multiple range test.

TABLE OF MEANS FOR RETURN TO WEED FREE TIMES

Year	Form[1]	Rate[2]	Means[3]
1	1	1	43.8 bc
1	1	2	25.3 c
1	2	1	39.8 bc
1	2	2	35.3 bc
2	1	1	28.5 c
2	1	2	102 a
2	2	1	89.5 ab
2	2	2	46.5 bc

Duncan's multiple range test presented at the 1% level

[1]= Form 1 is granular, Form 2 is suspension concentrate

[2]= Rate 1 is 2.24 kg ai ha^{-1} , Rate 2 is 3.36 kg ai ha^{-1}

[3]= Means are expressed as % of the control (control value / treatment value x 100)

Table 2.6. Means of the weight of fresh weed biomass recorded 110 DAP (2009) and 127 DAP (2010) in response to pre-emergence herbicides in the hydromulch cap. The F-test for the Year x Herbicide Form x Rate interaction was not significant. The treatment factor of form had a significant effect on weed biomass.

TABLE OF MEANS FOR FRESH WEED BIOMASS (kg / m^2)

Year	Form[1]	Rate[2]	Means[3]	Treatment[4]	Untreated[5]
1	-	-	29.8	3.93	13.8
2	-	-	24.4	2.00	8.14
-	1	-	20.9*	2.34	11
-	2	-	32.4*	3.60	11
-	-	1	30.8	3.41	11
-	-	2	22.5	2.53	11

* Indicates significant differences at the 5% level

** Indicates significant differences at the 1% level

[1]= Form 1 is granular, Form 2 is suspension concentrate

[2]= Rate 1 is 2.24 kg ai ha^{-1} , Rate 2 is 3.36 kg ai ha^{-1}

[3]= Means are expressed as % of the control (control value / treatment value x 100)

[4]= Recorded treatment values

[5]= Recorded untreated values

Table 2.7. Means of the weight of *S. virginicus* aboveground dry biomass recorded 110 DAP (2009) and 127 DAP (2010) in response to pre-emergence herbicides in the hydromulch cap. The F-test for the Year x Herbicide Form x Rate interaction was not significant. A significant interaction was detected between Form x Rate, with means separated using Duncan's multiple range test.

TABLE OF INTERACTION MEANS FOR FORM x RATE *S. VIRGINICUS* ABOVEGROUND BIOMASS (g / m^2)

Form[1]	Rate[2]	Means	Untreated[3]
1	1	324.2 a[4]	56
1	2	179.2 b	56
2	1	152.1 b	56
2	2	185.4 b	56

Duncan's multiple range test at 1% significance level

[1]= Form 1 is granular, Form 2 is suspension concentrate

[2]= Rate 1 is 2.24 kg ai ha^{-1} , Rate 2 is 3.36 kg ai ha^{-1}

[3]= Recorded untreated values

[4]= Means followed by the same letter are not significantly different based on Duncan's Multiple range test at the 1% level

Table 2.8. Means of *S. virginicus* percent visual coverage recorded 110 DAP (2009) and 127 DAP (2010) in response to pre-emergence herbicides in the hydromulch cap. The F-test for the Year x Herbicide Form x Rate interaction was not significant. The treatment factor of form indicated a significant effect on percent coverage.

TABLE OF MEANS FOR *S. VIRGINICUS* VISUAL PERCENT COVERAGE (%)

Year	Form[1]	Rate[2]	Means	Treatment[3]
1	-	-	71	70.6
2	-	-	69	68.7
-	1	-	76*	76.2
-	2	-	63*	63.1
-	-	1	71	71.3
-	-	2	68	64.2

* Indicates significant differences at the 5% level

** Indicates significant differences at the 1% level

[1]= Form 1 – granular, Form 2 - suspension concentrate

[2]= Rate 1 is 2.24 kg ai ha^{-1} , Rate 2 is 3.36 kg ai ha^{-1}

[3]= Recorded treatment means

Figures

Figure 2.1. Completed installation of the random complete block experimental design with five treatments and four replications.

Figure 2.2. Harvesting of 40 -60 cm *S. virginicus* cut stems from stock vegetative material plots.

Figure 2.3. *S. virginicus* vegetative cuttings being soaked in a diluted Dip N Grow® rooting hormone and water solution (1:35) for 24 hours.

Figure 2.4. Cut stems of *S. virginicus* in experimental plots making full ground contact, at a planting rate of 1236 kg ha^{-1}.

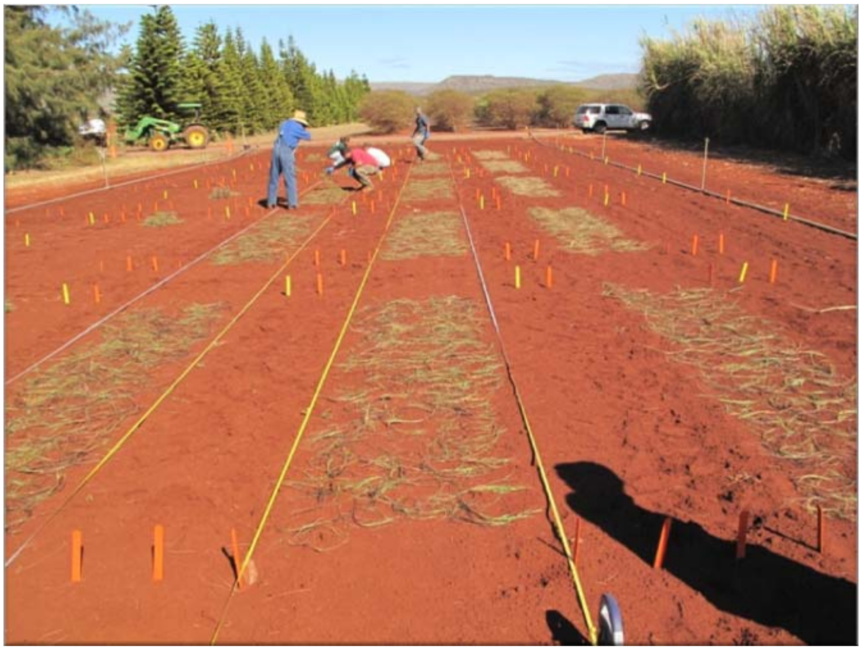


Figure 2.5. Application of hydromulch over cut stems of *S. virginicus.*

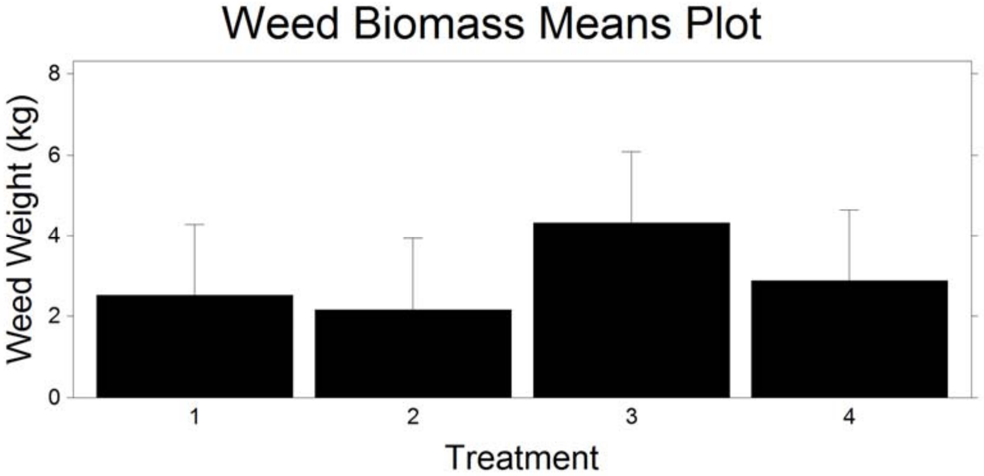
Figure 2.6. Illustration of the proper density to apply hydromulch over cut stems of *S. virginicus*.

Figure 2.7. *S. virginicus* plots during early establishment (47 DAP) trial one. Comparison photographs (from left to right) of the control plot, the 2.24 kg ai ha^{-1} and 3.36 kg ai ha^{-1} of granular oxadiazon. Significantly greater weed biomass was found in the lower rate of oxadiazon.

Figure 2.8. Area within the black box is the site of the second *S. virginicus* trial prior to experimental installation. This photo illustrates the inconsistent, heavy weed pressure that the field was exposed to.

Figure 2.9. *S. virginicus* plots at 110 DAP. Comparison photographs, post hand weeding (from left to right) of the control plot, the 2.24 kg ai ha^{-1} granular oxadiazon and the 2.24 kg ai ha^{-1} of the suspension concentrate. Significantly greater *S. virginicus* biomass was found in the granular form of oxadiazon.

Figure 2.10. Means of the weight of fresh weed biomass recorded 110 DAP (2009) and 127 DAP (2010) in response to pre-emergence herbicides in the hydromulch cap. Higher weeding times were found in the suspension formulation treatments.



Treatment 1= Granular formulation at 2.24 kg ai ha^{-1}
Treatment 2= Granular formulation at 3.36 kg ai ha^{-1}
Treatment 3= Suspension concentrate formulation at 2.24 kg ai ha^{-1}
Treatment 4= Suspension concentrate formulation at 3.36 kg ai ha^{-1}

Chapter 3

The response of directed seeded *Heteropogon contortus* (Pili grass) and weeds to a spray application of pre-emergence herbicide applied over the top of a hydromulch cap.

Introduction

In Hawaii, *Heteropogon contortus* has been extensively used as a restoration (Daehler and Goergen 2005) and erosion control species for severely degraded sites (Daehler and Carino 1998), due to its drought tolerance and ability to grow under low fertility soils. In addition to its significance as a conservation species, *H. contortus* is culturally significant since ancient Hawaiians used it for roof construction, floor coverings and torches (Okamura 1980).

H. contortus produces viable seed (Brown and Emery 1958), allowing for direct seeding protocols for re-vegetation efforts (Daehler and Goergen 2005). However, weed control with direct seeded grass is very difficult when using pre-emergence herbicides due to injury to sensitive seedling roots and shoots (Kolhe et al. 1984). The utilization of safeners and protectants to permit the use of otherwise phytotoxic herbicides has been investigated in many crops over the past 50 years (Clay, Dixon and Willoughby 2006). Safening herbicides against seed germination and subsequent growth requires the presence of a strongly adsorptive material above a direct seed crop at the time of chemical application (Sudhakar and Dikshit 1999). The adsorption process is a surface phenomenon, which depends upon the number of sites available, porosity and specific surface area of adsorbent as well as various types of interactions. Activated carbon, due to its high surface area and porosity, is very efficient in removing varieties of organic compounds from water and wastewater (Sudhakar and Dikshit 1999). Charcoal placement in a narrow band on the soil surface after planting, but before pre-emergence herbicide application, is the most successful placement for safening direct seeded crops against pre-emergence herbicides. (Chandler, Wooten and Fulgham 1978)

Hydromulching has been the most widespread method used for roadside re-vegetation in the past few decades (Bochet et al. 2010). Hydromulch has traditionally contained paper or wood fibers, binding agents, nutrients and ground cover seed. Additional components may include pre-emergence herbicides when capping vegetative planting material (see Chapter 2) or charcoal for adsorption of herbicides and other organic compounds. The research reported here will characterize the response of direct seed Pili grass to pre-emergence herbicides applied after the application of a hydromulch cap both with and without activated charcoal.

Materials and Methods

Experiment One, Charcoal Safening

Plant Material

Heteropogon contortus seed was acquired from the USDA NRCS PMC, Hoolehua, Molokai. It was determined that 10 grams of raw *H. contortus* grass seed from a packed seed bale contain 300 filled seeds with an average of 30% viability or 90 live seed per 10 grams of raw seed bale weight (Figure 3.1). In this experiment, 2.0 grams will be spread over the middle of the plot (0.91 m. x 0.15 m = 0.136 m^2) to provide an estimated 130 live seeds/square meter.

Experimental Design

The experiment was conducted at the University of Hawaii, Magoon Research and Instructional Facility in Manoa valley, Honolulu, beginning in June of 2010. The experimental design was a split plot with activated charcoal levels as the main plot and herbicide treatment as the sub plot with four blocks established to account for variation in overhead irrigation (Figure 3.2). Hydromulch followed by herbicide treatments were applied directly over direct seeded *H. contortus*. Applications of hydromulch with and without charcoal along with two rates of oxadiazon 50WP were evaluated , 2.24 kg ai ha^{-1} and 3.36 kg ai ha^{-1}, with one no herbicide treatment.

Meteorological and Irrigation Data

The day of planting 6/9/2010 overhead irrigation was set to water every day at 9:00 pm and 4:00 am for 30 minutes each cycle. On day one (6/10) the watering duration was reduced to 15 minutes each cycle. At seven DAP (6/15) irrigation times were changed to 4:00 am and 1:00 pm for a duration of 30 minutes each cycle. Thirty days after planting

(7/7) irrigation was stopped due to abundant natural rainfall and remained off for the duration of the experiment.

Meteorological data was collected from the University of Hawaii Magoon Research Station, which was located 100 m from the experimental field. Mean ambient temperature during the two month duration of the experiment was 25.3°C with a mean daily precipitation value of 1.3mm.

Hydromulch material

The hydromulch tank holds 190 liters of mixture with an estimated coverage potential of 50 m^2. The area direct seeded in each plot is 0.14 m^2 of *H. contortus*. The center 0.30 m. x 0.91 m. portion of the plot was covered with hydromulch over the direct seeded area. A 76 liter batch of hydromulch was prepared with an estimated cover potential of 9.6m^2. Material not applied to the plots was discarded.

A rate of 672 kg ha^{-1} of activated charcoal was applied as a component of the hydromulch cap, capable of absorbing the high level of oxadiazon (3.36 kg ai ha^{-1}). It is generally reported that 112-448 kg ha^{-1} (100-400 lbs/a) of charcoal for every 1.12 kg ai ha^{-1} (1.0 lb ai/a) of chemical is needed for adequate binding (McCarty 2011). The maximum rate of chemical used in our study is 3.36 kg ai ha^{-1} (3.0 lb ai/a). Using middle rate of 224 kg ha^{-1} of charcoal for 1.12 kg ai ha^{-1} of active herbicide ingredient means an amount of 672 kg ai ha^{-1} of charcoal is necessary to deactivate up to 3.36 kg ai ha^{-1} of oxadiazon. The charcoal product used in this experiment was Clean Carbon® by Aquatrols (Aquatrols, Cherry Hill NJ).

Clean Carbon® contains 85% activated carbon with 15% inert unspecified ingredients. Seventy six liters of hydromulch cap was prepared to contain 0.64 kilograms of activated charcoal. With a cover potential of 9.6 m^2, a 76 liter batch of hydromulch cap will provide and effective rate of 672 kg ha^{-1} of activated charcoal.

One batch of hydromulch is enough material to cover the main plot area. The hydromulch mixture without charcoal was applied to the treatments first, followed by the batch containing charcoal. Components for the 76 liter batch of hydromulch consist of 1.13 kg of Nature's Own Organic® paper, 1.00 kg of Hydro® straw, 10.8 g of Hamilton Manufacturing® tackifier (Table 3.1).

Herbicide Application

Herbicide applications were made using the TeeJet Spray Systems MeterJet® spray application device. The MeterJet allows for repeated spray volumes with every pull of the trigger, regardless of spray pressure. The MeterJet was fitted with a 9504 TeeJet Spray Systems EVS nozzle tip and calibrated to deliver 19 ml with every trigger pull. Each treatment plot was 0.84 m^2 (0.91 m X 0.91 m) and received a total of 76 ml (4 spray passes, two passes perpendicular to each other) for a final application rate o 90 l/ha (97 gallons/a). Three liters of finished spray solution were prepared and applied with the MeterJet using a pump-up back pack spray, modified to draw liquid from a 3 liter plastic beverage bottle.

A polyvinylchloride (PVC) frame (0.91m x 0.91 m x 0.76m), covered with plastic sheeting was used to contain spray drift to treatment plots due to the persistent winds, small plot size and close proximity of adjacent plots. Spray delivery from the MeterJet applicator was made from the top of the drift containment structure. For each treatment, the constructed spray box was set directly over the entire plot. The four pass spray pattern was set at the height of the top of the containment box at 0.76 m (Figure 3.3).

Data collection

Data was collected at 48 DAP which included measurements of biomass accumulation and plant counts for Pili grass. The aboveground biomass of *H. contortus* was dried at 67° C to a constant weight prior to weighing.

Data Analysis

Data were analyzed using the statistical software Statistix® 9.0 (Analytical Software, Tallahassee, FL) as a split plot design with charcoal level as the main plot and oxadiazon treatments as the sub plot. Chemical treatment means were separated using Tukey's mean testing.

Experiment Two, Expanded Rates

Plant material

Heteropogon contortus seed was acquired from the USDA NRCS PMC, Hoolehua, Molokai. It was observed that 10 grams of raw *H. contortus* grass seed from a packed bale contain 300 filled seeds with an average of 30% viability or 90 live seed per 10 grams raw seed bale weight. In this experiment, 4.0 grams was spread over the middle of the plot (0.91 m. x 0.15 m = 0.136 m^2) to provide an estimated 258 live seeds per m^2 (Figure 3.1).

Experimental Design

The experiment was conducted at the University of Hawaii, Magoon Research and Instructional Facility in Manoa valley, Honolulu, beginning in October 2010. The experiment was installed as a randomized complete block design with four rates of oxadiazon and one control treatment, with four replications (Figure 3.4). Hydromulch and herbicide treatments were applied directly over seeded *H. Contortus* as previously described. Applications of oxadiazon 50WP at four rates were evaluated, 1.4 kg ai ha^{-1}, 1.68 kg ai ha^{-1}, 1.96 kg ai ha^{-1} and 2.24 kg ai ha^{-1} , with one control treatment.

Meteorological and Irrigation Data

On the day of planting 10/5/2010, overhead irrigation was set to water at 6:00 am and 12:00 pm for 10 minutes each cycle every day. Thirteen days after planting (10/18) the watering duration was increased and times were changed to 7:20 am, 11:20 am and 3:20 pm for 10 minutes each cycle. To prevent oversaturation, 25 DAP (10/30) irrigation times were reduced from 10 minutes each cycle to 7 minutes each cycle. 58 DAP (12/2) irrigation was reduced again to one start time at 7:20 am for a duration of 7 minutes on Monday, Wednesday, Friday and Sunday. It was found that the average mean irrigation volume of the experimental field was 1735 liters ha^{-1} $minute^{-1}$.

Meteorological data was collected from the University of Hawaii Magoon Research Station, which was located 100 m from the experimental field. Mean ambient temperature during the duration of the experiment was 24.1°C with a mean daily precipitation value of 5.47 mm.

Hydromulch material

The hydromulch tank holds 190 liters of mixture with an estimated coverage potential of 50 m^2 of coverage. The area to be direct seeded in each plot is 0.14 m^2 of *H. contortus*. The center 0.30 m. x 0.91 m. portion of the plot will be covered with hydromulch over the direct seeded area. A 76 liter batch of hydromulch was prepared with an estimated cover potential of 9.6m^2. Material not applied to the plots was discarded. Components for the 76 liter batch of hydromulch consist of 1.13 kg of Nature's Own Organic® paper, 1.00 kg of Hydro® straw, 10.8 g of Hamilton Manufacturing® tackifier (Table 3.2).

Herbicide Application

The application of herbicide treatments in this study followed the same spray protocol as previously described in the first experiment. Herbicide treatments for application with Meter Jet system were determined to be 908 liters per hectare. This rate of application is obtained when 19 ml are applied to an area of 0.91 m x 0.91 m = 0.84m^2 with four passes to distribute material evenly across the entire plot. Herbicide treatments were prepared in 3 liter bottles and applied with a research pump up backpack sprayer. The sprayer was flushed after each chemical treatment application.

To ensure containment of the chemical application, an enclosed plastic sided, polyvinylchloride (PVC) framed box was used. For each treatment the constructed 0.91 m x 0.91 m spray box was set directly over the entire plot (Figure 3.3). The four pass spray pattern was set at the height of the top of the containment box at 0.76 m.

The response of weeds and Pili grass were characterized for 4 rates of oxadiazon (1.4, 1.68, 1.96 and 2.24 kg ai ha^{-1}) and an untreated control.

Data collection

Two data collection times were evaluated throughout the course of the experiment. The first collection was at 35 DAP in which a visual percent weed control rating and aboveground dry weed biomass were recorded to determine weed pressure. The visual percent weed control rating was based on the three most predominant weed species found throughout all of the control plots, *Eleusine indica* (goosegrass), *Eragrostis spp*. and *Chamaesyce hirta* (garden spurge). The weed biomass was collected by cutting plants at the soil surface. Following weed removal, 56 kg of nitrogen ha^{-1} was applied to the entire experiment as a blended fertilizer (10N-6P-10K) by applying 0.21 kg to each of the four replications. At 63 DAP the 0.91 m length strip of *H. contortus* in each plot was cut at the soil surface to determine biomass accumulation. All samples of biomass were dried at 67° C prior to weighing.

Data Analysis

All of the data collected was analyzed using the statistical software Statistix® 9.0 (Analytical Software, Tallahassee, FL). The individual data is expressed as percent of the control. The transformed data at both intervals at 35 and 63 DAP will be analyzed using regression analysis.

Results

Experiment One, Charcoal Safening

Percent Weed Control (48 DAP)

In herbicide treated plots, weed control for all weed species present (see materials and methods section) was 100% (no weeds), compared to heavy weed pressure in the no herbicide treatment (data not presented).

Heteropogon contortus Aboveground Biomass (48 DAP)

The ANOVA indicated that charcoal levels in the hydromulch cap did not have a significant effect on biomass accumulation nor was there a significant interaction between charcoal levels in the cap and herbicide treatments. Means for biomass will be pooled across charcoal level in all further discussions. The ANOVA indicated a significant F-test for the herbicide treatment effect (F = 7.65, P = 0.007). The pooled means for the biomass of *H. contortus* were 8.6 grams, 2.4 grams and 11.6 grams for treatments of 2.24, 3.36 kg ai ha^{-1} and untreated, respectively (Figure 3.5) (Table 3.3). Tukey's analysis of mean separation of the treatments indicated that the 3.36 kg ai ha^{-1} rate provided significantly lower biomass than that of the control which was not significantly different than 2.24 kg ai ha^{-1} application (Appendix B).

Heteropogon contortus Plant Counts (48 DAP)

The split plot ANOVA indicates that there are no significant differences between the effects of charcoal on *H. contortus* on plant counts nor was there a significant interaction between charcoal levels in the cap and herbicide treatments. Thus allowing for the pooling of means across charcoal levels. The ANOVA indicated a significant F-test for herbicide treatment effect for plant counts (F = 14.19, P = 0.001). Treatment means were 9, 2 and 34 for 2.24, 3.36 kg ai ha^{-1} and untreated, respectively (Figure 3.5) (Table 3.4). Tukey's analysis of mean separation of the treatments indicated that both of the herbicide rates were not significantly different, but had significantly lower plant counts from the control (Appendix B).

Experiment Two, Expanded Rates

In the first experiment with direct seeded Pili grass, charcoal was used to safen germination against the impact of oxadiazon, a pre-emergence herbicide noted for grassy weed control. It was surprising to discover that Pili grass seeds could germinate and grow normal plants with exposure to highly effective rates of oxadiazon regardless of charcoal levels in the hydromulch cap. In this experiment, expanded rates of oxadiazon are evaluated to determine if lower levels can maintain adequate weed control while improving the stand counts and seedling vigor of Pili grass.

Percent Weed Control (35 DAP)

Percent weed control of all of the oxadiazon treatments for all weed species recorded [*Eleusine indica* (goosegrass), *Eragrostis spp*. and *Chamaesyce hirta* (garden spurge)] was 100% control (no weeds) compared to no control in untreated plots (Figure 3.6) (data not presented).

Weed Biomass (35 DAP)

Due to the fact that there were no weeds emerging throughout any of the oxadiazon plots, no weed biomass existed for *Eleusine indica* (goosegrass), *Eragrostis pectinacea* (Carolina love grass) and *Chamaesyce hirta* (garden spurge). The control plots did exhibit heavy weed pressure, with mean biomass of 21.65 g, 18.5 g and 8.1 g for *Eleusine indica* (goosegrass), *Eragrostis pectinacea* (Carolina love grass) and C*hamaesyce hirta* (garden spurge) respectively (Figure 3.6).

Heteropogon contortus Plant Counts (63 DAP)

The least squares linear regression analysis revealed a highly significant negative linear correlation between stand counts of *H. contortus* and rates of oxadiazon (F = 15.78, P = 0.001), no significant quadratic or cubic responses were detected. Counts decreased with increasing rates of oxadiazon (Figure 3.7). The R-squared valued indicated that 53% of the variation in stand counts could be accounted for by the linear regression model (Table 3.5) (Appendix C).

Heteropogon contortus Aboveground Biomass (63 DAP)

The least squares linear regression analysis indicates that there is a highly significant negative linear correlation between biomass of *H. contortus* and rates of oxadiazon (F = 13.56, P = 0.002), no significant quadratic or cubic responses were detected. Biomass decreased with increasing rates of oxadiazon (Figure 3.7). The R-squared valued indicated that 49% of the variation in biomass could be accounted for by the linear regression model (Table 3.6) (Appendix C).

Discussion

Pili grass counts and biomass accumulation data were not significantly affected by the charcoal levels contained in the hydromulch cap. The growth and biomass of *H. contortus* was inhibited by the application of oxadiazon 50WP as compared to growth in the untreated plots. Pili grass stand counts and biomass accumulation were decreased as rates of oxadiazon decreased (Figure 3.5). Weed control was 100 % (no weed pressure) in the chemical treatments and less than 10 % (heavy weed pressure) in the control plots, data not presented (Figure 3.5).

Literature has shown that oxadiazon is not a well safened herbicide. Factors which attribute to the adsorption of oxadiazon by activated carbon are dependent on contact time, pH of the solution, and dosage of adsorbent (Arvand et al. 2009). The herbicides, oxadiazon (Ronstar) and prosulfalin (Sward) were not influenced by charcoal applied to the surface of established turfgrass (Jagschitz 1980). The failure of charcoal in the hydromulch cap to improve Pili grass stand counts and biomass accumulation in the presence of oxadiazon is consistent with previous reports on limited efficacy of charcoal safening against the effects of oxadiazon.

It is also possible that the charcoal did not have an effect on the safety of *H. contortus* because it bound to components in the hydromulch cap, instead of adsorbing the herbicide. A thorough review of the pertinent literature reveals no studies utilizing charcoal in a hydromulch mixture scenario. Regardless of the lack of charcoal effects, it appears that *H. contortus* germination and growth have good tolerance to oxadiazon.

This study demonstrates that charcoal is not a necessary component of the hydromulch cap to provide safety for *H. contortus* seedlings when oxadiazon is used for pre-emergence weed control immediately after planting. Although oxadiazon did reduce stand counts and biomass accumulations, the high level of weed control provides sufficient incentive for application at the time of planting.

The tolerance of Pili grass germination and growth was unexpected due to the well documented performance of oxadiazon for grassy weed control (Dennis and Lillie 1974, Wilson and Hines 1977). In the second experiment, lower rates of oxadiazon were evaluated to determine if adequate levels of weed control could be obtained while improving Pili grass stand counts and growth vigor.

It was determined that all of the tested rates of oxadiazon provided complete weed control of the three main weed species present (Figure 3.6). The growth of *H. contortus* was inhibited as rates of oxadiazon increase. If was found that the highest *H. contortus* plant counts and biomass were achieved with the lowest rate (1.4 kg ai ha^{-1}) of oxadiazon application (Figure 3.7).

Although there was a significant negative linear response in both the plant counts and biomass ratings, both regression analyses produced R-Squared values accounting for around 50% of variation. The remainder of variation could be attributed to differences in irrigation levels as a result of the overhead irrigation. The experimental layout was designed to account for irrigation and wind variation between blocks. However, when irrigation water was collected (after the experiment began) from individual plots, variation was found to be very high both within and between blocks. Within the experimental plots the irrigation rates ranged from 66445 and 152823 liters ha^{-1} per hour (Table 3.7).

Another source of variation can be attributed to the nature of the wild seed utilized for the planting. It was established that the *H. contortus* seeds used have a germination potential of 30%, this low germination percentage could be a factor in the distribution of live seeds throughout each experimental plot. This germination variation would be exaggerated by the fact that the plots sizes used were relatively small (0.91 m. x 0.15 m = 0.136 m^2) due to available field size constraints and limited amounts of seeds.

Despite the unaccounted variation, the reliable tolerance found in the growth response of *H. contortus* in the presence of oxadiazon is an important discovery. Cases of oxadiazon selectivity have been found in vegetable crops and rice varieties. Oregano (*Origanum*) was shown to tolerate oxadiazon when applied pre-planting and when sprayed on to foliage soon after planting (Bucsbaum et al. 1985). There is also evidence that shows differences in translocation may be a factor in the selective action of certain herbicides (Achhireddy, Kirkwood and Fletcher 1984). This is illustrated by the proportion of oxadiazon or oxadiazon metabolites translocated to the roots of rice (0.3%) and barnyard grass (0.5%) (*Echinochloa crus-galli*), a species controlled by oxadiazon (Achhireddy et al. 1984). Specific rates of oxadiazon translocation, that impart tolerance, are species dependant. (Achhireddy et al. 1984). No literature was found to indicate that the mode of oxadiazon tolerance in rice and barnyard grass is responsible for oxadiazon tolerance in *H. contortus.*

Since the lowest rate (1.4 kg ai ha^{-1}) of oxadiazon provided control of all weed species present, even lower rates need to be evaluated to determine where adequate weed control is maintained and *H. contortus* growth is acceptable for large scale establishment for both seed production and natural landscape plantings.

Tables

Table 3.1. Components with charcoal added and chemical contained within a 75 liter batch of hydromulch.

<table>
<tr><td colspan="2">Tank components</td><td colspan="2">Amount in 75 liters</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">C-tak</td><td colspan="2">10.8 grams</td></tr>
<tr><td colspan="2">Hydromulch straw</td><td colspan="2">1.04 kg</td></tr>
<tr><td colspan="2">Hydromulch paper</td><td colspan="2">1.13 kg</td></tr>
<tr><td colspan="2">Activated charcoal</td><td colspan="2">0.64 kg</td></tr>
<tr><td colspan="4">Amount of Oxadiazon (Ronstar 50 WP)</td></tr>
<tr><td>Herbicides</td><td>Amount ha^{-1}</td><td>ai ha^{-1}</td><td>Components /3 liter</td></tr>
<tr><td>1 Untreated</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>2 Ronstar 50WP</td><td>4.48 kg</td><td>2.24 kg</td><td>14.8 g</td></tr>
<tr><td>3 Ronstar 50 WP</td><td>6.72 kg</td><td>3.36 kg</td><td>22.2 g</td></tr>
</table>

Table 3.2. Components and chemical contained within a 75 liter batch of hydromulch.

<table>
<tr><td colspan="3">Tank components</td><td>Amount in 75 liters</td></tr>
<tr><td colspan="3"></td><td></td></tr>
<tr><td colspan="3">C-tak</td><td>10.8 grams</td></tr>
<tr><td colspan="3">Hydromulch straw</td><td>1.04 kg</td></tr>
<tr><td colspan="3">Hydromulch paper</td><td>1.13 kg</td></tr>
<tr><td colspan="4">Amount of Oxadiazon (Ronstar 50 WP)</td></tr>
<tr><td>Herbicides</td><td>Amount ha^{-1}</td><td>ai ha^{-1}</td><td>Amount / 3 liter</td></tr>
<tr><td>1 Untreated</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>2 Ronstar 50WP</td><td>2.8 kg</td><td>1.40 kg</td><td>9.3 g</td></tr>
<tr><td>3 Ronstar 50WP</td><td>3.36 kg</td><td>1.68 kg</td><td>11.1 g</td></tr>
<tr><td>4 Ronstar 50WP</td><td>3.92 kg</td><td>1.96 kg</td><td>13.0 g</td></tr>
<tr><td>5 Ronstar 50WP</td><td>4.48 kg</td><td>2.24 kg</td><td>14.8 g</td></tr>
</table>

Table 3.3. Means of *H. contortus* aboveground dry biomass recorded 48 DAP in response to pre-emergence herbicides and charcoal in the hydromulch cap for safening over *H. contortus* seeds. The F-test for the effect of charcoal was not significant. Treatment rates had a significant effect on *H. contortus* biomass.

TABLE OF THE MEANS OF *H. CONTORTUS* ABOVEGROUND BIOMASS (g)

Charcoal[1]	Treatment rate[2]	Means		
		Untreated	Treatment	
1	-	11.6	6.8[a]	
2	-	11.9	4.4	
-	1	-	11.5**[b]	a[3]
-	2	-	8.6	ab
-	3	-	2.4	b

* Indicates significant differences at the 5% level

** Indicates significant differences at the 1% level

[1]= Charcoal effect 1 is without charcoal, 2 is with charcoal

[2]= Treatment rate 1 is untreated, rate 2 is 2.24 kg ai ha^{-1}, rate 3 is 3.36 kg ai ha^{-1}

[3]= Tukey's mean separation at 1% level

[a]= Pooled mean values of biomass from both chemical treatments

[b]= Treatment means pooled over charcoal levels

Table 3.4. Means of *H. contortus* plant counts recorded 48 DAP in response to pre-emergence herbicides and charcoal in the hydromulch cap for safening over *H. contortus* seeds. The F-test for the effect of charcoal was not significant. Treatment rates had a significant effect on plant count numbers.

TABLE OF PLANT COUNT MEANS

Charcoal[1]	Treatment rate[1]	Means		
		Untreated	Treatment	
1	-	34.8	5.4[a]	
2	-	27.4	5.8	
-	1	-	34.5**[b]	a[3]
-	2	-	8.7	b
-	3	-	2.5	b

* Indicates significant differences at the 5% level

** Indicates significant differences at the 1% level

[1]= Charcoal effect 1 is w/o charcoal, 2 is w/ charcoal

[2]= Treatment rate 1 is untreated, rate 2 is 2.24 kg ai ha^{-1}, rate 3 is 3.36 kg ai ha^{-1}

[3]= Tukey's mean separation at 1% level

[a]= Pooled mean values of plant counts from both chemical treatments

[b]= Treatment means pooled over charcoal levels

Table. 3.5. Linear regression analysis of *H. contortus* plant counts recorded 63 DAP in response to pre-emergence herbicides in the hydromulch cap. The F-test indicated a significant negative linear response of *H. contortus* plant counts to increasing levels of oxadiazon (F = 15.78, P = 0.001).

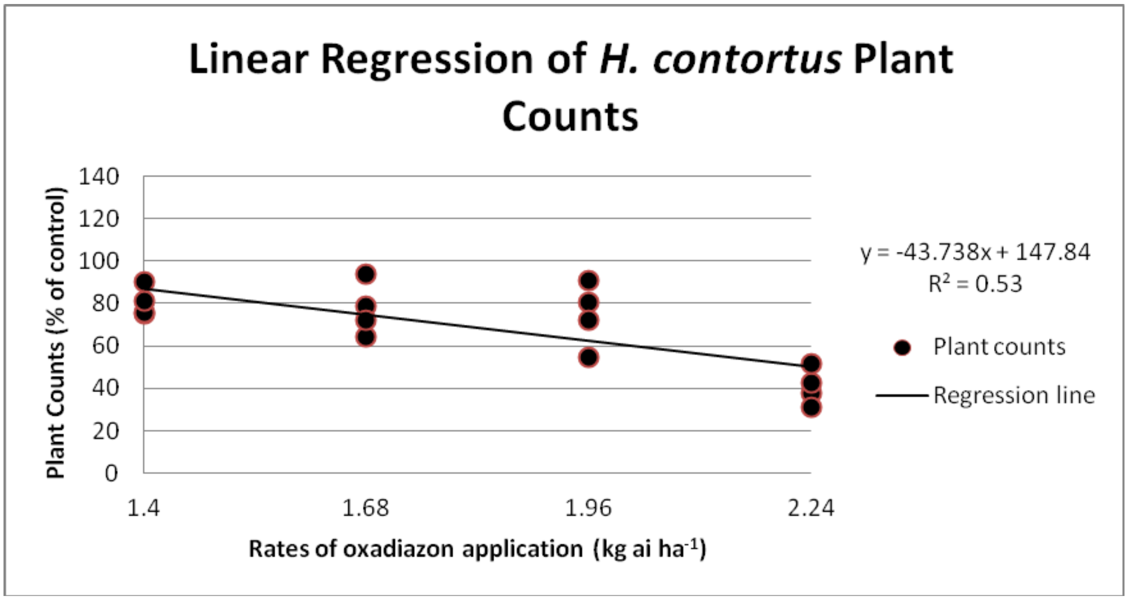


Table. 3.6. Linear regression analysis of *H. contortus* aboveground biomass recorded 63 DAP in response to pre-emergence herbicides in the hydromulch cap. The F-test indicated a significant negative linear response of *H. contortus* biomass to increasing levels of oxadiazon (F = 13.56, P = 0.002).

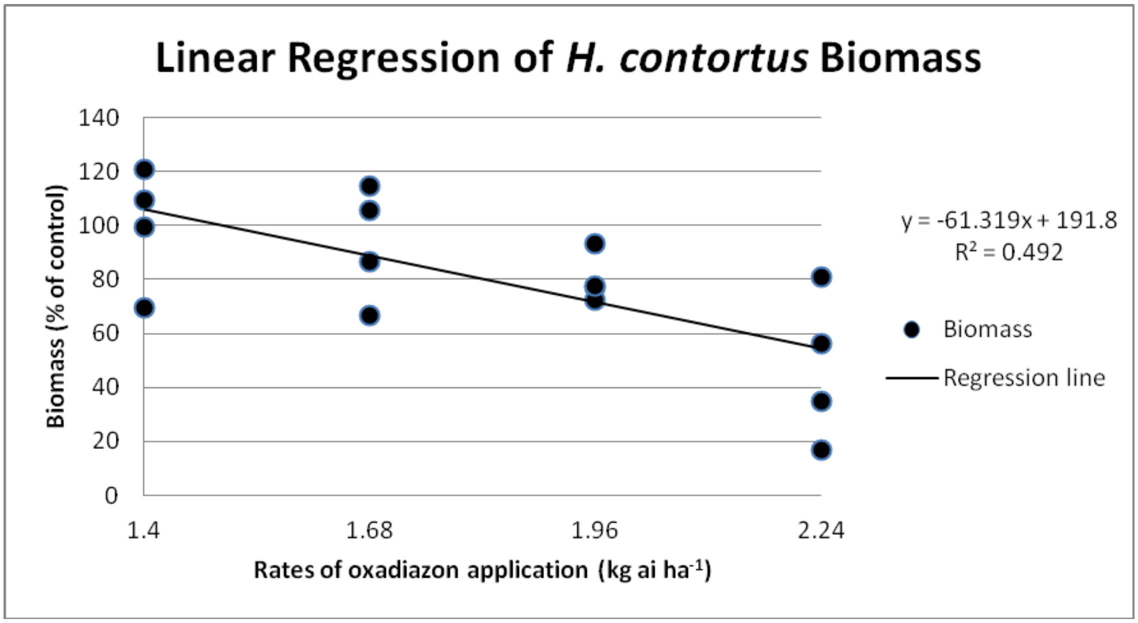


Table 3.7. Plot map of expanded rates of oxadiazon experiment. Irrigation rates (liters ha^{-1} hour^{-1}), plant counts and biomass measured in each plot. Randomized treatments listed in each plot followed by plant counts, biomass weights (g) and irrigation values on the bottom. Treatments with (-) irrigation values were due wind tipping of the collection cups.

Replication			
4	3	2	1
5 10 3.2g 79734	**3** 20 32.8g 172757	**3** 26 24.8g -	**3** 30 24.1g 86378
4 23 14.8g 79734	**1** 31 28.6g 146179	**5** 14 8.18g 126245	**4** 29 21.4g 86378
3 23 12.8g 66445	**5** 16 16.1g 152823	**2** 25 25.7g -	**2** 24 24.5g 112956
1 32 19.1g 93023	**4** 25 20.7g 93023	**4** 18 21.9g -	**1** 32 27.8g -
2 26 19.0g 106312	**2** 28 19.9g 73089	**1** 33 23.4g -	**5** 12 12.5g 86378

Figures

Figure 3.1. *H. contortus* seed ball directly from bale. Approximately 130 live seeds are a 2.0 gram portion and 258 in a 4.0 gram portion.

Figure 3.2. Split plot experimental design of *H. contortus* seed experiment of charcoal for safening effects of pre-emergence herbicides contained within the hydromulch cap. Main plot effect is charcoal and sub plot effect is oxadiazon treatment, with four replications.

Figure 3.3. Spray box (0.91 m. x 0.91 m.) utilized to eliminate herbicide treatment cross contamination between experimental plots.

Figure 3.4. Experimental design installed as a random complete block with four rates of oxadiazon and one control treatment, with four replications.

Figure 3.5. Comparison of weed pressure and *H. contortus* plant counts at 48 DAP. Representative photographs are in order of control, 2.24 kg ai ha^{-1} and 3.36 kg ai ha^{-1} treatments (from top to bottom). Higher plant counts were found in the low rate of the chemical treatment.

Figure 3.6. Weed biomass and percent weed control at 35 DAP. Rate of oxadiazon application, Treatment 1 =1.4 kg ai ha^{-1}, treatment 2 = 1.68 kg ai ha^{-1}, treatment 3 = 1.96 kg ai ha^{-1} and treatment 4 = 2.24 kg ai ha^{-1}. 100 weed control is found throughout all of the oxadiazon plots, compared to that of the control.

Control

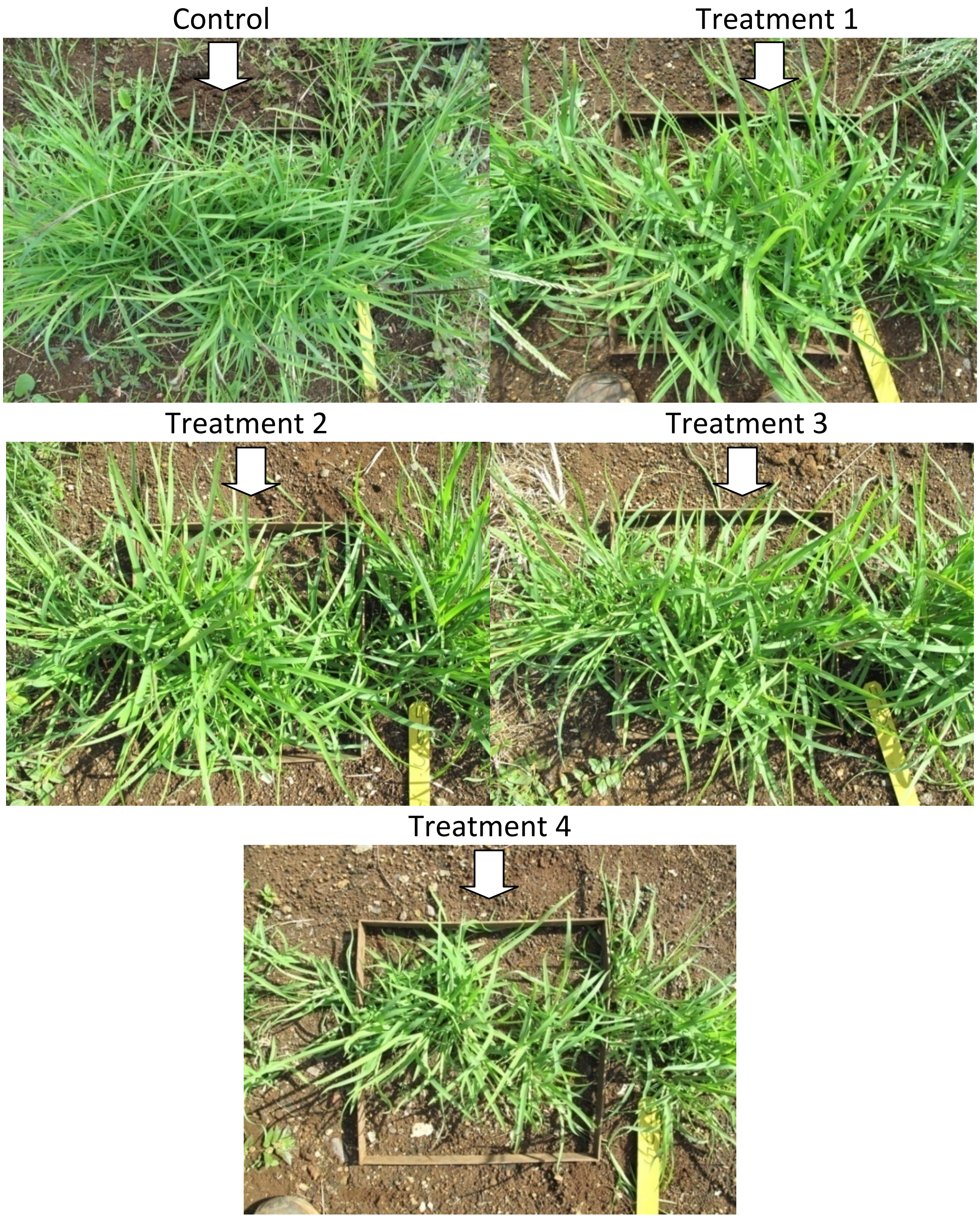
Treatment 1

Treatment 2

Treatment 3

Treatment 4

Figure 3.7. H. contortus growth at 63 DAP. Rate of oxadiazon application, Treatment 1 =1.4 kg ai ha^{-1}, treatment 2 = 1.68 kg ai ha^{-1}, treatment 3 = 1.96 kg ai ha^{-1} and treatment 4 = 2.24 kg ai ha^{-1}. Highest biomass and plant counts were determined in the low rate of the oxadiazon treatment.


Control

Treatment 1

Treatment 2

Treatment 3

Treatment 4

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Appendix A

Apical Shoot Counts Analysis of Variance (Trial one 36 DAP, Trial two 42 DAP)

```
                 A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                 Degrees of   Sum of         Mean          F
Value    Source       Freedom    Squares        Square       Value     Prob
-----------------------------------------------------------------------------
  1      Year            1     122388.781    122388.781      8.4645   0.0094
  3      R(Y)            6     626861.438    104476.906      7.2257   0.0005
  4      Form            1     199870.031    199870.031     13.8232   0.0016
  5      YF              1      26277.781     26277.781      1.8174   0.1943
  8      Rate            1        258.781       258.781      0.0179
  9      YR              1       3507.031      3507.031      0.2425
 12      FR              1        810.031       810.031      0.0560
 13      YFR             1      32067.781     32067.781      2.2178   0.1537
-15      Error          18     260262.313     14459.017
-----------------------------------------------------------------------------
         Total          31    1272303.969
```

Time to weed free status Analysis of Variance (Trial one 47 DAP, Trial two 78 DAP)

```
                 A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                 Degrees of   Sum of         Mean          F
Value    Source       Freedom    Squares        Square       Value     Prob
-----------------------------------------------------------------------------
  1      Year            1        790.031       790.031     73.7533   0.0000
  3      R(Y)            6        159.938        26.656      2.4885   0.0624
  4      Form            1          0.031         0.031      0.0029
  5      YF              1         52.531        52.531      4.9041   0.0399
  8      Rate            1         57.781        57.781      5.3942   0.0321
  9      YR              1          1.531         1.531      0.1429
 12      FR              1          1.531         1.531      0.1429
 13      YFR             1         19.531        19.531      1.8233   0.1937
-15      Error          18        192.813        10.712
-----------------------------------------------------------------------------
         Total          31       1275.719
```

New Apical Shoot Counts Analysis of Variance (Trial one 47 DAP, Trial two 78 DAP)

```
                 A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                    Degrees of   Sum of          Mean          F
Value    Source          Freedom    Squares        Square       Value     Prob
-----------------------------------------------------------------------------
  1     Year                1    177459.031    177459.031     51.4587   0.0000
  3     R(Y)                6    146107.938     24351.323      7.0613   0.0005
  4     Form                1     69844.531     69844.531     20.2532   0.0003
  5     YF                  1      6699.031      6699.031      1.9426   0.1804
  8     Rate          1        270.281       270.281      0.0784
  9     YR                  1      7719.031      7719.031      2.2383   0.1520
 12     FR                  1      2096.281      2096.281      0.6079
 13     YFR                 1        38.281        38.281      0.0111
-15     Error              18     62074.313      3448.573
-----------------------------------------------------------------------------
        Total              31    472308.719
```

Time to Weed Free Status Analysis of Variance (Trial one 110 DAP, Trial two 127 DAP)

```
                 A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                    Degrees of   Sum of          Mean          F
Value    Source          Freedom    Squares        Square       Value     Prob
-----------------------------------------------------------------------------
  1     Year                1      7472.531      7472.531      6.6314   0.0191
  3     R(Y)                6     12623.688      2103.948      1.8671   0.1422
  4     Form                1        69.031        69.031      0.0613
  5     YF                  1         0.031         0.031      0.0000
  8     Rate                1        26.281        26.281      0.0233
  9     YR                  1      1417.781      1417.781      1.2582   0.2767
 12     FR                  1      5227.531      5227.531      4.6391   0.0451
 13     YFR                 1      8482.531      8482.531      7.5277   0.0134
-15     Error              18     20283.063      1126.837
-----------------------------------------------------------------------------
        Total              31     55602.469
```

Duncan’s Multiple range test

Year	From	Rate	Means
1	1	1	43.8 bc
1	1	2	25.3 c
1	2	1	39.8 bc
1	2	2	35.3 bc
2	1	1	28.5 c
2	1	2	101.8 a
2	2	1	89.5 ab
2	2	2	46.5 bc

Fresh Weed Biomass Analysis of Variance (Trial one 110 DAP, Trial two 127 DAP)

```
                 A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                    Degrees of   Sum of         Mean         F
Value    Source          Freedom    Squares        Square       Value     Prob
-----------------------------------------------------------------------------
  1     Year               1        162.000        162.000      0.7970
  3     R(Y)               6       2021.500        336.917      1.6576   0.1890
  4     Form               1       1058.000       1058.000      5.2054   0.0349
  5     YF                 1         40.500         40.500      0.1993
  8     Rate               1        544.500        544.500      2.6790   0.1190
  9     YR                 1         32.000         32.000      0.1574
 12     FR                 1        392.000        392.000      1.9287   0.1819
 13     YFR                1        760.500        760.500      3.7417   0.0689
-15     Error             18       3658.500        203.250
-----------------------------------------------------------------------------
        Total             31       8669.500
```

S. virginicus Biomass Analysis of Variance (Trial one 110 DAP, Trial two 127 DAP)

```
                 A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                    Degrees of   Sum of         Mean         F
Value    Source          Freedom    Squares        Square       Value     Prob
-----------------------------------------------------------------------------
  1     Year               1          2.820          2.820      0.0482
  3     R(Y)               6        237.512         39.585      0.6764
  4     Form               1        475.090        475.090      8.1182   0.0106
  5     YF                 1        144.925        144.925      2.4764   0.1330
  8     Rate               1        216.840        216.840      3.7053   0.0702
  9     YR                 1         13.913         13.913      0.2377
 12     FR                 1        551.950        551.950      9.4315   0.0066
 13     YFR                1         75.953         75.953      1.2979   0.2695
-15     Error             18       1053.396         58.522
-----------------------------------------------------------------------------
        Total             31       2772.400
```

Percent Visual Cover Analysis of Variance (Trial one 110 DAP, Trial two 127 DAP)

```
                 A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                    Degrees of   Sum of         Mean         F
Value    Source          Freedom    Squares        Square       Value     Prob
-----------------------------------------------------------------------------
  1     Year               1         24.500         24.500      0.1360
  3     R(Y)               6        620.000        103.333      0.5738
  4     Form               1       1378.125       1378.125      7.6527   0.0127
  5     YF                 1        120.125        120.125      0.6671
  8     Rate               1         91.125         91.125      0.5060
  9     YR                 1         91.125         91.125      0.5060
 12     FR                 1       1012.500       1012.500      5.6224   0.0291
 13     YFR                1        684.500        684.500      3.8010   0.0670
-15     Error             18       3241.500        180.083
-----------------------------------------------------------------------------
      Total             31       7263.500
```

Appendix B

Heteropogon contortus Plant Counts Analysis of Variance (48 DAP)

```
Analysis of Variance Table

Source                         DF        SS        MS        F         P
Rep                             3    116.46     38.82
Carcoal                         1      0.04      0.04     0.00    0.9914
Error Rep*Carcoal               3    918.79    306.26
Treatment                       2   4616.08   2308.04    14.19    0.0007
Carcoal*Treatment               2      6.08      3.04     0.02    0.9815
Error Rep*Carcoal*Treatment    12   1952.50    162.71
Total                          23
```

Heteropogon contortus Aboveground Biomass Analysis of Variance (48 DAP)

```
Analysis of Variance Table

Source                          DF        SS        MS       F         P
Rep                              3    26.547     8.849
Charcoal                         1    11.662    11.662    0.46    0.5446
Error Rep*Charcoal               3    75.392    25.131
Treatment                        2   343.125   171.563    7.65    0.0072
Charcoal*Treatment               2    30.747    15.373    0.69    0.5225
Error Rep*Charcoal*Treatment    12   269.081    22.423
Total                           23
```

Appendix C

Heteropogon contortus Plant Counts Analysis of Variance (63 DAP)

```
Least Squares Linear Regression of Counts

Predictor
Variables   Coefficient   Std Error         T         P
Constant        98.8503     8.44166     11.71    0.0000
Rates          -12.2467     3.08246     -3.97    0.0014

R-Squared           0.5300      Resid. Mean Square (MSE)    190.031
Adjusted R-Squared  0.4964      Standard Deviation          13.7852
AICc                89.818
PRESS               3365.5

Source        DF        SS        MS        F        P
Regression     1   2999.63   2999.63    15.78   0.0014
Residual      14   2660.43    190.03
Total         15   5660.06

Lack of Fit    2   1120.58   560.292     4.37   0.0376
Pure Error    12   1539.85   128.321
```

Heteropogon contortus Aboveground Biomass Analysis of Variance (63 DAP)

```
Least Squares Linear Regression of Percent

Predictor
Variables   Coefficient   Std Error         T         P
Constant        191.803     30.7516      6.24    0.0000
Treatments      -61.3193     16.6519     -3.68    0.0025

R-Squared           0.4920      Resid. Mean Square (MSE)    434.786
Adjusted R-Squared  0.4557      Standard Deviation          20.8515
AICc                103.06
PRESS               8346.6

Source        DF        SS        MS        F        P
Regression     1    5895.8   5895.76    13.56   0.0025
Residual      14    6087.0    434.79
Total         15   11982.8

Lack of Fit    2    731.83   365.914     0.82   0.4637
Pure Error    12   5355.18   446.265
```