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Weed control and the response of transplanted uhaloa in the presence of two pre-emergence herbicides applied at the time of planting

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Abstract

The Hawaii Statewide Noxious Invasive Pest Program (SNIPP) and associated storm water management plans provide statutory justification for increased use of native plants along the State of Hawaii transportation corridors. The demand for native plants exceeds the availability of plant materials or seed. To produce seed stock and ensure seed lot purity, establishment protocols for weed control must first be defined. Uhaloa (*Waltheria indica)*, a native Hawaiian broadleaf shrub has been identified for increased roadside usage, thus will be the focus of this research. Weed control during the establishment phase of uhaloa is essential for optimising establishment success. In this study, the efficacy and phytotoxicity of the pre-emergence herbicides oxadiazon and indaziflam, applied over uhaloa transplants, were evaluated. Crop and weed response to granular oxadiazon at 2.24 kg ai ha^{-1} and 4.48 kg ai ha^{-1} and flowable indaziflam at 24 g ai ha^{-1} and 49 g ai ha^{-1} were determined. Unacceptable uhaloa injury with both rates of indaziflam was recorded. Oxadiazon provided excellent broad-spectrum weed control with acceptable injury to uhaloa.

Key words: Establishment, Hawaii, herbicide tolerance, native plant, seed production, *Waltheria indica*.

Introduction

Utilizing pre-emergence herbicides to reduce weed competition is well established in crop production. Production of native plant species for seed or restoration purposes does not differ in the requirements of weed control (Grilz and Romo, 1995; Hitchmough *et al.*, 1994; Tjelmeland *et al.*, 2008). However, there are a limited number of commercial herbicides available in North America for application to native plant species (Smith and Whalley, 2002). In the State of Hawaii, initiatives called for planting of native species along the Department of Transportation roadway corridors (Tamimi, 1999). To comply with federal presidential acts, the State of Hawaii initiated the Statewide Noxious Invasive Pest Program (SNIPP) (Hawaii Dept. of Transportation, 2011). One aspect of the SNIPP plan calls explicitly for the re-vegetation of native species along roadway corridors. Aside from the SNIPP plan, statutory regulations of the Clean Water Act, National Pollutant Discharge Elimination System (NPDES) and associated stormwater pollution prevention plans for roadways on Oahu, Hawaii integrates the planting of native species as a best management practice (BMP) (Hawaii Dept. of Transportation, 2007). Weed interference is the primary constraint to successful establishment of native plant communities (Masters *et al.*, 1996). Herbicides are an essential component of management strategies that are being developed to establish native grasses in restoration projects (Masters *et al.*, 1996). Using roadways as sites for growing native plants allows for legal usage of herbicides labelled for rights-of-way sites. Most modern herbicides have product labels that list "rights-of-way" or "non-crop area" as legitimate sites of application. When native Hawaiian plants are used in roadside landscapes or grown on roadsides for seed production, herbicides labelled for use on highway rights-of-way can be applied during establishment and for maintaining weed-free status without violating label instructions. Roadside rights-of-way represent a unique area for growing native plants due to the wide range of chemicals available for weed control during establishment, growth and seed production cycle.

Uhaloa belongs to the order Malvales and family Sterculiaceae. It is a short-lived shrub or subshrub, sometimes reaching 2 m in height and 2 cm in stem diameter (Duvachelle, personal communication, 2014). The shrub usually has a single strong stem, but frequently branches near the ground. A variety of upright and prostrate growth forms have been observed from seedling populations. Axillary inflorescences are usually dense glomerules that contain fragrant, yellow to orange flowers. Each 2-mm capsule holds one small, black, obovoid seed (Howard, 1974).

Uhaloa is a pan-tropical shrub species which occurs in diverse populations in the Americas, Mexico and Brazil. One report states that in Hawaii, uhaloa was naturalized soon after the arrival of non-native colonists (Haselwood and Motter, 1966). Despite Haselwood's report, uhaloa is more widely classified as a native plant, postulating that the small seeds may have attached to birds which distributed the plant to Hawaii (Wester, 1992). Reinforcing the native status, during Captain Cook's voyage to Hawaii in 1779, onboard botanist, David Nelson noted uhaloa in regions with arid, xerophytic scrub vegetation and an annual rainfall of about 50 cm (St. John, 1979). In certain regions of the world, uhaloa is considered an invasive weed (Sãnchez and Uranga, 1993). It is found in well-drained soils of all types. In Hawaii, the species elevation ranges from sea level to 1220 meters. Current populations tend to occur in altered sites, where soil disturbance has occurred (Long and Lakela, 1971). Uhaloa is a good candidate for re-vegetation and seed production purposes due to high drought tolerance and continual year-round production of flowers and seeds.

Uhaloa is one of the target species identified for the development of seed production protocols in Hawaii and will be the focus of this research. The identification of pre-emergence herbicides effective for use in the establishment of uhaloa is necessary for increased usage as a ground cover and weed-free seed production. The identification of uhaloa response to pre-emergent chemicals has not been reported in scientific literature. Recent work conducted on weed control in native Hawaiian plant species indicates that the best establishment success is achieved by applying pre-emergence herbicides over the top of transplanted plants. In the native Hawaiian grass akiaki (*Sporobolus virginicus)*, transplants treated with granular oxadiazon at 4.48 kg ai ha^{-1} exhibited highest above-ground dry biomass followed by the plants treated with oxadiazon at 2.24 kg ai ha^{-1}, while maintaining weed control throughout the establishment period (Baldos *et al.*, 2010). Similarly, newly transplanted mau aki'aki (*Fimbristylis cymosa)* (a native Hawaiian sedge) was determined to have a tolerance to the pre-emergence herbicide oxadiazon, while maintaining adequate weed control (Baldos *et al.*, 2012). Conclusions from the research on other native Hawaiian species reinforce oxadiazon as effective at controlling weeds and at specific rates do not exhibit high levels of phytotoxicity. Another pre-emergence herbicide, indaziflam was recently introduced in 2010 to control grasses and broadleaf weeds in turf, which is effective for 3-5 months at low rates of application (Shaner, 2014). There have been no published reports on the phytotoxic effects of indaziflam on newly established native Hawaiian plants. The herbicides and application rate selection reported here is based on related literature and instructions on the product label oxadiazon (Bayer, 2012) and indaziflam (Bayer, 2010).

The objectives of this study has been to determine the response of uhaloa transplants and weeds to low and high rates of oxadiazon and indaziflam.

Materials and methods

Uhaloa seeds (USDA NRCS Hoolehua PMC accession # 9079945) were sown 70 d before the start of the experiment (2/15/2014 for the first experiment and 4/11/2014 for the second experimental repeat). Seeds were sown in Sunshine mix #4 with mycorrhizae (Sun Gro Horticulture®, Agawam, Massachusetts) in SC-10 dibble tubes (Stuewe & Sons Inc., Tangent, Oregon). Fertilization and irrigation were provided as needed throughout the pre-transplant production period. The herbicide tolerance experiment was conducted twice with starting dates of 04/02/2014 and 06/20/2014.

Experimental design: Planting of transplants and treatment applications were conducted on the first experiment in April 2014 and the replicate experiment in June 2014 in a field adjacent to the first.

Before planting, the soil was rototilled to incorporate 100 kg nitrogen acre^{-1} (formulation 21-4-7) to a depth of 4 inches in both experimental fields. The soil type in both of the experimental fields was Makiki stony clay loam (isohyperthermic typic haplustepts). Soil nutrient analysis was conducted after both experiments by the University of Hawaii agricultural diagnostic service centre. The first experimental field contained 221 ppm phosphorus (P), 1203 ppm potassium (K), 5056 ppm calcium (Ca), 1468 magnesium (Mg), 0.30 % nitrogen (N) with a 7.2 pH. The second experimental field contained 201 ppm P, 803 ppm K, 8199 ppm Ca, 986 ppm Mg, 0.14 % N with a 7.4 pH.

The experiments were designed as a complete random block with four chemical treatments and one untreated plot with four replications. Four uhaloa transplants were used in each 0.65 m × 1.5 m (1 m^2) experimental plot. Chemical treatments consisted of granular oxadiazon (Ronstar® G, Bayer CropScience, Research Triangle Park, NC) and flowable indaziflam (Specticle® FLO, Bayer CropScience, Research Triangle Park, NC) applied over the top of transplanted uhaloa at 2.24 & 4.48 kg ai ha^{-1} and 24 & 49 g ai ha^{-1}, respectively. Experimental treatments were applied directly after transplanting. Granular oxadiazon was applied in pre-weighed aliquots by hand to individual plots to ensure uniform distribution. Spray treatments of indaziflam were applied using a compressed carbon dioxide gas sprayer operating at 35 PSI, outfitted with a single Teejet® (TeeJet Technologies, Wheaton, Illinois) 9095 EVS nozzle (even spray pattern) calibrated to deliver 375 L ha^{-1}.

After the application of chemical treatments overhead irrigation was applied for 10 min to activate the chemicals. Trial one and two irrigation volumes measured were 1612 L ha^{-1} min^{-1} and 1520 L ha^{-1} min^{-1}, respectively (these rates were maintained for all irrigation applications). Starting on day 2, overhead sprinkler irrigation was delivered two times per day at 6:30 AM and 12:00 PM for 15 min each start time for the first trial. Moisture levels of the first trial were determined to be too high based on visual assessment, so the second trial irrigation level was reduced to 10 min each start time for the first 6 d then cut to one start time at 6:00 AM for 10 min on Monday, Wednesday and Friday.

Data collection: During the first trial, four predominant weeds were present within the experimental plots, which were assessed individually for per cent control at 45 DAP. In Trial one weed species present were spreading dayflower (*Commelina diffusa)*, common purslane (*Portulaca oleracea)*, graceful spurge (*Euphorbia hypericifolia)* and goosegrass (*Eleusine indica)*. During the second trial only two predominant weeds were present, morning glory (*Ipomoea triloba)* and goosegrass (*Eleusine indica)*.

Data were collected at three-time points at 15-day intervals starting at 15 days after planting (DAP), 30 DAP and 45 DAP. The first (15 DAP) and second (30 DAP) data collection points consisted of visual uhaloa per cent of maximum growth vigour ratings. Per cent of maximum vigour ratings of uhaloa was based on the author's familiarity of uninhibited plants grown as nursery stock and personal observations of wild plants. The third (45 DAP) and final data collection point consisted of uhaloa per cent of maximum vigour, uhaloa dried plant biomass (g/4 plants) accumulation, timed removal of weeds from experimental plots (s/m^2), dried weed biomass (g/m^2), and percent control of individual weed species present. The timed removal of weeds from the plot was used to quantify the level of weed pressure and was recorded as the time it took to return the plots to a weed-free status. The second replicate trial was conducted with all data collection times and ratings consistent with the first trial.

Data analysis: Data were analysed using the statistical analysis program Statistix™ 10.0 (Analytical Software, Tallahassee, Florida). Separate analyses were conducted for uhaloa per cent of maximum vigor for each data collection time and were analysed over both trials as a split-plot with experimental trial as the main effect and treatment as the split-plot effect. Uhaloa dry above-ground biomass accumulation in the third rating period (45 DAP) was analysed over both trials as a split-plot with experimental trial as the main effect and treatment as the split-plot effect. If no significant trial × treatment interactions were detected, data from trials were combined (Brosnan *et al.*, 2011).

Due to different weed species present in trials one and two, all weed response data were analysed individually based on trial. Weed response data were analysed using a randomised complete block design analysis of variance. Individual species per cent control data in both trials were square-root transformed to conform to the assumptions of the analysis of variance (Ahrens *et al.*, 1990). When significant effects were detected, means were separated using Tukey's all pairwise HSD test at $\alpha = 0.05$.

Results and discussion

Data collection 1 (15 DAP): Results of the analysis for per cent of maximum growth vigour did not detect a significant trial × treatment interaction (P=0.118); thus results were pooled over trial; however a significant treatment effect was detected (P< 0.001). No significant differences were detected in plant vigour of uhaloa between the untreated and the low rate of oxadiazon plots (99 % and 98 %, respectively). A significant reduction in percent of maximum vigour was recorded for the high rate of oxadiazon (88 %) and both rates of indaziflam (low rate = 57 % and high rate = 26 %) (Table 1).

Data collection 2 (30 DAP): The results of the analysis for uhaloa per cent of maximum vigour did not reveal a significant interaction between the factors of trial × treatment (P= 0.078); thus results were pooled over trials. A significant treatment effect was detected (P< 0.001). The untreated and low rate of oxadiazon treatments resulted in the significantly highest per cent of maximum vigor (97 % and 94 %, respectively), followed by the high rate of oxadiazon and the low rate of indaziflam (69 % and 46 %, respectively), the high rate of indaziflam imposed the highest level of percent of maximum vigor suppression (Fig. 1 and 2) (Table 1).

Table 1. Uhaloa percent of maximum vigor response to the pre-emergence herbicides oxadiazon and indaziflam applied at low and high label rates. Means are separated using Tukey's HSD comparison at P=0.05. Means within columns followed by the same letter are not significantly different

Treatment		Uhaloa percent of maximum vigor		
Chemical	Rate (kg ai ha^{-1})	15 DAP	30 DAP	45 DAP
Oxadiazon	2.24	98 A	94 A	82 A
	4.48	88 B	69 B	60 B
Indaziflam	0.024	57 C	46 B	37 B
	0.049	26 D	18 C	24 B
Untreated	-	99 A	97 A	69 B

Fig. 1. Experimental plots (1 m^2) with four uhaloa plants. Uhaloa percent of maximum vigor response at 30 DAP to oxadiazon at 2.24 kg ai ha^{-1} (left) compared to indaziflam at 49 g ai ha^{-1} (right).

Fig. 2. Experimental plots (1 m^2) with close up image of uhaloa plants. Uhaloa percent of maximum vigor response at 30 DAP to oxadiazon at 2.24 kg ai ha^{-1} (left) compared to indaziflam at 49 g ai ha^{-1} (right). Unacceptable injury is visible in the uhaloa plants treated with the high rate on indaziflam.

Data collection 3 (45 DAP): Results of the analysis for uhaloa per cent of maximum vigor did not indicate an interaction between the factors of trial × treatment (P= 0.056); thus results were pooled over trials. A significant treatment effect was detected (P<0.001). The highest per cent of maximum vigor was observed with the low rate of oxadiazon (82 %), the untreated and high rate of oxadiazon significantly lowered the per cent of maximum vigor (69 % and 60 %, respectively). The lowest level of per cent of maximum vigor was recorded in plots treated with indaziflam (Table 1). The decreased uhaloa per cent of maximum vigor in the untreated plots was attributed to weed competition.

Results of the analysis for the aboveground uhaloa dry plant biomass indicated a significant interaction between the factors of trial × treatment (P= 0.003); thus, treatment means were presented separately over trials. The highest uhaloa biomass was found in the second trial with both low and high rates of oxadiazon (137 g and 141 g, respectively). In both trials the numerically lowest biomass was detected with the high rate of indaziflam (trial 1 = 26 g and trial 2 = 7 g) (Table 2). Based on the treatment means by trial, the second trial exhibited increased biomass of uhaloa, and this can be attributed to seasonal variation as the second trial was in June compared to the first in April. Another reason for the increased biomass in the second trial may be due to the reduction of irrigation, as mentioned previously uhaloa is extremely drought-tolerant, and appears to be inhibited by excessive watering.

Table 2. Weed and uhaloa response to the pre-emergence herbicides oxadiazon and indaziflam applied at low and high label rates at 45 DAP. Means are separated using Tukey's HSD comparison at P=0.05. Means for weed response within columns followed by the same letter are not significantly different. Means for uhaloa response within columns and rows followed by the same letter are not significantly different

Treatment		Weed response				Uhaloa response	
Chemical	Rate (kg ai ha^{-1})	Weed free time (s/m^2)		Weed biomass (g/m^2)		Dry biomass (g)	
		Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Oxadiazon	2.24	12 A	16A	24 A	43A	40 BCD	137 A
	4.48	5 A	4A	6 A	3A	16 D	141 A
Indaziflam	0.024	20 A	8A	34 A	79A	20 CD	80 B
	0.049	19 A	4A	16 A	41 A	7 D	26 CD
Untreated	-	118B	102B	163 B	521 B	18 D	75 D

In the first trial, a significant effect of treatment on weeding times (P< 0.001) was observed. Weeding times were significantly lower in all herbicide treated plots compared to the untreated control (Table 2). Numerically lowest weeding times were found in the high rate of the oxadiazon treatment (5 seconds). In the second trial, a significant effect of treatment on weeding times (P< 0.001) was observed. Significantly lower weeding times were found in all herbicide treated plots compared to the untreated control (Table 2).

During the first trial, the results of the analysis indicated a significant effect of treatment on weed biomass within experimental plots (P< 0.001). Weed biomass was significantly lower in all herbicide treated plots compared to the untreated control (Table 2). During the second trial, the results of the analysis indicated a significant effect of treatment on weed biomass within experimental plots (P< 0.001). Weed biomass was significantly lower in all herbicide treated plots compared to the untreated control (Table 2). Morning glory was present during this trial and was not adequately controlled with a low rate of indaziflam.

During the first trial, spreading dayflower control in herbicide treated plots did not differ from the untreated control (Table 3) indicating a lack of commercially acceptable control. Common purslane and graceful spurge were well controlled by all herbicide treatments with oxadiazon at the high rate providing 100 % control. The low rate of indaziflam did not provide commercially acceptable control of common purslane and graceful spurge. Total (100 %) control of goosegrass was recorded for both herbicides at both high and low rates of application during both runs of the experiment. During the second trial, morning glory emergence was variable throughout the experimental area, with only weak suppression imposed by the low rate of indaziflam.

In both experiments, broadleaf weed control was consistently higher with oxadiazon than indaziflam. Both herbicides, well-controlled the single grass species (goosegrass) present during both experiments at rates of application recommended by the product label. Reported literature confirms indaziflam as very effective in controlling grass species such as smooth crabgrass (*Digitaria ischaemum)* and annual bluegrass (*Poa annua)* (Brosnan *et al.*, 2011; Hunter Perry *et al.*, 2011).

Uhaloa growth in indaziflam treated plots was significantly reduced, indicating that this herbicide will not be useful for weed control during early establishment using transplants. Oxadiazon, applied in a granular formulation to Uhaloa transplants, was shown to provide a satisfactory level of grass and broad leaf weed control with an acceptable level of growth inhibition.

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Table 3. Percent control of individual weed species present in trials one and two at 45 DAP. Means are separated using Tukey's HSD comparison at P=0.05. Means within columns followed by the same letter are not significantly different

Treatment		Percent of weed species controlled					
Chemical	Rate (kg ai ha^{-1})	Trail 1				Trail 2	
		Spreading dayflower	Common purslane	Graceful spurge	Goosegrass	Morning glory	Goosegrass
Oxadiazon	2.24	72A	93A	95A	98A	66AB	100A
	4.48	82A	100A	100A	100A	92A	100A
Indaziflam	0.024	72A	71A	72A	94A	28AB	100A
	0.049	72A	97A	94A	98A	65AB	100A
Untreated	-	72A	3B	0B	0B	2B	5B

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