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Bermudagrass suppression and goosegrass control in seashore paspalum turf

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Abstract

Seashore paspalum has gained increased popularity in Hawaii due to its salt tolerance and the use of non-potable water on golf courses. Bermudagrass and goosegrass are problem weeds infesting both fairways and greens on many seashore paspalum golf courses. Herbicide efficacy studies were conducted at the West Loch Golf Course ('Salam' seashore paspalum, greens cut) on the island of Oahu in Hawaii. The herbicides metribuzin, topramezone, mesotrione, and ethofumesate were evaluated in tank mixtures for bermudagrass and mature goosegrass control and seashore paspalum injury. Goosegrass was controlled with tank mixes that included topramezone (0.01 kg ha^{-1}) + metribuzin (0.10 kg ha^{-1}) with an acceptable level of seashore paspalum discoloration. Incorporating a post-spray dry down allowed for complete control of goosegrass with one spray application. Maximum bermudagrass injury was seen in treatments with mesotrione (0.07 kg ha^{-1}) and/or ethofumesate (1.12 kg ha^{-1}). Applications of mesotrione did not result in goosegrass control. Seashore paspalum turf bleaching from mesotrione and topramezone can be reduced with the addition of metribuzin and/or ethofumesate to the tank mix.

Key words: *Paspalum vaginatum* Swartz, *Cynodon dactylon* x *Cynodon transvaalensis*, *Eleusine indica* (L) Gaertn, metribuzin, topramezone, mesotrione, ethofumesate, postemergence herbicide, turfgrass, weed control

Introduction

Traditionally, most golf courses in Hawaii use bermudagrass as the primary turfgrass species. However, in recent years, a number of new golf courses in Hawaii have adopted seashore paspalum as the primary turfgrass species and others are replacing bermudagrass greens with seashore paspalum. This recent change in turfgrass species has been attributed to increased soil salinity. According to Duncan and Carrow (1998), major contributors to soil salinity include: increased use of recycled water on turfgrass, location of golf courses on shorelines and on nutrient poor sites, the use of high sand root zone mixes that more readily become salinized compared to fine-textured soils, and the emphasis on potable water conservation.

Seashore paspalum has excellent tolerance to saline soils and irrigation (Lee *et al.,* 2004). This salinity tolerance may support the use of granular sodium chloride salt applications to control grassy weeds in seashore paspalum (Duncan and Carrow, 2000). Seashore paspalum may also require fewer nutrient inputs than bermudagrass to maintain a commercially acceptable turfgrass appearance (Duncan, 1996). Bermudagrass turf quality is reduced when irrigated with non-potable water containing high salt levels. Bermudagrass treated with 55 dS m^{-1} (ocean water) for 6 d resulted in injured up to 30 %, at 37 dS m^{-1} only minor injury occurred, and at 19 dS m^{-1} there was no injury (Wiecko, 2003). Seashore paspalum tolerates soil salinity levels as high as 54 dS m^{-1} (Brosnan and Deputy, 2008).

An ongoing challenge of seashore paspalum management is bermudagrass contamination and continuous goosegrass infestation (Brosnan, 2015). In Hawaii, grassy weed infestation is the most persistent pest problem in seashore paspalum turf due to environmental conditions favoring year-round growth of weed populations and limited herbicide availability (Brosnan and DeFrank, 2008).

Bermudagrass infestation is common in seashore paspalum since it is adapted to similar environments and use patterns. Herbicide efficacy studies have been conducted to identify compounds that can suppress bermudagrass in other warm-season turfgrasses. Sequential applications of ethofumesate plus atrazine provided excellent control of common bermudagrass (*Cynodon dactylon*) in St. Augustinegrass (*Stenotaphrum secundatum*) (McCarty, 1996). However, this treatment is not useful for bermudagrass control in seashore paspalum. Atrazine is not registered for use in Hawaii and causes excessive injury to seashore paspalum (Purdue University, 2018; Yu *et al.,* 2015). Multiple applications of fenoxaprop + triclopyr or fluazifop + triclopyr suppressed bermudagrass in zoysiagrass (*Zoysia* sp.) (McElroy and Breeden, 2006). McCullough (2017) concluded that fenoxaprop, fluazifop, and triclopyr are not safe to use on seashore paspalum. Traditionally, golf courses have relied on spot treatments of glyphosate for bermudagrass control (Johnson, 1988).

Currently, ethofumesate is the only selective herbicide labeled for bermudagrass suppression in seashore paspalum (Bayer Crop Science, 2017a). Bermudagrass suppression is attributed to higher foliar and root absorption of ethofumesate compared to seashore paspalum (McCullough *et al.,* 2016). Sequential applications of ethofumesate plus flurprimidol provided maximum suppression when applied as the bermudagrass broke cold induced dormancy, but were less successful once active growth began. Although bermudagrass suppression was achieved, the seashore paspalum injury was considered unacceptable for practical use (Johnson and Duncan, 2000). McCullough (2017) evaluated bermudagrass management with ethofumesate, fluazifop, and clethodim concluding that single herbicide or combinations were ineffective so far and caused too much damage to seashore paspalum.

Goosegrass is well adapted to highly compacted soils with year round growth and seed production in tropical areas like Hawaii (Wiecko, 2000). Topramezone and mesotrione are the only herbicides currently labeled for postemergence goosegrass control in seashore paspalum; however, label warnings describe persistent foliar bleaching. (BASF Corporation, 2017; Syngenta Crop Protection, 2017). Goosegrass control has been achieved in other turf species, but options are limited for seashore paspalum. In creeping bentgrass and non-overseeded bermudagrass, the best option for effective preemergence control of goosegrass on putting greens was bensulide + oxadiazon (Brosnan, 2015). Selective postemergence herbicide control of goosegrass in other turf species include diclofop plus metribuzin, monosodium methanearsonate (MSMA) plus metribuzin, and foramsulfuron plus metribuzin (Busey, 2004; Nishimoto and Kawate, 2003). Goosegrass control in bermudagrass with minimal reduction in turf density can be achieved by the use of topramezone alone or tank-mixed with triclopyr; however, significant turf discoloration occurs (Cox *et al.,* 2017). The addition of chelated iron to a tank mix with topramezone provided control of goosegrass and acted as a safener to bermudagrass by reducing turf discoloration (Boyd *et al.,* 2016a, 2016b). In bermudagrass greens, the best option for goosegrass control is mechanical removal before weed populations become problematic (Brosnan, 2015). Brosnan *et al.* (2009) evaluated sodium chloride applications as an alternative to herbicide control of goosegrass in seashore paspalum turf. However, sequential granular applications of sodium chloride did not effectively control goosegrass in the study.

Tee-boxes, aprons and greens are maintained at low heights of cut on golf courses, which results in shallow roots systems and a low tolerance to herbicide injury. The greater potential for turf injury in these areas deters pesticide manufacturers from including these sites on their product labels. The objective of this study was to evaluate herbicide treatments for bermudagrass and goosegrass control and seashore paspalum injury on golf course greens maintained in a manner consistent with industry standards in Hawaii.

Materials and methods

Studies were conducted on a 'Salam' seashore paspalum green with natural infestations of bermudagrass and mature goosegrass at the West Loch Golf Course (Ewa Beach, HI) in Feb, 2017 and Mar, 2017. The seashore paspalum green was a 30 yr. old native soil green, established on soils consisting of a Helemano silty clay (Very-fine, kaolinitic, isohyperthermic Rhodic Eutrustox) and Keaau clay, saline soil (Very-fine, smectitic, calcareous, isohyperthermic Cumulic Vertic Endoaquolls), and topdressed with sand (D. Kira, personal communication). Plot sizes were 0.9 m wide by 4.6 m long, with a 0.3 m nontreated buffer between plots.

Herbicide treatments were: topramezone (0.01 kg ha^{-1}) + metribuzin (0.10 kg ha^{-1}); topramezone (0.01 kg ha^{-1}) + metribuin (0.10 kg ha^{-1}) + ethofumesate (0.56 kg ha^{-1}), followed by ethofumesate (0.56 kg ha^{-1}) 2 weeks after initial treatments (WAIT); topramezone (0.01 kg ha^{-1}) + metribuin (0.09 kg ha^{-1}) + ethofumesate (1.12 kg ha^{-1}); and ethofumesate (0.56 kg ha^{-1}), followed by mesotrione (0.07 kg ha^{-1}) + metribuzine (0.10 kg ha^{-1}) + ethofumesate (0.56 kg ha^{-1}) 2-WAIT. Due to space limitations, a nontreated control could not be accommodated. However, bermudagrass and goosegrass infestations were observed outside of the test area throughout the duration of the study. Treatments were developed from previous research at the Pali Golf Course (Windward Oahu, HI) and at the Hoakalei Country Club (Ewa Beach, HI). At the Pali Golf Course, goosegrass control was achieved with topramezone + metribuzin and topramezone applied alone resulted in undesired turf bleaching to the seashore paspalum (DeFrank, 2016). At the Hoakalei Country Club, the treatments mesotrione + metribuzin + ethofumesate and topramezone + metribuzin + ethofumesate resulted in bermudagrass injury with minimal damage to seashore paspalum fairways (Lindsey *et al.*, 2019). Treatments were applied using a single-nozzle boom fitted with an air induction nozzle tip (TeeJet AI 9508 E, Spraying Systems Co., Wheaton, IL). The herbicide spray solutions were prepared in 3-L plastic bottles and applied with a carbon dioxide (CO_2) powered backpack sprayer calibrated to apply 411.6 L ha^{-1} at 206 kPa. The spray system was thoroughly rinsed with water between treatments to prevent cross contamination. Trial 1, initial treatments were applied on 14 Feb, 2017 and the second series of treatments were applied on 23 Mar, 2017 (37 d apart). Trial 2, initial treatments were applied on 7 Mar, 2017 and the second series of treatments were applied on 20 Apr, 2017 (44 d apart). No irrigation was applied for 16 d following the initial herbicide treatments in trial 1, due to an undetected failure in the automated irrigation system following a facility wide power outage. Trial 2 received regular irrigation (*i.e.*, irrigation amount and frequency consistent with commercial greens appearance and usage) throughout the experiment.

The experimental design was a split-plot with four replications. Trial run was the main factor with herbicide treatment as the sub-factor. Visual ratings of green color (0 = brown/white to 100 = maximum attainable green color) were recorded as the treatment response for seashore paspalum and bermudagrass. For this experiment, maximum turfgrass green color was the highest level of green color observed outside of the test area and unaffected by experimental spray applications. Commercially acceptable green color ratings in response to herbicide treatments is 80 % and above for seashore paspalum turf. Visual estimates of percent control of mature goosegrass (0 = no control to 100 = complete control/all dead) was also recorded. Bermudagrass and goosegrass populations were present outside of the treated area throughout the duration of this study. Visual ratings and estimates were conducted by A. Lindsey and J. DeFrank. Analysis of variance using the statistical software Statistix® 10.0 (Analytical Software, Tallahassee, FL) was performed on green color ratings and goosegrass control. If no interaction between trial and treatment effect occurred, means were pooled across trials. Means were separated using Tukey's mean testing.

Results and discussion

The analysis of variance (ANOVA) indicated a significant herbicide treatment effect and an interaction between trial and herbicide treatment effect ($P < 0.05$) on seashore paspalum visual green color ratings (Table 1). Topramezone + metribuzin was the

Table 1. Response of 'Salam" seashore paspalum greens to postemergence herbicides applied at the West Loch Golf Course (Ewa Beach, HI) in 2017.

Herbicide Treatment[a]	Rate ($kg\ ha^{-1}$)[b]	Visual green color rating (%)[c]										
		1-WAIT[d]		2-WAIT	3-WAIT	4-WAIT	1-WAST		2-WAST		3-WAST	
		Trial 1	Trial 2	Pooled[e]	Pooled	Pooled	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Topramezone + Metribuzin	0.01 + 0.10	81 b[f]	72 c	85 b	95 a	97 a	78 d	88 c	87 b	94 a	91 c	96 a
Topramezone + Metribuzin + Ethofumesate + 2-WAIT Ethofumesate	0.01 + 0.10 + 0.56 + 0.56	85 b	82 b	87 b	92 a	95 a	91 bc	96 ab	94 a	94 a	93 abc	96 a
Topramezone + Metribuzin + Ethofumesate	0.01 + 0.10 + 1.12	84 b	87 b	87 b	93 a	96 a	89 c	96 ab	95 a	96 a	92 bc	96 ab
Ethofumesate + 2-WAIT Mesotrione + Metribuzin + Ethofumesate	0.56 + 0.07 + 0.10 + 0.56	97 a	97 a	96 a	80 b	91 b	94 ab	97 a	94 a	95 a	87 d	94 abc
F value		4.96		16.4	40.32	27.63	3.84		6.51		3.28	
P value		0.011		< 0.0001	< 0.0001	< 0.0001	0.0275		0.0036		0.045	

[a] Herbicides were applied on the following dates: trial 1 initial treatments were applied on 14 Feb, 2017 and the second series of treatments were applied on 23 Mar, 2017; trial 2 initial treatments were applied on 7 Mar, 2017 and the second series of treatments were applied on 20 Apr, 2017.

[b] All treatments received methylated seed oil (1.0 % v/v), added for enhanced foliar penetration.

[c] Visual green color rating (0 = brown/white, 100 = maximum attainable green color). Maximum turfgrass green color was the highest level of green color observed outside of the test area and unaffected by experimental spray applications.

[d] WAIT = weeks after initial treatments, WAST = weeks after the start of the second series of treatments.

[e] No trial and treatment interaction, data pooled over trial.

[f] Means within weekly rating columns followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.05$

only treatment that resulted in seashore paspalum green color ratings below the commercially acceptable standards (*i.e.* below 80 %). However, green color recovered to acceptable standards by 2-WAIT and 2 weeks after the start of the second series of treatments (WAST). The unintentional post-spray cessation of irrigation after the initial applications of treatments in trial 1 did not affect seashore paspalum green color ratings.

All treatments caused minimal seashore paspalum green color loss and the stoppage in irrigation had little impact on green color in nontreated portions of the green. The addition of metribuzin to topramezone or mesotrione was effective at reducing seashore paspalum bleaching with minimal loss of green color. The green color response of seashore paspalum was consistent with results recorded in a prior study at the Pali Golf Course (DeFrank, 2016). The addition of a photosystem II inhibitor, such as metribuzin, to a tank mixture with an 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor (topramezone and mesotrione) herbicide was reported to increase phototoxicity due complementary mode of actions or synergism (Armel *et al.,* 2005; BASF Corporation, 2017; Bayer Crop Science, 2017b; Syngenta Crop Protection, 2017). The results reported here indicate that the tank mix of topramezone or mesotrione and metribuzin did not reduce seashore paspalum green color below commercially acceptable standards (*i.e.* 80 % of maximum green color). The addition of ethofumesate slightly enhanced the safening of metribuzin when included in a tank mix with HPPD inhibitors. The reduced expression of seashore paspalum foliar bleaching by HPPD inhibitors was attributed to growth inhibition imposed by metribuzin and/or ethofumesate of new foliage, where the expression of foliar bleaching by HPPD inhibitors is most prominent (Bayer Crop Science, 2017a; Bayer Crop Science, 2017b; Gunsolus and Curran, 2002; Lindsey *et al.,* 2019; Syngenta Crop Protection, 2017).

The ANOVA indicated a significant interaction between trial and herbicide treatment effect ($P < 0.05$) on bermudagrass green color ratings (Table 2). The stoppage of irrigation following initial treatments in trial 1 appeared to have an effect on bermudagrass green color ratings. Bermudagrass had significantly lower green color ratings 2-WAIT in trial 1 (with post-spray dry down) compared to trial 2 (no post-spray dry down). The lowest bermudagrass green color ratings were in treatments that included ethofumesate. Although all treatments resulted in bermudagrass injury, none of them provided bermudagrass removal.

Maximum bermudagrass injury occurred in treatments that had ethofumesate and/or mesotrione and included a post-spray dry down (irrigation failure after initial spray applications in trial 1). Contributing factors to this response include higher seashore paspalum drought tolerance and longer residency of herbicides in the root zone (Duncan and Carrow, 2000). Lewis *et al.* (2016) reported that metribuzin, mesotrione, and topramezone have high water solubility (1165, 1500, and 100000 mg L^{-1}, respectively) with moderate to very high groundwater ubiquity score (GUS) due to high leaching potential index (2.57, 2.69, and 4.75, respectively). Herbicide movement from the root zone, under regular irrigation (trial 2), can account for a shortened bermudagrass recovery period.

The ANOVA indicated a significant interaction between trial and herbicide treatment effect ($P < 0.05$) on percent control of goosegrass (Table 3). At 3-WAST, treatments that contained topramezone + meribuzin, followed by a post-spray dry down (trial 1) resulted in significantly higher percent control of goosegrass compared to the same treatments under normal irrigation (trial 2). However, all treatments that contained topramezone + metribuzin were highly effective at controlling goosegrass in both trials. The treatment that included mesotrione instead of topramezone was not effective at controlling goosegrass.

Table 2. Response of bermudagrass in greens to postemergence herbicides applied at the West Loch Golf Course (Ewa Beach, HI) in 2017

Herbicide Treatment[a]	Rate (kg ha^{-1})[b]	Visual green color rating (%)[c]											
		1-WAIT[d]	2-WAIT		3-WAIT		4-WAIT	1-WAST		2-WAST		3-WAST	
		Pooled[e]	Trial 1	Trial 2	Trial 1	Trial 2	Pooled	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Topramezone + Metribuzin	0.01 + 0.10	21 b[f]	48 cd	90 a	72 a	75 a	97	36 b	92 a	95 a	96 a	96 a	95 a
Topramezone + Metribuzin + Ethofumesate + 2-WAIT Ethofumesate	0.01 + 0.10 + 0.56 + 0.56	24 b	14 e	63 bc	2 b	66 a	82	84 a	11 b	94 a	30 b	95 a	95 a
Topramezone + Metribuzin + Ethofumesate	0.01 + 0.10 + 1.12	28 b	7 e	35 de	1 b	81 a	91	80 a	7 b	94 a	13 c	95 a	96 a
Ethofumesate + 2-WAIT Mesotrione + Metribuzin + Ethofumesate	0.56 + 0.07 + 0.10 + 0.56	98 a	86 ab	95 a	5 b	12 b	84	92 a	96 a	92 a	93 a	95 a	5 b
F value		180.16	6.08		11.61		2.01	119.06		234.58		3452.02	
P value		< 0.0001	0.0048		0.0002		0.149	< 0.0001		< 0.0001		< 0.0001	

[a] Herbicides were applied on the following dates: trial 1 initial treatments were applied on 14 Feb, 2017 and the second series of treatments were applied on 23 Mar, 2017; trial 2 initial treatments were applied on 7 Mar, 2017 and the second series of treatments were applied on 20 Apr, 2017.

[b] All treatments received methylated seed oil (1.0 % v/v), added for enhanced foliar penetration.

[c] Visual green color rating (0 = brown/white, 100 = maximum attainable green color). Maximum turfgrass green color was the highest level of green color observed outside of the test area and unaffected by experimental spray applications.

[d] WAIT = weeks after initial treatments, WAST = weeks after the start of the second series of treatments.

[e] No trial and treatment interaction, data pooled over trial.

[f] Means within weekly rating columns followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.05$

Table 3. Response of goosegrass in greens to postemergence herbicides applied at the West Loch Golf Course (Ewa Beach, HI) in 2017

Herbicide Treatment[a]	Rate (kg ha^{-1})[b]	Control (%)[c]											
		1-WAIT[d]		2-WAIT		3-WAIT		4-WAIT	1-WAST	2-WAST		3-WAST	
		Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Pooled[e]	Pooled	Trial 1	Trial 2	Trial 1	Trial 2
Topramezone + Metribuzin	0.01 + 0.10	98 a[f]	84 bc	99 a	95 a	100 a	95 a	94 a	95 a	99 a	90 b	100 a	90 b
Topramezone + Metribuzin + Ethofumesate + 2-WAIT Ethofumesate	0.01 + 0.10 + 0.56 + 0.56	97 a	73 c	99 a	95 a	100 a	91 a	93 a	95 a	99 a	88 b	100 a	89 b
Topramezone + Metribuzin + Ethofumesate	0.01 + 0.10 + 1.12	93 ab	74 c	98 a	94 a	100 a	91 a	91 a	95 a	99 a	90 b	100 a	89 b
Ethofumesate + 2-WAIT Mesotrione + Metribuzin + Ethofumesate	0.56 + 0.07 + 0.10 + 0.56	1 d	2 d	4 b	7 b	15 b	28 b	1 b	1 b	1 c	1 c	1 c	1 c
F value		10.32		6.22		11.47		462.56	2883.44	15.18		6.42	
P value		0.0004		0.0044		0.0002		< 0.0001	< 0.0001	< 0.0001		0.0038	

[a] Herbicides were applied on the following dates: Trial 1 initial treatments were applied on 14 Feb, 2017 and the second series of treatments were applied on 23 Mar, 2017; Trial 2 initial treatments were applied on 7 Mar, 2017 and the second series of treatments were applied on 20 Apr, 2017.

[b] All treatments received methylated seed oil (1.0 % v/v), added for enhanced foliar penetration.

[c] Visual green color rating (0 = brown/white, 100 = maximum attainable green color). Maximum turfgrass green color was the highest level of green color observed outside of the test area and unaffected by experimental spray applications.

[d] WAIT = weeks after initial treatments, WAST = weeks after the start of the second series of treatments.

[e] No trial and treatment interaction, data pooled over trial.

[f] Means within weekly rating columns followed by the same letters are not significantly different as determined by Tukey HSD at $P < 0.05$

A single application of the topramezone + metribuzin tank mix was effective at controlling goosegrass with a post spray dry down (Trial 1). Two applications of the topramezone + metribuzin tank mix were required for goosegrass control under conventional greens level irrigation (Trial 2). In Hawaii, incorporating a post-spray dry down is currently being deployed by the turf industry to maximize goosegrass control with the topramezone + metribuzin tank mix (DeFrank, 2019).

In conclusion, applications of topramezone + metribuzin provided effective goosegrass control. The addition of ethofumesate to the topramezone + metribuzin tank mix reduced seashore paspalum color loss. Although treatments reported here caused significant bermudagrass green color loss, no treatment provided complete canopy removal. A post-spray dry down, following herbicide application improved goosegrass control and increased bermudagrass injury. Additional research is needed to determine the length of the post-spray dry down and if it could be incorporated into other weed control strategies.

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