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Fairway Renovation with Fraise Mowing Cultivation and Dazomet Fumigation

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***Abstract*. Renovation is an opportune time for golf courses to address annual bluegrass (*Poa annua* L.) weed populations. Dazomet (tetrahydro-3,5-dimethyl-2*H*-1,3,5-thiadiazine-2-thione) is an effective fumigant, but without a tarp cover, it is only effective at the highest labeled rates. Fraise mowing cultivation could be used to help remove surface material and allow practitioners to effectively fumigate at lower rates. In Summer 2018 and Summer 2019, two cool-season fairway renovation experiments were conducted in East Lansing, MI. The objective of these experiments was to assess annual bluegrass control and creeping bentgrass establishment following dazomet applications to fraise mowed surfaces. In the first experiment (fraise mowing surface disturbance experiment), dazomet was applied at a fixed rate (294 kg·ha^{-1}) to fraise mowed plots at varying levels of surface disturbance (0%, 15%, 50%, and 100%) to a depth of 1.9 cm. In the second experiment (dazomet rate experiment), fraise mowing removed 100% of surface material at a depth of 1.9 cm and dazomet was applied at five rates (0, 294, 588, 147 + 147, and 294 + 294 kg·ha^{-1}). Both experiments were conducted on two soils (sand topdressed vs. native) and evaluated two methods of fumigant incorporation (solid-tine cultivation vs. tillage). Five days after treatments were applied, plots were seeded with 'Pure Select' creeping bentgrass (*Agrostis stolonifera* L.). The level of fraise mowing surface disturbance had no effect on annual bluegrass emergence, and creeping bentgrass cover was poorest in native soils at the highest levels of surface disturbance. In the dazomet rate experiment, dazomet applied twice at 294 kg·ha^{-1} provided the most consistent control of annual bluegrass. With the exception to single applications of 294 in 2018, all dazomet treatments allowed for greater creeping bentgrass establishment than the nontreated control. Fraise mowing cultivation may simplify the removal of surface material from large areas; however, even when combined with dazomet applied at the highest rates, it fails to provide complete annual bluegrass control.**

The consequences of "chemical dependency" and lack of herbicide rotation have had lasting effects on annual bluegrass (*Poa annua* L.) management in southern and transition zone climates of the United States. In these regions, reliance on selective herbicides has resulted in evolved resistance to several sites of action, reducing the number of effective annual bluegrass control herbicides. Currently, it is the third most herbicide-resistant weed species globally (Heap, 2019). A key characteristic that contributes to the ubiquity, diversity, and widespread resistance of annual bluegrass (or any successful weed population), is its fecundity—specifically, the seedbank size and the rate at which it accumulates (Mengistu et al., 2000; Mithila and Godar, 2013; Norsworthy et al., 2012; Renton et al., 2014). In one season alone, a single population can produce hundreds of thousands of seeds per square meter (Lush, 1988). A majority of those viable reside at shallow depths (Branham et al., 2004; Green et al., 2019). To prolong the sustainability of a production system, the seedbank must be managed (Norsworthy et al., 2012). Effective seedbank management methods for turfgrass systems have not been identified. Consequently, when annual bluegrass colonizes a turf system where it is not the primary species being managed, sustainable management is often compromised. Golf course renovation is an opportune time for practitioners to mitigate the annual bluegrass seedbank. During a typical renovation, soils are either fumigated or excavated.

The only fumigant currently labeled for turfgrass systems is dazomet (Basamid G) (Basamid Granular; AMVAC Chemical Corporation, Los Angeles, CA). Manufactured as a granular fumigant, dazomet is activated by water and quickly hydrolyzes to the bioactive gas, methyl isothiocyanate (MITC) (Fang et al., 2018; Roberts and Hutson, 1999). In moist soils, dazomet and MITC are both very short-lived (Dungan et al., 2003; Fritsch and Huber, 1995; Ruzo, 2006). As the 2017 Basamid G label states, dazomet can be applied for weed control to golf course fairways at 244 to 588 kg·ha^{-1} when mechanically incorporated or at 244 to 294 kg·ha^{-1} when incorporated by water (Anonymous, 2017). For either method, irrigation must be applied immediately after application to activate the bio-active MITC and create a water seal at the soil surface. Methyl isothiocyanate is most efficacious when contained by tarp cover (Bravo et al., 2018; Park and Landschoot, 2003; Landschoot et al., 2004). Covering large-scale areas such as fairways with a tarp would be laborious, costly, and impractical. The need for tarp cover can be partially offset when a portion of seed-contaminated soil is removed before dazomet is applied (Bravo et al., 2018). However, practical excavation methods applicable to fairways have not yet been identified.

Fraise (fraize, fraze) mowing cultivation, which was originally purposed for thatch and organic matter management of athletic fields (Daily, 2016), effectively removes surface material from large areas. Functioning similar to a flail mower, a Power take-off (PTO)-driven rotor spins at a prescribed depth and removes cultivated material using a conveyor belt. One of the most prominent models today is the Koro FieldTopMaker (Campey Turf Care Systems, Cheshire, UK), which may be equipped with configurable rotors that strip or aggressively cultivate surface material at depths between 0 and 50 mm. Such innovations have expanded the application of fraise mowing to hybrid turf system grooming and hygiene, athletic field renovation, and warm-season turfgrass establishment and management (Brosnan et al., 2020; McCauley et al., 2019; Munshaw et al., 2017). No prior work has evaluated its use for cool-season golf course fairways.

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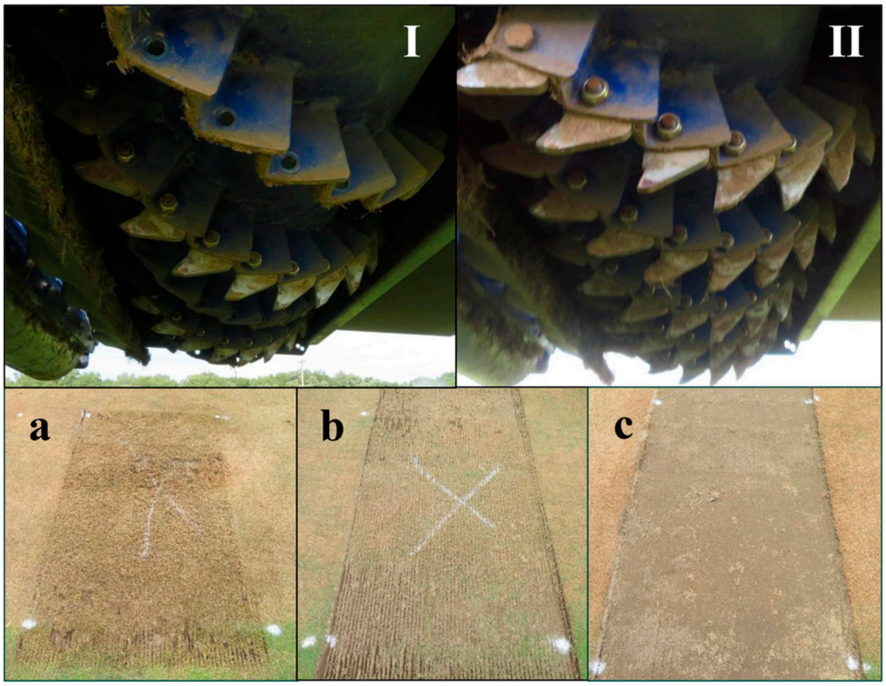

Fig. 1. Fraise mower (**I**) 2 spiral and (**II**) 4 spiral Koro Universe rotor configuration and visual representation of fraise mowing surface disturbance effects on plots fraise mowed to 1.9 cm: (**a**) 15% surface disturbance; (**b**) 50% surface disturbance; and (**c**) 100% surface disturbance.

Table 1. Analysis of variance with the effects of fraise mowing surface disturbance, incorporation, and soil type on annual bluegrass grid counts 8 weeks after seeding (WAS) and creeping bentgrass cover combined during 2018–19 at 4 and 8 WAS in plots at the Hancock Turfgrass Research Center, East Lansing, MI.

	Annual bluegrass plant counts[z]		Creeping bentgrass cover[y]	
Treatment	2018	2019	4 WAS	8 WAS
Soil type (S)[x]	NS	NS	NS	NS
Surface disturbance (D)[w]	NS	NS	*	**
Incorporation method (I)[v]	NS	**	NS	**
S × D	NS	NS	**	*
S × I	NS	NS	NS	NS
D × I	NS	NS	NS	NS
S × D × I	NS	NS	NS	NS

[z]Average number of annual bluegrass parts touching intersections spaced 6.5 cm^2 from two randomly placed 0.10-m^2 grids.
[y]Plots seeded with 49 kg 'Pure Select' creeping bentgrass seed/ha at 5 d after dazomet fumigation.
[x]Experiments conducted on native and topdressed sand quadrants. Topdressing was applied between 2011 and 2015, accumulating a total of 3.8 cm.
[w]Denotes level of fraise mowing surface disturbance that corresponds with the proportion of material removed by each rotor configuration at a depth of 1.9 cm.
[v]Dazomet applied at 294 $kg{\cdot}ha^{-1}$ using shaker bottles incorporated to 3.8 cm using solid-tine or tillage cultivation at 5 d after application.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to Fisher's protected least significant difference test.

Integrated weed management (IWM) programs that incorporate both chemical and mechanical strategies are an effective and sustainable approach to weed management (Buhler, 2002; Harker and O'Donovan, 2013; Swanton and Weise, 1991). In the summers of 2018 and 2019, two experiments combining dazomet fumigation and fraise mowing cultivation were conducted in Michigan. The experimental objectives were: 1) to assess the application of fraise mowing cultivation for use in cool-season fairway renovations and 2) to evaluate their combined treatment effects on annual bluegrass control and creeping bentgrass (*Agrostis stolonifera* L.) establishment.

Materials and Methods

Experimental site description, maintenance, and preparation

Two experiments were conducted at the Michigan State University Hancock Turfgrass Research Center (HTRC), East Lansing, MI, on a creeping bentgrass, annual bluegrass mixed species site divided into six 502-m^2 quadrants. In 2011, three quadrants were randomly selected and topdressed until 2015, accumulating a total of 3.8 cm of sand. Annual bluegrass populations accounted for ≈50% to 55% and 55% to 60% of the species composition in topdressed and nontopdressed quadrants, respectively. Native soil on site was a Capac loam (fine-loamy, mixed, active, mesic, Aquic Glossudalf). Site management emulated practices typical of cool-season golf course fairways. Mowing was conducted three times per week at a height of 1.1 cm. In 2018 and 2019, the site received 0.49 $kg{\cdot}m^{-2}$ N (28–0–0) twice per month and was irrigated with 1.1 cm per week based on soil moisture and weather.

On 15 June 2018 and 14 June 2019, blocks of both experiments were sprayed with a 2.0% glyphosate solution applied at 440 $L{\cdot}ha^{-1}$ using a CO_2-propelled backpack sprayer (R&D Sprayers, Bellspray, Inc., Opelousas, LA). Ten days after, areas were scalped to a 0.50-cm mowing height. Treatments of both experiments were applied 11 and 12 d after glyphosate was applied.

Surface disturbance experiment. Treatments were arranged as a 4 × 2 × 2 factorial, split-plot design. Blocks were treated as random effects within main plots of two soils (topdressed, native soil). Eight subplots within each main plot were fraise mowed with the Universe rotor to a depth of 1.9 cm [KORO FieldTopMaker (FTM) 1.2; Campey Turf Care Systems, Cheshire, UK] at one of four levels of surface disturbance (0%, 15%, 50%, and 100%). The proportion of surface material removed by fraise mowing was a function of the fraise mowing blade width and blade arrangement on the rotor (Fig. 1). Disturbance treatments of 15 and 50% used 3- and 10-mm blades and were arranged in a two-spiral configuration. Disturbance treatments of 100% used 10-mm blades that were arranged in a four-spiral rotor configuration (Fig. 1). Following cultivation, dazomet (Basamid Granular; AMVAC Chemical Corporation, Los Angeles, CA) was applied at 294 $kg{\cdot}ha^{-1}$ using shaker bottles and a wooden windscreen to provide uniform application. After all subplots were fumigated, sub-subplots were mechanically incorporated by either solid-tine cultivation or tillage to a 3.8-cm depth. Plots incorporated with solid tine were cultivated (1.3-cm solid tines, spaced 5.1 × 5.1 cm, 4.9% surface disturbance; Toro ProCore 648; The Toro Company, Bloomington, MN) before dazomet was applied but after fraise mowing was conducted. Tilled plots were cultivated after dazomet was applied with three passes in each sub-subplot (Honda FRC 800 rear-tine tiller; American Honda Power Equipment Division, Alpharetta, GA). Immediately after mechanical incorporation, all plots were hand-watered following methods described by the Basamid G label. Water was applied for 4 d following fumigation, declining by half each following day [d-1 = 2.5 cm (25.6 $L{\cdot}m^{-2}$), d-2 = 1.3 cm (12.8 $L{\cdot}m^{-2}$), d-3 = 0.64 cm (6.4 $L{\cdot}m^{-2}$), and d-4 = 0.32 cm (3.2 $L{\cdot}m^{-2}$). A custom watering wand (GPI/FLOMEC TM-150N; GPI Meters, Sparta, NJ) was used to ensure that a precise volume of water was delivered to each plot.

Table 2. The effects of soil type, fraise mowing surface disturbance, and fumigant incorporation method on annual bluegrass counts measured 8 weeks after seeding from plots at the Hancock Turfgrass Research Center, East Lansing, MI, 2018–19.

Treatment	Level	Annual bluegrass plant counts[z] 2018	2019
Soil type	Topdressed	22	310
	Native	42	235
Surface disturbance[y]	0	64	333
	15	5	212
	50	33	235
	100	41	245
Incorporation method[x]	Solid-tine	32	309 a[w]
	Till	30	203 b

[z]Average number of annual bluegrass parts touching intersections spaced 6.5 cm^2 from two randomly placed 0.10-m^2 grids. Reported as plants per m^2. 0.0929 plants/m^2 = 1 plant/ft^2

[y]Denotes level of fraise mowing surface disturbance that corresponds with the proportion of material removed by each rotor configuration at a depth of 1.9 cm.

[x]Dazomet applied at 294 $kg\cdot ha^{-1}$ using shaker bottles incorporated to 3.8 cm using solid-tine or tillage cultivation at 5 d after application.

[w]Means within a column followed by the same letter are not significantly different from $P \leq 0.05$.

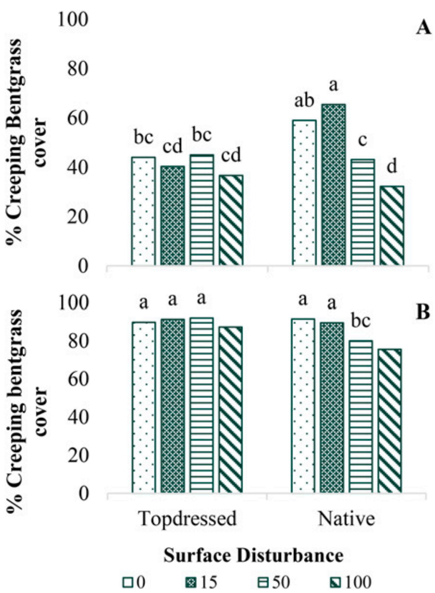

Fig. 2. Effects of fraise mowing surface disturbance × soil type on percent creeping bentgrass cover as evaluated by digital image analysis at 4 (**A**) and 8 (**B**) weeks after seeding. Letters above treatments at each interval indicate significance at $P = 0.05$ according to Fisher's protected least significant difference test.

Dazomet rate experiment. Treatments were arranged as a 5 × 2 × 2 factorial, split-plot design. Ten subplots within topdressed and native soil main plots were stripped by fraise mowing to a 1.9-cm depth and then fumigated with dazomet at one of five levels (0, 294, 588, 147 + 147, and 294 + 294 $kg\cdot ha^{-1}$). Treatments with sequential applications were applied 10 d after the first application. All dazomet treatments were incorporated in the same manner described in the previous experiment. In this experiment, incorporation procedures were repeated for all treatments applied twice.

Seeding and postmaintenance

In the dazomet rate experiment, incorporation procedures were repeated for treatments that received a second application. Five days after all fumigant treatments were applied, plots were smoothed using a steel-drum roller and fertilized with triple phosphate (0–46–0) at 49 $kg\cdot ha^{-1}$ phosphorus. A tire-dimpling device was rolled over each plot before 'Pure Select' (Tee-2-Green, Hubbard, OR) creeping bentgrass (*Agrostis stolonifera*) seed was applied at 49 kg seed/ha. Fertilizer and seed were applied by hand using shaker bottles and then hand-raked gently in two directions to incorporate seed in to the top 0.5 cm of soil. After seeding, the site was irrigated daily with 0.25 cm until seed germination and then applied for stress prevention and growth thereafter.

Plots were mowed twice monthly at 0.64 cm. Granular urea (46–0–0) was solubilized in water and applied to subplots at 14.7 $kg\cdot ha^{-1}$ N using a CO_2 backpack sprayer beginning 3 weeks after seeding (WAS); then, it was applied weekly at 4.9 $kg\cdot ha^{-1}$ N beginning 4 WAS. All weeds (excluding annual bluegrass) were hand-pulled 3 times per week until 4 WAS. Mefenoxam {Subdue GR; Syngenta, Greensboro, NC; (R,S)-2-[(2,6-dimethylphenyl)-methoxyacetylamino]-propionic acid methyl ester} was applied at 42.7 $kg\cdot ha^{-1}$ on both 13 July 2018 and 29 July 2019 to prevent *Pythium* spp. infection. On 3 Aug. 2019, quinclorac (3,7-dichloro-8-quinolinecarboxylic acid; Drive XLR8; BASF Corporation, Research Triangle Park, NC) was applied at 0.70 $L\cdot ha^{-1}$ to provide additional summer annual weed control.

Data collection and analysis

Annual bluegrass emergence was determined from grid counts obtained 8 WAS. The methods were similar to those described by Bravo et al. (2018). Each 0.10-m^2 grid consisted of 144 intersections spaced every 6.5 cm^2. Two grids were randomly placed in each plot and the average number of intersections touched by annual bluegrass plant parts were tallied. Counts are reported as plants per m^2.

Creeping bentgrass cover was assessed using digital image analysis at 4 and 8 WAS. Images were captured inside of a custom 0.8 × 0.6 × 0.6 m lightbox with a Canon PowerShot SX710 HS (Canon U.S.A., Inc., Melville, NY). Camera settings were fixed (manual; F-stop = 3.5; exposure = 1/20; ISO = 1600; macro) across measuring periods. Images were processed through the Java applet TurfAnalyzer (http://turfanalyzer.com) to determine green turfgrass cover (hue, 45–140; saturation, 10–100; brightness, 0–100). Green cover was quantified as the proportion of green pixels to the total number of pixels in each image (Karcher and Richardson, 2013).

Data for both experiments were analyzed in JMP (1989–2019 JMP Pro version 13; SAS Institute Inc., Cary, NC) by year using the "Fit Model" platform. Blocks were treated as random effects, with three in each soil type. Creeping bentgrass cover means were subjected to log-transformation for analysis. All means of main effects were subjected to an analysis of variance and separated using Fisher's protected last significant difference ($\alpha = 0.05$) test when $P \leq 0.05$. Back-transformed means are reported and significant interactions are presented graphically.

Results

Surface disturbance experiment. Method of fumigant incorporation was the only factor to influence annual bluegrass emergence, although its effects were not consistent across years (Table 1). In 2019, annual bluegrass counts of solid-tine plots (309 plants/m^2) were nearly 52% greater than counts of tilled plots (203 plants/m^2) (Table 2).

An analysis of creeping bentgrass cover revealed no differences at 4 and 8 WAS between years; therefore, data were combined for analysis. Creeping bentgrass cover was significantly influenced by the main effects of surface disturbance, method of fumigant incorporation, and surface disturbance × soil type interaction (Table 1). In general, increased surface disturbance impeded creeping bentgrass establishment (data not shown). By 8 WAS, solid-tine cultivation yielded ≈15% more creeping bentgrass cover than tillage. The significant disturbance by the soil type interaction (Fig. 2) revealed that creeping bentgrass cover was poorest in native soil plots that were fraise mowed with 50 and 100% surface disturbance, but it did not differ by treatment in topdressed blocks.

Dazomet rate experiment. Annual bluegrass was significantly affected by the dazomet application rate (Table 3). Across years, all dazomet treatments resulted in lower annual bluegrass cover than the nontreated control (Table 4). Although no single treatment was deemed superior, treatments applied twice at 294 $kg\cdot ha^{-1}$ provided the most consistent control across years (Table 4). Relative to the control, annual bluegrass counts were reduced by 87% in 2018 and 85% in 2019. Single applications of 294 and 588 $kg\cdot ha^{-1}$ in 2018 and split applications of 147 $kg\cdot ha^{-1}$ in 2019 had comparable effects (Table 4).

Creeping bentgrass cover differed by the dazomet rate in 2018 and increased with higher rates (Table 5). Except for single applications of 294 $kg\cdot ha^{-1}$, all 2018

Table 3. Analysis of variance with the effects and interaction between soil type, dazomet rate, and method of fumigant incorporation on annual bluegrass grid counts 8 weeks after seeding and creeping bentgrass cover at 4 and 8 weeks after seeding in plots at the Hancock Turfgrass Research Center, East Lansing, MI, 2018–19.

	Annual bluegrass plant counts[z]		Creeping bentgrass cover[y]			
			4 WAS		8 WAS	
Treatment	2018	2019	2018	2019	2018	2019
Soil type (S)[x]	NS	NS	NS	NS	NS	NS
Dazomet rate (R)[w]	***	***	***	NS	**	NS
Incorporation method (I)[v]	NS	NS	NS	*	NS	**
S × R	NS	NS	NS	NS	NS	NS
S × I	NS	NS	NS	*	NS	*
R × I	NS	NS	NS	NS	NS	NS
S × R × I	NS	NS	NS	NS	NS	NS

[z]Average number of annual bluegrass parts touching intersections spaced 6.5 cm^2 from two randomly placed 0.10-m^2 grids.
[y]Creeping bentgrass cover (%) determined using digital image analysis. Measurements taken from plots seeded at 49 kg 'Pure Select' creeping bentgrass seed/ha 5 d after dazomet fumigation.
[x]Experiments conducted on native and topdressed sand quadrants. Topdressing was applied between 2011 and 2015, accumulating a total of 3.8 cm.
[w]Rate of dazomet applied in kg·ha^{-1}. All treatments applied to plots fraise mowed to 1.9 cm using shaker bottles.
[v]Dazomet treatments incorporated to 3.8 cm using solid-tine or tillage cultivation at 5 d after application.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, according to Fisher's protected least significant difference.

Table 4. Effects of dazomet rate on annual bluegrass counts measured 8 weeks after seeding from plots at the Hancock Turfgrass Research Center, East Lansing, MI, 2018–19.

	Annual bluegrass plant counts[y]	
Dazomet rate[z]	2018	2019
0	65 a[x]	286 a
294	10 bc	173 b
588	8 c	120 bc
147 + 147[w]	22 b	86 cd
294 + 294	9 c	43 d

[z]Rate of dazomet in kg·ha^{-1}. All treatments applied to plots fraise mowed to 1.9 cm using shaker bottles.
[y]Average number of annual bluegrass parts touching intersections spaced 6.5 cm^2 from two randomly placed 0.10-m^2 grids. Reported as plants per m^2. 0.0929 plants/m^2 = 1 plant/ft^2.
[x]Means within a column followed by the same letter are not significantly different from $P \leq 0.05$.
[w]Split applications of dazomet applied sequentially at 10 d after the initial application.

Table 5. Effects of dazomet rate on creeping bentgrass cover in plots established at the Hancock Turfgrass Research Center, East Lansing, MI, at 4 and 8 weeks after seeding in 2018.

	Creeping bentgrass cover[y]	
Dazomet rate[z]	4 WAS	8 WAS
0	39 c[x]	78 b
294	54 b	83 b
588	63 ba	96 a
147 × 2[w]	88 a	95 a
294 × 2	86 a	96 a
Significance	***	**

[z]Rate of dazomet in kg·ha^{-1}. All treatments applied to plots fraise mowed to 1.9 cm using shaker bottles.
[y]Creeping bentgrass cover (%) determined using digital image analysis. Measurements taken from plots seeded at 49 kg 'Pure Select' creeping bentgrass seed/ha at 5 d after dazomet fumigation.
[x]Means within a column followed by the same letter are not significantly different from $P \leq 0.05$.
[w]Split applications of dazomet applied sequentially at 10 d after the initial application.
**, ***Significant at $P \leq 0.01$ or 0.001, respectively, according to Fisher's protected last significant difference.

dazomet treatments yielded greater cover than the control. The significant rate by soil type interactions of 2019 revealed native plots fumigated with 588 kg dazomet/ha yielded 9% less cover than treatments applied twice at 146.8 kg·ha^{-1} to native soil plots and 14% less cover than single applications of 294 kg·ha^{-1} applied to topdressed plots (data not shown). Creeping bentgrass cover in 2019 was also significantly affected by the fumigant incorporation method (Table 6). When compared with tillage, solid-tine cultivation was less invasive and provided greater creeping bentgrass cover.

Discussion

Based on the recommendations of Branham et al. (2004) and Green et al. (2019), excavating the upper 1.3 to 3.8 cm of soil should remove the majority of the annual bluegrass seedbank. In these experiments, fraise mowing to a depth of 1.9 cm was inadequate and failed to provide complete or acceptable levels of annual bluegrass control. When combined with dazomet applied at the lowest label rate (294 kg·ha^{-1}), annual bluegrass control was poor to insignificant. Dazomet applied at or equivalent to the highest labeled rate (588 kg·ha^{-1}) resulted in improved annual bluegrass control and provided the highest reduction of emergence (87%) relative to the nontreated control. Bravo et al. (2018), who removed 3.8 cm of sod before fumigating, had similar success. Annual bluegrass control has varied with the excavation depth previously. Baker et al. (2005) reduced annual bluegrass cover in perennial ryegrass (*Lolium perenne* L.) stands by 50% after fraise mowing to 1.8 cm. Brosnan et al. (2020), who fraise mowed 2.5 cm of material from *Zoysia* spp. stands, achieved annual bluegrass reductions of only 24% and reported little effect on the annual bluegrass seedbank. Collectively, these findings suggest that 1) greater excavation depth may not necessarily translate to greater annual bluegrass control, and 2) depth of the annual bluegrass seedbank can vary significantly from site to site. Moreover, failing to consider variables such as management history or species composition may affect the efficacy of a control program.

Seasonal weed emergence can be influenced by many factors, such as anthropic dispersal and disturbance, dynamic seedbank properties, or changes in environmental conditions (Buhler et al., 1997; Cavers, 1995; Dyer, 1995). In these experiments, the disparity in annual bluegrass emergence between years may have been physiologically, phenologically, or chemically related. 1) Physiologically, any seed that was in a quiescent state at the time when dazomet was applied in 2019 would have escaped control, and fumigants are ineffective when the target organism is not present or actively respiring (Anonymous, 2017; Klose et al., 2008; Mappes, 1995). 2) Phenologically, there was a large difference in the accumulated growing degree days (GDD) between years relative to the time when fumigant was applied each year. Annual bluegrass emergence and seed flush have been characterized by growing-degree days (Calhoun, 2010; Danneberger and Vargas, 1984). In East Lansing, MI, Calhoun (2010) observed that peak annual bluegrass spring seed flush occurred between 800 and 1000 GDD (T_{base} = 10 °C). When plots were fumigated in June and July 2018, the site had accumulated more than 900 GDD. Conversely, only 650 GDD (T_{base} = 10 °C) had accumulated by the time when dazomet was applied in 2019. This difference would mean that any seed that was absent or not yet emerged by the time of fumigation in 2019 would have been subject to block-to-block seed recruitment during routine maintenance. 3) Chemically, treatments in 2018 may have been more efficacious due to the weather conditions that surrounded fumigation procedures. In 2018, fumigation was proceeded by overcast conditions and an additional 1.3 cm of precipitation over the 5 d that followed. Under prolonged periods of adequate or supraoptimal soil moisture, the conversion of dazomet to the bioactive MITC is enhanced, microbial degradation of MITC is slowed, and, subsequently, MITC off-gassing declines (Fang et al., 2018; Zheng et al., 2006). If weather contributed to reduced losses of MITC, prolonged exposure to the

Table 6. Effects of fumigant incorporation methods on creeping bentgrass cover in plots established at the Hancock Turfgrass Research Center, East Lansing, MI, 4 and 8 weeks after seeding in 2019.

Incorporation method[z]	Creeping bentgrass cover[y]	
	4 WAS	8 WAS
Solid-tine	88 a[x]	92 a
Till	78 b	84 b

[z]Dazomet treatments incorporated to 3.8 cm using solid-tine or tillage cultivation at 5 d after application.
[y]Creeping bentgrass cover (%) determined using digital image analysis. Measurements taken from plots seeded at 49 kg 'Pure Select' creeping bentgrass seed/ha at 5 d after dazomet fumigation.
[x]Means within a column followed by the same letter are not significantly different from $P \leq 0.05$.

gas would have resulted in increased annual bluegrass control. Tillage cultivation should not be considered as a viable option for fumigant incorporation. Bravo et al. (2018) also evaluated tillage for dazomet incorporation and achieved comparable control. Likely, tillage was effective against annual bluegrass populations, not for its ability to better incorporate dazomet, but rather for its ability to bury seed. Although it reduced annual bluegrass emergence in the rate experiment, its effects on creeping bentgrass establishment and long-lasting effects on the soil surface and structure make it a poor choice in an applied renovation setting.

Creeping bentgrass cover was antagonized by fraise mowing cultivation (disturbance experiment) and enhanced by higher dazomet fumigation (dazomet rate experiment). In the surface disturbance experiment, seed propagated in plots subjected to little or no surface disturbance were provided an environment more conducive to germination and establishment. Conversely, material was stripped from the surface of 100% disturbance treatments and translated to poor establishment, which was exacerbated in native soils. Similar effects were reported by Munshaw et al. (2017). In warm-season preplant overseeding trials, fraise mowing cultivation was the only treatment to result in poor perennial ryegrass (*Lolium perenne* L.) cover in the early stages of establishment.

In the dazomet rate experiment, higher dazomet application rates improved creeping bentgrass establishment. An enhanced growth response following dazomet fumigation has been frequently reported in the literature (Altman, 1970; Branham et al., 2004; Jenkinson et al., 1972; Park and Landschoot, 2003). For many fumigants, this response is attributed to nitrogen mineralized from lysed microbial populations. For dazomet, however, the ammonium byproduct mineralized during degradation can also contribute to growth (Fritsch and Huber, 1995; Gasser and Peachey, 1964).

Conclusions

Fraise mowing is a useful cultivation technique for the removal of surface material from large areas. However, when combined with low rates of dazomet, annual bluegrass control is poor and just as effective as fumigation without fraise mowing. The most effective annual bluegrass control was achieved when dazomet was applied at the highest rates. Therefore, practitioners who are considering fraise mowing during fairway renovation should not rely on this practice solely for annual bluegrass seedbank management and should apply dazomet at the highest labeled rates or use sequential applications of intermediate rates. A consequence of the latter is prolonged golf course closure. In addition to fraise mowing for fairway use, practitioners might also consider its application for grading areas like tee boxes. Future research should investigate the combined effects of fraise mowing cultivation and dazomet fumigation at higher application rates when surfaces are fraise mowed at greater depths.

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